

Primary Gold Ltd

Toms Gully Project Pit water geochemical modelling report

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Table of contents

1.	duction1	
	1.1	Background1
	1.2	Purpose of this report1
	1.3	Disclaimer1
2.	Litera	ture review3
3.	Analy	sis scenarios and methodology4
	3.1	Geochemical modelling scenarios4
	3.2	Summary of quantity and pit level assumptions6
	3.3	Conservativeness of assumptions7
	3.4	Water quality assessment8
4.	Resul	ts and discussion9
	4.1	Scenario 19
	4.2	Scenario 2a10
	4.3	Scenario 2b11
	4.4	Scenario 312
	4.5	Summary13
5.	Concl	usions and recommendations15
	5.1	Conclusions
	5.2	Recommendations15
6.	Refer	ences16

Table index

Table 3-1 Waste rock and tailings quantity assumptions	6
Table 3-2 Volumetric assumptions	6
Table 3-3 Conservativeness of assumptions	7
Table 3-4 SSTVs applicable at Toms Gully (Stauber and Batley 2018)	8
Table 4-1 Scenario 1 - Quicklime and caustic masses required	9
Table 4-2 Modelled pit water quality following treatment with lime/caustic	9
Table 4-3 Modelled precipitate masses following treatment with lime/caustic	10
Table 4-4 Modelled pit water quality - Scenario 2a	11
Table 4-5 Modelled pit water quality - Scenario 2b	11

Table 4-6 Modelled pit water quality – Scenario 3	12
Table 4-7 Indicative quicklime requirements for pit water pH adjustment	14

Appendices

- Appendix A Baseline pit water quality
- Appendix B In situ water quality depth profiles
- Appendix C Waste rock and tailings mineralogy

1. Introduction

1.1 Background

The Toms Gully Project (the Project), located near Marrakai in the Northern Territory, has been in operation intermittently since 1988. The Toms Gully resource was discovered in 1986 by the Carpentaria Exploration Company. Following its discovery, the Project has operated under the ownership of several different entities, most recently Crocodile Gold until 2010; then after a period of care and maintenance, it was divested to Primary Gold Limited (Primary).

Primary, the current lease holder, has applied to recommence underground mining and ore processing at Toms Gully, as described in the Project's Environmental Impact Statement (EIS), Supplementary Environmental Impact Statement (SEIS) and Section 14A amendment (refer to <u>https://ntepa.nt.gov.au/environmental-assessments/register/toms-gully-underground-project</u>). Recent project amendments as described in the Section 14A notification include:

- Subaqueous storage of future underground sulfidic waste rock, almost all from the proposed boxcut and mine development.
- Subaqueous storage of all existing sulfidic tailings from previous operations on site from tailings storage facilities 1 and 2, potentially following re-treatment, plus all future tailings into the Toms Gully pit using a floating head system.
- Treatment of the existing pit water *in situ* throughout operations to maintain circumneutral pH values and thereby reduce dissolved bioavailable metal concentrations by the addition of quicklime or caustic soda.
- Treatment of displaced water from the pit using the proprietary BioAqua process (or contingency option) as waste rock and tailings are added, for off-site licenced discharge once approved.

Primary engaged GHD Pty Ltd (GHD) to undertake geochemical modelling of the pit water to better understand pit water quality risk during operations and post-closure. The work will also assist in determining the most appropriate *in situ* pit water treatment reagent and the volume/mass of reagent which may be required.

1.2 Purpose of this report

The purpose of this report is to assess the risk of water quality impacts to pit water and predict water quality over time from the operational and post-closure scenarios as noted above using geochemical modelling. The work therefore assesses the potential impacts from the proposed modification (Section 14A) to the current project description in the EIS and SEIS. It is also to assist in determining the most appropriate *in situ* pit water treatment reagent and the possible volume/mass of reagent required.

Modelling inputs included pit water quality, waste rock and tailings geochemical composition, densities, volumes and schedules, plus the currently proposed water treatment technologies. It interfaced with completed or concurrent studies for Toms Gully including reports on geochemistry (GHD 2018a and GHD 2019c), the water balance model (GHD 2019a), and groundwater (GHD 2019b).

1.3 Disclaimer

This report has been prepared by GHD for Primary Gold Ltd and may only be used and relied on by Primary Gold Ltd for the purpose agreed between GHD and the Primary Gold Ltd as set out in section 1.2 of this report. GHD otherwise disclaims responsibility to any person other than Primary Gold Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

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

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

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

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The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

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2. Literature review

Acid mine drainage (AMD), acid rock drainage or more commonly now, acid and metalliferous drainage is formed when certain sulfide minerals, most commonly pyrite, are exposed to oxidising conditions (Skousen *et al.* 1998). The conventional practice of land-based disposal of sulfide bearing waste rock and mine wastes including tailings has often resulted in the generation of acidic water and the concomitant leaching of trace metals (Rescan Environmental Services 1989). Subaqueous disposal of mine wastes is a mitigation method commonly used by mines where the water balance deems it appropriate, as it limits oxygen ingress into water-filled pores, which greatly reduces sulfide oxidation, minimises metal leaching and prevents the development of acid drainage (Campbell and Price 2018). Simply, there is less available oxygen in water than in air, not considering anoxic conditions deeper underwater.

In determining the minimum depth of subaqueous disposal required to minimise sulfide oxidation, the key variables are wave activity and the sediment properties of the mine tailings relating to entrainment (Mine Environment Neutral Drainage (MEND) 1998). A review of case histories by MEND (1998) found that subaqueous disposal depths of between one and five metres below the water surface in constructed impoundments had been effective in minimising sulfide oxidation. While dissolved oxygen (DO) concentrations in water at such depths may still be significant, and even supersaturated (depending on submerged photosynthetic activity), this oxygen is preferentially used for the bacterial oxidation of organic matter in sediments (where there is sufficient organic matter present) (Rescan Environmental Services 1989). In most lake sediments, the organic carbon content is usually sufficient to establish anoxic conditions at sediment depths ranging from a few millimetres to one decimetre (Rescan Environmental Services 1989). When complimented by stoichiometrically balanced concentrations of sulfate and metals, sulfate reducing bacteria sequester metals as sulfides, thereby reducing the pool of potential environmental contaminants. This is a natural phenomenon that is found in reducing environments such as peat-bogs and estuarine or lacustrine backswamps.

Actual measurements of DO concentrations in sediment pore water, reported by Campbell and Price (2018), indicate that oxygen can penetrate up to 10 cm depths in sandy sediments, but in silts the oxic-anoxic interface is rarely deeper than one centimetre. Campbell and Price (2018) state that a minimum depth of water cover of one metre is usually sufficient to establish anoxic conditions in sediments overlying subaqueously disposed tailings. Results of field and laboratory testing have confirmed that submerging AMD-generating materials is one of the best available methods for limiting AMD generation over the long term (MEND 2001).

Analysis scenarios and methodology

3.1 Geochemical modelling scenarios

Geochemical modelling was undertaken using the PHREEQc (Parkhurst and Appelo 1999) program. The database minteq.v4.dat (Allison *et al.* 1990; USEPA 1998) was used to define thermodynamic data for aqueous species as it contains each of the metals that were to be modelled and is applicable to the temperature and ionic strength of the water being investigated. The following assumptions applied to each modelling scenario:

- Dissolved (or bioavailable), rather than total metals concentrations.
- Half of the laboratory limit of reporting (LOR) was used where laboratory non-detects were retuned.
- Pit water level was set at 15 m AHD. This level returns a volume of 4.1 GL under existing conditions, and is a stable water level under existing conditions based on field notes included with the surface water quality data provided by Primary. It is acknowledged that the groundwater modelling report (GHD 2019b) has indicated the potential for pit water level reductions during mining based on the adopted dewatering and groundwater inflow mitigation methodologies. As such, the water level of 15 m AHD was assumed in order to model the maximum volume of water which could be affected by the oxidation of metal sulfides in deposited tailings and waste rock.
- Interaction of existing sulfides in the walls of the pit with the pit water was not considered, as oxide material in the pit walls is likely to be primarily inert, and any sulfidic material at depth would be flooded,.

Three scenarios with a total of four geochemical modelling runs were undertaken as described in Sections 3.1.1 to 3.1.4 below. In summary, the scenarios were:

- Scenario 1 the initial treatment of the existing pit water was modelled using quicklime and caustic soda (Section 3.1.1)
- Scenario 2 pit water quality was modelled after a nominal two years of operations, the two geochemical modelling runs were:
 - Scenario 2a pit water stratification as per the current conditions was assumed, i.e. anoxic conditions at the solids level in the pit
 - Scenario 2b loss of pit water stratification due to either a pit water turnover event or migration of oxic water to the bottom of the pit associated with losses of pit water to the groundwater table, i.e. oxidising conditions at the solids level in the pit
- Scenario 3 pit water quality post closure was modelled. Loss of pit water stratification
 was not considered due to the predicted final solids level being within the oxic water
 layer.

3.1.1 Scenario 1 – Initial treatment of pit water

This scenario modelled the reaction of the median pit water quality (refer Appendix A) with quicklime/burnt lime (CaO) and caustic soda (NaOH) (modelled separately) to determine the preferred treatment chemical. It was based on the quantity, and therefore cost, required of each reagent to reach a pH of approximately 8.5, at which metal solubility is generally reduced. Scenario 1 assumes vertically consistent DO concentrations in the pit; the rationale for which is the limited effect DO has on neutralisation reactions between the reagents and sulphuric acid.

Initially, the modelling did not allow for the precipitation of solids following the reaction, and as such, was conservative in terms of the mass of chemicals required. The Scenario 1 output files were inspected for solids with positive saturation indices. Positive saturation indices imply that precipitation of the particular solids was predicted by the model. The solids identified were then entered into the PHREEQc input files to allow for precipitation, and the modelling was repeated to fine-tune estimates of the quantity of quicklime or caustic required to reach the desired pH. The resulting water quality was then tabulated, as were the predicted quantities and nature of precipitates.

3.1.2 Scenario 2a – Pit water quality during operations

Scenario 2a assumed equilibration of the treated pit water quality following the initial treatment modelled under Scenario 1. The following was added to the pit:

- all of the boxcut rock and waste rock extracted from the boxcut and underground mine workings following two years' of mining operations (approximately 1.18 Mt). One third of this rock was assumed to be sulfidic (i.e. approximately 0.39 Mt); and
- the entirety of tailings from the existing, historic tailings storage facilities TSF1 and TSF2.
- a quantity equivalent to two years' tailings deposition during operations (approximately 0.5 Mt). Refer to Appendix C for the waste rock and tailings mineralogy data drawn from GHD (2018a).

As implied above, all boxcut and waste rock has been assumed to be deposited in the pit to conservatively estimate the ratios of solids to water for each modelling scenario. Refer to GHD (2019c) for validation of these assumptions.

The majority of the waste rock and tailings to be deposited subaqueously will lie below a depth of -15 m AHD. That is, in anoxic water (refer to the dissolved oxygen figure in Appendix B in this regard). However, based on the mine schedule and solids densities reported in GHD (2019a), the final solids level in the pit will reach a depth of -7.6 m AHD (when depositing 100 percent of the waste rock in the pit).

Minimal mixing of anoxic and overlying oxic water was assumed. Therefore, the Scenario 2a results will not represent water quality that would be observed in the upper 25 m of the pit.

The waste rock and tailings mineralogy used for Scenario 2a are presented in Appendix C; being from GHD (2018a). Maximum, rather than mean or median, mineral concentrations were used in the modelling to conservatively represent the 'worst case scenario' in terms of acid-forming minerals in waste rock and tailings. These assumptions are deemed conservative as:

- using a maximum value is essentially a 100th percentile for the sulfide, thereby making the assumption that the maxima is in fact the 'average' within the mineral waste. This will increase the maximum potential acidity within the mineral waste.
- all of the minerals present in the waste rock and tailings were assumed to equilibrate with the anoxic water in the pit. In reality, a large proportion of the minerals present would be unreactive, due to being either contained within waste rock/tailings particles (i.e. not directly exposed to the water), or buried beneath more recently deposited waste rock/tailings.

3.1.3 Scenario 2b – Pit water quality during operations, assuming loss of pit water stratification

Modelling for Scenario 2b was based on the same assumptions as those for Scenario 2a, though with a saturated DO concentration based on that which is observed at the surface of the pit under existing conditions. This DO concentration was 7.01 mg/L (refer to the DO figure in Appendix B).

3.1.4 Scenario 3 – Pit water quality post closure

Scenario 3 assumed equilibration of the treated pit water quality following the initial treatment modelled under Scenario 1. No loss of pit water stratification was modelled, as the final solids level in the pit was predicted to be within the oxic water layer. As the water balance model predicts the final 4.6 m of deposited solids to be comprised solely of new tailings generated during mine operations, the new tailings mineralogy (refer Appendix C) was the only addition to this scenario. The post closure solids level in the pit was predicted as -6.9 m AHD (GHD 2019c), i.e. with 3.1 m of tailings within the existing oxic water layer (based on existing conditions). As such, the quantity of new tailings within this oxic layer (approximately 0.283 Mt) was added for Scenario 3.

3.2 Summary of quantity and pit level assumptions

Waste rock and tailings quantities used in the modelling are presented in Table 3-1. Table 3-2 provides oxic and anoxic water volumes within the pit for the modelling.

Modelling scenario	Time	Total quantity of waste rock produced (Mt)	Quantity of sulfidic waste rock deposited in the Pit (Mt)	Quantity of new tailings deposited in the Pit (Mt)	Quantity of old tailing deposited in the Pit (Mt)
Scenario 1	Prior to the deposition of waste rock or tailings in the pit.	No waste rock or tailings deposited in the pit.			
Scenarios 2a and 2b	Following two years of mine operation	1.180	0.393	0.5	0.375 (0.250 from TSF1 and 0.125 from TSF2)
Scenario 3	Following completion of all mining activities	1.51*	0.503*	0.884 (Quantity used in model = 0.283)	0.375*

Table 3-1 Waste rock and tailings quantity assumptions

* Mineralogy not included in the modelling for Scenario 3. Only the rock within the existing oxic water layer was modelled to react with the pit water in Scenario 3.

Table 3-2 Volumetric assumptions

Modelling scenario	Time	Waste rock/tailings level in the Pit (m AHD)	Volume of anoxic water in the Pit (ML)	Volume of oxic water in the pit (ML)
Scenario 1	Prior to the deposition of waste rock or	No waste rock or tailings deposited in the pit.	NA	4,123 (Scenario 1 assumed all water in the Pit to be

Modelling scenario	Time	Waste rock/tailings level in the Pit (m AHD)	Volume of anoxic water in the Pit (ML)	Volume of oxic water in the pit (ML)
	tailings in the pit.			oxic, as discussed in Section 3.1.1.)
Scenario 2a	Following two years of	-19.8	642	2,470
Scenario 2b	operations of the mine		0	3,112
Scenario 3	Following completion of all mining activities	-6.9	0	2,246

3.3 Conservativeness of assumptions

The key assumptions adopted for the geochemical modelling have been qualitatively ranked (low, moderate, and high) with justifications in Table 3-3. As Table 3-3 shows, the geochemical modelling undertaken was, overall, highly conservative.

Scenario(s)	Assumption	Conservativeness	Justification
All	Half of the laboratory LOR was used where laboratory non- detects were retuned.	Moderate	This is standard practice for assuming a concentration below the LOR. The LOR value could be used but this is inaccurate as the LOR, can by definition be observed.
All	Interaction of existing sulfides in the pit with the pit water is not considered	Moderate	Sulfides in the pit walls likely have some effect on pit water quality, though this was not considered for the modelling as the effect is captured by the existing water quality data.
All	Biological processes are not factored into the modelling.	High	Biological processes such as bacterial oxidation of organic matter would likely limit sulfide oxidation through the generation of anoxic conditions leading to sulfate reduction and metals sequestration (Campbell and Price 2018, MEND 2001). However these processes are not readily incorporated into geochemical modelling. Therefore, oxidation reactions which would be unlikely to occur were modelled.
2a, 2b and 3	Waste rock and tailings mineralogy is assumed to be the maxima from GHD (2018a).	High	This accounts for any potential deviation in waste rock and tailings mineralogy from that of the average or median of the samples analysed for GHD (2018a).
2a and 2b	One third of the boxcut and waste rock is assumed to be sulfidic, the	High	Results from GHD (2019c) indicate that the majority of the boxcut rock is inert.

Table 3-3 Conservativeness of assumptions

Scenario(s)	Assumption	Conservativeness	Justification
	remaining two- thirds inert.		
2a and 2b	All deposited material is assumed to equilibrate with the pit water.	High	At any one time during site operations, only the topmost layer of deposited material is likely to interact with the overlying water (Rescan Environmental Services 1989). This assumption was as conservative as possible.
3	All material deposited above -10 m AHD is assumed to equilibrate with the pit water	High	While water above -10 m AHD has been shown to be oxic, only the topmost layer of deposited material is likely to interact with the overlying water (Rescan Environmental Services 1989).
3	Pit water is assumed to be in equilibrium with the atmosphere.	High	This allows for the complete oxidation of sulfidic materials in the new tailings, i.e. the 'worst case scenario'

3.4 Water quality assessment

The water quality results from each of the geochemical modelling scenarios were compared to the Site-Specific Trigger Values (SSTVs) for discharge to the environment at the Tom's Gully site (Stauber and Batley 2018), which are reproduced below in Table 3-4.

Parameter	units	SSTV
pН	pH units	5.8-8.0
EC	µS/cm	41
TSS	mg/L	54
Turbidity	NTU	87
Sulfate	mg/L	210
Aluminium (pH>6.5)	mg/L	0.295
Arsenic	mg/L	0.042
Cadmium	mg/L	0.0004
Chromium	mg/L	0.006
Copper	mg/L	0.0018
Iron	mg/L	2.7
Lead	mg/L	0.0056
Manganese	mg/L	2.5
Nickel	mg/L	0.013
Zinc	mg/L	0.015
Total ammonia (pH 8)	mg/L	1.4

Table 3-4 SSTVs applicable at Toms Gully (Stauber and Batley 2018)

The comparisons allowed for an assessment of potential impacts at Toms Gully on aquatic life in the pit and in the receiving environment during operations (in the case of a managed release) and post-closure (in the case of wet weather passive release). This comparison does not take into consideration further treatment of water prior to release that Primary proposes.

4. **Results and discussion**

4.1 Scenario 1

The initial results for Scenario 1, where the modelling did not account for the precipitation of solids following reactions with quicklime and caustic soda, are presented below in Table 4-1. When accounting for precipitation, the target pH of 8.5 was not reached due to the establishment of equilibria in the pit with atmospheric carbon dioxide and the precipitated solids modelled. Modelling additional reagent use did not result in substantial increases to the pit water pH value.

	Units	CaO	NaOH
Molecular mass	g/mole	56.077	39.997
Modelled reagent concentration	mg/L	149	220
Resulting pH	pH units	8.54	8.51
Resulting pH accounting for atmospheric equilibrium	pH units	7.851	7.888
Total mass required for the pit	t	611	907

Table 4-1 Scenario 1 - Quicklime and caustic masses required

The modelled water quality in the pit following treatment with lime/caustic is shown in Table 4-2. The modelling predicts that following treatment with quicklime or caustic soda, the pit water would exceed the SSTVs for EC, sulfate, cadmium, copper, lead, nickel and zinc. Modelled masses of precipitates resulting for these treatment methodologies are shown in Table 4-3.

Parameter	Units	CaO treatment	NaOH treatment	Target SSTV for off- site managed release under licence ¹
рН	pH units	7.851	7.888	5.8-8.0
EC	µS/cm	2401.3	2502.3	41
Total alkalinity as CaCO ₃	mg/L	44	47	NA
Sulfate as SO ₄	mg/L	1371	1402	210
Chloride	mg/L	7	7	NA
Calcium	mg/L	304	215	NA
Magnesium	mg/L	148	157	NA
Sodium	mg/L	22	148	NA
Potassium	mg/L	8	8	NA
Aluminium	mg/L	0.0005	0.0006	0.295
Arsenic	mg/L	0.005	0.005	0.042
Cadmium	mg/L	0.077	0.079	0.0004
Cobalt	mg/L	<0.001	<0.001	NA
Chromium	mg/L	0.002	0.002	0.006
Copper	mg/L	0.003	0.003	0.0018
Iron	mg/L	<0.001	<0.001	2.7
Lead	mg/L	0.010	0.010	0.0056
Manganese	mg/L	<0.001	<0.001	2.5
Nickel	mg/L	1.342	1.373	0.013
Uranium	ma/L	0.031	0.032	NA

Table 4-2 Modelled pit water quality following treatment with lime/caustic

Parameter	Units	CaO treatment	NaOH treatment	Target SSTV for off- site managed release under licence ¹
Zinc	mg/L	5.982	5.246	0.015

1: SSTVs are for off-site managed release under licence. Indicative only for operational pit water quality purposes. Results in **yellow bold** indicate exceedances of the SSTVs.

Table 4-3 Modelled precipitate masses following treatment with lime/caustic

Precipitate		CaO tre	eatment	NaOH treatment		
Name	Formula	g/L	Total (kg)	g/L	Total (kg)	
Cobalt ferrite	CoFe ₂ O ₄	0.0013	6135	0.0013	6135	
Cupric ferrite	CuFe ₂ O ₄	0.0011	5305	0.0011	5310	
Diaspore	AIOOH	0.0420	197,430	0.0420	197,430	
Dolomite (ordered)	CaMg(CO ₃) ₂	0.0712	334,537	0.0235	110,501	
Hematite	Fe2O ₃	0.0011	5061	0.0011	5056	
Pyrolusite	MnO ₂	0.0193	90,913	0.0193	90,913	
Zincite	ZnO	0.0028	13,029	0.0039	18132	

The results of Scenario 1 identified quicklime as the preferred reagent. As such, modelling for the following scenario was undertaken using the modelled water quality following treatment with quicklime, and all further in situ treatment of the pit water was assumed to be with quicklime.

4.2 Scenario 2a

Table 4-4 shows the modelled water quality in the Pit for Scenario 2a. Note that this water quality is predicted to apply only to anoxic water at or below -15 m AHD, due to pit stratification being maintained.

Without the addition of quicklime, this scenario results in reduced pH values and increased EC compared to Scenario 1, due to the oxidation of sulfides in the waste rock and tailings allowed by the low DO concentrations observed below -15 m AHD. Calcium, magnesium, potassium and iron concentrations were predicted to increase compared to the Scenario 1 results, whereas aluminium, arsenic and copper concentrations were predicted to decrease. pH, EC, sulfate, cadmium, iron, lead, nickel and zinc were predicted to exceed the SSTVs.

The addition of 112 mg/L of quicklime was predicted to raise the pH of the anoxic water in the pit to about 7.8. This was associated with slightly reduced EC, along with a slightly increased alkalinity and reduced concentrations of sulfate and iron through the precipitation of solids. pH and the iron concentration were predicted to no longer exceed the SSTVs. As a result of the conservative assumptions summarised in Table 3-3, the model predicted acid production to be high for the scenario, thereby requiring more quicklime for neutralisation and pH adjustment than may otherwise be required in reality.

Parameter	Units	Scenario 2a	112 mg/L CaO added	Target SSTV for off- site managed release under licence ¹
pH	pH units	5.22	7.758	5.8-8.0
EC	µS/cm	13,522	13,324	41
Total alkalinity as CaCO ₃	mg/L	<1	42	NA
Sulfate as SO ₄	mg/L	9721	9558	210
Chloride	mg/L	7	7	NA
Calcium	mg/L	421	423	NA
Magnesium	mg/L	1337	1329	NA
Sodium	mg/L	22	22	NA
Potassium	mg/L	2623	2623	NA
Aluminium	mg/L	<0.001	<0.001	0.295
Arsenic	mg/L	<0.001	<0.001	0.042
Cadmium	mg/L	0.077	0.077	0.0004
Cobalt	mg/L	<0.001	<0.001	NA
Chromium	mg/L	0.002	0.002	0.006
Copper	mg/L	<0.001	<0.001	0.0018
Iron	mg/L	67.3	0.002	2.7
Lead	mg/L	0.010	0.010	0.0056
Manganese	mg/L	0.001	0.001	2.5
Nickel	mg/L	1.342	1.342	0.013
Uranium	mg/L	0.031	0.031	NA
Zinc	mg/L	5.984	5.984	0.015

Table 4-4 Modelled pit water quality - Scenario 2a

1: SSTVs are for off-site managed release under licence. Indicative only for operational pit water quality purposes.

Results in **yellow bold** indicate exceedances of the SSTVs.

4.3 Scenario 2b

Table 4-5 shows the modelled water quality in the pit following two years of mine operations, assuming loss of stratification within the pit, i.e. oxic conditions throughout the water column

A slightly acidic pH value of approximately 5.1 is predicted for this scenario as a result of the oxidation of acid-forming minerals in the deposited waste rock and tailings to the results for Scenario 2a, the addition of quicklime was predicted to raise the pH, and reduce sulfate and iron concentrations, though exceedances of the SSTVs for pH, EC, sulfate, cadmium, nickel and zinc were predicted.

Parameter	Units	Scenario 2b	73 mg/L CaO added	Target SSTV for off-site managed release under licence ¹
рН	pH units	5.078	8.258	5.8-8.0
EC	µS/cm	7415.2	7223.0	41
Total alkalinity as CaCO3	mg/L	<1	2	NA
Sulfate as SO4	mg/L	4904	4773	210
Chloride	mg/L	7	7	NA
Calcium	mg/L	485	487	NA
Magnesium	mg/L	585	585	NA

Table 4-5 Modelled pit water quality - Scenario 2b

Parameter	Units	Scenario 2b	73 mg/L CaO added	Target SSTV for off-site managed release under licence ¹
Sodium	mg/L	22	22	NA
Potassium	mg/L	985	985	NA
Aluminium	mg/L	<0.001	<0.001	0.295
Arsenic	mg/L	<0.001	<0.001	0.042
Cadmium	mg/L	0.077	0.077	0.0004
Cobalt	mg/L	<0.001	<0.001	NA
Chromium	mg/L	0.002	0.002	0.006
Copper	mg/L	<0.001	<0.001	0.0018
Iron	mg/L	74.4	<0.001	2.7
Lead	mg/L	0.010	0.010	0.0056
Manganese	mg/L	0.001	0.001	2.5
Nickel	mg/L	1.343	1.343	0.013
Uranium	mg/L	0.031	0.031	NA
Zinc	mg/L	5.989	1.866	0.015

1: SSTVs are for off-site managed release under licence. Indicative only for operational pit water quality purposes. Results in **yellow bold** indicate exceedances of the SSTVs.

4.4 Scenario 3

Modelled water quality following closure of the mine is presented in Table 4-6. More acidity is predicted to be produced in this scenario than in Scenario 2a resulting in lower pit pH values, primarily as a result of the oxidation of pyrite in the new tailings that lie within the oxic zone of the pit. This raised the predicted EC and sulfate concentration.

The addition of 230 mg/L of quicklime is predicted to raise pH to approximately 7.5, and reduce EC and concentrations of sulfate and iron. The EC, and concentrations of sulfate, cadmium, copper, nickel and zinc were predicted to exceed the SSTVs both with and without the addition of quicklime.

Parameter	Units	Scenario 3	230 mg/L CaO added	Target SSTV for off-site managed release under licence ¹
рН	pH units	2.3	7.509	5.8-8.0
EC	µS/cm	15,339	14,409	41
Total alkalinity as CaCO3	mg/L	<1	31	NA
Sulfate as SO4	mg/L	12,421	1247	210
Chloride	mg/L	1	1	NA
Calcium	mg/L	432	597	NA
Magnesium	mg/L	2465	2477	NA
Sodium	mg/L	22	22	NA
Potassium	mg/L	469	2477	NA
Aluminium	mg/L	<0.001	<0.001	0.295

Table 4-6 Modelled pit water quality – Scenario 3

Parameter	Units	Scenario 3	230 mg/L CaO added	Target SSTV for off-site managed release under licence ¹
Arsenic	mg/L	<0.001	0.001	0.042
Cadmium	mg/L	0.077	0.077	0.0004
Cobalt	mg/L	0.001	<0.001	NA
Chromium	mg/L	0.002	0.002	0.006
Copper	mg/L	0.003	0.003	0.0018
Iron	mg/L	0.466	<0.001	2.7
Lead	mg/L	0.010	0.010	0.0056
Manganese	mg/L	0.001	<0.001	2.5
Nickel	mg/L	1.349	1.355	0.013
Uranium	mg/L	0.031	0.031	NA
Zinc	mg/L	6.013	6.041	0.015

4.5 Summary

Modelling for Scenario 1 indicated that quicklime/burnt lime (CaO) would be the preferred chemical reagent for the initial treatment of the pit water, due to the lower tonnage of the reagent required and therefore the lower cost for the treatment. The model indicated that approximately 611 tonnes would be required to reach a pH of around 7.8. As atmospheric equilibria with the pit water was assumed, carbonate buffering was established by the model, and additional reagent use did not result in further increases in pit water pH values. However, it is likely that other factors that affect carbonate buffering, such as the consumption of dissolved carbon dioxide by algae for photosynthesis, would result in more alkaline pH values, further reducing the concentrations of some metals through precipitation.

Modelling for Scenario 2, which assumed conditions based on two years of mine operations, indicated that some acidity would be produced as a result of the subaqueous deposition of sulfidic waste rock and tailings. However, it is noted that the modelling did not account for biological processes, such as oxidative organic matter decomposition and bacterial sulfate reduction, which would not only limit the oxidation of sulfides, but would also reduce sulfate and metal concentrations through the precipitation of sulfides. Depending on the thermal and saline stratification of the pit water column, impacts may not be observable at the water surface. In the case of loss of stratification, the modelling indicated slightly acidic pH values in the pit. Such impacts could be actively managed during operations through the addition of further quicklime into the tails deposition stream or applied as an overall pit water treatment. Due to the conservative nature of the modelling, the amount of acidity produced under each modelling scenario was likely overestimated, though it is noted that the volume of water affected could be lower depending on the dewatering and groundwater inflow mitigation methodologies adopted during mining.

For the post-closure scenario (Scenario 3), no pit water turnover event was modelled, as the final solids level in the pit was predicted to be within the oxic water layer. The modelling suggests that acidity would be produced if biological processes do not result in anoxic conditions below the sediments which would accumulate on the surface of the deposited tailings. If routine water quality monitoring indicated acid production in the pit, additional quicklime could be used to adjust the pit pH and reduce metal and sulfate concentrations. A summary of the quicklime requirements for each modelled scenario is presented in Table 4-7, along with indicative costs.

As above, the conservative assumptions used for the post-closure scenario mean that the water quality impacts from the subaqueous deposition of tailings would likely be less than those predicted by the modelling, particularly if active pit water treatment is undertaken during operations.

Routine monitoring of pit water quality prior to, and during operations, will provide confidence in understanding pit limnology, and therefore, post-closure water quality risk.

Table 4-7 Indicative quicklime requirements for pit water pH adjustment.

Scenario	Modelled CaO concentration required for pH adjustment (mg/L)	Volume of acidic water to treat (ML)	Total mass of CaO required (t)
1	149	4100	611
2a	112	642	72
2b	73	3112	227
3	230	2246	517

NB: Costs are indicative only and do not include the capital and operational costs associated with the storage and usage of the quicklime.

5.1 Conclusions

Geochemical modelling of pit water for operational and post-closure scenarios at Toms Gully Mine has indicated that the use of quicklime/burnt lime (CaO) would most cost-effectively raise pH in the pit to reduce the concentrations of target metals in solution.

The results for the scenario which modelled conditions after two years of operations indicated that only some acidity would be generated in the pit, even in the very unlikely event that the low concentrations of dissolved oxygen present are thermodynamically available for the oxidation of sulfides. When the model accounted for loss of stratification, the higher concentration of dissolved oxygen resulted in more acidity being generated, though for both of these models pH adjustment was shown to be achievable through the further addition of quicklime. Continuous injection of quicklime into the tailings stream would allow for the neutralisation of any acidity produced, should oxidation of sulfides within the tailings occur. The rate of quicklime addition to the tailings would ideally be calibrated based on the results of tailings static and kinetic geochemical results, and pit water quality monitoring.

More acidity was predicted to be generated for the post closure scenario, as the final solids level in the pit is predicted to be within the oxic layer of pit water. This meant that oxidation of all of the sulfides within the oxic water layer was predicted, resulting in a pit water pH lower than that which is currently observed. While a literature review has shown that only the uppermost 10 centimetres of deposited solids are likely to be exposed to oxidation, the acidity predicted by the model could still be actively managed through quicklime addition in the event that reduced pH values are observed in the pit during operations.

The use of quicklime to manage pH in the pit would result in residual alkalinity in the pit, however this was not predicted by the model to raise pH above the upper target SSTV, and no SSTV for alkalinity is required for the project.

5.2 **Recommendations**

Of the initial pit water treatment options considered in the Section 14A notification, the use of quicklime (CaO) is the preferred solution as it will raise pH within the pit to a suitable level more efficiently that caustic soda.

While this report has shown that acid generation in the pit can be actively managed even in the event of loss of dissolved oxygen stratification in the pit, such an occurrence may result in the requirement of additional quicklime for pit water pH adjustment.

To further refine the risk of loss of stratification in the pit at Toms Gully, a limnological assessment could be undertaken, with the results within this report subsequently validated against the findings of the limnological assessment. Otherwise, if monitoring identifies divergence from the predicted water quality, planned water treatment will need to be undertaken.

It is recommended that a minimum of one metre of water coverage over deposited tailings and waste rock be maintained, as the literature review identified this as a standard minimum depth of cover to ensure the minimisation of metal sulfide oxidation.

Regular monitoring of pit water quality should be continued following the closure of the mine for at least a year, or until stable water quality has been established. This will allow for active management in the case that acidity is generated in the pit post closure, despite the risk of which having been assessed as low.

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Appendices

Appendix A – Baseline pit water quality

Statistical summary of pit water quality results (Primary site TGMPIT, November 2010 – December 2017), and comparison with results for sampling at depth (Site TGM25, sampled 27 May 2017).

Parameter	Units	n	20 th %ile	Median	80 th %ile	TGDP25
Physicochemical pa	arameters	;				
рН	pH units	28	3.1	3.2	3.3	3.02
EC	µS/cm	27	2125	2260	2458	2275
Turbidity	NTU	16	0.5	1.5	5	0.54
Total Suspended Solids	mg/L	26	2.5	2.5	11	NA
Major ions						
Total alkalinity as CaCO ₃	mg/L	27	1	1	3	<5
Sulfate as SO ₄	mg/L	26	1300	1400	1500	1400
Chloride	mg/L	27	6	7	7	7
Calcium	mg/L	26	198	220	230	230
Magnesium	mg/L	26	150	160	169	160
Sodium	mg/L	26	18	22	24	24
Potassium	mg/L	26	7	8	8	8.5
Dissolved metals						
Aluminium	mg/L	28	19.6	24.6	28.36	22
Arsenic	mg/L	28	0.0039	0.0050	0.0071	0.008
Cadmium	mg/L	28	0.0612	0.0788	0.1260	0.052
Cobalt	mg/L	28	0.288	0.327	0.351	0.250
Chromium	mg/L	28	0.0010	0.0018	0.0026	0.001
Copper	mg/L	28	0.224	0.302	0.500	0.180
Iron	mg/L	28	1.7	2.3	5.6	1.9
Lead	mg/L	28	0.0064	0.0097	0.0136	0.007
Manganese	mg/L	28	11.68	12.20	13.60	11
Nickel	mg/L	28	1.24	1.37	1.45	1.2
Uranium	mg/L	18	0.030	0.032	0.034	0.028
Zinc	mg/L	28	7.65	8.33	12.00	6.90

NA – Not analysed

Appendix B – *In situ* water quality depth profiles





Appendix C – Waste rock and tailings mineralogy

Sulfidic waste rock (GHD 2018a)

Mineral	Maximum % from mineralogy studies	Assumed mass in sulfidic waste rock to be deposited in pit (t)
Jarosite	8.9	44,797
Pyrite	1.4	6543
Siderite	0.1	503
Calcite	0.2	1007
Arsenopyrite	0.4	2013
Gypsum	0.4	2013

Metallurgical tailings sample 1 – assumed to represent 70 percent of the future tailings (GHD 2018a)

Mineral	Maximum % from mineralogy studies	Assumed mass to be deposited in pit (Total over life of mine)
Pyrite	0.5	3150
Marcasite	0.2	1260
Calcite	1.2	7560
Dolomite	22.3	140,490
Siderite	0.6	3780
Gypsum	0.2	1260

Metallurgical tailings sample 2 – assumed to be representative of 30 percent of the future tailings (GHD 2018a)

	%	Assumed mass to be deposited in pit (t)
Total sulfur from static geochemistry analysis	17.4	46,980
%S in FeS ₂	53.4	NA
% FeS ₂ (Assuming all S in Met tails 2 is present as FeS ₂)	32.6	87,954

Old tailings dam (TSF1) (GHD 2018a)

Mineral	Maximum % from mineralogy studies		Assumed mass to be deposited in pit (t)
Pyrite	e e e e e e e e e e e e e e e e e e e	6.2	15500
Marcasite	(0.4	1000
Arsenopyrite	Į	5.0	12500
Jarosite	Į	5.5	13750
Gypsum	(0.6	1500

New tailings dam (TSF2) (GHD 2018a)

Mineral	Maximum % from mineralogy studies	Assumed mass to be deposited in pit (t)	
Pyrite	3.9	4875	
Arsenopyrite	2.5	3125	
Jarosite	0.1	125	
Gypsum	4.0	5000	
Dolomite	2.0	2500	
Siderite	1.1	1375	

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