12. Acid and Metalliferous Drainage

12.1 Introduction

This chapter summarise information that is relevant to the broader understanding AMD at the Mt Todd mine site. The focus is on AMD with regard to waste rock handling and disposal, either to the WRD, LGO or TSFs. AMD associated with process facilities and other infrastructure is discussed to some extent. Specifically this chapter:

- describes the existing environment as it pertains to AMD;
- discusses potential AMD impacts; and
- identifies AMD management and mitigation strategies.

The potential impacts and associated mitigation measures identified in this chapter contribute to the AMD component of the project risk assessment undertaken in Chapter 5. The project risk assessment includes consequence, likelihood and residual risk ratings for AMD impacts after management measures are implemented.

The primary source for this chapter is *Mt Todd Gold Project Geochemistry Program, Draft Final Report* (Appendix L).

For the purposes of this chapter the term potentially acid forming (PAF) is used and is considered synonymous with the term potentially acid generating (PAG) which is used in some of the specialist reports referenced. Similarly, non-acid forming (NAF) is used synonymously with non-acid generating (non-PAG), and acid and metalliferous drainage (AMD) with acid rock drainage (ARD) and acid rock drainage / metal leaching (ARD/ML).

12.2 Existing and Proposed Environment

There are existing features on the Mt Todd site that currently present an AMD risk and those that have not yet been characterised to rule them out as presenting an AMD risk. These features are discussed below. In addition, there are new features proposed that have the potential to expose sulfide minerals and as such present an AMD risk. Subsequent sections address the AMD related potential impacts and management measures for each of these features respectively. The features discussed in this section are presented in Figure 2-1.

12.2.1 Batman Pit

The existing Batman Pit is both a source of and storage for AMD. Iron sulfides are visible in the pit wall above the pit lake water level. Tetra Tech (Appendix L) provides detail on AMD risk associated with Batman Pit geology. Based on this work and on visual observation, much of the existing pit wall (especially the highwall to the west and north) is PAF; however the wall has not been disturbed and therefore exposed to air.

The Batman Pit has been used as a repository for AMD water since 2005 (MWH 2006). As a result, existing pit water level and chemistry is unlikely to represent leachate associated with wall rock runoff (and inflow) alone with chemistry more reflective of the input chemistry from other water retaining structures on site.

Conceptual models have been developed to explain the existing hydrogeological conditions in and adjacent to the Batman Pit. These models indicate that at higher pit lake levels, groundwater

contamination is likely to occur in the south eastern corner of the pit, but very unlikely to occur elsewhere around the pit, due to pit geometry and the likely permeability of the rock mass. This situation will cease once the pit is dewatered and, following closure, allowed to reach its own natural level of equilibrium.

The existing conditions of the rock mass within the expanded Batman Pit shell are discussed in Tetra Tech (Appendix L).

Acid-base Accounting Criteria

Waste rock classification criteria using acid-base accounting (ABA) are presented in Table 12-1. The criteria use the neutralisation potential ratio (NPR) which is a ratio of the acid neutralising capacity (ANC) to the maximum potential acidity (MPA). Similarly, the criteria also use net acid production potential (NAPP) which is the ANC minus the MPA. Rather than using total sulfur to calculate MPA, nitric acid (HNO_3) extractable sulfide sulfur is used.

Table 12-1 Acid-base Accounting Criteria

Criteria	NPR (ANC/MPA)	NAPP (ANC-MPA) (kg H_2SO_4/t)
Potentially acid forming	> or equal to 2	> or equal to 5
Uncertain	1 up to 2	0 up to 5
Non-acid forming	< 1	< 0

Sulfur Content Criteria

Preliminary specific sulfur cut-off values for waste rock management were developed based on ABA and NAG pH. The criteria are:

- NAF waste rock defined by total sulfur content from <0.005 weight percentage (wt.%) to 0.25wt.%;
- waste rock with uncertain acid generation potential ranges from >0.25wt.% to 0.4 wt.% total sulfur; and
- the total sulfur content of PAF waste rock is >0.4 wt.%.

The low sulfur content required to potentially form acid in Mt Todd waste is attributed to the limited neutralising capacity of the bulk of the material.

Waste Rock Characterisation

Waste rock characterisation demonstrated that the exploration block model (containing total sulfur) could be used as robust proxy for preliminary static ABA and NAG pH. This method allows for an initial screen and risk based approach in the prediction of AMD. To demonstrate this, the following tests were undertaken:

- static ABA on 87 waste rock samples from five drill holes;
- six samples were subjected to short term kinetic testing and three samples subjected to long term humidity cell tests;
- mineralogy by quantitative x-ray diffraction (XRD) on the same subset of nine samples; and
- NAG testing on samples submitted to an assay laboratory.

Rock types at Mt Todd were consolidated down to three key units for the purpose of AMD classification. The sample selection process consisted of taking 18 quarter core samples over 4m intervals from three diamond drill holes (six samples each), over the three key rock units. Sections containing average to average plus one standard deviation sulfur content were sampled.

Tetra Tech (Appendix L) describes a second sampling regime which selected 75 samples from a further two diamond drill holes. These samples were selected from the three key rock units within waste rock with the aim that the samples were geospatially representative of in situ waste within the proposed pit at the time of sampling. The locations of these samples are presented in Figure 12-1.

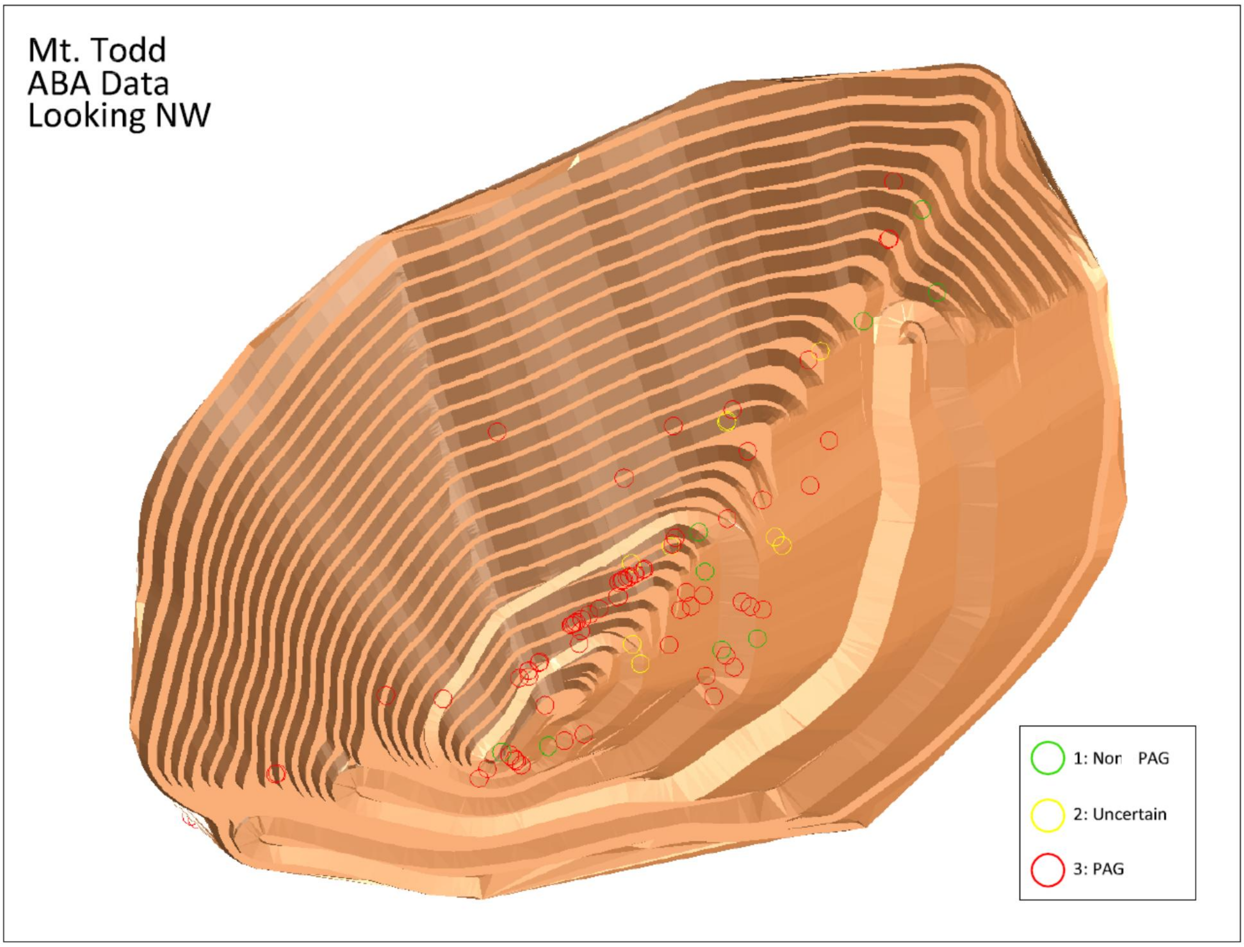

Figure 12-1 Location of AMD Classification Samples

Selected Waste Rock AMD Characterisation Results

Static Tests

Static testing on future waste rock samples (Table 12-2) determined that:

- approximately 30% of samples are highly unlikely to generate acid (< 0 kg H_2SO_4/t); and
- a majority are potentially acid forming (> 5 kg H_2SO_4/t).

Maximum NPR ratios were 14.3, 14.0 and 6.9 for greywacke, shale and interbedded samples respectively (based on sulfide sulfur). Average NPR ratios were 2.4, 3.4, and 2 for greywacke, shale and interbedded samples respectively (based on HNO_3 extractable sulfide sulfur).

Table 12-2 Summary of Waste Rock Acid-base Accounting Results

	Paste pH	Total S (wt.%)	Exploration Database Total S (wt.%)	HCl Extractable S (wt.%)	HNO_3 Extractable S (wt.%)	Insoluble S (wt.%)	MPA* (kg H_2SO_4/t)	ANC (kg H_2SO_4/t)	NAPP* (kg H_2SO_4/t	NPR*
Greywacke (n=31)										
Average	8.8	0.36	0.48	0.01	0.19	0.16	6.0	9.2	-3.3	2.4
Median	9.0	0.36	0.46	0.01	0.18	0.10	5.2	7.8	-2.7	1.6
Minimum	7.5	0.01	0.00	0.01	0.01	0.01	0.1	0.8	-18.9	0.6
Maximum	9.2	1.10	1.36	0.03	0.52	0.76	15.9	27.2	4.7	14.3
Shale (n=26)										
Average	8.3	0.47	0.67	0.01	0.31	0.15	9.5	8.5	1.0	3.4
Median	8.5	0.36	0.74	0.01	0.22	0.08	6.7	5.7	-2.2	1.7
Minimum	5.8	0.01	0.01	0.01	0.01	0.00	0.1	0.5	-28.4	0.2
Maximum	9.4	1.82	1.16	0.02	1.79	1.04	54.8	31.8	46.1	14.0
Interbedded (n=30)										
Average	8.6	0.77	0.60	0.01	0.51	0.26	15.5	10.8	4.7	2.0
Median	8.8	0.51	0.48	0.01	0.20	0.14	6.1	6.8	-0.4	1.3
Minimum	6.7	0.01	0.01	0.01	0.01	0.00	0.1	0.7	-65.0	0.0
Maximum	9.4	3.81	1.77	0.02	3.61	1.11	110.6	83.7	106.5	6.9

*Based on HNO_3 extractable sulfide sulfur

Note: values for NAPP and NPR are based on average, median, minimum and maximum values for the whole data set for each test / method

Sulfide minerals observed in the waste samples include sphalerite, arsenopyrite, galena, pyrite, pyrrhotite and marcasite (Appendix L). Of these, arsenopyrite, pyrite, pyrrhotite and marcasite present a higher risk of AMD due to their reaction kinetics under atmospheric conditions (DITR 2007). Sulfide minerals are also associated in and around the main gold mineralisation (Vista Gold *pers. comm.*). The major carbonate minerals present in the samples are calcite, siderite and ankerite / dolomite. Silicate minerals which have the potential to provide neutralising capacity under specific conditions include clinochlore, muscovite, biotite, K-feldspar, plagioclase and actinolite. It is recognised that reaction kinetics renders these silicate minerals largely ineffective in most situations (DITR 2007).

Kinetic Tests

The nine waste rock samples selected for kinetic testing were subjected to up to 146 weeks of humidity cell testing. Weekly leachate quality results were obtained for pH, acidity, alkalinity, electrical conductivity and sulfate over the entire test duration. Monthly leachate composites for dissolved constituent concentrations were also obtained over the testing period. Of the nine samples subjected to kinetic testing, a shale sample with 0.43 wt.% HNO_3 extractable sulfide sulfur and low neutralisation potential (3.7kg $CaCO_3$/t) produced acidic leachate ($pH < 6$) from the initiation of testing. Elevated copper, lead, nickel and zinc levels were observed in leachate from the acid generating cell. Cells producing neutral pH leachate showed comparatively high levels of arsenic and antimony suggesting water contact could result in release of these constituents.

Wall Rock Characterisation in Batman Pit

Using the sulfur content criteria described above, in conjunction with the block model and proposed pit shell; the relative proportions of each classification of material were calculated. The results predict that 229Mt (41%) of NAF material, 101Mt (18%) of uncertain material and 233Mt (41%) of PAF material are contained in rock within the Batman Pit. In general PAF material dominates the western half of the pit with the NAF on the eastern potion (Figure 12-2). Alteration associated with granite in the western side of the pit and the abundance of sulfides may be related to this distribution.

12.2.2 Waste Rock Dump

Existing WRD and RP1

The existing WRD is a source of AMD (MWH 2006). RP1 partially contains seepage from the dump. Sulfides are visible in the waste rock and are oxidising as demonstrated by leachate water quality and the presence of secondary salts on weathered rocks. No engineered cover is present on the WRD to manage infiltration and no liner is evident beneath the dump to manage leachate. The WRD consists of up to four lifts using a combination of end and paddock dumping.

At present, much of the incident rainfall infiltrates the highly permeable WRD and likely discharge points are at its toe (which flow via v-notch weirs into RP1), or into the bedrock and groundwater.

The Tetra Tech (Appendix L) study for the mine expansion has relevance to the existing WRD in that it can be extrapolated that the WRD contains a significant proportion of PAF material as mining will occur in the same deposit as was previously mined.

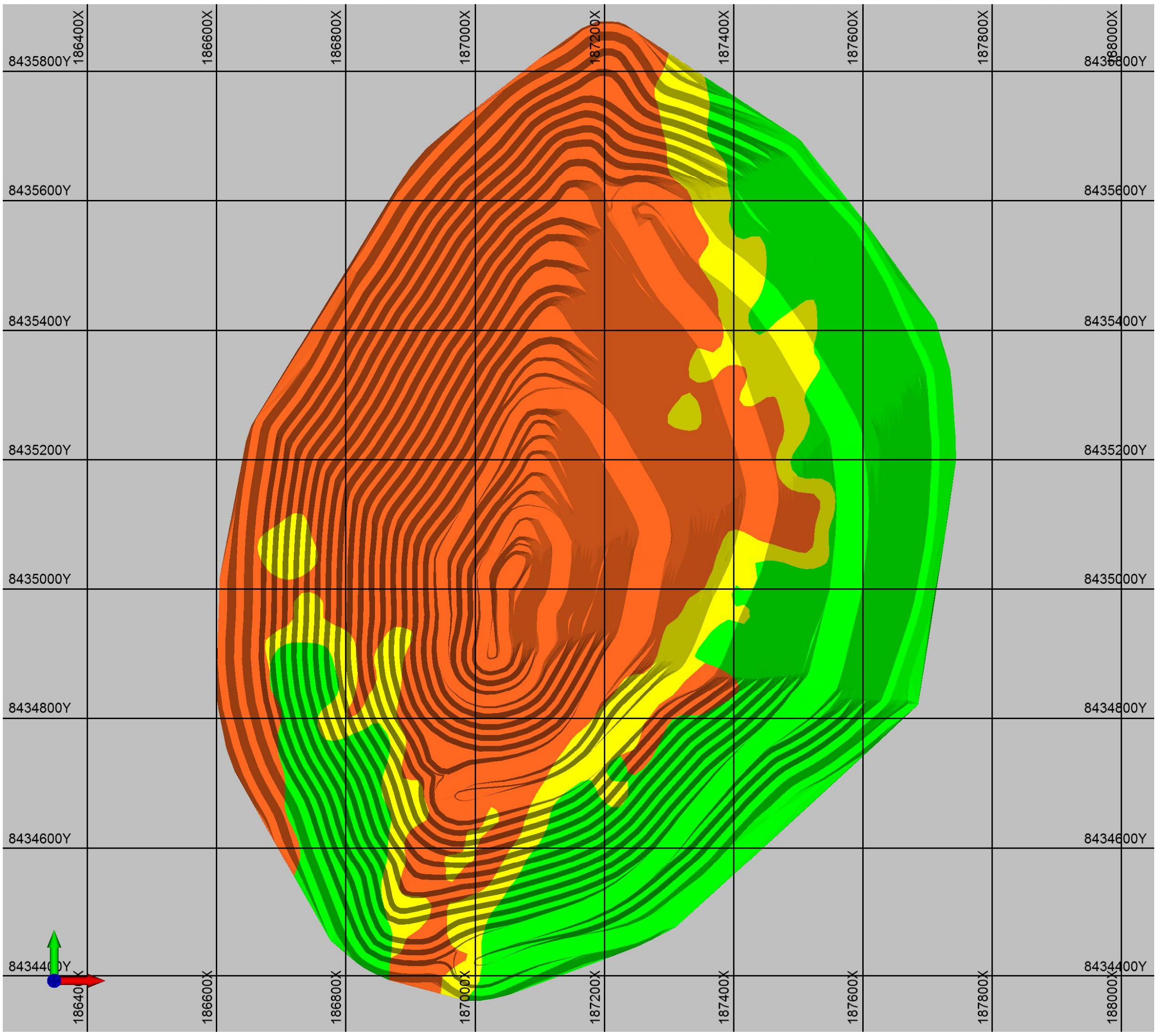

Figure 12-2 Acid-base Accounting Criteria for the Proposed Batman Pit

Orange = PAF, yellow = uncertain and green = NAF

Expansion of the WRD

Waste rock proposed to be placed in the WRD will be sourced from the Batman Pit in approximately the following proportions (Appendix L):

- NAF 160Mt (32%);
- uncertain 101Mt (21%); and
- PAF 233Mt (47%).

Waste from ore processing (approximately 172Mt) will be disposed to TSF1 and TSF2. The balance of the NAF material from the pit (approximately 68Mt) will be used for construction (TSF1 raising, TSF2 and site roads) and cover (HLP, TSF1 and TSF2) requirements.

12.2.3 Tailings Storage Facilities

TSF1

TSF1 contains tailings generated from previous site operations. No surface cover (other than a partial water cover) and no liner are present under TSF1 to prevent seepage of leachate. TSF1 contains a number of drains (under and over) which play a major role in the movement of water within the structure. TSF1 and its current condition are described in Tetra Tech (2012b). Seepage modelling relating to the proposed raising of TSF1 is relevant to the existing structure.

Field investigations show that AMD is discharging from TSF1 into the groundwater system and Horseshoe Creek. The current understanding of AMD in TSF1 is:

- the presence of sulfidic minerals, the low NPR values and high NAPP values demonstrate the potential affinity for AMD generation in the tailings materials (Earth Systems 2011a); and
- a downward migrating oxidation front is observed due to the lack of residual alkalinity and carbonate dissolution to neutralise acid production. As TSF1 is being seasonally recharged the deeper tailings (>3-4m) are continually saturated causing limited oxidation and acidity (Earth Systems 2011b).

Like the Batman Pit, the existing water chemistry in TSF1 will not represent leachate associated with tailings porewater because TSF1 has been one of the primary facilities for storing excess water from the remainder of the site. This complicates the chemistry and gives less confidence in using the conditions that have developed in TSF1 as an analogy for future conditions. There is a decant system under TSF1 which will be used to capture and recycle water during operations. At closure this system will be closed off.

Tailings Characterisation

Tailings characterisation from an AMD perspective was undertaken as part of the original EIS (NSR Environmental Consultants 1992), and for the current proposal by Earth Systems (2011, a and b) and Tetra Tech (2013 and Appendix Y). Historical methods for tailings characterisation include (Appendix L):

- static testing (ABA, elemental analysis) on the solids and supernatant, and kinetic testing on tailings with similar total sulfur content as later tailings (NSR Environmental Consultants 1992);
- a site investigation in 2011 focusing on tailings solids, porewater and supernatant to assess the affinity for acid generation and migration associated with the current tailings storage facility (RP7/TSF1) (Earth Systems 2011, a and b):
- static testing in 2010 including Synthetic Precipitation Leaching Procedure, ABA and XRD assessments on tailings solids and water quality analysis on the supernatant (Tetra Tech 2013); and
- static testing in 2011/12 which included Synthetic Precipitation Leaching Procedure, ABA and XRD assessments on the tailings solids, water quality analysis on the supernatant and kinetic humidity cell testing (Appendix L).

Selected Tailings AMD Characterisation Results

Static Tests

Summary results for the acid base accounting of two tailings samples are presented in Table 12-3.

These data demonstrate that the tailings have the potential to generate acid upon oxidation.

Table 12-3 Summary of Tailings Acid-base Accounting Results

Paste pH	HNO_3 Extractable S (wt.%)	Total S (wt.%)	MPA* (kg H_2SO_4/t)	ANC (kg H_2SO_4/t)	NAPP* (kg H_2SO_4/t)	NPR*
7.9	1.04	1.25	31.9	12.1	19.8	0.4
N/A	0.16	1.13	5.0	1.4	3.6	0.3

*Based on HNO_3 extractable sulfide sulfur
N/A – not analysed

Kinetic Tests

Kinetic testing of a 1.4 wt.% sulfur tailings sample conducted in support of the 1992 EIS (NSR Environmental Consultants 1992) generated leachate with acidic pH after approximately one year.

As of December 2012, the single tailings humidity cell had been running for 32 weeks with the following observations (Appendix L):

- pH values steady declined and are currently at 7.2;
- sulfate concentrations dropped after an initial flush of likely soluble sulfate salts to a low of 20mg/L at week 4 before slowly increasing with time towards 200mg/L;
- concentrations of aluminium and iron steadily decreased with time;
- total metal concentrations of copper, lead, nickel, and zinc steady climbed after initially decreasing during the initial flushes. Total metals decreased over the initial four weeks of testing to below 0.01mg/L, before steadily increasing to 0.1mg/L;
- arsenic and antimony concentrations decreased by an order of magnitude after an initial flush;
- alkalinity values appeared to stabilise after week 20 near a concentration of 10mg/L; and
- thiocyanate and total cyanide generally decreased during testing with final values reported at 0.2mg/L and 0.02mg/L, respectively. WAD cyanide remained constant after the initial flushes and was several orders of magnitude lower than total cyanide.

Sulfate production and carbonate consumption rates quickly decreased after the initial weeks and have reported similar values throughout the 32 weeks of testing. After Week 32, abundant sulfide sulfur content (95%) still remains, while only an estimated 18% of the neutralization potential remains).

Proposed TSF2

The proposed TSF2 is located in an area associated with small-scale historical mining and minor AMD is observable associated with some of these workings. Two up-gradient groundwater monitoring bores were installed as part of the EIS study to provide baseline groundwater conditions. These bores demonstrated that the bedrock is relatively permeable at depth.

12.2.4 Process Related Facilities

HLP and Moat

The HLP has an existing HDPE liner system at its base. No cover exists on the HLP. Material in the HLP is likely to be metalliferous due to the metals and low pH conditions observed in the surface water and seepage stored in the HLP ponds.

LGO1

Water chemistry in RP2 (MWH 2006) demonstrates that LGO1 is currently a source of AMD. The stockpile has no liner or cover. The geochemical characterises of the material in LGO1 has not been determined, however, a conservative approach is to assume that it is PAF.

Scats Stockpile / Proposed LGO2

A stockpile of mining scats is present at the proposed LGO2 site. The uniform gravel sized mill rejects stockpile (scats) appears to be mildly oxidised on the surface of the pile. Drainage on the eastern side of the stockpile reports to TSF1. The stockpile has no liner or cover. Like LGO1, it is reasonable to assume, based on site geochemical results, that it is PAF. During mining this site will be used for a new LGO stockpile.

ROM Pad

The ROM Pad is located immediately to the east of Batman Pit and was used to stockpile ore for feed to the primary crusher. It has a footprint of approximately 9ha and is estimated to contain 1.3Mm^3 of material. This stockpile will be relocated to the WRD and a new pad established.

Process Plant and Pad Area

Water chemistry in Batman Creek, RP5 and RP6 (MWH 2006) indicates that AMD is occurring from the existing process plant and pad area. This indicates that material in this area is PAF or that this water is from other up-gradient sources. The WTP and associated equalisation pond will be located in this area. It is proposed that during mining all water from this area will be directed to the equalisation pond prior to treatment in the WTP.

12.2.5 Other Mine Infrastructure

Mine Roads

Whilst unproven, there remains the potential that the current network of mine roads on site was constructed from mine waste from previous operations at Mt Todd. Similar to the material in the WRD, it remains unclear if the road construction material was characterised and segregated, such that only NAF material was used in construction. No assessment of this material has been undertaken.

Drainage Diversion Channels

A network of large drainage diversion channels have been excavated around major mine infrastructure features. Most of these structures are shallow and have been constructed through oxidised NAF material (for example the channels surrounding RP1). In deeper channels where non-oxidised material has been encountered there is the potential for the base and wall rock of these features to contain sulfides and to therefore be an AMD source. No assessment of this material has been undertaken.

Historical Mine Workings

In addition to the existing Batman Pit, there are numerous small-scale historical mine workings including the Golf / Tollis Pits and Quigleys workings. These provide additional, but as yet unquantified, sources of AMD to the system. Baseline groundwater monitoring data indicates that metals and metalloids are elevated above reference values. It is unclear if these baseline readings are a function of the historic workings or due to naturally high background concentrations in this mineralised area.

Proposed Horseshoe Creek and Stow Creek Diversion Channels

The proposed Horseshoe Creek and Stow Creek diversion channels are planned to be excavated through bedrock. The base and wall rock of this diversion has the potential to contain sulfides potentially resulting in AMD generation. No assessment of this material has been undertaken.

Existing Topsoil / Plant Growth Material (PGM) Stockpiles

Two PGM stockpiles exist on-site, one adjacent to (east of) the WRD and a second adjacent to (north west of) TSF1, and numerous additional topsoil stockpiles across the site. It is assumed that PGM will be available from these stockpiles and from salvage below disturbance areas such as TSF 2 and the expanded WRD. No testing of chemical or physical characteristics such as sodicity, salinity or dispersive potential of these materials has been undertaken.

Constructed Wetland for Passive AMD Treatment

It is planned to construct three passive or semi-passive water treatment systems to treat AMD flows from TSF1 and the HLP during mining, and from the rehabilitated WRD and TSF2 post-mining once flow rates and pH are reduced to levels that makes passive treatment viable.

The most likely treatment system is an anaerobic wetland as these are commonly used for treatment of mining impacted waters. Subsurface wetlands, when properly constructed, create an oxygen deficient environment which enables the growth of sulfate-reducing bacteria. Growth of the sulfate-reducing bacteria is encouraged by the presence of the desired electron acceptor (sulfate) and electron donors (organic carbon substrates), while minimising the population of other bacteria that would compete for the electron donors. Maintaining an oxygen deficient system is critical in minimising the population of bacteria that may scavenge the electron donors from the sulfate-reducing bacteria and thereby minimise the growth of the sulfate-reducing bacteria populations.

The presence of the electron acceptor, sulfate, is provided in the source water. The electron donors in the form of organic carbon substrates must be supplied in the constructed wetland.

The key mechanisms for treatment within a subsurface constructed wetland include:

- sulfate reducing bacteria respire sulfate and transform the sulfate to soluble sulfides (H_2S, HS^- and S^{2-}); and
- the soluble sulfides react with cationic metal ions (i.e. Me^{2+} such as Fe, Ni, Cu, Zn) to form highly insoluble metal sulfides.

The reaction can be simplified as follows:

$$2CH_2O + SO_4^{2-} \rightarrow 2HCO_3^- + H_2S$$

where CH_2O is a simple organic carbon source. In addition, sorption of dissolved metals to negatively charged substrates may result in short or long-term immobilisation (Halverson 2004).

The location of these wetlands is yet to be determined and consequently no assessment of AMD can be made at this stage in relation to their construction.

12.3 Potential Impacts

12.3.1 Batman Pit

Mining will expose PAF wall rock which will potentially result in the generation of additional AMD. Geochemical modelling of the proposed pit returned a predicted pH 3.98, with metal concentrations similar to RP1 water quality (Appendix L). Pit walls containing PAF material will be exposed to oxygen and water (rainfall and groundwater inflow). During mining, pit water will be treated via the WTP.

At the completion of mining the pit will be allowed to flood until it reaches its steady state level (Appendix K). The conclusion from this study was that Batman Pit geometry is likely to result in an excess of evaporation over rainfall and runoff reporting to the pit, which will result in a pit lake level below the level of the regional water table. This will result in the void acting as a localised groundwater sink, preventing outward migration of pit water.

The modelled results indicated that a deep pit lake will develop after closure. Given the existing conditions in Batman Pit, and the large exposure of PAF material on the highwall (much of which will remain above water), it is highly likely that post-mining the Batman Pit lake will become acidic.

12.3.2 Waste Rock Dump

Existing WRD and RP1

Left unmanaged AMD from the WRD and RP1 has the potential to impact local surface waters. RP1 is not large enough to effectively manage runoff from its catchment and therefore not capable of containing AMD from the WRD (MWH 2006). RP1 has been observed to overflow in large storm events with AMD affected waters discharging to the Edith River in flood. AMD discharging at the toe of the WRD has the potential to impact flora and fauna which come into contact with it.

Expanded WRD

The existing WRD contains approximately 16Mt of waste rock and this will be expanded to provide capacity of around 510Mt. Most of the material to be placement in the WRD will come from the extension to the Batman Pit. Additional material destined for the WRD include existing materials from the process plant area and, potentially, sludge from the WTP. These additional sources will make up minor amounts in terms of volume.

A total of 233Mt of PAF material is planned to be placed in the WRD. A further 101Mt of waste rock classified as uncertain, along with the existing 16Mt will form the core of the planned WRD.

Tetra Tech (Appendix L) produced a geochemical model of the proposed WRD to estimate water chemistry in RP1 during mining. The results indicated that seepage waters from the WRD would likely be acidic with an approximate pH 4. Modelled concentrations of surface water chemistry in RP1 (i.e. WRD leachate diluted by rainfall) revealed the following concentrations:

- Cobalt at 0.136mg/L;
- Copper at 0.569mg/L;
- Cadmium at 0.007mg/L;
- Sulfate at 115.4mg/L;
- Nickel at 0.173mg/L; and
- Lead at 0.023mg/L.

AMD discharge from the WRD has the potential to impact flora and fauna which come into contact with it.

Tetra Tech (2012c) modelled three proposed WRD designs to estimate likely seepage rates post-closure and capping. The modelled designs produced acidic pH seepage due to the minimal alkalinity in the NAF rock to neutralise the acidity generated by the PAF rock.

The model indicated that by using the preferred closure design the amount of water that will travel through the facility is minimal (i.e. it reaches a steady state of 4 - 5m^3/h in year three after closure). Tetra Tech (2012c) indicated that a thicker GCL cover could be placed on the WRD benches than was modelled (52m rather than 25m) so modelled seepage rates would be lower if this new cover was incorporated into the seepage model. This discharge water is likely to remain acidic and if not managed this AMD could contaminate surface water and groundwater.

12.3.3 Tailings Storage Facilities

TSF1

During production, management measures including reinstating the existing underdrainage system will minimise potential impacts at TSF1. As discussed above, ABA and previous kinetic testing has demonstrated that tailings have the potential to produce acid. Tetra Tech (Appendix L) states that available neutralisation capacity is likely to be exhausted at increasing depths leading to the onset of acidic conditions and higher metal loads if TSF1 is left unmanaged. As a consequence, AMD from TSF1 has the potential to impact on local groundwater and surface waters. There is also the potential for flora and fauna to be impacted through contact with AMD:

- in waters discharging from TSF1 at the toe of the facility;
- in artesian flow through poorly constructed monitoring bores adjacent to TSF1; or
- from surface water in Horseshoe Creek.

Raising of TSF1 and Proposed TSF2

Tailings in the raised TSF1 and new TSF2 will be PAG. 62Mt of thickened tailings will be placed in the raised TSF1 during the initial four years of mining with 161Mt planned for TSF2 over a period of 8 years.

There remains the potential for impact from AMD via uncontrolled seepage resulting in contamination of surface waters and groundwater from a raised TSF1, as currently occurs from the existing TSF1. Additional lifts would result in additional head within the raised TSF1 thereby increasing uncontrolled seepage flow rates if left unmanaged. It should be noted that use of the existing underdrainage system correctly is expected to significantly lower uncontrolled seepage rates. In addition, alkaline process water is planned to be pumped into TSF1 during mining, potentially lowering dissolved metal concentrations in leachate.

Seepage analysis was conducted to:

- estimate the steady state phreatic surface within the TSF1 and TSF2 impoundments;
- estimate seepage quantities from TSF1 and TSF2 during mining; and
- estimate post-closure drain down flows from the impoundment.

Modelled seepage flow rates from the capped TSF1 peak at approximately 53m^3/day after mining ceases, gradually decreasing to approximately 35m^3/day after 100 years and a continued decrease beyond that to a steady state of approximately 10m^3/day (Tetra Tech 2012d).

Modelled seepage flow rates from the capped TSF2 peak at approximately 175m^3/day after mining ceases, gradually decreasing to approximately 45m^3/day after 100 years and a continued decrease beyond that.

12.3.4 Process Related Facilities

HLP and Moat

Left unmanaged the HLP and moat is likely to be a source of AMD with the potential for AMD to overtop the liner and moat. This has the potential to result in surface and groundwater contamination and to potentially impact flora and fauna in contact with AMD waters. It is proposed that HLP material will be processed in mining years 12 and 13 with the site then rehabilitated.

LGO1

Left unmanaged LGO1 is likely to be a continued source of AMD generation. There is potential for AMD generated in LGO1 to impact groundwater and surface water in Batman Creek and to potentially impact flora and fauna in contact with AMD waters. Ore within the stockpile will be reprocessed and the existing LGO1 footprint will be consumed by the proposed Batman Pit.

Existing Scats Stockpile

Left unmanaged the scats stockpile is likely to be a source of AMD generation. There is the potential for AMD generated from the stockpile to impact surface water and to potentially impact flora and fauna in contact with AMD waters. Scats will initially drain to TSF1 and then will be reprocessed and the site used for the new LGO2.

Proposed LGO2

The new LGO2 will contain low grade ore which will be progressively processed and replenished throughout the mining phase. Although AMD predictions on this ore have not been conducted it is likely that it will be a source of AMD if left unmanaged. It is therefore assumed that AMD from LGO2 will have the potential to impact surface and groundwater.

ROM Pad

The existing ROM Pad will be relocated to the WRD and a new pad established to service the Project. The new pad will be constructed from NAF material.

Process Plant and Pad Area

The process plant and pad area is potentially a source of AMD. A remedial action plan for this area will be prepared prior to removal of infrastructure and earthworks in the area. If left unmanaged this may continue to produce AMD beyond closure.

12.3.5 Other Mine Features

Mine Roads

Left unmanaged the existing mine roads could produce AMD over a broad area if they have been constructed from PAF material with the potential for AMD to impact groundwater and surface water across the site. The extent of impact (if any) from existing mine roads has not yet been quantified.

New mine roads will only be constructed from NAF material.

Drainage Diversion Channels

The existing drainage diversion channels were constructed to protect infrastructure from flooding in addition to segregating clean and dirty water. If the deeper channels were constructed in bedrock containing PAF material, there is potential for surface water and groundwater in contact with the channels to be impacted by AMD. Furthermore, several channels are down hydraulic gradient from existing AMD sources, thereby having the potential to act as AMD conduits to Horseshoe Creek and the Edith River.

Horseshoe Creek and Stow Creek Diversions

The Horseshoe Creek and Stow Creek diversion channels will be excavated into bedrock and there is the potential to intersect PAF materials. The extent of impact (if any) from AMD associated with excavation of the diversion channel has not yet been quantified.

Historic Mine Workings

If left unmanaged the historic mine workings on the Mt Todd site, including the Golf / Tollis Pits and Quigleys workings are likely to continue to be an AMD source. These features have the potential to impact surface and groundwater. The extent of impact (if any) from historical mine workings has not yet been quantified.

Constructed Wetland for Passive AMD Treatment

As the location and final form of the passive / semi-passive treatment has not yet been determined it is difficult to discuss the impacts of the discharged treated water on surface water quality. However, it is anticipated that the treatment systems will be designed to substantially reduce contaminants in the AMD (sulfate in particular), and allow the discharge to meet water quality criteria prescribed in the Waste Discharge Licence. Further, the use of the passive / semi-passive systems will minimise any adverse impacts caused by AMD entering the Edith River by removing contaminants and raising pH.

Potential impacts from the constructed wetlands include:

- under performance resulting in output water not being treated to adequate levels or under-sizing due to the large areas required by such systems;
- flooding (either by rainfall or by breaching of creek and river banks) resulting in remobilisation of precipitates and metals contained in the wetland causing downstream contamination; and
- groundwater contamination beneath the system.

12.4 Management Measures

Proposed management strategies for each mine feature are discussed below. Management strategies are discussed on the hierarchical approach proposed by DITR (2007):

- prevention;
- minimisation;
- control; and
- treatment.

12.4.1 Batman Pit

During Mining

During mining, groundwater inflow, rainfall into the pit and the resultant AMD generated will be managed via in-pit sump pumping to the WTP. No pit water will be discharged without treatment.

Post-mining

At the completion of mining the pit is likely to behave as a sink under average conditions, effectively confining AMD to the pit and preventing release to the environment outside of the pit (Appendix K). Mine water contained in the pit void is the long term passive solution for AMD containment.

The preliminary mathematical model of groundwater behaviour post-mining requires validation and the input of peak flow conditions to confirm the likelihood of sink conditions being maintained. In addition, detailed work has not been completed to date on in-pit water quality following closure.

12.4.2 Waste Rock Dump

Existing WRD and RP1

The existing WRD is proposed to be retained as the core of the expanded WRD. RP1 is also expected to be retained in a modified form to suit the revised catchment area. AMD management for both of these features during and post-mining is addressed below.

Expanded WRD

During Mining

Chapter 24 outlines construction techniques for the WRD.

A Waste Rock Management Plan will be developed that specifies how waste rock is to be handled to minimise the potential for AMD and maximise the beneficial use of NAF waste rock for closure. The Waste Rock Management Plan will include:

- routine waste rock testing procedures such as collecting monthly samples for analysis of carbon and sulfur that can be used to confirm data from the blast hole database;
- staging dump construction to minimise the contact of PAF rock with air and water;
- selective handling and isolation of the highest sulfide material;
- contouring WRD surfaces to shed precipitation and runoff away from PAF materials during production and at closure; and
- sequential closure of inactive dump areas and faces as mining progresses.

The results of this planning effort will include managing waste rock disposal so the outer layers of the WRD at closure are composed of NAF waste rock. The Waste Rock Management Plan will also emphasise the implementation of operational techniques and dump designs that encourage clean water diversion, rapid internal surface runoff, and seepage control during operations and at closure.

Seepage to surface (and potentially much of the groundwater seepage) is proposed for management in RP1. RP1 waters will be treated in the WTP prior to discharge during mining.

Post-mining

The design of the WRD and cover system (Chapter 24) represents a proactive approach to minimising AMD following closure by limiting infiltration and creating an anaerobic environment. AMD seepage that does occur from the WRD will be controlled and treated passively via a constructed wetland or multiple wetlands.

12.4.3 Tailings Storage Facilities

Raising TSF1

During Mining

Tetra Tech (2012d) describes the design and operational concepts for the recommissioning and raising of TSF1. From an AMD perspective the key item from the operational concept is that TSF1 will become a zero discharge facility with all contact water from TSF1 contained within the process circuit. Achieving this would result in improved outcomes during the mining period for TSF1, as controlled seepage via the drainage system would be managed and routed to the WTP.

Flow rates for TSF1 water requiring management during operations are estimated to be between 400 and 800m^3/h in Dry and Wet Seasons respectively. These rates include return water from the decant towers, seepage collected within the underdrain system and seepage from the upstream toe drain.

Furthermore, alkaline water from the process circuit is anticipated to provide significant buffering capacity for TSF1 during mining. The addition of alkaline water could be considered a buffering treatment for existing AMD in TSF1.

Post-mining

The closure strategy for TSF1 is outlined in Chapter 24.

The cover system is designed to minimise water infiltration and oxygen ingress and consequently to minimise AMD generation. The seepage collection system is designed to control and treat any AMD generated.

New TSF2

During Mining

The new TSF2 will be managed in the same manner as the raised TSF1. TSF2 will have a similar seepage and collection system as TSF1. The key difference with TSF2 will be the installation of a bottom liner for tailings containment consisting of a low-density polyethylene geomembrane. The liner will extend along the base of the impoundment as well as the upstream slopes of the stage 1 embankment (Tetra Tech 2012a).

Post-mining

TSF2 will be decommissioned and closed in a similar manner to TSF1. The cover system is designed to minimise water infiltration and oxygen ingress to minimise AMD generation, and the seepage collection system is designed to control and treat any AMD generated.

12.4.4 Process Related Facilities

HLP and Moat

The closure strategy for the HLP and moat is outlined in Chapter 24.

LGO1

Surface flowing AMD from this area will be contained and treated in the WTP. Any AMD impacting groundwater below LGO1 will be partially contained during mining by the general flow towards the operational pit (Appendix K). Ore within the stockpile will be reprocessed and the LGO1 area will be consumed by expansion of the Batman Pit. No specific closure management measures for AMD are required.

Scats Stockpile / LGO2

During Mining

Surface flowing AMD from this area will be collected and treated in the WTP during mining. Any AMD impacting groundwater below the stockpile will be partially contained during mining by the general flow towards the operational pit (Appendix K). This condition may continue in part post-mining if the pit continues to behave as a sink.

Post-mining

The closure strategy for the LGO stockpile area is outlined in Chapter 24.

ROM Pad

During mining runoff from the ROM pad will be contained and treated in the WTP. Any AMD impacting groundwater in the area will be partially contained during mining by the general flow towards the operational pit (Appendix K). This condition may continue in part post-mining if the pit continues to behave as a sink. At the completion of mining, any PAF material remaining in the pad will be removed and disposed to the WRD.

Process Plant Area

During Mining

Like the stockpile areas surface flowing AMD from this area during mining will be contained and treated in the WTP. Any AMD impacting groundwater in the area will be partially contained during mining by the general flow towards the operational pit (Appendix K). This condition may continue in part post-mining if the pit continues to behave as a sink.

Post-mining

The closure strategy for the Process Plant Area is outlined in Chapter 24.

12.4.5 Other Mine Features

Mine Roads

Only NAF material is proposed as construction material on new mine roads, thereby lowering the risk of AMD generation. Mine access roads will remain in place to provide post-mining access and mine haul roads will be closed by grading into surrounding topography, ripping subgrade materials, placing 0.2m of PGM and revegetating the areas when available. No subsequent management of AMD is expected.

Drainage Diversion Channels

Assessment of AMD in the drainage channels constructed through bedrock needs to occur and management measures will be developed once this work has been completed.

Historical Mine Workings

Assessment of AMD in historical mine workings needs to occur and management measures will be developed once this work has been completed.

Horseshoe Creek and Stow Creek Diversions

Assessment of AMD in the creek diversions needs to occur and management measures will be developed once this work has been completed.

Constructed Wetland for Passive AMD Treatment

The concept of the constructed wetland for passive AMD treatment is the preferred management measure for the ongoing treatment of AMD discharge from the TSF1, TSF2 and the WRD. No specific management measures have been documented for the management of AMD as the wetlands are at a conceptual stage.

12.5 Additional Studies

This chapter has focussed on AMD as it relates to waste rock handling and disposal to either the WRD or TSFs as this constitutes the greatest AMD risk during and post-mining. Additional work will be required to build a comprehensive understanding of AMD across the site, in relation to existing legacy issues and ongoing management of AMD. The following outlines additional work proposed by Vista Gold.

Throughout the mine-life, Vista Gold will anticipate, plan, design and implement effective plans for:

- identification of PAF and NAF materials;
- selective handling of PAF and NAF material and potentially direct treatment of PAF material to prevent or reduce the generation of AMD;
- short and long-term hydrologic isolation of PAF material from ground and surface water; and
- control of stormwater to prevent excessive erosion and sedimentation.

This work will cover waste rock together with existing potential site liabilities and liabilities associated with new developments including:

- mine roads;
- drainage diversion channels constructed through bedrock;
- historical mine workings;
- topsoil and PGM stockpiles;
- the site of the constructed wetland; and
- the new Horseshoe Creek and Stow Creek diversions.

As the Project progresses the following work will be undertaken:

- a predictive geochemical pit lake model will be developed to assess the long-term acidity after cessation of mining operations;
- additional ABA will be undertaken to confirm that waste rock is adequately represented by the characterisation program;
- a subset of waste rock samples will be subjected to NAG pH testing to assess the adequacy of the proposed technique as a method for waste rock segregation. The NAG test extract will be analysed to estimate the potential release of metals in proportion to sulfate as a result of sulfide oxidation;
- additional tailings samples will be subjected to static testing to confirm the preliminary findings to-date. Humidity cell testing will also be initiated to investigate long-term metal leaching and the potential to generate acid;
- a Waste Rock Management Plan will be developed to specify how the waste rock types will be handled to minimise the potential for AMD and maximise the use of NAF waste rock for closure; and
- a Tailings Management Plan will be developed to specify how tailings will be handled to minimise AMD, facilitate closure, rapid dewatering, and consolidation of tailings.

The following studies will be undertaken to advance the understanding of the WRD:

- confirm the composition and hydraulic properties of the fines material that will be placed to obtain the confining pressures;
- quantify the concentrations of sodium and magnesium associated with the fines material and rainwater due to the potential for elevated sodium and magnesium concentrations to increase the hydraulic permeability of the GCL; and
- confirm the viability of an engineered wetland to treat AMD emanating from the WRD and prevent impacts to local waters.

The following specific closure investigations will be undertaken to address information gaps:

- analysis of waste and cover material hydraulic properties;
- tailings trafficability study;
- precipitation-watershed yield study;
- site-wide soils, closure cover, and rehabilitation material inventory and characterisation study; and
- waste and closure cover erosion and sediment control study.

A design for the constructed wetland will be finalised to confirm that water quality exiting the wetlands will meet water quality objectives prescribed in the WDL.