

# FINAL REPORT

## POTENTIAL FOR METALLIFEROUS DRAINAGE AND PIT LAKE ACIDIFICATION AT THE TROPICANA GOLD PROJECT

*Prepared for*

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## Revision Code\*

A – Report Issued for Internal Review

1 – First Revision

B – Draft Report Issued for Client Review

2 – Second Revision

C – Final Report Issued to Client

3 – Third Revision

The sole purpose of this report and the associated services performed by Soil Water Consultants (SWC) was to undertake a geochemical assessment of the Tropicana Gold Project. This work was conducted in accordance with the Scope of Work presented to AngloGold Ashanti Australia on behalf of the Tropicana Joint Venture ('the Client').

SWC performed the services in a manner consistent with the normal level of care and expertise exercised by members of the earth sciences profession. Subject to the Scope of Work, the geochemical assessment was confined solely to the Tropicana Gold Project. No extrapolation of the results and recommendations reported in this study should be made to areas external to this project area. In preparing this study, SWC has relied on published soil reports from various soil researchers and information provided by the Client. All information is presumed accurate and SWC has not attempted to verify the accuracy or completeness of such information. While normal assessments of data reliability have been made, SWC assumes no responsibility or liability for errors in this information. All conclusions and recommendations are the professional opinions of SWC personnel.

SWC is not engaged in reporting for the purpose of advertising, sales, promoting or endorsement of any client interests. No warranties, expressed or implied, are made with respect to the data reported or to the findings, observations and conclusions expressed in this report. All data, findings, observations and conclusions are based solely upon site conditions at the time of the investigation and information provided by the Client.

This report has been prepared on behalf of and for the exclusive use of the Client, its representatives and advisors. SWC accepts no liability or responsibility for the use of this report by any third party.

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# Introduction

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Soil Water Consultants (SWC) were commissioned by AngloGold Ashanti Australia (AGAA) on behalf of the Tropicana Joint Venture (TJV) to undertake a geochemical assessment for the Tropicana Gold Project (TGP), which is located on the western edge of the Great Victoria Desert approximately 330 km NNE of Kalgoorlie (Figure 1.1). The TJV is a joint venture between AGAA (70%; Manager) and Independence Group (IG; 30%). This investigation focused on the following aspects within the operational area of the project (Figure 1.2):

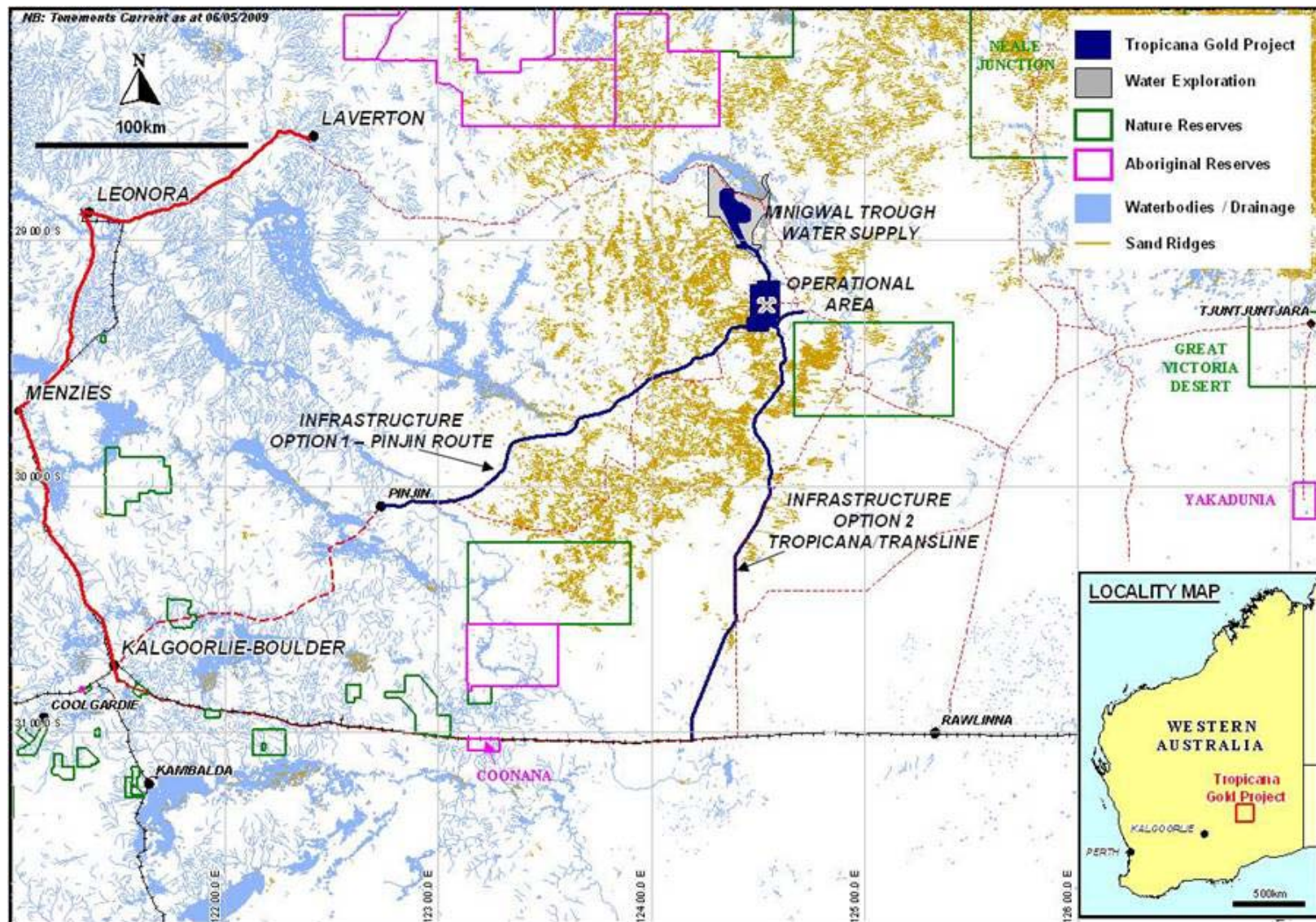
- Potential for metalliferous drainage from the Waste Material Landform (WML) and Tailings Storage Facility (TSF) (Section 2).
- Geochemical evolution of pit water quality (Section 3).

This investigation involved primarily a desktop study as a considerable amount of work had already been undertaken to characterise the geochemistry of the various waste rock materials and their acid rock drainage (ARD) potential. For this study the following reports and data were reviewed:

- Geochemical Characterisation of Tropicana Waste Samples: Phase 1 (Round A) (SRK, 2008a).
- Geochemical Characterisation of Tropicana Waste Samples: Phase 1 (Round B) (SRK, 2008b).
- Geochemical Characterisation of Waste Rock and Low Grade Ore: Static and Kinetic Testing (SRK, 2009).
- ARD leach column testwork data supplied by Graeme Campbell and Associates (GCA).
- Tropicana Gold Project Operational Area Groundwater Assessment (Pennington Scott, 2009).

Of particular importance to the assessment and prediction of seepage and pit water quality are the release rates or bioavailability of metals and solutes under varying geochemical conditions. This aspect was poorly covered by the previous studies, as only material types exhibiting high levels of sulfide mineralisation were targeted. These material types represent only a minor portion (< 10 %) of the total waste material and subsequently additional information was required as to the bioavailability of metals from benign or non-acid forming (NAF) materials. Given the time constraints for this project a short-term leaching study was undertaken using the Australia Standard Leaching Procedure (ASLP) to obtain leachate data for a wider range of material types from the TGP (Section 2).

This report documents the findings from this study.



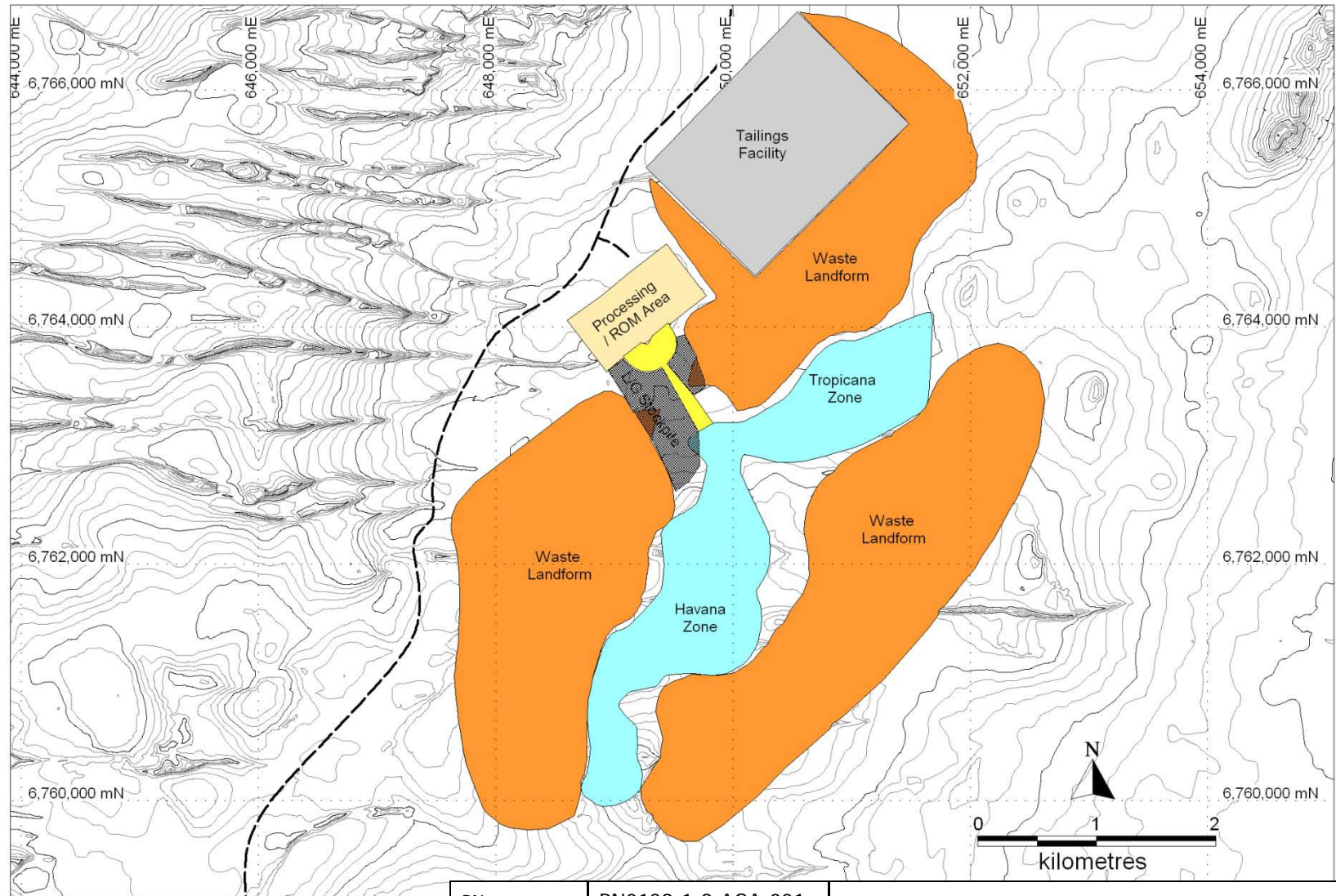
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 WATER ACIDIFICATION  
**GENERAL LOCATION MAP**

Figure 1.1







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 POTENTIAL METALLIFEROUS DRAINAGE AND PIT  
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**OPERATIONAL AREA**

**Figure 1.2**



## 2.1 Bioavailability of metals and solutes

The bioavailability or leachability of metals and solutes from the various waste materials generated by the proposed TGP were investigated using both short-term (ASLP – conducted by SWC) and long-term (column leaching – conducted by GCA) leach tests. The materials examined in both tests are provided in Table 2.1, and these represent 92 % of the total waste material to be disturbed at the TGP. Waste materials not covered by this work are provided in Table 2.2.

**Table 2.1:** Material types assessed for bioavailability of metals and solutes.

Material type	Number of samples assessed	% of total waste material
<b>Short-term leach testing (ASLP)</b>		
Saprolite (ALCY)	3	13.8
Feldspathic gneiss (Amphibole rich) (ANFA)	2	6.6
Garnet gneiss (undifferentiated) (ANG)	3	11.2
Garnet gneiss (Amphibole rich) (ANGA)	3	18.3
Archean schist (AZ)	3	2.7
Permian sediment (MS)	3	2.5
Quaternary sand (QLSD)	3	4.8
Tertiary cover (TL)	3	8.1
<b>Column leach testing</b>		
Ferruginous chert (ANC <sub>RT</sub> )	2	1.8
Feldspathic gneiss (undifferentiated) (ANF)	1	7.5
Feldspathic gneiss (K-fld >> quartz) (ANFF)	2	6.2
Feldspathic gneiss (fld + quartz = 7-25%) (ANFQ)	1	8.1
Sulfide rich rock (AX)	1	0.05
<b>Total waste distribution (%)</b>	<b>30</b>	<b>91.6</b>

### 2.1.1 Short-term leach tests

Short-term leach testing was undertaken at Soil Water Analysis (SWA) laboratories in Perth, with the elemental composition of the material and leachates analysed at ALS Laboratories. The ASLP (AS 4439.3-1997) was adhered to using a 1:20 crushed rock (< 75 µm fraction)/leaching solution ratio. To test the bioavailability of the metals and solutes under varying geochemical conditions two leaching solutions were used:

- Neutral 0.01M CaCl<sub>2</sub> solution: this leaching solution was buffered to pH 6.0 to simulate the pH of typical leaching solutions (i.e. rainfall percolating through the material).



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- Acidic 0.01 M CaCl<sub>2</sub> solution: this leaching solution had a pH of 2.5 and was used to simulate leaching of acidified solutions following sulfide oxidation and release of acidity.

Three replicates for each material type, with the exception of the ANFA where there was only two replicates (Table 2.1), were tested.

**Table 2.2:** Material types not assessed for bioavailability of metals and solutes, and their percentage distribution.

Material type	% of total waste material
Archean laterite (AL)	1.2
Archean gneiss (AN ?)	1.7
Archean amphibolitic gneiss (ANA)	1.2
Garnet gneiss (ANGQ)	-
Pegmatite (APP)	0.2
Archean pegmatite feldspar quartz (APPQ)	0.8
Schist (biotite) (AZB)	-
Schist (chlorite) (AZC)	-
Schist (sericite) (AZS)	-
Proterozoic basalt intrusive (PPB)	0.8
Proterozoic dolerite intrusive (PPD)	0.9
Other	1.6
<b>Total waste distribution (%)</b>	<b>8.4</b>

The material/solution mixtures were shaken on an end-over-end shaker at 30 rpm for 18 hours. Suspensions were filtered and analysed for elements listed in Table 2.3. In addition, the material samples were also assessed for the elements listed in Table 2.3 to calculate the proportion of the element released and therefore its bioavailability.

The proportion of each element released during leaching was determined using Equation 2.1 (ISO/DIS 21268-4).

$$w(X) = [c_1(X) - c_0(X)] \times \left[ \left( \frac{V_L}{m_D} \right) + \left( \frac{w_{H2O}}{100} \right) \right] \quad \text{Eqn. 2.1}$$

where,

$w(X)$  = release of a constituent X (mg/kg)

$c_0(X)$  = concentration of a constituent X in the blank (mg/L)

$c_1(X)$  = concentration of a constituent X in the leaching solution (mg/L)

$V_L$  = volume of leachate solution used (L)

$w_{H2O}$  = water content of the sample (%)

$m_D$  = mass of the sample used (kg)

**Table 2.3:** Elements assessed in the short-term leaching test.

• Calcium (Ca)	• Aluminium (Al)	• Cadmium (Cd)	• Mercury (Hg)	• Thorium (Th)
• Magnesium (Mg)	• Antimony (Sb)	• Chromium (Cr)	• Molybdenum (Mo)	• Tin (Sn)
• Sodium (Na)	• Arsenic (As)	• Cobalt (Co)	• Nickel (Ni)	• Uranium (U)
• Potassium (K)	• Beryllium (Be)	• Copper (Cu)	• Selenium (Se)	• Vanadium (V)
• Iron (Fe)	• Barium (Ba)	• Gold (Au)	• Silver (Ag)	• Zinc (Zn)
• Phosphorus (P)	• Bismuth (Bi)	• Lead (Pb)	• Strontium (Sr)	
• Total Sulfur (S)	• Boron (B)	• Manganese (Mn)	• Thallium (Tl)	

### 2.1.2 Long-term leach tests

Long-term leach tests were performed by GCA in Bridgetown, Western Australia, with the elemental composition of the rock and leachate samples determined at SGS Laboratories in Perth. Leaching columns were prepared using 2 kg of rock aggregate for each sample (Plate 2.1). Through each column 1 L of deionised water was leached over a one week period with the leachate collected and stored for analysis. This cycle was continued for 52 weeks, and subsequently 52 L of water was passed through the material resulting in a 1:26 rock/leaching solution ratio; similar to the soil/solution ratio used in the short-term leach study.

**Plate 2.1:** Setup of long-term leaching columns at GCA Laboratory

## Potential for Metalliferous Drainage

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The elements listed in Table 2.3 were assessed for the material and leachate, and their bioavailability determined using Equation 2.1.

### 2.1.3 Elemental composition of the material samples

The elemental composition of the material samples examined in the short- and long-term leach tests are provided in Table 2.4, whilst their relative enrichment (GAI) is provided in Table 2.5.

All material types assessed from the TGP contain low elemental compositions with sufficient relative enrichment (i.e. GAI > 3) only observed for As and Pb for selected samples from the AX (sulfide rich rock), ANFF (feldspathic gneiss) and ANC<sub>RT</sub> (ferruginous chert) material types. The remaining material types contain elemental compositions at or slightly below and above the average global crustal abundance.

The material types from the TGP therefore have a low potential to release metals and solutes into the environment as they typically contain negligible quantities of these elements.

### 2.1.4 Release of elements during leaching

The proportion of the total elemental composition of the waste material leached during the short- and long-term leach tests, which provides an indication of their bioavailability, are provided in Tables 2.6 (neutral leaching solution) and 2.7 (acidic leaching solution).

Under neutral conditions minimal release of metals and solutes occurred with only the major cations (Mg, Na, K) consistently removed in considerable quantities, which is likely to be due to cation exchange with the Ca<sup>2+</sup> contained within the 0.01 M CaCl<sub>2</sub> leaching solution. Relatively high levels of Ba, Mn, Sr and B were also observed suggesting that these elements are only weakly adsorbed and readily available for leaching – it is important to acknowledge that the neutral leaching condition simulates normal leaching under rainfall conditions and therefore the release of these elements is likely to occur naturally (albeit the quantities released will be significantly reduced by the low soil/solution ratio occurring in native soil/rock profiles). Elevated metals release was observed in isolated lithologies for Cd (3.9 %, AZ), Co (4.4 %, TL), Sn (4.4 %, ALCY), Zn (10.1 %, TL), Ni (2.1 %, TL) and Mo (2.2 %, TL), although this is due to the low corresponding metals contents in the actual rock/soil material. For all other elements, < 1 % of the total rock/soil content was leached.

The fraction of elements released by the acidic solution was considerably greater than the neutral solution indicating that structural or more strongly adsorbed metals were being released. In addition to the major elements (Ca, Mg, Na, K) and Ba, Mn, Sr and B, which were readily removed with the neutral leaching solution, Co, Be, Cd, Pb, Mo, Ni, Sn, Zn were also removed in elevated quantities (1.7 to 13.3 % of the total metal contents). For all other elements tested < 0.5 % of the total metals content was removed by the acidic solution, indicating that these elements are likely structural and not available for release even under acidic conditions.

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## Potential for Metalliferous Drainage

**Table 2.4:** Elemental composition of the various material types used in this assessment (all values are expressed in mg/kg).

Element	Short-term leach testing								Long-term leach testing					
	ALCY	ANFA	ANG	ANGA	AZ	MS	QLSD	TL	ANC <sub>RT</sub>	ANF	ANFF	ANFQ	ANG	AX
Calcium	4453.3	11060.0	27866.7	11410.0	4173.3	803.3	5540.0	1626.7	11370.5	25915	12653.5	30884	47583	19209
Magnesium	4536.7	11840.0	16560.0	6563.3	12853.3	436.7	320.0	1253.3	20858.5	14852	17049.5	16812	50290	20360
Sodium	1993.3	3105.0	946.7	2210.0	1150.0	903.3	173.3	1480.0	4511	30159	24594	20444	3905	13923
Potassium	1560.0	12450.0	3103.3	1473.3	6656.7	640.0	330.0	1113.3	11185.5	40036	42812	25618	10943	18520
Iron	25333.3	20300.0	30766.7	19033.3	30533.3	12683.3	25233.3	9160.0	81950	42700	30850	33800	84800	71000
Phosphorus	236.7	1320.0	276.7	293.3	<50	<50	<50	<50	697	1784	1181	1121	1820	388
Aluminium	8080.0	21100.0	18600.0	14773.3	12226.7	3486.7	4716.7	3180.0	37574.5	81994	70919.5	73799	66482	80276
Antimony	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.33	0.61	0.38	0.06	0.32	0.17
Arsenic	2.00	0.30	9.77	0.80	1.25	0.35	1.07	0.90	39.5	3.8	2.9	0.9	29.8	168.9
Beryllium	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	0.7	2.5	0.75	1.1	0.5	0.6
Barium	62.00	343.00	36.40	21.83	75.43	54.60	32.87	111.13	299.7	1076.7	1413.75	1514.9	183.2	558.7
Bismuth	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.20	0.10	0.135	0.49	0.115	0.1	0.34	0.08
Cadmium	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.45	0.2	1.05	0.1	0.5	0.4
Chromium	24.03	21.55	39.27	32.57	27.53	15.90	43.43	13.00	102.5	43	42.5	80	250	153
Cobalt	27.03	12.80	68.83	21.77	20.20	1.00	1.33	3.00	24	19	16.3	16.6	53.7	34
Copper	61.97	17.50	67.80	102.87	63.43	<0.10	4.10	4.30	116.5	56	61.5	34	79	111
Lead	4.77	8.45	34.63	2.80	25.03	<0.10	5.87	3.67	81.5	75	673	29	126	23
Manganese	157.00	193.50	255.00	247.07	183.70	19.90	26.87	33.40	1093	1021	294	516	2377	1482
Molybdenum	1.57	1.95	4.57	2.83	1.30	<0.10	0.73	2.43	4	2.6	7.85	2.7	0.6	3.9
Nickel	77.93	38.40	82.73	82.80	43.17	3.30	4.10	3.97	67.5	32	41.5	44	168	88
Selenium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.87	0.53	0.39	0.21	0.22	0.6
Silver	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.8	0.5	1	0.5	0.7	0.5
Strontium	15.47	83.70	19.70	17.27	18.83	<0.10	10.80	16.33	127.625	1779	665.8	593.4	38.97	297.8
Thallium	<0.10	0.3	<0.10	<0.10	0.20	<0.10	<0.10	<0.10	0.41	1.41	0.75	0.61	0.52	0.36
Thorium	2.10	2.55	1.35	0.60	2.50	1.50	5.00	3.93	4.45	58.38	12.215	6.79	0.34	4.92
Tin	0.25	0.20	0.30	0.17	0.35	0.25	0.47	0.37	0.7	1	1.4	1.2	0.9	0.3
Uranium	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.74	8.14	1.5	0.62	0.07	0.61
Vanadium	26.3	25.0	25.3	17.7	19.3	<1.0	37.0	16.0	68	105	70.5	73	233	127
Zinc	70.97	52.20	64.77	48.70	95.27	<0.10	4.20	3.77	224.5	113	262.5	87	167	169
Boron	<0.10	<0.10	<0.10	<0.10	1.25	<0.10	<0.10	<0.10	7.23	<50	<50	92	<50	114
Gold	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.025	0.26	0.165	<0.01	0.01	0.01
Mercury	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.01	<0.01	0.015	<0.01	0.02	<0.01

## SECTION 2

## Potential for Metalliferous Drainage

**Table 2.5:** Relative enrichment (GAI) of elements for the various material types.

Element	Short-term leach testing								Long-term leach testing					
	ALCY	ANFA	ANG	ANGA	AZ	MS	QLSD	TL	ANC <sub>RT</sub>	ANF	ANFF	ANFQ	ANG	AX
Calcium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Magnesium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sodium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potassium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iron	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phosphorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aluminium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Antimony	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Arsenic	0-1	0	0-4	0	0	0	0	0	0-5	0	0	0	3	6
Beryllium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barium	0	0	0	0	0	0	0	0	0	0	0-1	1	0	0
Bismuth	0	0	0-2	0	0	0	0-1	0	0-1	2	0	0	2	0
Cadmium	0	0	0-1	0	0-2	0	0	0	1	0	2	0	1	1
Chromium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cobalt	0-1	0	0-2	0	0	0	0	0	0	0	0	0	0	0
Copper	0	0	0	0-1	0-1	0	0	0	0	0	0	0	0	0
Lead	0	0	0-2	0	0-1	0	0	0	0-2	1	0-5	0	0	0
Manganese	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Molybdenum	0-1	0	0-2	0-1	0	0	0	0-2	0-1	0	2	0	0	0
Nickel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Selenium	0	0	0	0	0	0	0	0	2-3	2	2	1	1	3
Silver	0	0	0	0	0	0	0	0	2-3	2	2-3	2	2	2
Strontium	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Thallium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thorium	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Tin	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uranium	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Vanadium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zinc	0-1	0	0	0	0-1	0	0	0	0-1	0	1	0	0	0
Boron	0	0	0	0	0	0	0	0	0	0	0-2	2	0	2
Gold	0	0	0	0	0	0	0	0	2-4	7	4-7	0	2	2
Mercury	0	0	0	0	0	0	0	0	0	0	0	0	0	0



## SECTION 2

## Potential for Metalliferous Drainage

**Table 2.6:** Element release characteristics under neutral conditions (NR = No Result; Where leachate concentrations were below detection a value of 0 was assigned).

Element	Short-term leach testing (% released)								Long-term leach testing (% released)					
	ALCY	ANFA	ANG	ANGA	AZ	MS	QLSD	TL	ANC <sub>RT</sub>	ANF	ANFF	ANFQ	ANG	AX
Calcium	0.00	0.59	0.21	4.31	0.40	0.00	0.00	0.00	2.38	0.26	0.45	0.20	0.13	0.41
Magnesium	9.51	0.53	0.54	2.11	5.87	44.26	22.00	52.00	1.52	0.07	0.09	0.03	0.02	0.03
Sodium	59.05	9.13	14.64	19.39	82.44	58.50	20.51	83.07	0.07	0.05	0.04	0.05	0.25	0.06
Potassium	21.03	7.27	15.53	11.06	8.06	28.33	23.73	34.71	0.10	0.04	0.07	0.27	0.45	0.33
Iron	0.03	0.02	0.02	0.08	0.03	0.03	0.03	0.03	1.82	0.00	0.00	0.00	0.00	0.00
Phosphorus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aluminium	0.04	0.04	0.05	0.09	0.04	0.38	0.05	0.09	0.10	0.00	0.00	0.00	0.00	0.00
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.23	2.47	3.56	59.80	7.72	5.51
Arsenic	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.63	3.83	5.56	15.60	0.51	0.06
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.00	0.00	0.00	0.00
Barium	1.44	0.70	4.10	3.02	1.89	5.77	12.52	10.11	0.03	0.02	0.00	0.00	0.04	0.02
Bismuth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NR	NR	NR	NR	NR	NR
Cadmium	0.00	0.00	0.00	0.00	3.92	0.00	0.00	0.00	82.22	2.18	0.59	4.58	1.08	6.76
Chromium	0.10	0.00	0.06	0.10	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cobalt	0.09	0.00	0.02	0.15	0.27	0.00	2.78	4.44	42.68	0.11	0.14	0.14	0.04	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.99	0.39	0.36	0.67	0.29	0.20
Lead	0.00	0.00	0.01	0.00	0.00	0.05	0.00	0.00	0.27	0.14	0.03	0.59	0.14	0.63
Manganese	0.58	0.19	0.31	2.13	8.71	7.54	13.30	19.47	5.05	0.00	0.00	0.00	0.00	0.00
Molybdenum	1.37	0.48	0.76	1.25	0.83	0.00	0.00	2.22	0.40	2.40	6.62	1.66	47.06	0.39
Nickel	0.09	0.00	0.05	0.30	0.55	0.00	0.53	2.12	3.58	0.68	0.54	0.52	0.13	0.25
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.71	20.60	29.33	54.48	52.00	19.07
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.04	0.09	0.06	0.04
Strontium	13.22	4.45	3.11	6.87	21.19	21.21	23.45	40.08	0.48	0.06	0.13	0.10	1.87	0.19
Thallium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.06	0.07	0.09	0.06
Thorium	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00
Tin	4.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Uranium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	0.06	0.14	0.06	1.74	0.03
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zinc	0.37	0.00	0.00	0.00	0.03	0.00	0.00	10.10	6.95	0.43	0.17	0.53	0.27	0.26
Boron	122.22	0.00	0.00	0.00	231.88	2.08	15.38	28.27	NR	NR	NR	NR	NR	NR
Gold	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NR	NR	NR	NR	NR	NR
Mercury	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.05	0.00	14.73	0.00	5.53	0.00

## SECTION 2

## Potential for Metalliferous Drainage

**Table 2.7:** Element release characteristics under acidic conditions.

Element	Short-term leach testing (% released)							
	ALCY	ANFA	ANG	ANGA	AZ	MS	QLSD	TL
Calcium	5.895	9.610	7.182	13.973	5.447	12.730	28.779	0.000
Magnesium	11.864	1.266	0.992	3.151	7.864	50.902	29.504	55.586
Sodium	65.160	10.437	16.711	23.049	88.689	73.763	72.431	79.605
Potassium	26.915	10.677	21.932	14.436	11.391	35.430	32.177	34.199
Iron	0.056	0.205	0.103	0.774	0.341	2.431	2.661	0.094
Phosphorus	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aluminium	0.216	0.088	0.104	0.194	0.291	1.850	1.661	2.351
Antimony	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Arsenic	0.252	0.000	0.217	0.000	0.000	0.000	0.000	0.000
Beryllium	13.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barium	3.645	2.710	8.939	6.176	5.957	18.699	33.611	14.810
Bismuth	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	1.333	0.000	0.167	3.000	10.833	0.000	0.000	0.000
Chromium	0.234	0.140	0.267	0.153	0.076	0.226	0.380	0.255
Cobalt	1.787	0.400	0.452	4.467	3.905	6.734	11.111	11.025
Copper	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lead	0.000	0.000	0.034	0.000	0.000	0.288	0.109	1.667
Manganese	9.006	6.140	4.091	12.798	21.775	30.461	32.194	27.405
Molybdenium	2.745	0.952	3.575	0.000	0.000	0.000	0.000	0.000
Nickel	0.900	1.586	0.408	3.761	3.714	3.094	4.953	4.267
Selenium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Strontium	20.207	9.391	7.791	11.630	29.303	29.659	40.139	53.636
Thallium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Thorium	3.810	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tin	0.000	220.000	0.000	0.000	0.000	0.000	0.000	0.000
Uranium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vanadium	0.256	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zinc	0.333	0.273	0.000	1.591	3.289	2.745	16.366	3.810
Boron	222.222	0.000	0.000	0.000	207.246	4.167	5.128	64.328
Gold	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mercury	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

## Potential for Metalliferous Drainage

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### 2.2 Potential for metalliferous drainage from the waste material landform

#### 2.2.1 Geochemical conditions likely to prevail in the waste material landform

It is anticipated that approximately 750 Mt of waste material will be stored within the three proposed waste landforms (Figure 1.2). The predicted distribution of the various waste lithologies is provided in Table 2.8, with only 8 % of this material likely to be PAF (i.e. associated with the ANC<sub>RT</sub>, ANFF and AX rock types) and the remaining 92 % classified as NAF. Based on the estimated waste distributions and the corresponding carbonate neutralising potential (CarbNP) of the NAF materials and acid potential (AP) of the PAF material types, the mass of alkalinity and potential acidity likely to exist in the waste dumps was determined (Table 2.8).

The results clearly show that the mass of alkalinity (or potential buffering capacity) in the waste landforms will far exceed the potential acidity that may be released if all of the PAF material oxidised (i.e. the total mass of acidity represents 1/50<sup>th</sup> of the total readily available alkalinity present). It is therefore likely that the waste landforms will remain in a neutral to alkaline condition.

The potential for neutral to alkaline conditions to remain within the waste landforms is further supported when the actual acidity and alkalinity release rates of the PAF and NAF materials are considered. From the kinetic testwork (SRK, 2009) it was observed that the acid producing potential of the PAF materials varies according to their sulfide contents (See Figure 3.3). For the identified PAF materials the average sulfide contents are 0.97 % for ANFF material type, 3.12 % for AX material type and 3.49 % for ANC<sub>RT</sub>. The corresponding acid release rates are provided in Table 2.9. Based on these release rates and the total mass of each material type in the waste landforms, the total mass of acid likely to be released under optimal oxidation conditions (i.e. oxygen and water are non-limiting) is 180,518 kg H<sub>2</sub>SO<sub>4</sub>/wk. Based on an alkalinity release rate for the NAF materials of 3.9 × 10<sup>-3</sup> kg H<sub>2</sub>SO<sub>4</sub> eq./t/wk and a total mass of NAF material of 634,455,000 t the predicted release of alkalinity under optimal release conditions (i.e. wide soil/solution ratio) is 2,474,374 kg H<sub>2</sub>SO<sub>4</sub> eq./week. Subsequently, there is a net excess of alkalinity and the material will remain at pH > 7.

To prevent the PAF materials from oxidising, and thus further ensuring that the waste landforms remain neutral to alkaline and minimising the potential for metalliferous drainage, it is planned that all PAF material will be co-dumped with NAF and covered with at least 10 m of NAF material and 1 m of NAF growth medium (store/release cover system). Based on the paste pH and EC values reported in SRK (2009) any infiltrating rainfall moving through the surface NAF materials (see Section 2.2.2) will have an excess of alkalinity (average pH 7.8) and be extremely saline (average EC 408 mS/m). If any of this alkaline leachate reaches the PAF material it will supplement the CarbNP of the PAF source material providing additional buffering against any released acidity.

**Table 2.8:** Estimated waste distribution and quantity of the various waste material types.

<b>Non-acid Forming material (NAF)</b>				
Material type	Wt. Dist (%)	Mass of material (t)	CarbNP (kg H <sub>2</sub> SO <sub>4</sub> eq./t)	Mass alkalinity (t H <sub>2</sub> SO <sub>4</sub> eq.)
ALCY	13.8	95,220,000	5	476,100
AN?	1.7	11,730,000	1	11,730
ANA	1.2	8,280,000	62	513,360
ANF	7.5	51,750,000	22	1,138,500
ANFA	6.6	45,540,000	21	956,340
ANFQ	8.1	55,890,000	21	1,173,690
ANG	11.2	77,280,000	41	3,168,480
ANGA	18.3	126,270,000	19	2,399,130
APP	0.2	1,380,000	5	6,900
AZ	2.7	18,630,000	31	577,530
MS	2.5	17,250,000	2	34,500
PPB	0.8	5,520,000	25	138,000
PPD	0.9	6,210,000	46	285,660
QLSD	4.8	33,120,000	3	99,360
TL	8.1	55,890,000	23	1,285,470
Other	3.55	24,495,000	21.8	533,991
<b>Total</b>	<b>91.95</b>	<b>634,455,000</b>	<b>21.8</b>	<b>12,798,741</b>
<b>Potential acid forming material (PAF)</b>				
Material type	Wt. Dist (%)	Mass of material (t)	Acid potential (kg H <sub>2</sub> SO <sub>4</sub> /t)	Mass of potential acidity (kg H <sub>2</sub> SO <sub>4</sub> )
ANC <sub>RT</sub>	1.8	1,080,000	106.55	115,074
ANFF	6.2	3,720,000	29.67	110,372
AX	0.05	30,000	95.43	2,863
<b>Total</b>	<b>8.05</b>	<b>4,830,000</b>		<b>228,309</b>

**Table 2.9:** Acid Base Mass Balance for the waste landforms..

<b>Non-acid forming material (NAF)</b>				
Material type	Mass of material (t)	Average CarbNP (kg H <sub>2</sub> SO <sub>4</sub> /t)	Alkalinity release rate (kg H <sub>2</sub> SO <sub>4</sub> eq./t/wk)	Potential alkalinity release (kg H <sub>2</sub> SO <sub>4</sub> eq./wk) <sup>†</sup>
NAF material	634,455,000	21.8	$3.9 \times 10^{-3}$	2,474,374
<b>Potential acid forming (PAF)</b>				
Material type	Mass of material (t)	Average sulfide content (%)	Acid release rate (kg H <sub>2</sub> SO <sub>4</sub> /t/wk)	Potential acid release (kg H <sub>2</sub> SO <sub>4</sub> /wk)*
ANC <sub>RT</sub>	1,080,000	3.49	$1.48 \times 10^{-1}$	159,840
ANFF	3,720,000	0.97	$4.72 \times 10^{-3}$	17,558
AX	30,000	3.12	$1.04 \times 10^{-1}$	3,120
<b>Total acid</b>	<b>4,830,000</b>			<b>180,518</b>
<b>Acid Base Mass Balance</b>				<b>-2,293,856</b>
<sup>†</sup> Under optimal soil/solution ratios for dissolution and release of alkalinity.				
<sup>*</sup> Under optimal conditions for oxidation (i.e. Oxygen and water are non-limiting).				

### 2.2.2 Drainage through the waste landforms

Work conducted by Landloch (2009) shows that negligible moisture will drain below the surface 1 m growth medium, and when vegetated all infiltrating rainfall will be consumed by the revegetation. This work clearly highlights that there will be minimal water draining through the waste landform profile, and it is expected that moisture levels of only 2 % (0.02 m<sup>3</sup>/m<sup>3</sup>) will likely be maintained for at least 100 years after rehabilitation within

## Potential for Metalliferous Drainage

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the 10 m NAF layer. Based on this low residual moisture content within the NAF layer, it is expected that a soil/solution ratio of 1:0.008 will prevail within this material, significantly restricting the release of any metals or solutes into the soil solution. Any elements that are released will effectively be stored within this layer due to the presence of very low hydraulic gradients (i.e. there is no driver for water movement) and the properties of the waste material itself, which has a very small capillarity (i.e. the pore size distribution and water retention and hydraulic function is controlled by the macroporosity of the material).

### 2.3 Potential for metalliferous drainage from the TSF

At the TGP approximately 93 Mt of tailings will be produced. This material will be discharged into a purpose-built HDPE/clay lined TSF located to the north of the Tropicana pit (Figure 1.2). To determine the potential for metalliferous drainage into the underlying *in situ* profile, if leakage occurs, the geochemical conditions likely to exist in the TSF were reviewed. Given that the release characteristics (or bioavailability) of metals and solutes from the tailings material was not available for this investigation the results from a pilot leaching study (based on two representative ore samples) were examined to determine the quantity of elements remaining in the solid tailings after processing (and therefore potentially available for seepage) and the likely solubility of the various metals under the specific geochemical conditions that will exist in the TSF.

The tailings material stored within the TSF will have a pH of around 9 (strongly alkaline) and will be discharged at a solids content of 60 – 70 %. This solids content equates to a soil/solution ratio of approximately 1:0.3 (assuming a bulk density of 1.8 t/m<sup>3</sup>). As discussed in the previous section, the soil/solution ratio strongly influences the release characteristics of most metals, particularly under high pH conditions where more insoluble metal-complexes form on the solid particles; subsequently this soil/water (and lower ratios as the tailings dries) are likely to limit metals release under high pH conditions.

The elemental composition of the likely tailings material, and the proportion of metals and solutes released during the pilot study, is provided in Table 2.10. From these results it can be seen that the desorption characteristics for most of the environmentally-sensitive metals present in sufficient quantities (i.e. Ba, Co, Cr, Mn, Mo, Pb, and V) are very low under the geochemical conditions present in the tailing system. Only Cu shows significant mobilisation, and this is likely due to the increase solubility of most Cu-compounds in dilute alkaline NaCN solutions (Marsden and House, 2006).

Leaching of rainfall through the dried tailings materials, and subsequent altering of the geochemical conditions favouring metals release, is likely to be very small given the fine texture of tailings material and their corresponding very low permeabilities. Subsequently, the geochemical conditions favouring metal precipitation and sorption will prevail for a considerable time period, thus the risk of metalliferous drainage from the TSF is considered low.

### 2.4 Conclusions

Based on the limited bioavailability of metals and solutes for the various waste materials under neutral conditions, which are likely to be maintained given the considerable excess of alkalinity with the waste landforms, and the hydraulic parameters of the waste material, which will limit water infiltration and movement, it is expected that no metalliferous drainage will likely occur beneath the waste landforms. There is therefore negligible risk of groundwater contamination from metalliferous seepage from the long-term storage of environmentally hazardous waste material (such as PAF) given the proposed management strategies planned for the Project.



## Potential for Metalliferous Drainage

Similarly, no metalliferous drainage is likely to occur below the TSF, as the prevailing geochemical conditions are likely to restrict metal desorption and bioavailability. Any sulfides contained within the TSF are likely to remain in a reduced state as a result of the high residual water content of the tailings and subsequent low oxygen diffusion rates.

**Table 2.10:** Predicted elemental composition of the tailings material and proportion of the total solid content leached during processing.

Parameter	Sample: HS17851		Sample: HS17852	
	Tailings content (mg/kg)	% leached during processing	Tailings content (mg/kg)	% leached during processing
Au	0.24	97.90	0.23	26.37
Ag	0.3	91.46	0.3	21.55
Al	5.22	LD	5.34	LD
As	LD	LD	LD	LD
Ba	1637	0.22	1642	0.20
Bi	LD	LD	LD	LD
Cd	LD	LD	LD	LD
Co	23	3.12	23	3.46
Cr	539	0.08	517	0.79
Cu	45	23.09	42	12.68
Fe	3.53	90.21	3.61	89.85
Hg	0.1	0.08	0.2	LD
K	3.93	99.91	4.02	99.91
Li	18	29.86	17	30.84
Mg	1.94	99.98	1.97	99.98
Mn	552	0.04	547	0.04
Mo	44	1.84	38	2.33
Ni	302	0.81	287	0.07
P	1799	0.23	1820	0.23
Pb	27	0.76	28	0.73
Sb	LD	LD	LD	LD
Sr	486	39.98	495	40.03
Te	2.2	LD	2.2	LD
Ti	1998	0.02	1992	0.02
V	78	0.11	76	0.11
Y	8	0.51	8	0.51
Zn	114	11.17	115	4.71
Zr	85	0.24	87	0.24

LD = Lower than detection limit.

Ca and Na were removed as they were added in significant quantities as CaCO<sub>3</sub> and NaCN.

### 3.1 Introduction

#### 3.1.1 Determinants of Pit Water Quality

In mining operations that require dewatering to access the mineralised deposits, cessation of mining and decommissioning of the mine pit results in the recovery of groundwater levels overtime. Groundwater levels will rise until an equilibrium water level is reached which represents a balance between groundwater inflow and outflow, direct rainfall and evaporation (Ellerbroek *et al.*, 1996; Jones *et al.*, 1997). Unlike natural lakes and reservoirs, mine pit lakes have negligible surface water inflow as bunding around perimeter of the mine pit restricts water entry; subsequently groundwater inflow and rainfall often represent the only input sources to the void. In addition, groundwater outflows are often negligible and water loss may only occur through evaporation. In these cases the mine void becomes a sink and all solutes are retained within them, with their concentrations steadily increasing over time until the solubility of the various mineral phases (i.e. gypsum, calcite or halite) governs their final concentration.

In situations where residual sulfide mineralisation occurs on the mine pit faces, water level changes can strongly influence the pit water quality. Iron sulfide oxidation generally only occurs above the water table<sup>1</sup> (non-limiting oxygen environment), and subsequently rapid flooding and backfilling with waste material to levels above the exposed mineralisation (thus limiting the oxygen supply to the reaction) is generally regarded as best available technology for preventing sulfide oxidation. In cases where exposed wall sulfides remain above the final groundwater level they will potentially continue to react until all sulfide minerals have oxidised. This can have a significant effect on the final pit water quality and may result in a highly acidic pit lake.

Determining the acid-generating rate of materials that contribute solutes to an open pit is critical to estimating the final pH of the water. Acidification of pit water in response to the oxidation of sulfide minerals is often associated with elevated concentrations of dissolved metals. Acid water also accelerates the dissolution rates of other mineral phases so that at  $\text{pH} \leq 3$  significant concentrations of both major (i.e. Ca, Mg) and minor (i.e. metals – As, Cd, Zn etc) often exist in a highly saline aqueous environment. Although oxidation of sulfides will add acidity, the final pit water pH will be governed by the overall neutralising capacity of the other inflows, including the buffering capacity of pit wall materials, rainwater chemistry and the alkalinity of the groundwater. If the system has sufficient buffering capacity to neutralise all of the acid produced by the oxidation of sulfides present on the pit walls, then the pit water will likely remain at neutral pH (pH 7) or become alkaline (pH > 7).

The long term concentration of solutes and the potential for the pit water to become acidic is the primary focus of this first-order assessment. Second order processes such as chemical or thermal stratification of pit water, and precipitation, speciation and dissolution of secondary minerals and their effect on solute concentrations and final void quality, are not considered in this report. This first-order assessment will determine the pit water quality using a mass-balance approach, which is considered sufficient given the small quantities of potential ARD materials at this site (SRK 2008a, 2008b, 2009).

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<sup>1</sup> Note: Iron sulfide oxidation may occur in the absence of oxygen when sufficient ferric ion ( $\text{Fe}^{3+}$ ) is present in the water according to the following equation:  $\text{FeS}_2 + 14\text{Fe}^{3+} + 8\text{H}_2\text{O} \Leftrightarrow 15\text{Fe}^{2+} + 2\text{SO}_4^{2-} + 16\text{H}^+$  (DITR, 2007).

### 3.1.2 Premise of this approach

For this assessment groundwater inflows were considered to be the only external sources of solutes, with no addition of solutes from rainwater or seepage from the adjacent waste dump (Section 3) or TSF (Section 4). The oxidation of exposed ARD materials on the pit faces, and subsequent release of acidity and dissolved metals, was assumed to be the only internal source of acidity and solutes.

The initial screening calculation to predict pit water quality was based solely on the comparison of the mass of alkalinity in the groundwater with the mass of acid ( $\text{H}_2\text{SO}_4$ ) likely to be produced by the oxidation of exposed sulfidic material on the pit walls. The issue of evaporation is important since the volume of water predicted to be in the pit at any one time by the RL-time curve is the net result of all inflow and loss processes. Thus simply assuming that the mass of solutes in the water is equal to the product of the volume and the composition of the inflowing groundwater can substantially underestimate the load of solutes actually present. This is particularly important over the long term when evaporation starts to approach groundwater inflows and may exceed inflow.

If there is insufficient buffering capacity (alkalinity) in the inflowing groundwater to neutralise the acidity generated by the oxidising ARD materials, then the role of evaporation on solute concentration will be considered as well as inputs of alkalinity from weathering of NAF materials. The total mass of alkalinity from all sources will then be compared to the potential acidity to determine if there is still likely to be an excess of acid.

## 3.2 Input data and assumptions

### 3.2.1 Groundwater quality

Groundwater quality used in this assessment was obtained from Pennington Scott (consulting hydrologists) for the Tropicana and Havana productions bores, with the average concentration of solutes used (Table 3.1). The carbonate alkalinity of the groundwater was determined using Equation 3.1 (Morel, 1983).

$$\text{Carbonate alkalinity (as CaCO}_3\text{)} = 0.820[\text{HCO}_3^- \text{ (mg/L)}] + 1.667[\text{CO}_3^{2-} \text{ (mg/L)}] \quad \text{Eqn. 3.1}$$

From this equation the carbonate alkalinity of the groundwater was calculated to be 177.5 mg/L, which equates to 173.9 mg/L  $\text{H}_2\text{SO}_4$  equivalent. These values, together with the neutral pH, indicate that the groundwater in the Tropicana project area contains little neutralising capacity.

The groundwater is classified as Na-Cl type, with secondary  $\text{Mg}^{2+}$  and  $\text{SO}_4^{2-}$ , and is highly saline with a salinity of approximately 35,000 mg/L. Groundwater from these bores generally contains low levels of most metals (Fe, Al, Ni, Cd, Mn, Pb), with only moderate elevations of Cu (up to 9  $\mu\text{g/L}$ ) when compared to the ANZECC/ARMCANZ Water Quality Guidelines (2000).

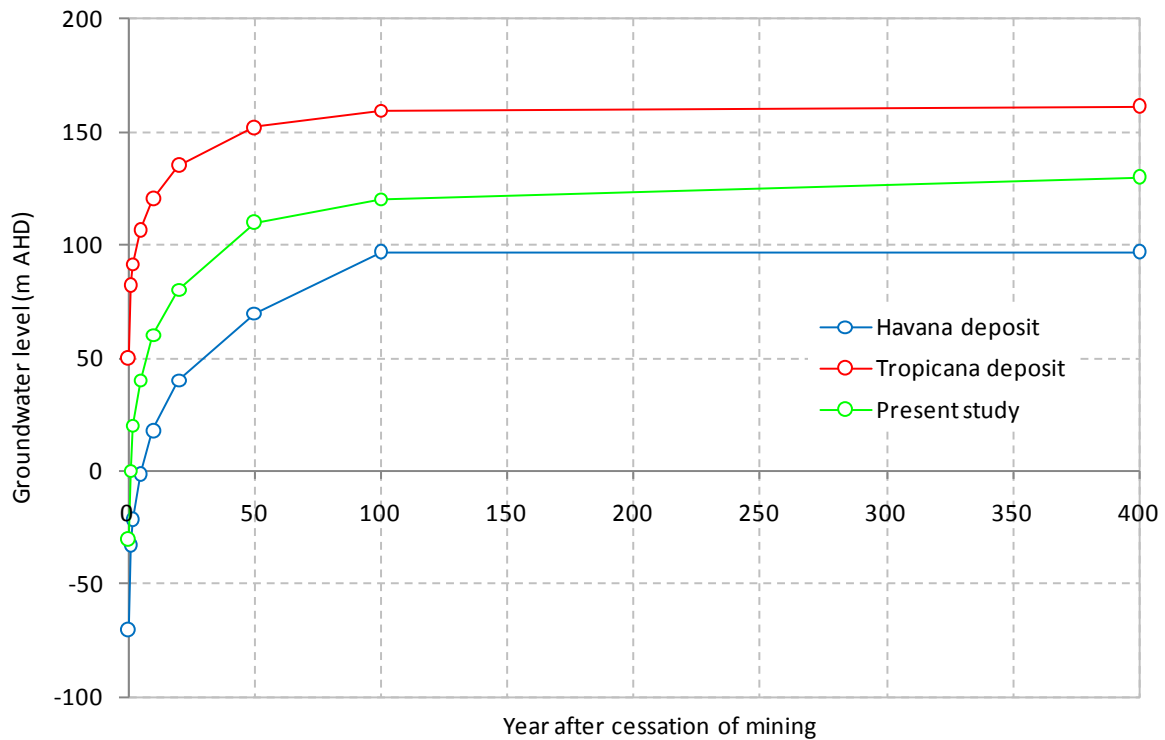
**Table 3.1:** Groundwater quality data used in this assessment (Data from bore monitoring: 01/10/06 – 24/02/09).

Parameter	Havana Bore	Tropicana Bore	Average
EC ( $\mu\text{S}/\text{cm}$ )	21111	48706	34908
pH	7.24	7.09	7.16
TDS (mg/L)	16100	41294	28697
CO <sub>3</sub> (mg/L)	< 1	< 1	< 1
HCO <sub>3</sub> (mg/L)	230.00	202.71	216.35
OH (mg/L)	< 1	< 1	< 1
Hard (mg/L)	4470	9441	6956
Cl (mg/L)	6730.00	18352.94	12541.47
SO <sub>4</sub> (mg/L)	1879.00	5423.53	3651.26
NO <sub>3</sub> (mg/L)	28.10	3.00	15.55
Na (mg/L)	3100.00	9164.71	6132.35
K (mg/L)	153.00	534.71	343.85
Ca (mg/L)	477.00	579.41	528.21
Mg (mg/L)	792.00	1935.29	1363.65
Fe (mg/L)	0.075	0.070	0.073
Cd (mg/L)	0.002	0.004	0.003
Cu (mg/L)	0.009	0.010	0.009
Mn (mg/L)	0.017	0.137	0.077
Pb (mg/L)	0.005	0.004	0.004

### 3.2.2 Groundwater recovery levels

The volume-RL and the RL-time groundwater recovery data for the Tropicana and Havana deposits were obtained from Pennington Scott and are shown in Table 3.2. For the purposes of this assessment the two pits were combined with the height of the water level taken as an approximate average for the two pits, whilst the total water volume was determined through summation of the individual pit volumes (Table 3.2).

FEFLOW finite element modelling predicts that groundwater levels will recover rapidly to produce a pit lake (Figure 3.1). For the combined pits, the water level will rise from -20 m AHD to the approximate equilibrium level at 130 m within 100 years, with 50 % of the equilibrium level achieved within 15 years after mining. Concentration factors for solutes were calculated for each timestep using the balance between inflows and evaporation. Groundwater outflows were predicted to be negligible during the period to achieve steady state levels (Pennington Scott, 2009).



**Figure 3.1:** Predicted groundwater recovery levels for the Tropicana and Havana Pits, and for the combined pit used in this study.

**Table 3.2:** Groundwater recovery levels and volumes predicted from hydrological modelling (Pennington Scott, 2009).

Year after mining	Havana Pit		Tropicana Pit		Data used in assessment	
	Water height (m AHD)	Water volume (m3)	Water height (m AHD)	Water volume (m3)	Water height (m AHD)	Water volume (m3)
0 (Base of pit)	-70	-	50	-	-20	-
1	-33	420,683	82.38	259,626	0	680,309
2	-21.51	794,221	91.51	538,467	20	1,332,688
5	-1.27	1,980,421	106.78	1,213,092	40	3,192,513
10	17.95	3,689,700	120.53	2,173,291	60	5,862,991
20	39.95	6,624,311	135.16	3,438,614	80	10,062,925
50	69.52	12,403,459	152.05	5,409,588	110	17,813,047
100	86.8	16,602,750	159.25	6,394,312	120	22,997,062
400	96.77	19,406,015	161.34	6,707,856	130	26,113,871



### 3.2.3 ARD potential of pit materials

Information regarding the ARD potential of pit materials was obtained from the Geochemical Characterisation studies undertaken by SRK (SRK, 2008a, 2008b, 2009). From these investigations the following material types were determined to be Potential Acid Forming (PAF):

- ANC<sub>RT</sub>: Ferruginous chert
- AX: Sulfide-rich rock
- ANFF: Feldspathic gneiss

These materials represent only 8 % of the waste material to be mined at the Tropicana and Havana deposits, and have sulfide contents varying from 0.97 to 3.49 % (SRK, 2009). These sulfide values equate to a potential acidity of 30 to 107 kg H<sub>2</sub>SO<sub>4</sub>/t. A bulk density of 2.5 t/m<sup>3</sup> was used throughout this assessment to convert between mass of waste material to volume (i.e. convert kg H<sub>2</sub>SO<sub>4</sub>/t to kg H<sub>2</sub>SO<sub>4</sub>/m<sup>3</sup>).

The predicted area of PAF material types to be exposed on the mine pit walls was determined from the intersection of the pit walls with the geological block model. For the combined Tropicana and Havana pits the total surface area exposed was determined for each 10 m bench extending from the surface (approximately 370 m AHD) to the predicted base of the mine pit (-20 m AHD; Table 3.3). The sulfide content of the exposed material types varies from < 0.01 to 2.94 %, with an average of 0.44 %. Using the groundwater recovery levels (Table 5.2), the area of PAF material exposed above the groundwater level for each time step was determined. These areas are shown in Table 3.4 and plotted in Figure 3.2.

To determine the volume of ARD material exposed to weathering (and hence oxidation) a weathering rate of 1 mm/year was assumed. This rate was determined following observation of drill core of PAF material types which had been exposed for up to 4 years, and through discussions with AGAA geologists. Photographs showing negligible weathering of core material for the ANC<sub>RT</sub> and ANFF (i.e. the most reactive material types) are shown in Plate 3.1.

In this study the 1 mm/year weathering rate was assumed constant throughout the entire time period (i.e. 400 years). This assumption is likely to overestimate the volume of material exposed to weathering, particularly in the latter stages, as armouring of material surfaces by reaction products (i.e. Fe-oxides) and the generation of secondary clay minerals is likely to retard the movement of water into the mine wall and exchange or release of by-products; hence a considerably lower weathering rate is likely to occur in the field.

To calculate the mass of acidity that may potentially be released during oxidation of the sulfide minerals the reactivity or acid-producing potential of the PAF materials was determined using the results from the kinetic studies (SRK, 2009). This work showed that the reactivity of the material increased with increasing sulfide content, according to Figure 5.3 and Equation 3.2. Material with a sulfide content of 0.5 % is expected to release  $2.8 \times 10^{-3}$  kg H<sub>2</sub>SO<sub>4</sub>/t/week, whilst the acid release rate increases to  $2.3 \times 10^{-1}$  kg H<sub>2</sub>SO<sub>4</sub>/t/week for material with 4 % sulfide.

$$\text{Acid producing rate (kg H}_2\text{SO}_4\text{/t/week)} = 2.56 \times 10^{-3} + [2.39 \times 10^{-3}(\text{Sulfide content} - \%)^{3.29}] \quad \text{Eqn. 3.2}$$

For this assessment two sulfide contents were examined (0.5 and 1.0 %) to cover the range of sulfide mineralisation in the bulk of the ARD material types exposed above the water table (Note: the average is 0.44 %; Table 3.3).

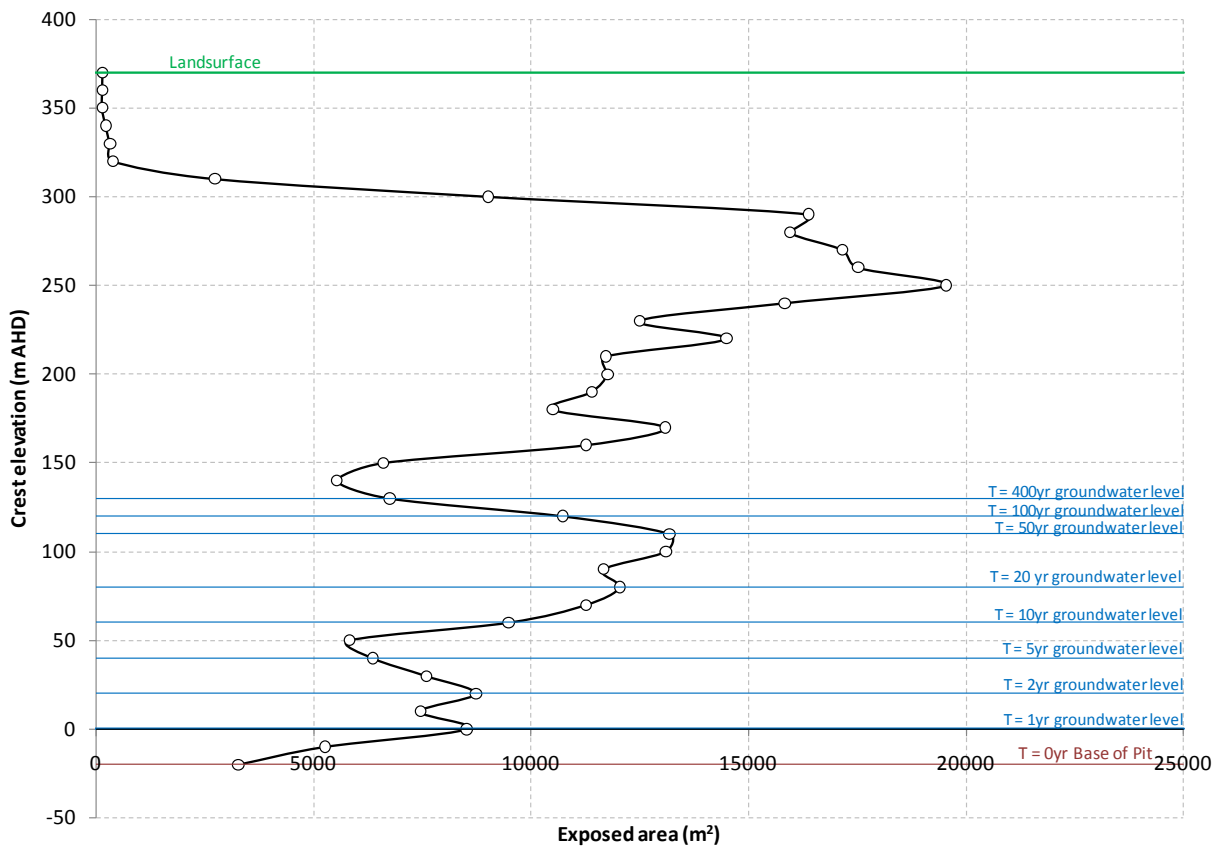
**Table 3.3:** Surface area of ARD material exposed on the pit walls throughout the combined Tropicana and Havana mine pits.

Bench		Surface area (m <sup>2</sup> )		Content
Crest	Toe	US\$1000 Shell	ARCRT, AX & ANFF rock types	Sulphide %
370	360	17,243	153	0.03
360	350	80,041	146	0.01
350	340	138,957	141	0
340	330	181,181	222	0
330	320	174,125	318	0.01
320	310	167,548	391	0.01
310	300	156,953	2732	0.06
300	290	148,165	9017	0.23
290	280	139,234	16386	0.44
280	270	131,084	15955	0.45
270	260	128,554	17165	0.49
260	250	130,056	17523	0.5
250	240	115,670	19535	0.62
240	230	101,342	15829	0.58
230	220	94,385	12494	0.49
220	210	89,764	14491	0.6
210	200	85,896	11717	0.5
200	190	81,413	11758	0.53
190	180	78,070	11395	0.54
180	170	76,477	10499	0.51
170	160	74,811	13093	0.65
160	150	70,873	11257	0.59
150	140	61,784	6613	0.4
140	130	58,276	5540	0.35
130	120	54,460	6751	0.46
120	110	51,019	10727	0.78
110	100	50,537	13181	0.96
100	90	45,677	13102	1.06
90	80	41,520	11671	1.04
80	70	38,216	12042	1.17
70	60	32,096	11267	1.3
60	50	27,157	9481	1.29
50	40	26,349	5830	0.82
40	30	26,169	6362	0.9
30	20	26,085	7589	1.08
20	10	24,354	8732	1.33
10	0	23,737	7458	1.16
0	-10	19,522	8521	1.61
-10	-20	16,969	5258	1.15
-20	-30	4,111	3272	2.94
<b>Total</b>		<b>3,089,880</b>	<b>365614</b>	<b>0.44</b>

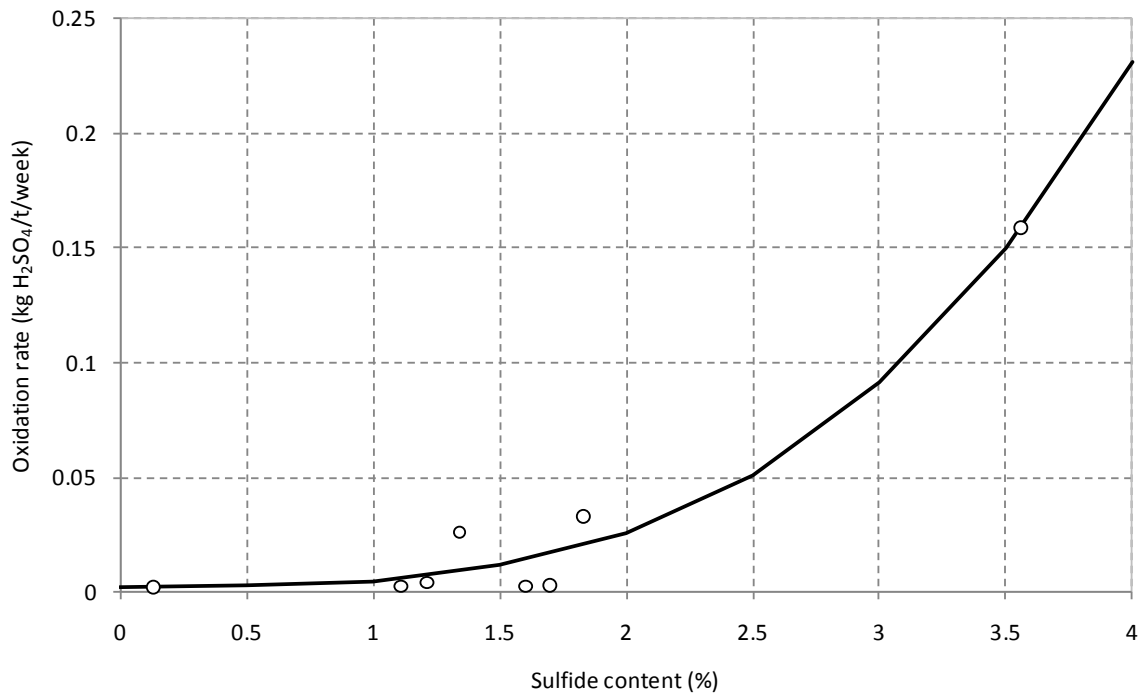


**Table 3.4:** Total area of potential ARD material above the water table at selected time periods.

Time (years)	Total area of ARD material above water table (m2)
0	2,724,266
1	2,741,317
2	2,757,507
5	2,771,458
10	2,786,769
20	2,810,078
50	2,848,032
100	2,858,759
400	2,865,510

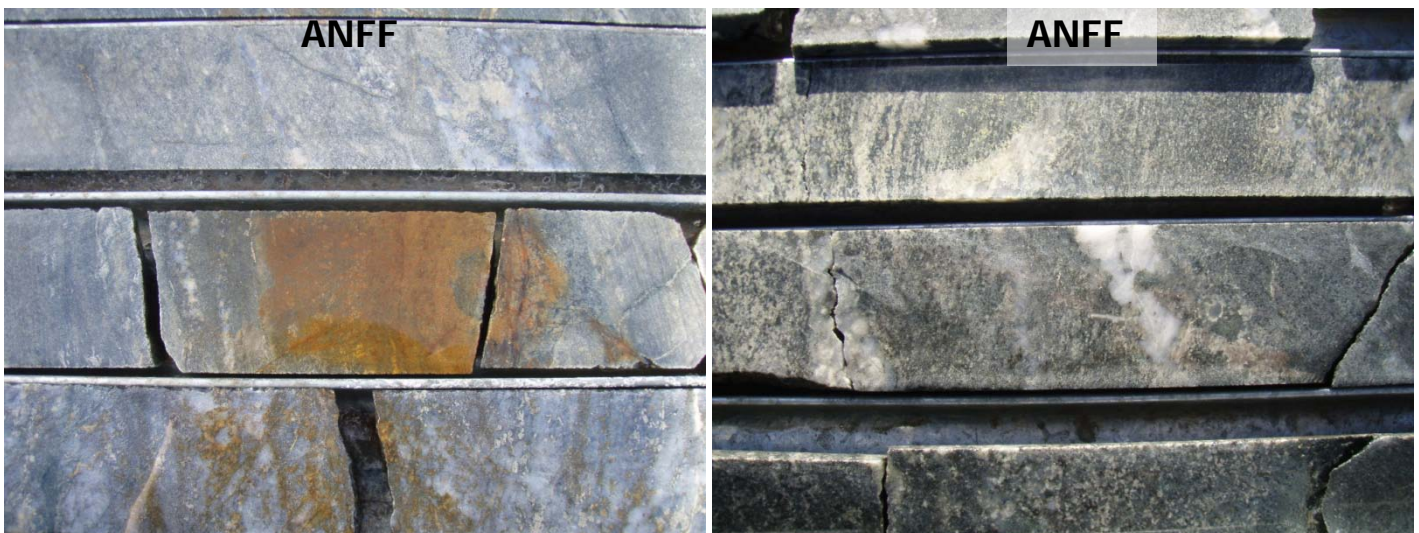


**Figure 3.2:** Predicted area of exposed ARD material above the recovering groundwater level at the various time steps.



**Figure 3.3:** Relationship between sulfide content and oxidation (or acid generation) rate derived from kinetic testing.

**Plate 3.1:** Negligible weathering of ARD core material after 4 years exposure.



To determine the contribution of alkalinity to the pit water from weathering of NAF material types exposed on the pit walls the alkalinity release rates determined from the kinetic studies were used. In this study it was observed



that the NAF materials release 4.05 mg alkalinity (as CaCO<sub>3</sub>)/kg/wk, which equates to  $3.9 \times 10^{-3}$  kg H<sub>2</sub>SO<sub>4</sub> eq./t/wk. Similar to the ARD rocks it was assumed that the weathering rate of NAF material was 1 mm/year.

### 3.3 Results

The results from the mass balance assessment for the combined Tropicana and Havana pits are provided in Table 3.5. It is predicted that the pit water will remain neutral to alkaline through time as the total mass of alkalinity entering the pit lake, from groundwater and weathering of NAF materials, far exceeds the total mass of acidity released from the exposed PAF material (for both sulfide levels). In the case of no evaporative concentration there is an excess of alkalinity between 120 (after the 1<sup>st</sup> year) to 130,000 t H<sub>2</sub>SO<sub>4</sub> eq. (after 400 years). This excess of alkalinity significantly increases when evaporative concentration is considered, such that in the 1<sup>st</sup> year there is an excess of 130 t H<sub>2</sub>SO<sub>4</sub> eq. whilst after 400 years this will increase to around 600,000 t H<sub>2</sub>SO<sub>4</sub> eq. – this result clearly shows the impact that evaporative concentration has on pit water quality, ensuring that the mass of alkalinity present in the pit lake exceeds the release of acid from the ARD material.

The results presented in Table 3.5 show that for the first 100 years after closure the alkalinity present in the inflowing groundwater (with no evaporative concentration) is sufficient to buffer all released acidity from the PAF material, due to their relatively small area of exposure on the pit walls. When evaporative concentration further is considered there is sufficient alkalinity to neutralise all acidity input for all time steps (i.e. up to 400 years). The increasing quantity of alkalinity released from the weathering NAF material will provide further protection against pH changes in the long term.

Table 3.6 shows how the major solutes are likely to evolve over time when only evaporative concentration is considered (i.e. no solute input from weathering of the pit wall rocks). It is expected that after 50 years the pit lake will become hypersaline with considerable concentrations of Na-Cl and Mg-SO<sub>4</sub>.

### 3.4 Conclusions

The pit water within the Tropicana and Havana mine pits will remain at pH levels > 7, with evaporative concentration of groundwater and alkalinity inputs from weathering of exposed NAF material being the primary drivers. Given the predicted alkalinity of the pit water it is not expected that metals will increase to problematic concentrations as the pH of the water will likely limit their solubility (Weiner, 2008). It is also predicted that the pit water will likely become hypersaline after 50 years.



## SECTION 5

## Geochemical Evolution of Pit Water Quality

**Table 3.5:** Predicted acidic and alkalinity inputs into the combined Tropicana and Havana pits, and resulting water pH.

Time	0y	1y	2y	5y	10y	20y	50y	100y	400y
Groundwater level (m AHD)	-30	0	20	40	60	80	110	120	130
Water volume (m <sup>3</sup> )		680,309	1,332,688	3,192,513	5,862,991	10,062,925	17,813,047	22,997,062	26,113,871
Evaporative concentration factor		1.09	1.09	1.30	1.49	2.08	2.78	4.14	4.39
<b>Mass of acidity (H<sub>2</sub>SO<sub>4</sub>) (tonnes) from weathering PAF rocks</b>									
Area of PAF above water level (m <sup>2</sup> )	365,614	348,563	332,373	318,422	303,111	279,802	241,848	231,121	224,370
Volume of PAF exposed above water level (m <sup>3</sup> )		366	349	997	1,592	3,031	8,394	12,092	69,336
Mass of acid (H <sub>2</sub> SO <sub>4</sub> ) released (tonnes)									
- > 0.5% sulfide (Reaction rate = 0.0028 kg H <sub>2</sub> SO <sub>4</sub> /t/wk)		0.13	0.13	1.09	2.90	11.03	91.66	220.08	7,572
- > 1.0% sulfide (Reaction rate = 0.0050 kg H <sub>2</sub> SO <sub>4</sub> /t/wk)		0.24	0.23	1.94	5.17	19.70	163.68	393.00	13,521
<b>Mass of alkalinity (H<sub>2</sub>SO<sub>4</sub> equivalents) (tonnes) from weathering NAF rocks</b>									
Area of NAF rocks above water level (m <sup>2</sup> )	2,724,266	2,741,317	2,757,507	2,771,458	2,786,769	2,810,078	2,848,032	2,858,759	2,865,510
Volume of NAF rocks exposed above water level (m <sup>3</sup> )		2,724	2,741	8,273	13,857	27,868	84,302	142,402	857,628
Mass of alkalinity (H <sub>2</sub> SO <sub>4</sub> equivalents) (tonnes) released		1.40	1.41	12.80	35.73	143.72	1,304	3,672	132,686
<b>Mass of alkalinity (H<sub>2</sub>SO<sub>4</sub> equivalents) (tonnes) from groundwater inflow</b>									
Mass of Alkalinity (H <sub>2</sub> SO <sub>4</sub> equivalents) (tonnes) - 1st pass		118	232	555	1,020	1,750	3,098	3,999	4,541
Mass of Alkalinity (H <sub>2</sub> SO <sub>4</sub> equivalents) (tonnes) - 2nd pass (incl. Evap. Concentration)		129	253	722	1,519	3,640	8,612	16,557	19,936
<b>Total Alkalinity inputs (H<sub>2</sub>SO<sub>4</sub> equivalents) (tonnes) - 1st pass</b>		<b>120</b>	<b>233</b>	<b>568</b>	<b>1,055</b>	<b>1,894</b>	<b>4,402</b>	<b>7,671</b>	<b>137,227</b>
<b>Total Alkalinity inputs (H<sub>2</sub>SO<sub>4</sub> equivalents) (tonnes) - 2nd pass</b>		<b>130</b>	<b>254</b>	<b>738</b>	<b>1,572</b>	<b>3,939</b>	<b>12,237</b>	<b>31,758</b>	<b>602,428</b>
<b>Acid Base Balance (H<sub>2</sub>SO<sub>4</sub> equivalents) (tonnes) for 0.5% sulfide</b>									
- 1st pass		-119.58	-233.04	-566.89	-1,052.41	-1,882.63	-4,310.29	-7,451.00	-129,655.83
- 2nd pass (incl. evaporative concentration)		-130.35	-254.03	-737.28	-1,569.51	-3,927.78	-12,145.77	-31,538.21	-594,856.57
Predicted pH of pit lake water - 1st pass		>7	>7	>7	>7	>7	>7	>7	>7
Predicted pH of pit lake water - 2nd pass		>7	>7	>7	>7	>7	>7	>7	>7
<b>Acid Base Balance (H<sub>2</sub>SO<sub>4</sub> equivalents) (tonnes) for 1.0% sulfide</b>									
- 1st pass		-119.47	-232.94	-566.03	-1,050.13	-1,873.96	-4,238.27	-7,278.08	-123,706.78
- 2nd pass		-130.25	-253.93	-736.43	-1,567.23	-3,919.11	-12,073.75	-31,365.29	-588,907.52
Predicted pH of pit lake water - 1st pass		>7	>7	>7	>7	>7	>7	>7	>7
Predicted pH of pit lake water - 2nd pass		>7	>7	>7	>7	>7	>7	>7	>7

## Geochemical Evolution of Pit Water Quality

**Table 3.6:** Predicted major solute concentration of the pit water for the combined Tropicana and Havana pits.

	0y	1y	2y	5y	10y	20y	50y	100y	400y
Major Ion Solutes (mg/L) - Evaporative concentration only									
Sodium (Na)	6,132	6,684	6,684	7,972	9,137	12,755	17,047	25,386	26,919
Magnesium (Mg)	1,364	1,487	1,487	1,773	2,032	2,837	3,792	5,647	5,988
Calcium (Ca)	528	576	576	686	787	1,098	1,468	2,186	2,318
Potassium (K)	344	375	375	447	513	716	956	1,424	1,510
Chloride (Cl)	12,542	13,671	13,671	16,305	18,688	26,087	34,867	51,924	55,059
Sulfate (SO <sub>4</sub> )	3,651	3,980	3,980	4,746	5,440	7,594	10,150	15,115	16,028
Calculated TDS	24,561	26,771	26,771	31,929	36,596	51,087	68,280	101,683	107,823

## SECTION 5

# References

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