



Taroborah Coal Project

Appendix 14a – Final Pit Water Quality Projections





TO: **IMC Mining**

ATTENTION: **Dave Thomas**

DATE: 27 October 2014

SUBJECT: Modelling of Water Quality in Final Voids - Taraborah Coal Project

1. Background

Two voids will remain at the completion of the open cut mining stage of the Taraborah Coal Project (Figure 1). At completion of the project the voids will be allowed to fill by natural inflows of ground water and rainfall within the void. Over the long term the water levels in the voids will stabilise at around RL 195 m, and when filled the volumes will be approximately 6.4 Mm³ for the void on the eastern side of the open cut, and 2.1 Mm³ for the western void.

Geochemical studies carried out by EGi for the EIS indicated that the majority of overburden and spoil that will be produced during mining of the open cut will be non-acid forming (NAF). However some rock units within the stratigraphy that will be intersected by the open cut are sulphidic and will be potentially acid forming (PAF) and have the capacity to generate acidic rock drainage (ARD) if exposed to atmospheric conditions. In addition to the two coal seams, it is expected that the interburden between the two seams will be PAF, as will floor material below Seam B. The occurrence of PAF material is a potential concern in relation to the quality of water that will collect within the final voids.

Monitoring of ground waters across the Project area indicates that ground waters within the Quaternary alluvium, Tertiary gravel, and the Aldebaran sandstone are alkaline, and hence ground water inflows to the voids at closure will serve to neutralise acid that is produced from PAF materials exposed around the final surfaces of the voids. Monitoring of local ground water bores indicates pHs typically around 7 to 8 and alkalinities typically in the range 200 to 500 mg/L. Monitoring also indicates that ground water inflows will be slightly brackish (or saline), predominantly due to elevated concentrations of sodium and chloride. The total dissolved salts (TDS) in ground water will likely average around 400 to 600 mg/L.

This memorandum presents the results and findings of hydrogeochemical modelling of the Taraborah open cut voids carried out by EGi to predict the quality of water within the voids through time as water level rises. The modelling was carried out in association with ATC Williams (who provided data on surface water inflows) and also AGE Consultants (who provided data on ground water inflows). To date, modelling of water quality has focused on the larger eastern void. As the western void has essentially the same stratigraphy and will be subject to inflows of the same surface and ground waters, it is expected that the quality of the pit lake that develops in the western void will be comparable to that predicted for the eastern void.

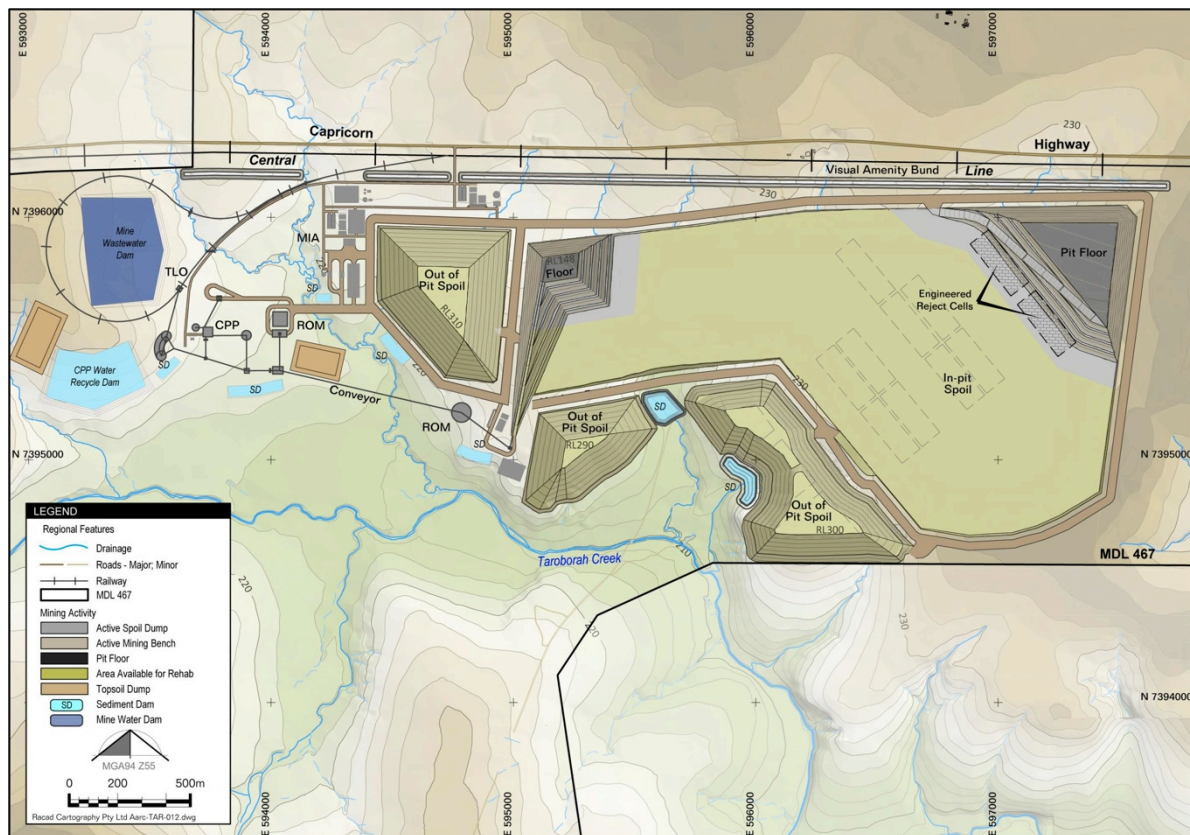


Figure 1: Plan of Taroborah open cut at closure

2. Model Software

The hydrochemical model for the Taroborah open pit voids was based around Microsoft *Excel* and the *Phreeqc* chemical speciation program. The use of *Phreeqc* means the calculations of pH and void water chemistry were based on fundamental chemical principals. By using thermodynamic principals rather than empirical relationships, it is possible to predict pH and full water chemistry for different scenarios with respect to void dimensions, wall rock types (including NAF and PAF characteristics), runoff chemistries from individual rock types, different inflow regimes for surface and ground waters, and development of water bodies within the voids through time.

The *Excel* component of the hydrogeochemical model contains data relevant to the void shell (lithology, NAF/PAF distribution), water balance information, and the chemistries assigned to runoffs from different wall rock units, and ground water inflows. The *Excel* component also has embedded macros that produce an input file that feeds into the *Phreeqc* computer program which predicts the pH and water quality of the combined pit water.

Phreeqc was developed and released for public use by the US Geological Survey (USGS), and is generally regarded as one of the leading hydrogeochemical programs currently available for simulating chemical reactions and transport processes in natural or contaminated water. *Phreeqc* has the capability to model the pH and chemical speciation reactions including solubility, redox, ion-exchange, and surface complexation for a

single solution or mixes of two or more solutions. Consequently, the output from *Phreeqc* provides an indication of the distribution of elements between dissolved and solid phases, which in the latter case may be a precipitate that is predicted to form due to a solubility constraint when different waters mix, or when an element is predicted to be adsorbed onto some colloidal surface such as iron oxide.

3. Modelling Approach

For modelling purposes the final void was partitioned into three main surfaces, namely the spoil slope, the high wall, and the void floor. These areas are illustrated in Figure 2. The highwall represents the original stratigraphic profile whereas the spoil represents a mixture of overburden and interburden materials that will be mined to access the coal seams and replaced in-pit.

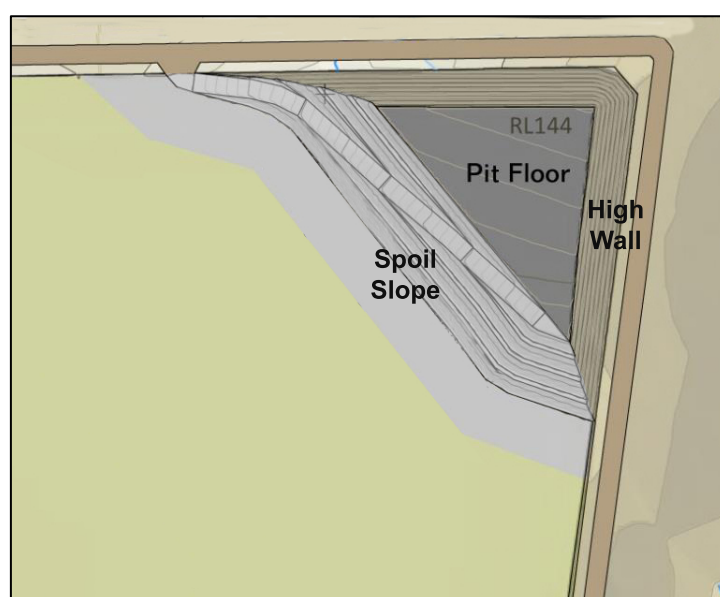


Figure 2: Plan of Eastern void showing areas designated as spoil slope (light grey), high wall (lined olive) and pit floor (dark grey)

The inputs considered in the water quality model of the Taraborah final void are illustrated in Figure 3. They include ground waters from the high wall and from the in-pit spoil, as well as runoffs from different geological surfaces. The model calculated pit lake water quality on a one-year time step, and for each step the model input file included data for the flow and chemistry of each source of water inflow. The only output was a loss of water via evaporation. There was no water overflow from the void.

It is understood that rejects may be placed within the void. Should this occur, the rejects will be placed in a manner that minimises the potential for sulphide oxidation to occur. This will involve blending with limestone and encapsulation of rejects within engineered isolation cells that are lined with geosynthetic clay to restrict oxygen ingress and to minimise leaching. Such measures will limit the exposure of rejects to conditions that are conducive to ARD generation. It was therefore assumed that any reject cells constructed within the void will be geochemically secure prior to and post flooding of the void, and consequently will not contribute significantly to pit lake water quality.

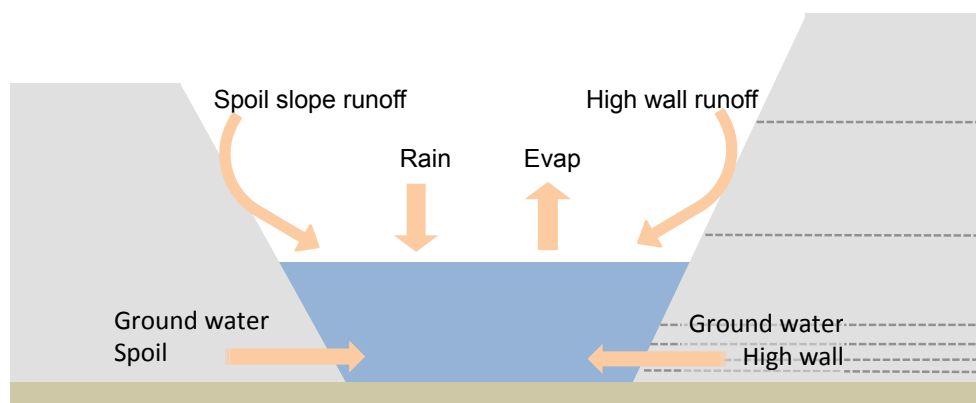


Figure 3: Schematic of input/outputs considered in the hydrogeochemical model of the pit lake in the Taraborah final void

4. Void Dimensions

The total surface area of the eastern void is 346,505 m². The spoil slope was assumed to be comprised of a homogenous material whereas the high wall was sub-divided into a number of strata representing the different rock units exposed on the wall at the completion of mining. A schematic of the layers within the high wall is given in Figure 4.

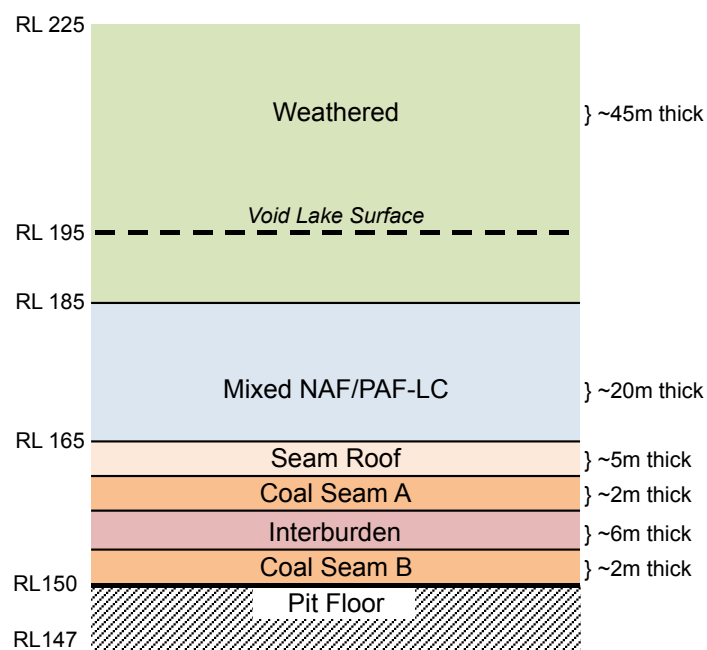


Figure 4: Schematic of high wall stratigraphy (not to scale)

The slope areas of different material surfaces within the Eastern void were provided by IMC and are summarised in Table 1. Plan areas for each material surface were also calculated by multiplying the spoil and high wall slope areas by a factor of 0.66.

Table 1: Surface areas for the Eastern pit void

Void Surface	Slope Area (m ²)	Plan Area (m ²)
Pit Floor	86,274	86,274
Spoil Slope	140,007	92,405
High Wall	120,224	79,348
Total	346,505	258,026
<u>High Wall Strata</u>		
<i>HW Weathered</i>	75,857	50,066
<i>HW Mixed</i>	18,435	12,167
<i>HW Seam Roof</i>	11,771	7,769
<i>HW Coal Seam A</i>	1,575	1,040
<i>HW Interburden</i>	10,233	6,754
<i>HW Coal Seam B</i>	2,353	1,553

The lowest point of the floor is at RL 147 m. It was assumed that the entire area of the floor will be exposed during the first year of filling, and thereafter entirely covered by water. The water level in the pit void was allowed to increase with inflows from ground water and surface runoff, based on staged storage capacities provided by IMC which are summarised in Table 2. It is understood from previous hydrologic modelling of the project area that the water level will rise to a maximum of RL 195 m.

Table 2: Volume and surface areas versus RL for the Eastern pit void

Relative Water Level A.S.L (m)	Volume (m ³)	Surface Area (m ²)
150	365,452	85,154
155	828,847	99,054
160	1,345,494	107,641
165	1,905,613	116,442
170	2,510,241	125,441
175	3,179,744	138,959
180	3,900,173	149,250
185	4,672,628	159,770
190	5,523,845	176,370
195	6,399,712	185,906

5. Ground Water and Surface Water Inflows

The rates of ground water inflow to the void were based on data provided by AGE Consultants. Rates were staged during filling using 5 m RL increments. Rates of surface runoff were calculated from exposed plan areas of spoil slope or high wall assuming an annual rainfall of 610 mm and an average runoff factor for the year of 0.3. The surface inflows based on this approach were comparable to estimates provided by ATC Williams using more sophisticated hydrologic modelling methods. Evaporation loss from the pit lake surface was based on an annual pan evaporation rate of 2100 mm and a pan coefficient of 1.3 (*i.e.* actual evaporation from pit lake surface of approximately 1600 mm per year).

Table 3 provides a schematic of inflows that contribute to pit water volume and quality as the void fills. The rates of inflow of ground water progressively decrease with increasing RL, as do the inflows of surface waters running off the spoil slope and the high wall as the void walls are progressively inundated. Conversely, the rate of inflow of rain directly into the pit lake, and the loss of pit lake water via evaporation, increase directly with increasing surface area of the lake. It should be noted that only wall rock above the water surface contributes to, or has any effect on, pit water chemistry (*i.e.* there is no chemical diffusion into or out of wall rock or the pit floor).

Table 3: Inflows contributing to pit lake volume and chemistry with increasing water level

Inflow/Outflow Source	Relative Water Level A.S.L (m)									
	150	155	160	165	170	175	180	185	190	195
Rain into Pit Lake										
Runoff - Spoil Slope										
Runoff - HW Weathered										
Runoff - HW Mixed										
Runoff - HW Seam Roof										
Runoff - HW Coal Seam A										
Runoff - HW Interburden										
Runoff - HW Coal Seam B										
Runoff - Pit Floor										
Groundwater - Spoil										
Groundwater - High Wall										

The actual staged inflow rates for each input source are given in Table 4.

Table 4: Inflow rates for surface and ground waters versus relative water level

Inflow Source	Inflow Rates (m³/year)										
	150 RL	155 RL	160 RL	165 RL	170 RL	175 RL	180 RL	185 RL	190 RL	195 RL	
Pit Lake	0	53,490	61,413	66,737	72,194	77,773	86,155	92,535	99,057	109,349	115,262
Runoff - Pit Floor	16,047	0	0	0	0	0	0	0	0	0	0
Runoff - Spoil Slope	17,187	17,187	15,908	15,049	14,168	13,268	11,915	10,885	9,832	8,171	7,217
Runoff - HW Weathered	9,312	9,313	9,131	9,215	9,904	9,696	9,100	8,782	8,444	7,017	6,198
Runoff - HW Mixed	2,263	2,263	2,263	2,263	2,263	1,697	1,132	566	0	0	0
Runoff - HW Seam Roof	1,445	1,445	1,445	1,445	0	0	0	0	0	0	0
Runoff - HW Coal Seam A	193	193	193	0	0	0	0	0	0	0	0
Runoff - HW Interburden	1,256	1,256	628	0	0	0	0	0	0	0	0
Runoff - HW Coal Seam B	289	289	0	0	0	0	0	0	0	0	0
SubTotal Runoff	47,993	85,436	90,983	94,709	98,529	102,435	108,301	112,768	117,333	124,538	128,676
Groundwater - Spoil	143,445	143,445	187,975	189,070	175,200	156,585	136,875	115,340	87,965	84,315	83,950
Groundwater - HW	109,135	109,135	113,150	104,025	91,250	77,015	62,415	46,355	27,010	24,455	23,725
SubTotal Groundwater	252,580	252,580	301,125	293,095	266,450	233,600	199,290	161,695	114,975	108,770	107,675
TOTAL	300,573	338,016	392,108	387,804	364,979	336,035	307,591	274,463	232,308	233,308	236,351

6. Chemistries of Input Water

Table 5 gives the chemistries assigned to ground water inflows and to surface runoffs from different material types. The input chemistries for runoff were based on results of column leach tests carried out by EGi for the Taroborah EIS. The chemistries assigned to ground water inputs were based on field monitoring data as summarised in the EIS. An input chemistry was also assigned to rainfall directly falling into the void lake once it begins to form.

The following water quality parameters are currently included as input to the hydrogeochemical model: pH, redox, alkalinity, Ag, Al, As, B, Ba, Ca, Cd, Cl, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sn, SO₄, U, and Zn.

The initial water falling directly onto the pit floor during Year 1 was assumed to be acidic, as were runoffs associated with the coal seams, roof and interburden layers. Conversely, surface runoffs from spoil slope and the upper two layers of the high wall were assumed to be alkaline, as were ground water inflows.

It should also be noted that the chemistries currently assigned to input sources are independent of the flow conditions being modeled. In reality, the chemistries of runoff could change depending on climatic conditions (intensity and duration of rainfall event) and also into the long term as freshly mined surfaces weather and become depleted with respect some elements. However, there is currently insufficient background data to quantify such changes.

Table 5: *Chemistries of input waters included in the hydrogeochemical model (mg/L except pH)*

Parameter	Groundwaters		Surface Runoff								Rain to Lake
	Spoil	High Wall	Spoil Slope	HW Weathered	HW Mixed	HW Seam Roof	HW Coal Seam A	HW Interburden	HW Coal Seam B	Pit Floor	
pH	8.4	7.7	7.4	8.2	7.4	2.3	2.2	2.3	2.2	2.5	6.5
Ag	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0
Al	0.01	0.01	2	0.3	2	337	1,000	135	1,000	54	0
As	0.003	0.003	0.04	0.1	0.0	2	3	0.3	3	0.09	0
B	0.07	0.07	0.08	0.2	0.08	0.05	0.1	0.05	0.1	0.05	0
Ba	0.18	0.18	0.03	0.02	0.03	0.005	0.01	0.01	0.01	0.01	0
Ca	71	53	314	40	314	102	100	66	100	71	0
Cd	0.0001	0.0001	0.006	0.0002	0.006	0.04	0.08	0.02	0.08	0.02	0
Cl	534	197	22	180	22	6.7	500	7	500	3	0
Co	0.002	0.002	0.2	0.002	0.2	2	4	1	4	2	0
Cr	0.001	0.001	0.002	0.001	0.002	0.5	1	0.2	1	0.08	0
Cu	0.001	0.001	0.03	0.01	0.03	2.0	4	1.11	4	1	0
Fe	1	1	7	0.1	7	2154	3000	648	3,000	190	0
Hg	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0
K	6	6	26	3	26	1	5	4	5	3	0
Mg	95	55	492	61	492	100	800	77	800	168	0.1
Mn	0.03	0.03	20	0.03	20	5	20	6	20	28	0
Mo	0.005	0.005	0.001	0.009	0.001	0.05	0.1	0.008	0.1	0.001	0
Na	263	160	27	144	27	3	250	5	250	3	0
Ni	0.002	0.002	0.5	0.01	0.5	5	10	2	10	3	0
Pb	0.001	0.001	0.002	0.001	0.002	0.002	0.003	0.01	0.003	0.01	0
Sb	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.002	0.001	0
Se	0.001	0.001	0.09	0.02	0.09	0.2	0.5	0.09	0.5	0.03	0
Sn	0.001	0.001	0.001	0.003	0.001	0.007	0.01	0.004	0.01	0.004	0
SO4	150	100	2,871	243	2,871	8,618	15,000	3,202	15,000	1,922	0.1
U	0.001	0.001	0.003	0.001	0.003	1	1	0.2	1	0.09	0
Zn	0.005	0.005	0.8	0.008	1	12	24	12	24	10	0
Alkalinity	251	381	50	120	50	-	-	-	-	-	1

7. Model Settings

Thermodynamic Database

The *Phreeqc* component of the model includes a selection of thermodynamic databases that define the various reactions that can occur, such as the precipitation of mineral phases. For the model runs reported in this memorandum, the thermodynamic database known as *Minteq.v4* was utilised in its existing form¹, with the exception that some mineral phases were excluded because they are unlikely to exist under the environmental conditions that will prevail in a setting such as exists within the final voids.

pH Determination

The pHs of source waters are specified as inputs to the model but the *Phreeqc* component of the model computes the pH of the combined pit water mix. This capability is essential as the solubilities of many elements (and especially metals) are pH-dependent, and therefore the model can compute concentrations of dissolved and solid phases. In the latter case, solid-phases of elements will occur when the total concentration in the mix exceeds the solubility product of one or more of the compounds included in the thermodynamic database.

O₂ Constraint

It was assumed that the pit lake was equilibrated with atmospheric oxygen (*i.e.* pO₂ set to -0.67)

CO₂ Constraint

Based on past experience, it is generally the case that pit waters that result from a combination of acid and alkaline waters are not fully equilibrated with atmospheric carbon dioxide (*i.e.* defined as pCO₂=3.5). Therefore, a pCO₂ of 2.5 was used.

8. Prediction of Pit Water Quality

Year-by-year predictions of pit lake quality for the eastern void were made for a period of 100 years. Figure 5 shows the predicted volume of water within the void during filling, and Figure 6 shows the cumulative inflows of ground water and surface runoff from different sources. Table 6 gives a summary of water quality predictions at the end of each decade during the 100 year period, and time series plots for pH and major elements are also given in Figure 7.

The pit water is predicted to be circum-neutral throughout the 100 year period, with salinity gradually increasing due primarily to the inflow of slightly saline ground water and the concentrating effect of evaporative water loss.

¹ Some of the thermodynamic values included in the database may need to be modified to more accurately reflect the system being modelled. As a general rule, the precipitates that tend to form under field conditions tend to be somewhat impure and amorphous and typically have solubilities that are higher than those included in the thermodynamic database which are based on pure mineral phases. Assessment of the need for changes to the thermodynamic database will require additional laboratory experimentation (*e.g.* a series mixing tests) to provide experimental data against which the model can be calibrated.

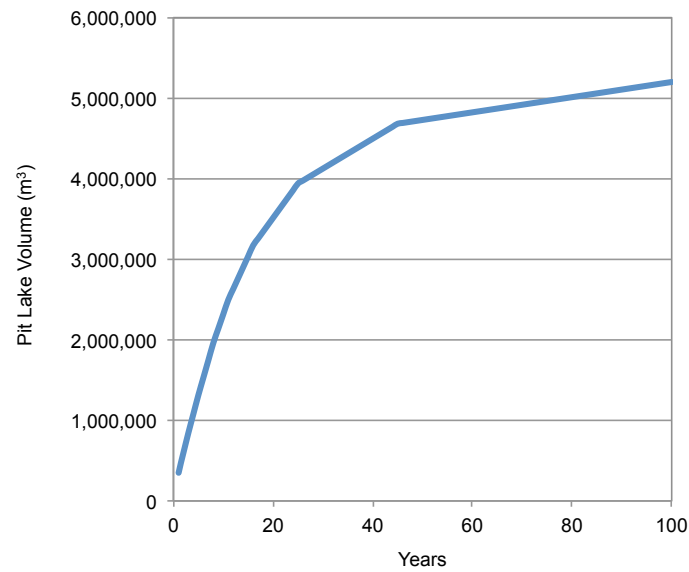


Figure 5: Predicted volume of water within Eastern void

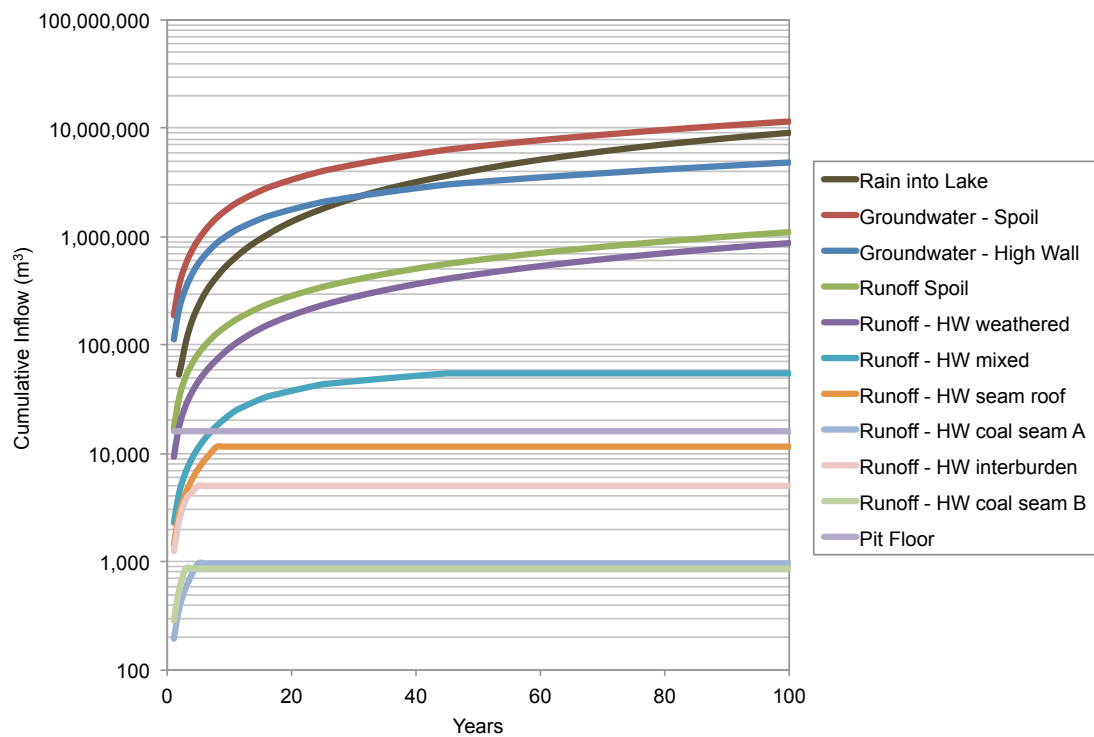


Figure 6: Cumulative inflows of ground and surface waters from different sources for the Eastern void (note: logarithmic scale)

Table 6: Predictions of pit water quality in the Eastern void during pit lake development

Parameter	Unit	Year after Start of Filling										
		1	10	20	30	40	50	60	70	80	90	100
pH		7.5	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.8	7.8
<i>Major anions</i>												
Cl	mg/L	359	527	619	714	815	909	1008	1093	1195	1274	1350
SO ₄	mg/L	451	475	537	611	686	774	858	939	1021	1057	1125
<i>Major cations</i>												
Ca	mg/L	78	62	60	59	58	60	62	64	65	57	58
Mg	mg/L	108	143	167	194	220	247	273	298	324	346	368
Na	mg/L	200	292	341	392	447	497	550	596	650	692	733
K	mg/L	2	2	3	3	3	4	4	5	5	6	6
<i>Trace elements</i>												
Ag	mg/L	0.001	0.001	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003
Al	mg/L	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
As	mg/L	0.00003	0.00003	0.00004	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.001	0.002
Ba	mg/L	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6
B	mg/L	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Cd	mg/L	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
Co	mg/L	0.1	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.04	0.04
Cr	mg/L	0.006	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004
Cu	mg/L	0.003	0.002	0.002	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.004
Fe	mg/L	0.006	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Hg	mg/L	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003
Mn	mg/L	2	2	2	2	3	3	3	4	4	4	4
Mo	mg/L	0.005	0.007	0.008	0.009	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Ni	mg/L	0.19	0.08	0.08	0.08	0.08	0.09	0.10	0.11	0.12	0.11	0.12
Pb	mg/L	0.00003	0.00003	0.00004	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0004	0.0004
Sb	mg/L	0.001	0.001	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003
Se	mg/L	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
Sn	mg/L	0.001	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.004	0.004
U	mg/L	0.011	0.005	0.005	0.004	0.004	0.005	0.005	0.006	0.006	0.004	0.004
Zn	mg/L	0.5	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2

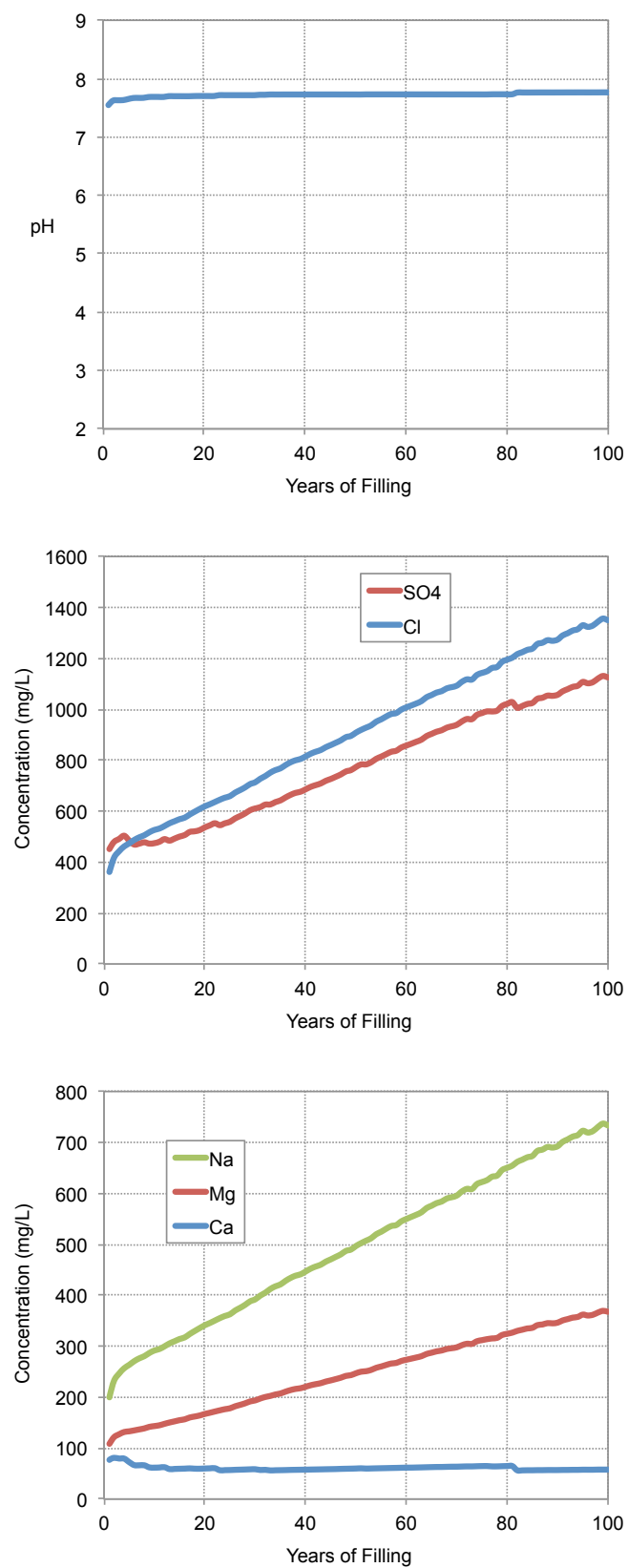


Figure 7: Time series plots of predicted pH and concentrations of major anions and cations

9. Sensitivity of Pit Water pH to Runoff from PAF Strata

The first few years will be of greatest concern in relation to ARD as this is when PAF floor rock and high wall strata will be exposed. Based on current assumptions, the model predicts that at the end of the first year there will be sufficient inflow of alkaline ground water and alkaline runoff from the spoil slope and weathered portion of the high wall to negate the acidity of surface runoff from PAF rock exposed around the base of the void. The model predicts that in Year 1, the inflows from PAF units represents less than 6% of total inflow, and in Years 2 and 3 when the pit floor is fully submerged the percentage of inflows from PAF units decreases to less than 1%. From Year 9 onward all PAF units are fully submerged.

In the event that surface runoff during the first few years is higher than currently assumed relative to the inflow of ground water inflow, then the pH of the developing pit lake could initially be lower than the base case shown in Figure 7. Figure 8 shows the effect of increasing the percentage of total inflow from PAF strata runoff on the pH of pit water for Year 1. The pH under the base case is marked as Point A in Figure 8. If the relative contribution of runoff from PAF strata was double in comparison to the base case then pit water at the end of the first year would be approximately pH 5 (Point B). At three-times higher the pH would be less than 4 (Point C).

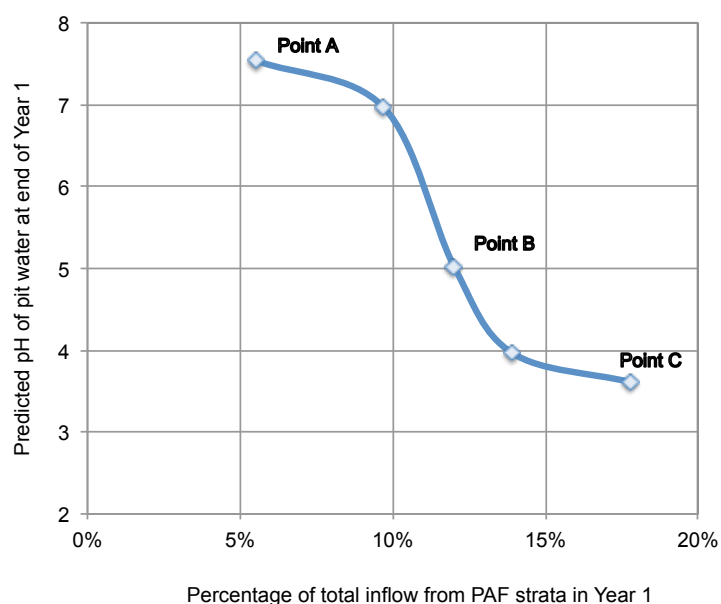


Figure 8: Effect of the relative percentage of inflow from PAF strata on the predicted pH of pit water in Year 1.

However, it can be assumed that floor rock and PAF strata in the high wall will only contribute acidic runoff when they occur above the water level in the pit. This is based on the premise that a water cover, whilst not always preventing sulphide oxidation, will invariably decrease the availability of oxygen to submerged material to a level where the rates of sulphide oxidation and acid generation are unlikely to be inconsequential to the surrounding environment. Therefore, even if the relative contribution of surface runoff from PAF strata is much higher than expected during the first few years, it is expected that the amount of acid generation within the void

will be markedly lower once the void floor is fully inundated, and will effectively cease once the water level rises above the seam roof (around Year 7). The pH of the pit lake will then trend higher due to dilution and neutralisation by ongoing inflows of alkaline ground water and surface runoff from NAF spoil and the weathered portion of the high wall. Figure 9 shows the predicted change in pit water pH for a scenario where the proportion of inflow from surface runoff is about three times higher than for the base case. The pH of the pit water is predicted to be moderately acidic for the first six years, then increase markedly in Year 7, and remain circum-neutral thereafter.

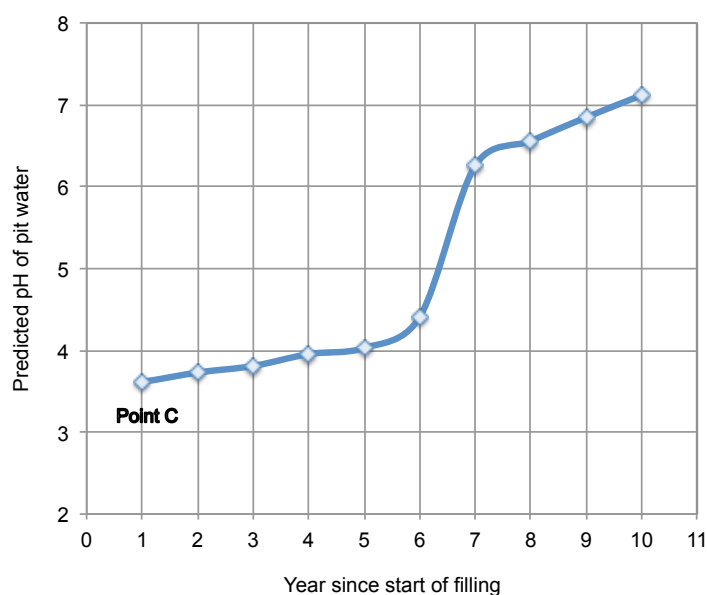


Figure 8: Effect of the relative percentage of inflow from PAF strata on the predicted pH of pit water in Year 1.

10. Summary

This memorandum provides predictions of pit lake quality for the final voids within the proposed Taroborah open cut. The predictions were based on a hydrogeochemical model developed for the eastern void that combined a mass-balance component for water and chemical inflows from a number of ground water and surface runoff sources, and a chemical speciation component (*Phreeqc*) for computation of the pH and chemical composition of the pit lake through time.

The pit floor and lower strata of the high wall (roof, coal seams and interburden) will comprise PAF materials and have the potential to generate ARD. However, the model predicts that inflows of alkaline ground water, together with alkaline runoff from in-pit spoil and upper weathered strata of the high wall, should be sufficient to neutralise acidity produced by the PAF rock units. Based on the assumptions made in the model, pit water is predicted to be circum-neutral throughout the 100 year period modelled. It is also predicted that salinity will gradually increase due to the inflow of slightly saline ground water and the concentrating effect of evaporative water loss.