Annexure 2:

Back Road WRS Geochemical Model - MWM

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MEMORANDUM

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From:	Paul Weber – Mine Waste Management Limited
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Document Title:	BRWRS Geochem Model

Mine Waste Management Limited (MWM) has been engaged by OceanaGold (New Zealand) Limited (OceanaGold) to provide environmental geochemistry support for the assessment of environmental effects (AEE) for the Macraes Phase 4 (MP4) Project at the Macraes Gold Mine (Macraes).

OceanaGold has requested that MWM develop a geochemical model for the proposed Back Road Waste Rock Stack (BRWRS) to quantify the likely water quality from that mine facility as if it was part of the existing environment. MWM have done this using an updated relationship for sulfate concentration as a function of waste rock stack (WRS) height (e.g., MWM, 2023; Navarro-Valdivia et al., 2024). The geochemical outputs will be used by GHD Limited to understand effects and potential risk to the receiving environment using the existing water balance model (e.g., Deepdell Creek).

BACKGROUND

Babbage (2019) conducted an assessment of WRS seepage water quality at the Macraes Gold Mine as part of OceanaGold's Deepdell North Stage III Project consent application (RM20.024) to the Otago Regional Council. The information provided by Babbage (2019) included Ca, Mg, and sulfate concentration data. Babbage (2019) also analysed several physical parameters of each WRS, including the footprint area, waste rock volume, and height. The analysis revealed a relationship between the average height of the WRS and its age.

Data in the Babbage (2019) report shows that the average height of WRSs at Macraes (as of 2019) ranged from 15 m to 37 m, with taller WRSs producing higher sulfate concentrations. Most WRSs at Macraes are constructed using tipheads greater than 10-20 m in height (e.g., the 'traditional' method).

Recent work by MWM (2023) confirmed a similar relationship between WRS height and sulfate peak concentrations, using data sets comparable to those used by Babbage (2019). This was a conservative approach using maximum data. For instance, shallow groundwater data was used for the Frasers West WRS (FWWRS), which had a sulfate concentration of 4,900 mg/L (MWM, 2023). Given this flow path does not represent the main flow emanating from the WRS, which is seepage from the WRS toe, it was considered conservative. The effect of this conservative approach was to predict high sulfate concentrations for WRS that were of greater height outside the empirical dataset. In the future, higher WRS may be constructed at Macraes, and a more reliable tool was required.

A contaminant load model was developed by Navarro-Valdivia et al. (2024) using measured flows and concentration data for the FWWRS as another method to forecast water quality for higher WRS. The results (Navarro-Valdivia et al., 2024) are presented graphically in Figure 1 showing seepage sulfate concentrations of 3,200 mg/L for FWWRS corresponding to ~40m average height. This was considered a reasonable approach to understand sulfate concentrations for higher WRS with the adjustment generating a strong linear trend.

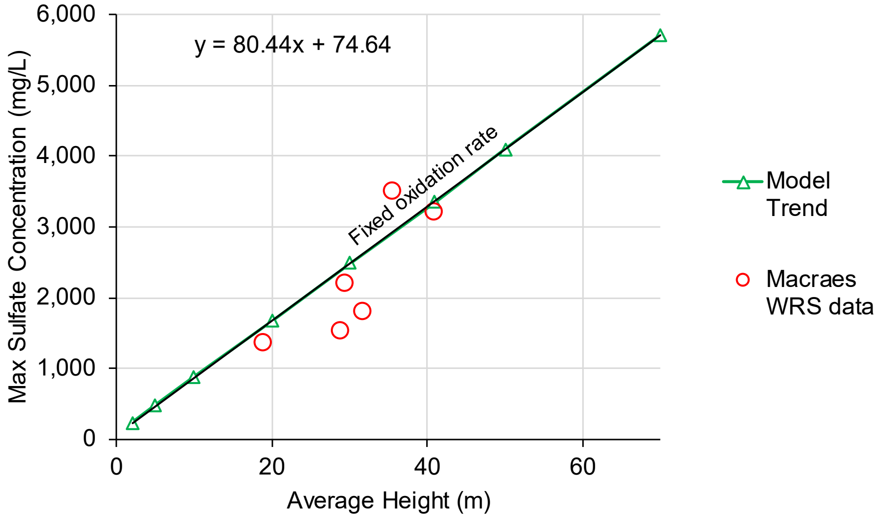

Figure 1. Sulfate concentration as a function of WRS height using adjusted sulfate concentration data for Frasers West WRS.

Note: The approach is based on Frasers West WRS geometry where the total measured load (WRS seepage flow rate and water quality) is allocated to cells within the WRS model to generate the measured concentrations as a function of WRS height.

CONTAMINANT LOAD MODEL

Previous work (e.g., MWM, 2023) was based on a relationship between WRS height and concentration. The contaminant load model (Navarro-Valdivia et al., 2024) is based on flow rate, concentration data, and WRS geometry to allocate a sulfate load to each cell (1 m^3) within the WRS model.

The model is based on the FWWRS geometry and the allocated 'cell' load is designed to achieve the measured water quality for the FWWRS (3,200 mg/L). The required load per cell was adjusted till it was calibrated against the model (e.g., matched 3,200 mg/L) where the maximum column height was 90 m, which was the thickest part of the FWWRS. This cell load, derived from empirical data, can then be applied to other WRS to forecast water quality as a function of WRS geometry (e.g., surface area and height).

Figure 2 illustrates how thicker sections of the FWWRS accumulate higher solute concentrations (up to ~8,000 mg/L at the bottom of the WRS). By assuming one-dimensional flow, the entire behaviour of the WRS can be modelled using a single column representing its maximum height. The upper portion of this column is then applied to shorter columns to represent different column heights within the WRS. The overall WRS seepage is then estimated by "mixing" all the column flow paths together at the WRS base.

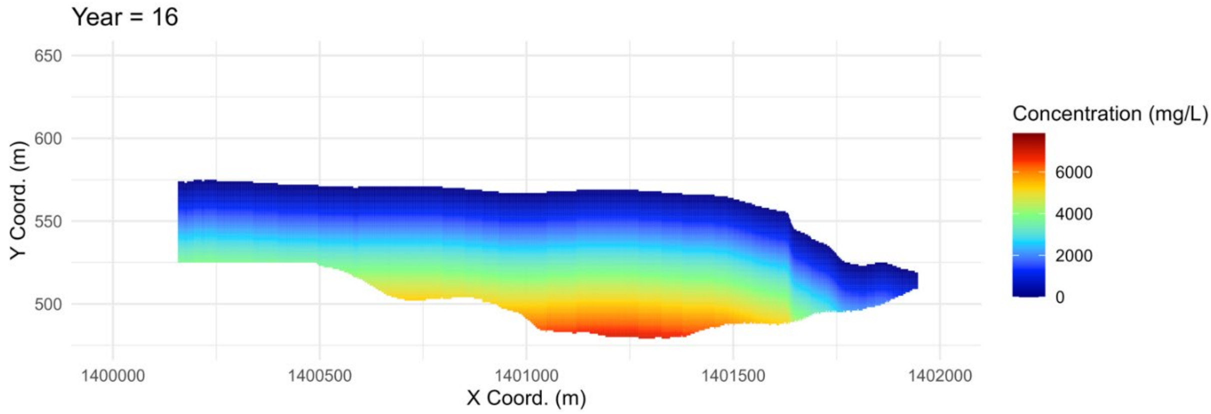

Figure 2. Cross-section of the Frasers West WRS and estimated concentrations of solutes.

Concentration Versus Flow

Previous work (e.g., Mackenzie, 2010; Weber et al., 2015) demonstrated that contaminant concentration in seepage from waste rock stacks can remain approximately constant irrespective of flow rate. However, with increasing flow, the contaminant load (i.e., mass per unit of time) increases proportional to flow rate (Figure 3; Figure 4). This demonstrates that the waste rock stack has a large reservoir of stored oxidation products that can be mobilised by greater infiltration flow through the waste rock driving an approximate constant concentration once the flow paths are established.

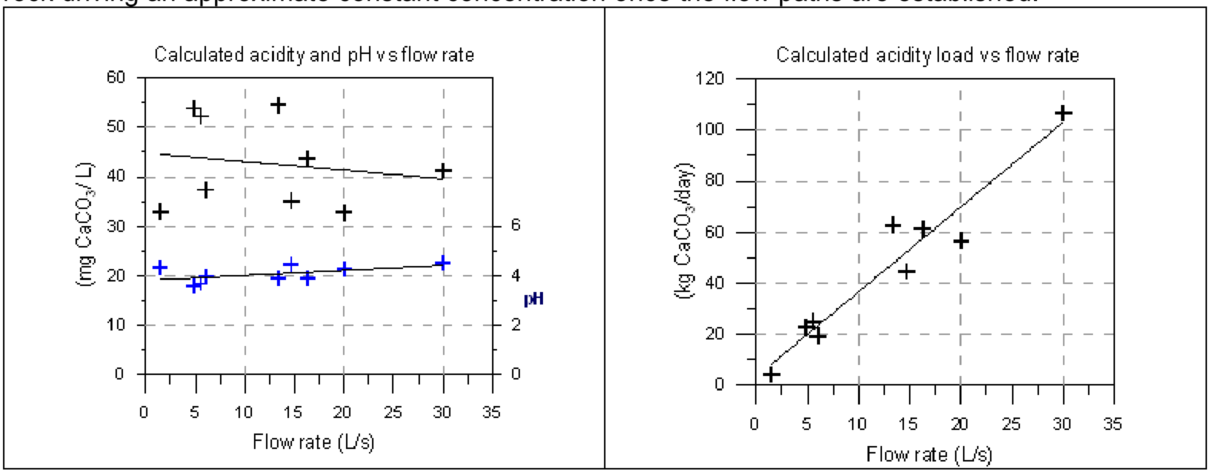

Figure 3. Fanny Creek Side Cast, Island Block Mine, West Coast

Source: Mackenzie (2010).

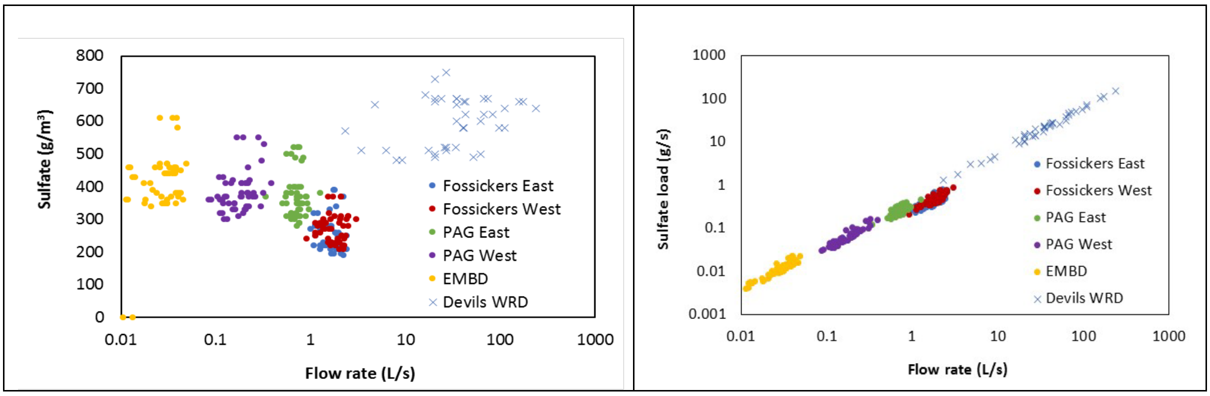

Figure 4. Globe Progress Mine, West Coast

Source: Weber et al. (2015).

Between August 2018 and December 2020, toe seepage flow rates were measured at the FWWRS. During the same period, 9 samples were taken with sulfate concentrations ranging from 2,300 to 3,200 mg/L and were reasonably consistent. Since the flow rates and samples were not taken on the same day, the available sulfate concentration data were interpolated against available flow rate data. This meant that sulfate load as a function of flow rate could also be determined. The results are shown in Figure 5. Results demonstrate that concentration remains comparable across different flow rates, yet sulfate loads increase with flow rate.

Hence, for water balance modelling it is recommended that constant concentration is used over any yearly time interval. However, concentrations will change with time (e.g., decades) as the WRS geochemical processes mature and sulfate concentrations decrease due to a diminishing reservoir of sulfides.

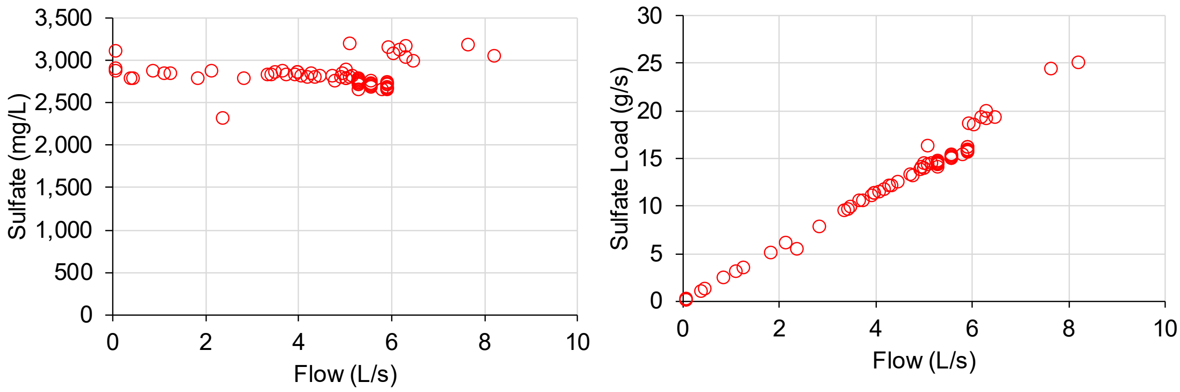

Figure 5. Flow rates and interpolated sulfate concentrations (mg/L) measured at Murphys Creek Toe monitoring location (left image) and derivation of sulfate load (g/s) (right image).

Model Approach: WRS Seepage Water Quality

An empirical mass-balance geochemical model was developed for application to waste rock stacks at Macraes, with the FWWRS used as a representative case study.

A topographical analysis, using raster images from Digital Elevation Models (DEM), prior to, and after WRS construction, was used to determine several characteristics of the FWWRS, such as footprint area and volume within the pre-WRS topographic catchment that contribute to flow at the monitoring point, as shown in Figure 6.

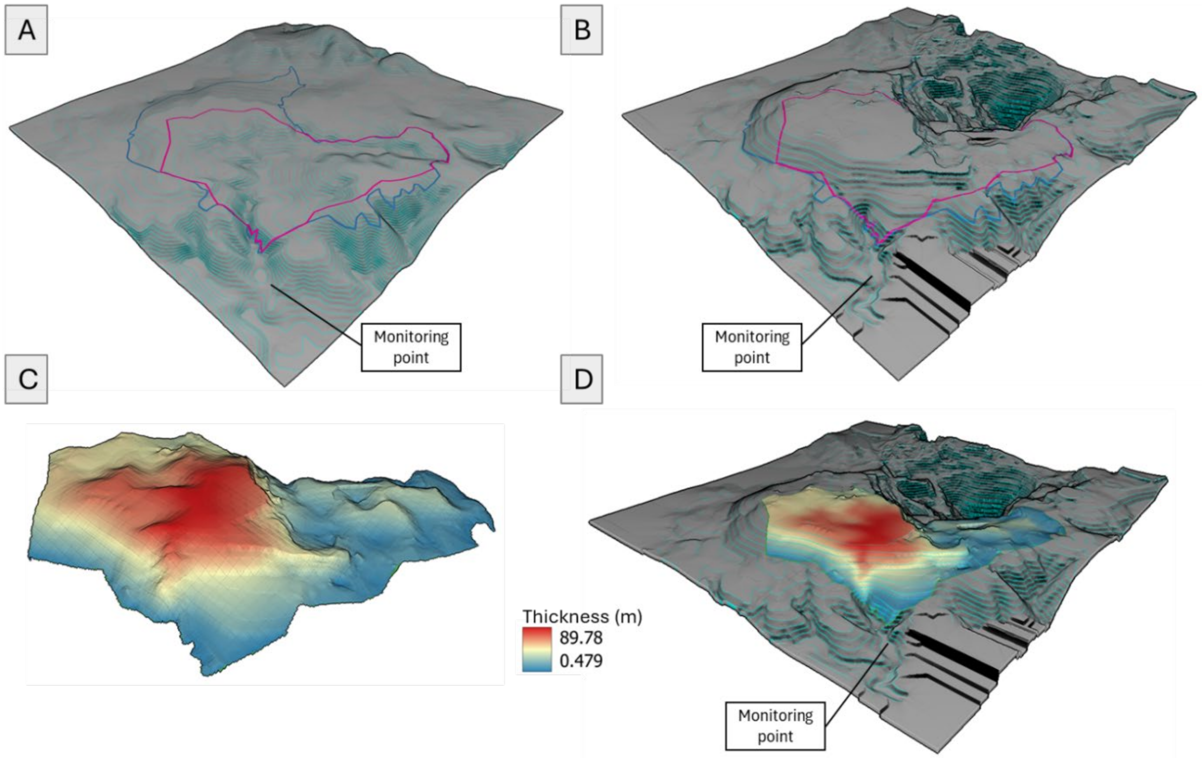

Figure 6. Frasers West WRS topographic analysis to determine the volume and area that contributes flow to the monitoring point (Murphys Creek Silt Pond).

Source: Navarro-Valdivia et al. (2024).

Model Components

Model sulfate concentrations and flow rates were calibrated against observations from the seepage monitoring point at Murphys Creek Silt Pond at the toe of FWWRS above Murphys Creek:

- A representative seepage rate of 5.4 L/s was used to determine infiltration into the WRS that being the average flow at Murphy's Creek Silt Pond. Given the basal topography of the WRS, the runoff surface area contributing to this monitoring point is estimated at 2.3 Mm² (23 ha). This results in an infiltration rate of approximately 74 mm/year. Considering the total yearly infiltration is around 600 mm, the infiltration represents about 12% of the total rainfall.

- It was assumed that the peak sulfate concentration in seepage from the FWWRS (3,200 mg/L) marked the moment when water flowing through the thickest columns of the WRS (90 m depth) reached the bottom and appeared as seepage at the toe, This occurred approximately 14.2 years after the start of the seepage monitoring period (Figure 8). This suggests that the volume of water passing through that column over this period was around 1050 mm (74 mm/year multiplied by 14.2 years). Therefore, there is around 1050 L of water stored in the 90-m column, i.e., equivalent to 1.05 m^3 over a total volume of 90 m^3, or an average volumetric water content of 1.16% (vol/vol).

The model consists of two components: water flow and sulfate concentration.

Water Flow

The water flow component assumes one-dimensional (1-D) vertical flow from the top to the bottom of the WRS, using the average volumetric water content (as explained above).

Sulfate Concentration

Each cell, representing 1 cubic meter (1 m³), has an initial sulfate load, which accounts for the sulfate (e.g., stored oxidation products = Initial Sulfate Load [ISL]) that dissolves rapidly upon contact with water. Additionally, each cell generates sulfate over time due to the ongoing oxidation of sulfides, as oxygen (air) is assumed to be present in the WRS.

Sulfate concentration is calculated by dividing the sulfate load per cell (ISL + ongoing oxidation sulfide oxidation products) by the volume of water in each cell. The model then accumulates the cell's sulfate load (based on flow rate and concentration) in the next cell below where more sulfate is added to the infiltration flow. As a result, thicker sections of the waste rock stack generate higher concentrations and hence load at the base of the column.

<u>Nitrate Load</u>

The nitrate load was assessed to understand the mobility of this soluble compound from waste rock as a function of time. It was assumed that nitrate was introduced from ANFO blasting residues and being highly water soluble, is flushed out of pore spaces by water infiltration.

The initial nitrate load (INL) was adjusted to match observed values, particularly, the decrease from the peak concentration around year 14 (Figure 7). Nitrate was modelled as a fixed INL with no additional generation (i.e., it was assumed to only originate from ANFO residue). The results, which are conservative relative to the monitored data in the first 13 years, are shown in Figure 7 and estimate the INL at approximately 0.262 mg/kg.

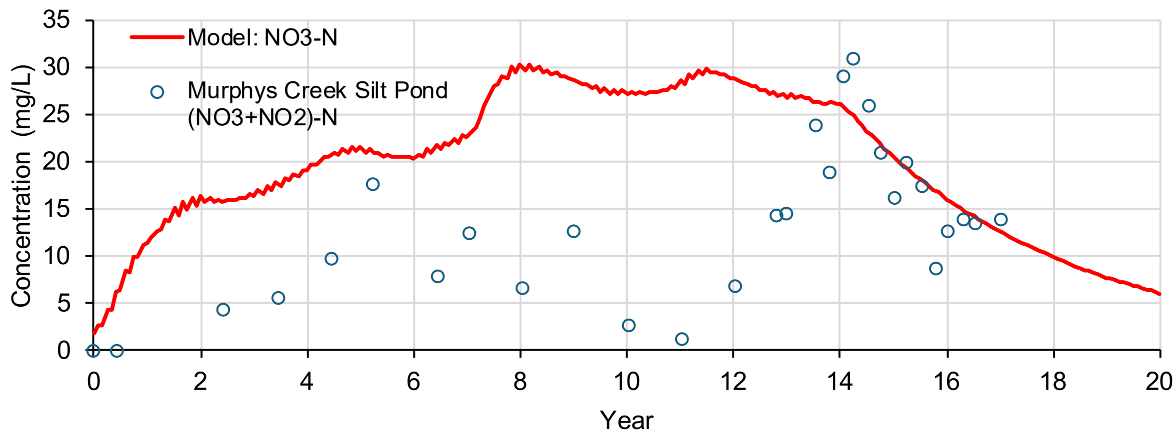

Figure 7. Frasers West WRS model for nitrate nitrogen.

Hence, the sulfate-to-nitrate ratio determined in the shake-flask leachate analysis for Macraes MP4 Project (MWM, 2024) can be used to estimate the initial sulfate load. Data provided in the MWM (2024) report showed that sulfate concentrations were 30 times higher than nitrate concentrations. Based on this ratio, the ISL is estimated to be 7.86 mg/kg[1].

<u>Sulfate Load</u>

In the available leachate tests (MWM, 2024), the ISL for in-situ waste ranged from 81 to 350 mg/kg. However, these tests were conducted in a laboratory that maximised interaction between solids and

[1] *7.86 mg/kg results from the multiplication of 0.262 mg/kg nitrate and the ratio of 30.*

water and does not consider preferential flow paths and/or immobile zones where water/rock reaction does not occur (e.g., Lopez et al., 1997; Malmström et al., 2000), which would generate lower loads per unit mass of waste rock. Hence the ISL value of 7.86 mg/kg is considered reasonable to demonstrate the influence of stored oxidation products on the model outputs.

Sulfate is derived from two sources:

- Sulfate mobilised from the ISL (represented by the green dashed line in Figure 8); and
- Ongoing sulfate generated from the ongoing oxidation of sulfides (if oxygen is not excluded).

The total sulfate concentration (sum of both sources) is represented by the blue line in Figure 8. This figure shows that the total sulfate concentration is also conservatively estimated at least in the period while the full infiltration flow is being established (as illustrated by the data points in Figure 8). The main criterion for adjustment was to match the 3,200 mg/L sulfate peak, and the subsequent decline in sulfate concentrations to understand longer term water quality risks.

The subsequent decline in sulfate concentrations after the peak concentration at Year 14 is assumed to be real and ongoing based on the available data. Future performance monitoring is required to validate this trend as it has a significant influence on model outputs in the longer term (e.g., concentration decay).

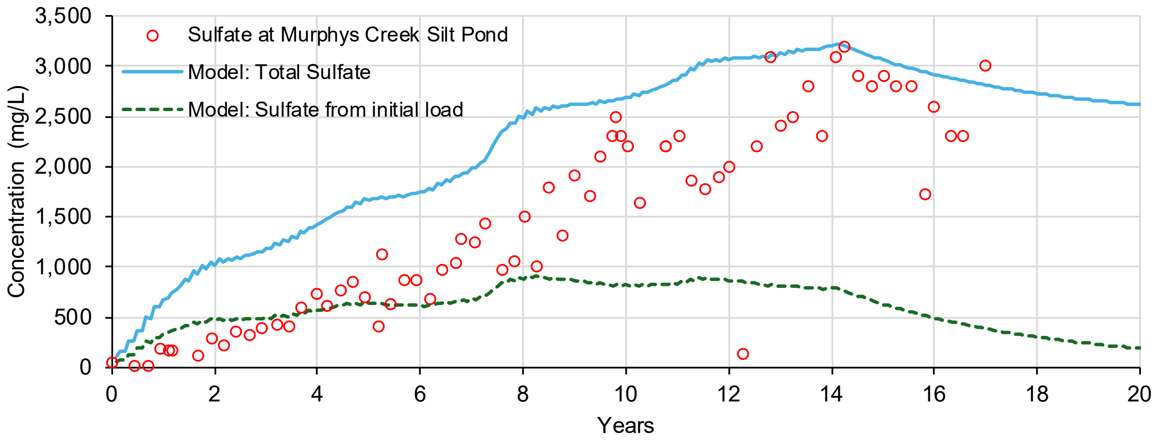

Figure 8. Frasers West WRS model for sulfate.

Additionally, based on previous experience (MWM, 2023), sulfate in WRS seepages tends to correlate with other elements. As a result, these elements can be estimated using linear correlations with sulfate, or by using the median value if the correlation is not significant (Table 1).

Table 1. Linear correlations parameters and median for estimation of parameters based on sulfate concentrations.

PARAMETER	SLOPE	INTERCEPT	SLOPE USED (A)	INTERCEPT USED (B)	MEDIAN	R^2
Alkalinity (mg $CaCO_3$/L)	0.142188	54.02	0	193.0	193	0.43
As (mg/L)	-6.1E-07	0.0059	0	0.004	0.004	0.01
Ca (mg/L)	0.1053	87.93	0.1053	87.9	240	**0.72**
Cl (mg/L)	0.000525	12.92	0	12	12	0.01
Cu (mg/L)	-1.4E-06	0.0054	0	0.0017	0.0017	0.02

PARAMETER	SLOPE	INTERCEPT	SLOPE USED (A)	INTERCEPT USED (B)	MEDIAN	R^2
Fe (mg/L)	-0.00125	2.75	0	0.04	0.04	0.02
K (mg/L)	0.001903	4.48	0	6.1	6.1	0.20
Mg (mg/L)	0.208292	-47.03	0.2083	-47.0	210	**0.92**
Na (mg/L)	0.014841	24.74	0.0148	24.7	52	**0.60**
NO_3 - N (mg/L)	0.00741	0.2326	0	12.6	12.6	0.43
Amm-N (mg/L)	-1.7E-05	0.1368	0	0.0	0.01	0.0004

MODEL OUTPUTS

Model Basis

For analysis purposes it is assumed that the current WRSs at Macraes, constructed by traditional methods, are not designed to exclude oxygen ingress[2]. Whereas a WRS designed and constructed to exclude oxygen ingress using good practice techniques is referred to as an engineered landform (ELF) (as explained in MWM, 2024). By constructing an ELF to limit oxygen ingress, lower contaminant concentrations are expected in the longer term.

A conceptual domain model has been developed to consider the depth of oxygen exclusion within an ELF. Previous work (Pope et al., 2014; Weber et al., 2014) has shown in a well-constructed ELF designed to exclude oxygen that:

- Horizontal ingress of oxygen can be up to 10 m in engineered landforms where 2 – 5 m high lifts have been utilised.
- Vertical ingress of oxygen is ~ 1 m through the running surfaces of an engineered landform

Hence, the following design criteria can be applied to the ELF geochemical model:

- Oxygen ingress is limited to 2 m depth for ELF flat surfaces; and
- Oxygen ingress is limited to 5 m horizontal depth for ELF batter slopes to reflect more difficulty in compaction of batter slopes compared to running surfaces (5 m lift heights).

A conceptual cross-section of the ELF that describes the oxygen ingress is shown in Figure 9.

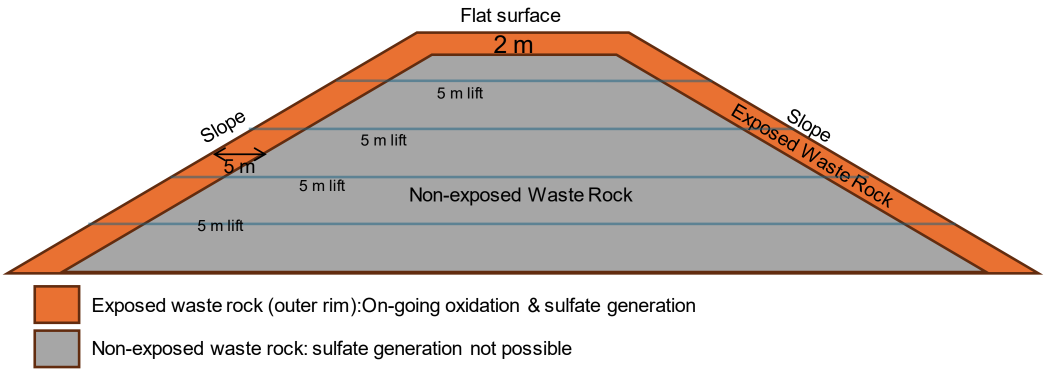

Figure 9. Conceptual cross-section of the ELF and oxidation zones.

[2] *Noting this assumption may not apply to Coronation North WRS.*

The model design criteria will need to be validated with observation of grainsize segregation, oxygen ingress measurements, and ongoing performance monitoring during the construction process. Scenario modelling should also be undertaken to understand risks for water quality if the zone of oxidation is greater than that shown in Figure 9.

Back Road ELF (BR-ELF)

A geochemical model has been developed for the proposed BR-ELF using the knowledge developed in earlier studies (Babbage, 2019; Navarro-Valdivia et al., 2024) and an understanding of how oxygen is excluded from WRSs (e.g., INAP, 2020). The model includes a topographic analysis, quantification of volume, and assessment of the footprint area based on the proposed mine plan:

- Total footprint area of 1.827 km^2 (183 ha)
- Total volume of 89.19 Mm^3
- Average height of 48.8 m (based on volume/surface area)

Note: these physical components could potentially have a ±5% error due to the methodology employed to define average height.

The BW-ELF was also divided up into 5 domains based on basal topography, potentially generating seepage at different points down slope from the ELF toe. Each of these domains is also separated into two areas: a flat surface, and batter slopes (for oxygen ingress modelling purposes). A map of the domains is shown in Figure 10, and areas volumes, and average heights are shown in Table 2.

Table 2. BR-ELF sectors characteristics.

DOMAIN	TYPE	AREA (m^2)	VOLUME (m^3)	AVERAGE HEIGHT (m)
A	flat	226,596	7,346,644	32.42
A	slope	140,212	2,096,251	14.95
B	flat	269,256	25,095,107	93.20
B	slope	234,288	12,471,302	53.23
C	flat	170,248	14,432,709	84.77
C	slope	280,824	10,416,325	37.09
D	flat	70,404	5,179,328	73.57
D	slope	414,228	11,834,845	28.57
E	slope	21,028	318,415	15.14
Overall		1,827,084	89,190,926	48.82

From Table 2 it can be noted that most of the waste rock will be placed in domains B and C, and they also have the highest average heights.

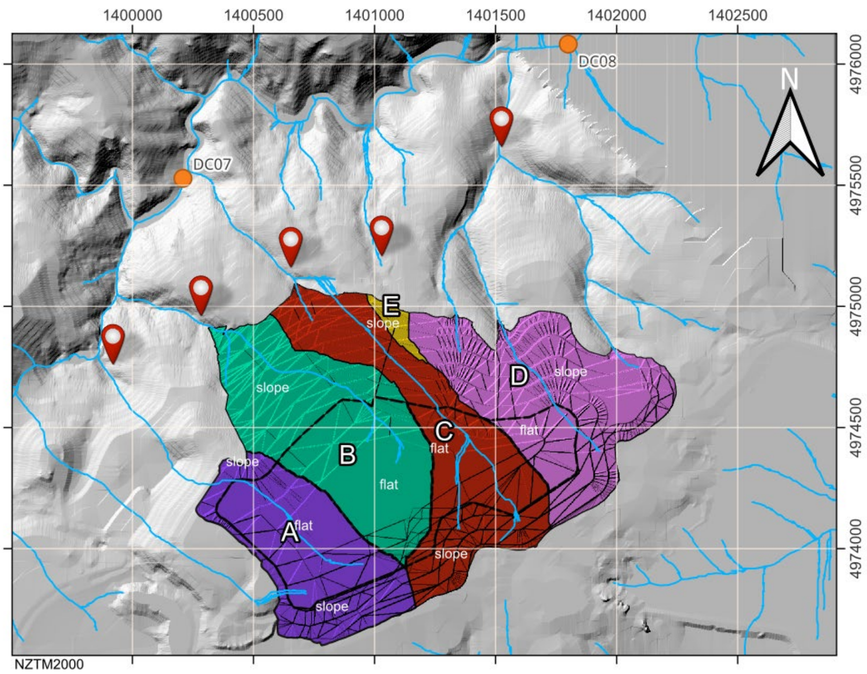

Figure 10. Classification of sub-catchments within the proposed BRELF (domains).

The monitoring points DC07 and DC08 are shown on the map for reference. Red markers indicate the locations where the model's seepage composition results are presented for each sector.

Four scenarios were defined for geochemical modelling to consider the base case against scenarios where oxygen is excluded from the BR-ELF (Table 3). The scenarios are expected to bracket the range of practicably achievable O_2 exclusion using tighter operational waste placement ('ELF construction') methods.

Table 3. Oxygen ingress scenarios for the BR-ELF.

SCENARIO	DESCRIPTION
Base case	No controls or reduced lift heights are considered – essentially formation of a typical WRS. There are no limits on sulfide oxidation due to oxygen availability (all rock oxidises at a similar rate; sulfate concentrations are a function of WRS height as shown in Figure 1.
20 m O_2 Model [20 m horizontal O_2 ingress 2 m ingress for flat surface]	Lower lift heights (~5 m) are implemented in the construction of the ELF. Oxidation is confined to the outer waste rock rim. Oxygen ingress is limited to the outer 20 m horizontally on slopes and 2 m on flat surfaces.
10 m O_2 Model [10 m horizontal O_2 ingress 2 m ingress for flat surface]	Lower lift heights (~5 m) are implemented in the construction of the ELF. Oxidation is confined to the outer waste rock rim. Oxygen ingress is limited to the outer 10 m horizontally on slopes and 2 m on flat surfaces.
5 m O_2 Model [5 m horizontal O_2 ingress 2 m ingress for flat surface]	Lower lift heights (~5 m) are implemented in the construction of the ELF. Oxidation is confined to the outer waste rock rim. Oxygen ingress is limited to the outer 5 m horizontally on slopes and 2 m on flat surfaces.

Model Results

A summary table is provided in Table 4, detailing the peak sulfate concentrations for each domain and the overall sulfate concentrations that were achieved in each model scenario. The table also presents concentrations at year 30, reflecting the steady state impact after ISL are flushed through and reflecting the concentration due to ongoing oxidation processes. Other parameters can be calculated from the relationships presented in (Table 1).

Table 4. Model results summary.

DOMAIN	PEAK SULFATE CONCENTRATIONS (mg/L)				CONCENTRATION AT YEAR 30 (mg/L)			
	Base Case	**20-m O2 Model**	**10-m O2 Model**	**5-m O2 Model**	**Base Case**	**20-m O2 Model**	**10-m O2 Model**	**5-m O2 Model**
A	2,134	1,168	1,074	985	1,413	281	200	126
B	5,612	2,481	2,249	2,091	4,073	488	313	194
C	4,630	1,987	1,737	1,562	3,503	495	311	183
D	3,796	1,600	1,352	1,186	2,940	524	323	177
E	1,427	1,183	941	723	826	596	365	155
Overall[1]	3,450	1,482	1,264	1,110	2,658	506	308	164

[1] – weighted by area

The results show that the highest peak concentrations are observed in Domain B, which has the thickest waste rock column, with a peak value of 5,612 mg/L. In year 30, concentrations in Domain B decrease to 4,073 mg/L in the base case and range from 194 mg/L to 488 mg/L across the different models. Other domains also show notable reductions in concentration over time. For instance, Domain A, which peaks at 2,134 mg/L, reduces to 1,413 mg/L in the base case and between 126 mg/L and 281 mg/L in the various oxygen cases. Overall, the model indicates a significant decrease in concentrations from their peak values to year 30, when the ISL (or stored oxidation products) are flushed out. Figure 11 presents the results for the overall modelled sulfate concentrations for the four scenarios in the first 30 years.

Results indicate that the peak concentration is 3,450 mg/L in the base case, less that the estimated concentration of 4,000 mg/L presented in Figure 1, which is due to the different BRWRS geometry compared to FWWRS and relative wetting up times. Overall, the difference is ~ 15% mainly due to the broad initial higher sulfate peak of the BRWRS that extends from approximately year 5 to year 14 (Figure 11).

Figure 12 shows the results for the models over a 100-year period. Key data to observed are:

- The initial sulfate load (ISL) is flushed out by ~30 years
- Long term loads are driven by the amount of waste rock that is assumed to be oxidising.

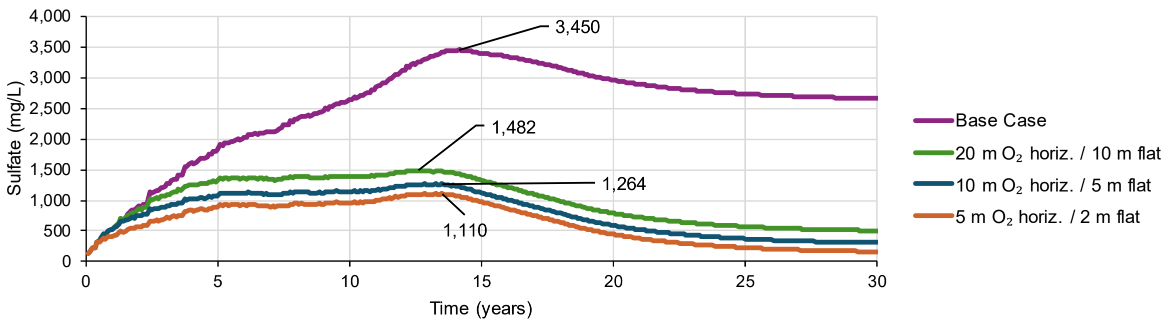

Figure 11. Overall sulfate concentration results for the four scenarios.

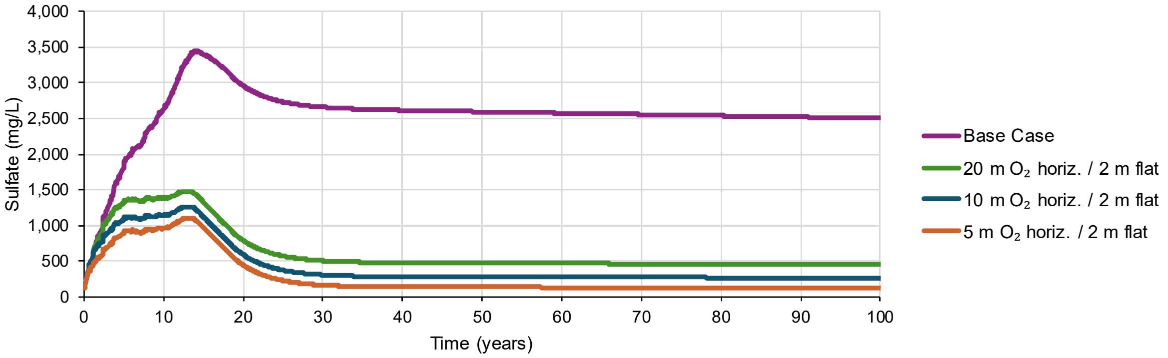

Figure 12. Overall sulfate concentration results for the four scenarios over a 100-year period.

Complete results over a 500-year period can be found in Attachment A.

CLOSING REMARKS

Please do not hesitate to contact Paul Weber at 027 294 5181 or paul.weber@minewaste.com.au should you wish to discuss this memorandum in greater detail.

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ATTACHMENT A – MODEL RESULTS (DIGITAL FILE)