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Memo

To:	Jim Scott, PolyMet	**Date:**	October 10, 2008
cc:	Miguel Wong, Barr Engineering	**From:**	Stephen Day
Subject:	NorthMet Project Geochemical Uncertainty Analysis for Proposed Action – DRAFT	**Project #:**	1UP005.001

This memorandum provides responses to mass balance and narrative requests as part of the evaluation of uncertainty in water chemistry predictions for the NorthMet Project by the Minnesota DNR and the EIS Contractor. The 'Tab' identifications refer to worksheet Tabs in the Draft Model Evaluation Proposed Project spreadsheet developed by MDNR and the EIS Contractor.

1 Tab 2c - Uncertainty Evaluation Plan for PolyMet Tailings Storage Facility Water Quality Model1- UA01-5

This response is provided to partially address the "Pond Water Quality" request. Two of the three aspects are covered:

- Effect of Process Water Variations.
- Effect of rock scaling factors on ore leaching.

A response on the request for a discussion of oxidation under subaqueous conditions will be provided separately.

1.1 Process Water

The following discussion evaluates the effect of using a range of process water values in the pond water quality calculation.

As indicated in the memorandum dated June 16, 2008 responding to the RS46 Agency Work Plan (Section 3.4), the METSIM model did not calculate process water chemistry for the flotation circuit. A basis to consider the uncertainty of the modeled process water in the tailings storage facility is the 2006 Pilot Plant test results, which were provided in the previous memorandum.

To assess the effects of using the Pilot Plant data on pond water quality, ratios were calculated comparing the minimum, median and maximum of the twelve 2006 Pilot Plant supernatant results with the base case modeled tailings pond water. The ratios were then used to change the load sent to the tailings pond in the model for selected parameters representing different ranges of ratios:

- Sulfate was selected because the ratio range extends from below 1 to above 1.
- Arsenic was selected because all arsenic concentrations in the Pilot Plant supernatants were greater than predicted by the model (up to a factor of 3.2). Other parameters showing similar ratio ranges were cadmium (up to a factor of 2.0) and selenium (up to a factor of 3.7).

- Nickel and copper were selected because the range of ratios was below 1. Cobalt showed a similar range.

Results are shown in Table 1.

The range of ratios for sulfate resulted in median modeled concentrations from 132 to 160 mg/L compared to the base case of 151 mg/L. The maximum concentrations modeled in the pond varied from 155 to 181 mg/L compared to 173 mg/L for the base case.

The range of ratios for arsenic resulted in median modeled concentrations from 0.006 to 0.009 mg/L compared to the base case of 0.006 mg/L. Maximum concentrations were typically 0.001 mg/L above the median.

Nickel ratios were below 1 and showed little variation compared to arsenic. Median and maximum concentrations varied little (0.014 to 0.015 mg/L, and 0.032 to 0.034 mg/L, respectively). Median and maximum base case concentrations were 0.021 and 0.039 mg/L, respectively. Copper, like nickel, showed little variation.

1.2 Effect of Scaling Factors

As described in RS46, kinetic test results for ore were used to evaluate the contribution from leaching of ore oxidation products generated between blasting of the rock and processing. The scaling factors were the same as those applied to estimate water chemistry for the waste rock stockpiles.

The uncertainty analysis requested consideration of the effect of different scaling factors as selected for waste rock. The same approach was applied as for the waste rock uncertainty analysis. Three cases were considered:

1. Base case as described in RS46 (maximum ore weathering rates, base case scale-up factors).
2. Median ore rates, scale-up of 0.15.
3. Maximum ore weathering rates, scale-up of 0.11.

Results of the calculation are provided in Table 1. The difference between all three cases for sulfate, copper and arsenic was negligible. For nickel, slightly greater differences were apparent. The two uncertainty cases yielded lower concentrations than the base case.

2 Tab 2d - Additional Support Requests Related to PolyMet Tailings Storage Facility Simulations - UA01-5

SRK was requested to provide results of Metsim modeling by Bateman that indicates the range of water quality from the ore-recovery processing circuit (if this modeling was conducted). These results will be used as inputs for pond water quality in the PolyMet tailings facility.

As indicated in the memorandum dated June 16, 2008 responding to the RS46 Agency Work Plan (Section 3.4), the METSIM model did not calculate process water chemistry for the flotation circuit.

Table 1. Tailings Pond Uncertainty Evaluation

Case	SO_4			Cu			Ni			As		
	Ratio	Median Pond	Maximum Pond	Ratio	Median Pond	Maximum Pond	Ratio	Median Pond	Maximum Pond	Ratio	Median Pond	Maximum Pond
Base Case	1	151	173	1	0.007	0.011	1	0.021	0.039	1	0.006	0.007
Pilot Plant Water Chemistry Used as Input												
Minimum Pilot Plant/Model	0.48	132	155	0.046	0.005	0.010	0.23	0.014	0.032	1.2	0.006	0.007
Median Pilot Plant/Model	0.73	140	163	0.092	0.005	0.010	0.25	0.014	0.033	1.6	0.007	0.007
Maximum Pilot Plant/Model	1.2	160	181	0.25	0.005	0.010	0.38	0.015	0.034	3.2	0.009	0.010
Effect of Scaling Factors for Ore Weathering												
Median Ore Rate, Scale-up 0.15	1	145	167	1	0.006	0.011	1	0.015	0.034	1	0.005	0.007
Max Ore Rate, Scale-up 0.11	1	146	168	1	0.006	0.011	1	0.019	0.037	1	0.006	0.007

3 Tab 3a – Mass Balance Tests for Evaluation of PolyMet Waste Rock Storage Facilities Water Quality Model – UA01A

The attached Excel spreadsheet provides results of the requested mass balance test.

Sample calculations are provided for Year 20 for the Category 1/2 stockpile and Category 4 stockpile.

4 Additional Support Request for DEIS Preparation, PolyMet Waste Rock Storage Facilities Water Quality Model

4.1 Tab 3c – Concentration of Nitrate in Waste Rock Drainage – UA01D

SRK agreed to summarize nitrate concentrations in drainage from waste rock at the Ekati™ Diamond Mine ("Ekati") located in the Northwest Territories, Canada. Ekati extracts diamonds from kimberlite ore hosted by unaltered granite and meta-sediments. The host rocks are unaffected by emplacement of the kimberlite. While the geological setting is different in some respects, much of the waste rock at Ekait is unaltered intrusive rock, which also describes Duluth Complex rock that would be generated at the NorthMet Project.

Several kimberlite pipes have been mined since 1997. About 162 million tonnes of waste rock were produced mainly by open pit mining of the Panda, Koala and Beartooth Pipes up until 2006. Ongoing waste rock production is mainly from the Beartooth Pit. All waste rock from these pipes is placed in a single waste rock storage area ("Panda WRSA").

The satellite Misery Pipe was mined from 2000 to 2005. Granite (10.8 mt), metasediments (15 mt) and diabase (1.2 mt) were deposited in a single waste rock storage area ("Misery WRSA").

The waste rock stockpiles are typically between 50 to 100 feet high and situated on low relief tundra.

The Ekati region is somewhat drier than the Hoyt Lakes area. Precipitation at Ekati is 333 mm/year (13 inches per year) compared to 28 inches per year at Hoyt Lakes.

Seepage has been monitored at a number of locations. At both the Panda and Misery WRSAs, two main flowing seeps have been monitored since construction began. The permit (Water License) currently requires bi-annual monitoring to capture snowmelt (June) and late summer low flow (September) conditions. Samples have been collected at other times to supplement the database. For the purpose of this assessment, only data collected from July onwards was considered because water in June tends to be diluted by nearby melting snow at the monitoring locations.

The distributions of nitrate concentrations (mg N/L) in the seepage at the two WRSAs are provided below in Table 2. These results are reported annually to the Wek'èezhìi Land and Water Board[1]. The data are publicly available and BHP Billiton Diamond Inc. has agreed the data can be used for the purpose of comparison to the NorthMet Project.

Table 2. Summary of Nitrate Concentrations During Low Flows from Waste Rock Seepage at the Ekati Diamond Mine

WRSA	n	Minimum	P5	P50	P95	Maximum
Panda	27	<0.006	<0.006	23.8	180.2	218
Misery	31	0.334	3.565	13.3	81.75	143

[1] SRK, 2008. 2007 Waste Rock and Waste Rock Storage Area Seepage Survey Report. Prepared for BHPBilliton Diamonds Inc. March 2008.

In each case, the elevated concentrations represented by the 95th percentile occurred early in construction of the WRSAs. Within a few years, concentrations stabilized to values nearer the median. The lower median for Misery reflects some data collected in 2006 and 2007 when the pit was not active and concentrations began to decrease. Typical concentrations for the Misery Pit WRSA during operations were comparable to Panda WRSA.

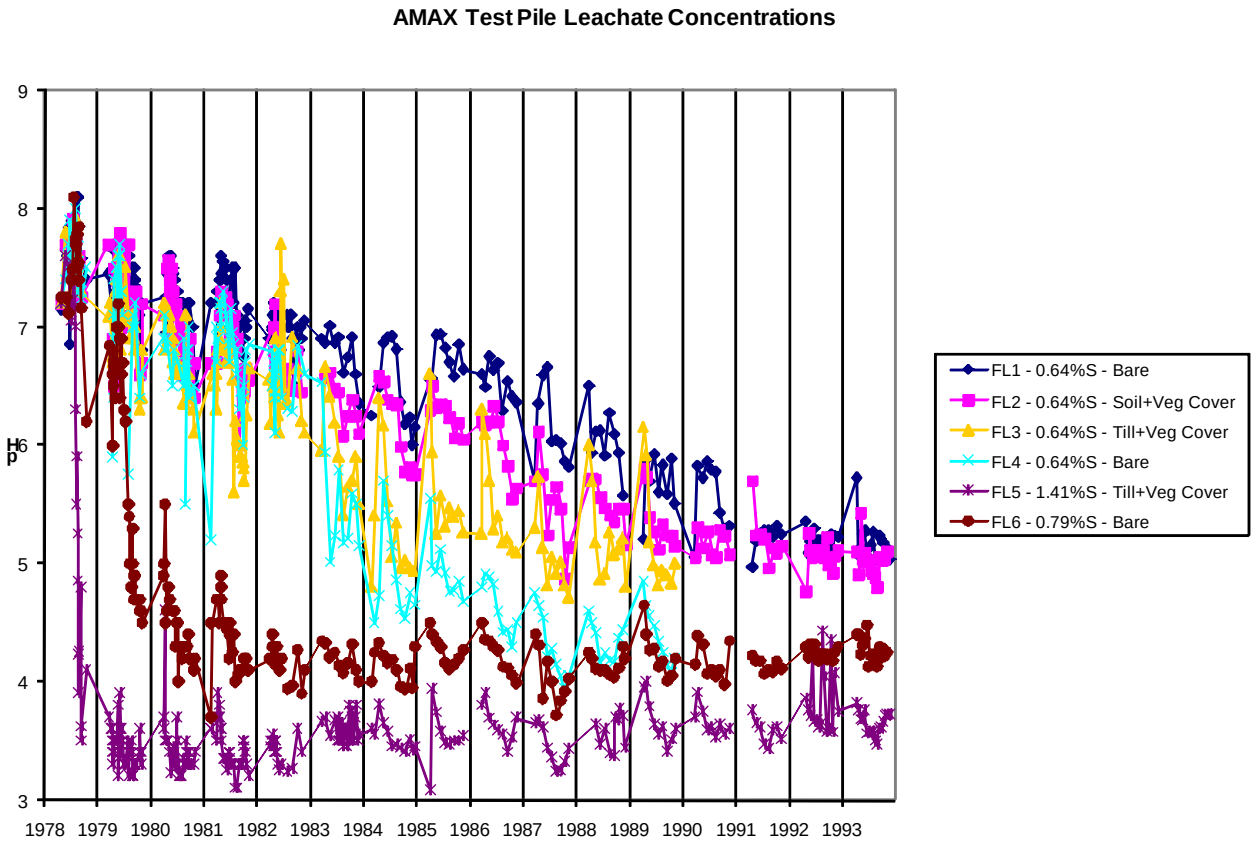
If all other factors are similar for the two projects, nitrate concentrations at NorthMet would be expected to be lower by a factor of about 50% due to the higher annual precipitation compared to Ekati. Median concentrations of 10 mgN/L might be expected.

4.2 Estimation of Time to Acidification and Increase in Rates for Acidic Conditions – UA01E

4.2.1 Time to Acidification for Category 3 rock

Time to acidification was estimated based on the pH trend for the AMAX test piles. Piles 1 to 4 contain rock that is approximately equivalent to NorthMet Project Category 3 rock though the sulfur content of 0.64% is greater than the 0.6% concentration which defines the upper limit of the sulfur concentrations in Category 3 rock. Pile 4 showed the most rapid transition to lower pH conditions. From 1978 to 1983, pHs remained above 6 (with a few seasonal exceptions) but after 1983 pHs were consistently below 6 and by 1986 were below 5. The sharp transition occurring in 1983 was interpreted to represent a change from conditions for which carbonate buffering was occurring to buffering by precipitation of aluminum compound. Pile 1, though composed of the same materials and fully exposed to weathering took about 10 to 11 years to show the same transition.

Based on these observations, 5 years was conservatively taken as the time for which to apply non-acidic oxidation rates for Category 3 rock.



4.3 Ratio of Acidic to Non-Acidic Release Rates for Category 3 rock

These ratios were estimated based on examination of sulfate release trends for the reactor tests performed on Dunka Pit blast hole samples. These tests samples are on rock that contains sulfur that is near the high end of the rock that would be in the Category 3 stockpile and more than twice the average sulfur content of rock in the stockpile. Only tests for which long term data were available were considered.

Table 3 summarizes lowest concentrations and highest concentrations for each test, and the resulting ratio. Concentrations are related to the loadings by the volume of leachate recovered, which is assumed to be nearly constant for the experiments. The low values of 1 mg/L for Reactors 7 and 9 appeared to be isolated concentrations below more typical low concentrations near 2 mg/L. These resulted in the higher peak to lowest ratios compared to the other reactors.

The ratio of average peak to average lowest is 10.3, which is the ratio used in RS42. The median ratio for comparison is 9.9.

Table 3. Low and Peak Sulfate Concentrations in MDNR Reactors Contained Dunka Pit Blast Hole Samples

Reactor	S %	Lowest mg/L	Peak mg/L	Ratio
Reactor 7	0.41	1	16.6	24.5
Reactor 9	0.51	1	24.5	24.5
Reactor 10	0.51	2.2	27.7	12.6
Reactor 12	0.54	2.9	28.6	9.9
Reactor 11	0.54	3.9	19.9	5.1
Reactor 14	0.57	2	18.2	9.1
Reactor 13	0.57	2.5	25.5	10.2
Reactor 15	0.58	2.4	23.6	9.8
Reactor 16	0.58	2.5	20.8	8.3

5 Tab 4a. Mass Balance Tests for Evaluation of PolyMet Pit Lake Water Quality Model – UA01F and UA01G

Four example spreadsheets are provided in the workbook attached to this memorandum:

- East Pit during flooding phase (pre-overflow to West Pit)
- East Pit during overflow phase.
- West Pit during flooding phase.
- West Pit during overflow phase.

Each spreadsheet represents one month, which is the time step used in the model. The spreadsheets show:

- The water balance which is used to determine the volume of water in the pit and the water level.

  These inputs were provided by Barr Engineering (values provided are for the average case). For the East Pit, groundwater flow numbers were provided directly by Barr. For West Pit, Barr provided groundwater inflow rates based on elevation. Table 6-2 of RS31 provides an example of the type of polynomial equation used to calculation groundwater inflow.

- Flooding and exposure of walls.

  The next section shows the calculation of wall areas based on the water elevation. For Category 1/2 rock, the area of rock above and below the water elevation is shown. The change in water elevation indicated by the increase in volume indicates how much rock is flooded during the month.

  For Categories 3, 4 and ore, it is necessary to determine how much rock is assumed to have reached its peak weathering rate. Since the oldest walls are at the higher elevations, the age of the walls are used to estimate which walls are at peak. As time progresses, this elevation decreases (moves downward). In the early stage of filling, rock that has not yet reached its peak weathering rate remains exposed above the water level. The "calculated peak elevation" is used to make this determination.

  Note that for computational simplicity, Category 3 and ore rocks have been combined. The approach used to estimate ore leaching was to assign the higher rate of Category 3 or 4 rock. This conservative approach resulted in assignment of Category 3 rates to ore.

  The age of wall flooded is tracked because this determines how much is flushed from the wall as it floods.

- Sources of load to the pit water.

  The load calculation is shown in two parts. The first part shows concentrations and loads for water inflows. These are obtained from flow multiplied by concentration.

  The second part shows loads from walls. For each rock category, the input laboratory rate is shown, followed by conversion to the field rate using scaling factors. The field rate is then expressed on the basis of pit wall area.

  The total load from each type of wall is shown in two parts – the load from rock flooded in the month (i.e. due to leaching of weathering products by the rising water level) and load from rock remaining exposed above the water elevation. To confirm these loads are consistent with the input rates, these loads were then back calculated on an area basis for comparison with the input rate used in the calculation. For Category 1/2, walls, the "average" rate is the same as the input rate because a constant value is used. For Categories 3, 4 and ore, the average rates reflect a combination of the pre-peak and rate indicated by the decay curve. Depending on the time step, the average rate may be between the pre-peak and peak rates (earlier in the calculation) or less than the peak and pre-peak rates (later in the calculation).

  For the East Pit Model, the load leached from backfill is calculated. Note that in the example provided, the calculated water level is very close to the backfill elevation and no load is shown as originating from exposed backfill. This simply indicates that the relationships used to calculate the elevation of backfill and water produce very similar numbers. In reality, some backfill will be exposed.

  The final step is the addition of load from all sources. The values in this spreadsheet were compared to the load calculated in the model. The concentration was obtained from the total load in the pit and the water volume. If this concentration exceeds pre-assigned concentration limits, the excess load is allowed to precipitate and the remaining dissolved load is carried over to the next time step.

6 Tab 4b. Uncertainty Evaluation Plan for PolyMet Pit Lake Water Quality Model – UA01I

6.1 Inputs from subaqueous oxidation

Tab 4b indicate that inputs from subaqueous oxidation should be considered in the water quality predictions for the open pits. PolyMet proposed a narrative explanation as part of the uncertainty analysis rather than as an input into the Monte Carlo simulations.

MDNR proposed an approach similar to that by Lapakko (1994)[2]. This approach used a simple numerical calculation of subaqueous oxidation due to diffusion processes as presented by Morin (1993)[3]. Lapakko (1994) reviewed the method and provided some corrections on Morin's (1993) approach. SRK downloaded the post-publication revised version of the Morin (1993) paper from www.mdag.com which incorporated Lapakko's (1994) corrections. The derivation of the equations in Morin (1993) was not clear but on the basis of Lapakko's critical review and SRK's finding that the results of the calculation could be reproduced approximately using another approach, the following discussion is based on the Morin (1993) method.

To evaluate the significance of subaqueous oxidation, SRK calculated oxidation rates using the Morin (1993) method and compared them to the method used to estimate rates in RS31. The calculation was performed on based on the assumption in RS31 that most surface area in pit walls comes from waste rock rather than fractured walls.

Flux (J) of dissolved oxygen into a 1 m^2 column of tailings/rock (in mg O_2 m^{-2} s^{-1}) is indicated by:

$$J = 6.2 \times 10^{-8} . DO(pond) \sqrt{\frac{(n - n^2).PYR}{d.T}}$$

Where DO(pond) = concentration of dissolved oxygen in the overlying pond (mg/L)
n = porosity
PYR = percentage of pyrite in the rock
d = particle diameter (m)
T = Tortuosity

This equation incorporates various assumptions about the rate of oxidation of pyrite under subaqueous conditions for which no data are available for the NorthMet Project and the assumption that the particles are spherical.

The rate of pyrite consumption (CP, mg FeS_2 /$m^{2/}$ s^1) is defined as:

CP = FACT1.J

Where FACT1 is a factor based on the ratio of oxygen to pyrite in the oxidation of pyrite to ferric hydroxide. FACT1 is 1.00.

The inputs to the equation were selected as follows.

- DO(pond) is 10 mg/L (a typical value).

[2] Lapakko, K.A. 1994. Subaqueous disposal of mine waste: A laboratory investigation. In Proc. Third International Conference on the Abatement of Acidic Drainage, April 25-29, 1994, Pittsburgh, PA. Vol. 1. p. 270-278.
[3] Morin, K.A. 1993. Rates of sulfide oxidation in submerged environments: Implications for subaqueous disposal. IN: Proceedings of the 17th Annual Mine Reclamation Symposium, Port Hardy, British Columbia, May 4-7, p.235-247. Mining Association of British Columbia.

- n was selected as 0.1 to reflect that the comparable rate for exposed rock assumes waste rock rather than fractured wall rock.
- d was selected as 0.1 m (i.e. 10 cm) based on estimates of the median particle size of blasted rock.
- PYR was set as 1.1% being equivalent to S content of 0.6% and representing the high end of Category 3 rock. This is the most abundant rock type in the walls. The actual sulfide mineral in the walls is pyrrhotite but for the purpose of this approximate comparison, the difference is not expected to be significant.
- T was set as 3 as recommended by Morin (1993).

The resulting pyrite consumption rate per unit of wall area for subaqueous pit wall rock resulting from this calculation is 4.8×10^{-6} mg FeS_2 /m^2 /s^1 (20 mgSO_4/ $m^{2/}$ mo). Due to the square root, the relationship to the various inputs is not linear. For example, a decrease in the particle size to 0.01 m (1 cm), increases the rate to 1.5×10^{-5} mg FeS_2 /m^2/s^1.

The following inputs were used to provide a similar rate for exposed pit wall rock:

- Non-acidic rate – 10 mgSO_4/kg/week.
- Particle size factor – 0.1
- Rock thickness – 2 m.
- Rock density – 1.9 t/m^3

A temperature correction factor was not incorporated into this calculation because it did not appear to have been included in the calculation performed by Morin (1993).

The resulting rate per unit of wall area for subaerial rock is 17,000 mgSO_4/m^2/mo, which is 823 times the subaqueous rate. When the Category 3 walls become acidic, the rate ratio would increase further.

This calculation confirms that while oxidation does occur underwater, the loading contributed is negligible compared to exposed rock. Other qualitative factors should be considered when evaluating the significance of this effect:

- Sealing of reactive surfaces in the walls can be expected to occur as pit water inundates the oxidized rock and precipitates form.
- Oxygen saturated water will likely extend only to depths of 5 to 10 m below the water surface limiting the active oxidation zone.
- Oxidation will be limited under-ice during the winter.

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Memorandum

To:	SRK Vancouver	**Date:**	20 October 2008
Attention:	Stephen Day	**From:**	John Chapman
cc:	File	**Project No:**	SRKNAC Task 009
SUBJECT:	**POLYMET PROJECT (PROPOSED DESIGN) ASSESSMENT OF PONDWATER LOADINGS – DOC ID UA01-5 PART 4**		

1 INTRODUCTION

In the load assessment for the PolyMet Tailings Basin – Proposed Design (referred to here as the TSF) the solutes present in the pond water were assumed to seep unhindered through the tailings and exit at the base of the TSF where part of the seepage would be collected and pumped back to the pond. It was assumed that the contribution of dissolved constituents from the submerged tailings would be insignificant and therefore was not included in the calculations. The reasons that the calculations did not consider solute release from tailings below the pond included the following:

1. There is no significant accumulation of secondary minerals that may contribute to solute release over time, and,
2. Diffusion of oxygen through water column, unlike for unsaturated tailings, is very small and resulting solute generation from oxidation would be insignificant in comparison to the loadings generated by the exposed beaches and embankment.

Furthermore it should be noted that the pond will ensure a positive head across the water-tailings interface so that the advective transport (i.e. water flux) into the tailings will exceed diffusive transport out of the tailings, so that the net cross boundary flux would always be into the tailings; i.e. the potential for solute release from the tailings directly into the pond is very low. However, due to the advective transport, dissolved oxygen present in the pond water will be carried down into the tailings pore space where it may react with the tailings and thus generate additional soluble sulfate and metals. (Note - a comparison between advective and diffusive transport is provided in Section 3.)

This memorandum has been prepared to address the request to include a discussion of subaqueous dissolution contributions to water quality beneath the pond. Maximum incremental loadings from the fine tailings reacting with dissolved oxygen have been calculated herein and are compared to total loadings previously estimated.

2 ASSUMPTIONS

Dissolved oxygen concentrations in pure water vary with temperature and elevation (i.e. atmospheric pressure). Typically water at saturation with atmospheric oxygen contains about 10 mg/L of dissolved oxygen at 15 degrees Celsius and about 14 mg/L at 1 degree Celsius. The surface water in the TSF pond would be expected to increase to above 15 degrees Celsius in the summer and thus the dissolved oxygen concentration would decrease to below 10 mg/L. During the winter the pond would be expected to freeze

over. When frozen, the dissolved oxygen would be expected to decrease below the ice so that it is probable that anoxic conditions will develop. During short periods in spring and fall the water temperature may be below 15 degrees Celsius and dissolved oxygen concentrations may increase above 10 mg/L. On an annual basis, the average dissolved oxygen concentration is expected to be below 10 mg/L. For the purpose of this assessment it was assumed that the average dissolved oxygen concentration in the TSF pond will be about 10 mg/L.

It is further assumed that all of the oxygen that enters the tailings will react with the sulfide minerals (pyrrhotite) contained in the tailings, and that the reactions and solute molar release ratios will be the same as for the fine tailings.

3 OXYGEN LOADINGS

The total loading of oxygen that may be delivered to the tailings underlying the pond will depend on the total flux of water through the tailings. The recharge rates to the tailings beneath the pond, as estimated by Barr, are shown in Table 3.1. The table also shows the estimated total oxygen flux per unit area. The calculations assume a dissolved concentration of 10 mg/L.

Table 3.1 Summary of Cell 2E Pond Infiltration and Dissolved Oxygen Flux

Time (year)	Cell 2EPond Infiltration Inches	Water Flux ($L/m^2/yr$)	Oxygen Flux ($mg/m^2/yr$)
1	105	2,667	26,670
2	103	2,616	26,162
3	98	2,489	24,892
4	95	2,413	24,130
5	94	2,388	23,876
6	92	2,337	23,368
7	88	2,235	22,352
8	88	2,235	22,352
9	82	2,083	20,828
10	82	2,083	20,828
11	83	2,108	21,082
12	84	2,134	21,336
13	85	2,159	21,590
14	85	2,159	21,590
15	86	2,184	21,844
16	86	2,184	21,844
17	87	2,210	22,098
18	61	1,549	15,494
19	62	1,575	15,748
20	62	1,575	15,748

As noted before, the diffusion rate of oxygen through a water column is much lower than the advective transport. The diffusion coefficient for oxygen in water is about 2.2×10^{-9} m^2/s. The diffusion of oxygen into porewater of the saturated fine tailings is in the order of 1.77×10^{-11} m^2/s (based on the same calculation used for oxygen transport modelling into the unsaturated tailings as proposed by Elberling et al., 1993). Assuming that the oxygen is all consumed within the first 0.1 m (4 inches) of tailings, the maximum oxygen flux by diffusion would be in the order of 1.77×10^{-9} $g/m^2/s$ (assuming the surface water dissolved oxygen concentration is at 10 mg/L). This equates to about 0.2 % of the average advective transport (about 9.2×10^{-7} $g/m^2/s$) shown in Table 3.1 and is therefore considered negligible.

4 INCREMENTAL SULFATE LOADINGS

All of the oxygen that is transported into the tailings, as calculated above, was assumed to react with pyrrhotite to form sulfate. For an average pond area of about 158 Ha for Cell 2E (Base Case Assessment), the corresponding estimated annual sulfate load generated as a result of this oxygen influx has been calculated as shown in Table 4.1. The incremental load that is generated beneath the pond is compared to the total loading generated from the PolyMet coarse tailings embankment, the coarse tailings beach, the fine tailings beach and the pond seepage. As shown in the table, the maximum incremental loading is about 25.4 % in the early stages of operation. Note however that the maximum load of sulfate generated from oxidation and other sources reaches a peak only after about year 10. As result, even though the initial incremental loadings are not very different from those towards the end of operations, the relative loading is much higher during the early stages of operations (relative to the lower initial loadings from other sources). The incremental loading decreases to about 4.3 % of the total Cell 2E loading in Year 20. The significant period (with respect to solute concentrations) is from about year 10 to year 20 when the average incremental loadings is from dissolved oxygen transport is about 5.3 %. The increase in oxidation therefore is minimal.

Table 4.1 Summary of Annual Sulfate Flux and Loading in Cell 2E Pond Percolate

Time (Year)	SO_4 Flux (mg/m2)	Cell 2E SO_4 Load (tonne/year)	Fraction of Cell 2E Loading (%)
1	35,560	56.2	25.4
2	34,883	55.1	21.3
3	33,189	52.4	15.0
4	32,173	50.8	11.8
5	31,835	50.3	10.1
6	31,157	49.2	8.8
7	29,803	47.1	7.5
8	29,803	47.1	6.8
9	27,771	43.9	9.8
10	27,771	43.9	7.8
11	28,109	44.4	6.3
12	28,448	44.9	5.6
13	28,787	45.5	5.5
14	28,787	45.5	5.3
15	29,125	46.0	5.3
16	29,125	46.0	5.3
17	29,464	46.6	5.4
18	20,659	32.6	3.8
19	20,997	33.2	4.1
20	20,997	33.2	4.3

5 INCREMENTAL SOLUTE CONCENTRATIONS

As with the oxidation calculations for the unsaturated beaches, molar release ratios were used to estimate the potential incremental solute concentrations that may result from oxidation in the percolate from the tailings underlying the pond. Consistent with the conditions for the Base Case Assessment the fine tailings molar release ratios were adopted for these calculations. The results are shown in Table 5.1 below. The table also compares the incremental concentrations of the maximum concentrations in the percolate from the PolyMet tailings.

As shown, the incremental concentration varies from about 0.3 % (Ni) to about 64.2 % (V) depending on the specific solute. While the calculations suggest that the vanadium concentration could increase by up to 64.2 %, the incremental concentration of 0.0018 mg/L is well below the groundwater standard of 0.05 mg/L.

The results suggest arsenic could increase by about 19.2 %. It is noted that the molar release ratio of arsenic for the fine tailings is in excess of 4 times that of the coarse tailings, which explains the relatively large pontential increase in arsenic concentration compared to the coarse tailings beaches and other sources.

Note that solubility constraints for aluminium have not been considered in these calculations. Calculated increases for other solutes are as shown in the table.

Table 5.1 Summary of Estimated Incremental Concentrations in Pond and Cell 2E Percolate

Parameter	Maximum Incremental Conc. in Pond Percolate (mg/L)	Maximum Incremental Conc. in Cell 2E Percolate (mg/L)	Incremental Increase in Cell 2E Percolate (%)
SO_4	13.3	11.4	3.5
F	0.068	0.058	3.7
Cl	0.324	0.278	2.7
Al	0.194	0.166	14.0
Sb	0.001	0.001	7.6
As	0.006	0.005	19.2
Ba	0.002	0.001	2.0
Be	0.0003	0.0002	8.6
Bi	0.0003	0.0002	6.3
Cd	0.00006	0.00005	5.8
Cr	0.0003	0.0002	4.1
Co	0.0001	0.0001	0.7
Cu	0.004	0.003	9.4
Fe	0.066	0.057	8.8
Pb	0.0001	0.0001	3.3
Mn	0.007	0.006	0.9
Mo	0.0003	0.0002	33.8
Ni	0.001	0.001	0.3
Se	0.0003	0.0003	6.4
Ag	0.0001	0.0001	3.7
Tl	0.00003	0.00002	1.7
V	0.0021	0.0018	64.2
Zn	0.0022	0.0018	2.0

6 SUMMARY AND CONCLUSIONS

The incremental contributions to solutes that may occur as a result of dissolved oxygen transported into the tailings beneath the TSF pond have been assessed herein. Based on the assumptions adopted herein, the results suggest that the sulfate loading could in the first year initially be up to about 24 % higher than previously estimated during the early stages of operation. However, during the period of maximum sulfate loadings from other sources (i.e. year 10 to year 20) the average incremental loading is only about 5.3 %, which, when the conservative assumptions are considered, is minimal.

Concentrations of other solutes would also increase as a result. Whilst the vanadium loading could increase by up to 64.2 %, its concentration would remain well below the groundwater standard. The nickel loading was shown to increase by only about 0.3 %. Most notably arsenic could increase by about 19.2 %. It is noted that the arsenic molar release ratio for fine tailings is more than 4 times higher than for the coarse tailings.

It should be noted that the calculations are based on an average annual dissolved oxygen concentration in the pond water of 10 mg/L. That assumption requires that i) the pond water has no chemical or biological

oxygen demand that may decrease the dissolved oxygen concentration of the water before it enters the tailings; ii) the water column is always fully mixed and fully saturated with respect to dissolved oxygen; and, iii) the dissolved oxygen concentration remains constant under the ice during the time that the pond freezes over. This is unlikely to be the case and therefore the above estimates will over estimate the potential solute release that might occur within the tailings underlying the pond. In addition, mitigation measures proposed for the TSF should result in lower arsenic loadings associated with this mechanism.

Nonetheless, it is concluded that the significance of advective oxygen transport into the tailings underlying the pond will need to be re-assessed for the proposed final (mitigated) TSF design to determine to potential implications with respect to arsenic release.