MEMORANDUM

To: **NorthMet EIS Co-Lead Agencies Senior Management Team**

From: ERM

Date: **30 December 2010**

Re: **NorthMet Mine Tailings Basin Cover Options Evaluation and Recommendations**

1.0 INTRODUCTION

1.1 Purpose

The purpose of this memorandum is to recommend a Tailings Basin cover system at closure for inclusion in the Lead Agency's Draft Alternative for the proposed NorthMet Mine Project. On October 20, 2010, ERM presented a recommended Draft Alternative to the Agency's Senior Management Team. The Senior Management Team instructed ERM to take a closer look at the cover system for the Tailings Basin and to return with an updated recommendation. The primary drivers for this re-evaluation were the:

- Ability of the Tailings Basin discharges to meet the "waters that support the production of wild rice" (wild rice) standard of 10 mg/L of sulfate downstream in Embarrass Lake;
- Lead Agency's desire to avoid or minimize the need for any long-term operation, maintenance, or treatment of groundwater seepage from the Tailings Basin; and
- Need for the Tailings Basin to provide an adequate "factor of safety" from a geotechnical stability perspective.

This memo summarizes the findings and presents a recommendation with supporting rationale for the Tailings Basin cover system at the proposed NorthMet Project.

The Tailings Basin cover system is a very important environmental component of the overall NorthMet Project. The 2009 Draft Environmental Impact Statement indicated that the various alternatives considered could result in at least elevated sulfate concentrations and possibly exacerbate elevated aluminum, iron, and manganese concentrations currently found downgradient of the Tailings Basin. The overall Draft Alternative is being developed to reduce future water quality impacts based on screening level modeling. Final estimates of water quality impacts will follow completion of the current Impact Assessment Planning (IAP) process. At least some seepage is expected to occur long term (e.g., centuries) from the Tailings Basin after closure, so the quality of that seepage is of critical importance and will largely determine the need for long-term operation, maintenance, and/or treatment.

Process

ERM assembled a working group to assist it in evaluating tailings basin cover systems for the NorthMet Project. This working group consisted of agency staff (i.e., USACE and MnDNR), a PolyMet representative, PolyMet consultants (Barr and SRK), and ERM/Knight Piesold staff (principally Dave Blaha and Houston Kempton). The workgroup met seven times (October 21; November 9, 18, and 22; and December 1, 15, and 17) and gathered considerable information regarding tailings basin cover systems in general and the applicability of these systems to the NorthMet Mine in particular. This information included peer-reviewed literature and project files on the application and effectiveness of alternative cover systems, cost data, and screening level modeling (conducted by SRK) of several cover alternatives.

2.0 CLOSURE OPTIONS

The workgroup identified the following six tailings basin cover options for further screening level evaluation.

2.1 Wet Cover using a Bentonite Side Slope and Pond Amendment

This option would involve a large pond surrounded by a "beach" area. PolyMet would apply a bentonite amendment to the pond area to reduce seepage volumes and maintain pond water, which provides a barrier to oxygen diffusion. PolyMet would also apply bentonite to the NorthMet (not the existing LTV) exposed embankment outer side slopes to hold moisture that would provide a barrier to oxygen diffusion, which would, in turn, reduce the mass of tailings subject to oxidation, and thereby reduce the pollutant load generated. Typical bentonite amendments are between 3-8% by dry weight (Lupo and Morrison, 2007, in Kempton, 8 November 2010). PolyMet currently proposes a 3% bentonite amendment, which is predicted to achieve a hydraulic conductivity of $1 \times 10^{-6.5}$ cm/s. The exposed outer side slopes of the Tailings Basin are gentle enough (~4.5H:1V slopes) to allow the bentonite application and avoid the potential for slump failures. The bentonite would be blended with the LTV tailings and incorporated into the outer side slopes while the embankment lifts are being constructed, providing for incremental closure of the embankment slopes as part of operations, rather than as a final closure activity. PolyMet has adopted this option and it is referred to herein as the "PolyMet Proposal."

2.2 Wet Cover using a Bentonite Beach and Pond Amendment

This option is very similar to the PolyMet Proposal except that bentonite would be applied to the beach area of the pond instead of the side slopes, in addition to the pond itself, and is assumed to achieve the same reduction in hydraulic conductivity, moisture retention, and oxygen diffusion on a per unit area basis as noted above.

2.3 Wet Cover using a Bentonite Beach, Side Slope and Pond Amendment

This option is identical to the PolyMet Proposal, except that bentonite would also be added to the beach area as well as the side slope and pond areas and is assumed to achieve the same reduction in hydraulic conductivity, moisture retention, and oxygen diffusion on a per unit area basis as noted above.

2.4 Dry Cover using a Surface Bentonite Amendment

This option would eliminate the surface pond at closure and instead would provide a dry cover with a surface bentonite amendment over the entire surface of the Tailings Basin. It is assumed that the bentonite would achieve the same reduction in hydraulic conductivity and oxygen diffusion as assumed for the PolyMet Proposal. The conceptual design for this option assumes that a tailings pond would exist for most of mine operations, but starting about 5 years before closure, the tailings would be spigoted in such a way as to create a uniformly-sloped surface and gradually eliminate the pond towards the end of operations. The remaining pond water would be treated and removed at closure. A stormwater pond would be created to the east and outside of the Tailings Basin to help manage runoff and collect sediment.

2.5 Dry Cover using a Geomembrane

Geomembranes are a low permeability material typically constructed of low density polyethylene (LDPE) or high density polyethylene (HDPE). Although more impermeable than the bentonite amended tailings, these geomembranes usually have some holes or tears that can allow infiltration of water. The geomembrane requires an appropriate subgrade material to protect it from differential settlement of the underlying tailings and surface layer above it to protect it from degradation from UV light and puncture by vehicular use or roots. This option would eliminate the surface pond at closure in generally the same manner as described above; however, a geomembrane barrier layer, rather than a bentonite amendment, would be placed over the entire surface of the Tailings Basin (former beach and pond area, but not the side slopes). A stormwater pond would be created to the east and outside of the Tailings Basin to help manage runoff and collect sediment.

2.6 Dry Cover using a Geosynthetic Clay Liner (GCL)

A GCL typically consists of a layer of clay between two binding layers (e.g., ~1 cm layer of sodium bentonite sandwiched between two geotextiles). This option would eliminate the surface pond at closure in generally the same manner as described above; however, a GCL cover system, rather than a bentonite amendment or a geomembrane, would be placed over the entire surface of the Tailings Basin (former beach and pond area, but not the side slopes).

2.7 Other Variations

The option of applying bentonite to the exposed outer side slopes of the Tailings Basin as in the PolyMet Proposal could also be added to the dry cover options. This variation of each of the dry cover options is discussed qualitatively in Section 4.

3.0 SCREENING CRITERIA

NEPA and MEPA have slightly different requirements for considering alternatives. NEPA describes the consideration of alternatives as the "heart of the environmental impact statement." NEPA requires the consideration of all reasonable alternatives and a discussion of alternatives which were eliminated from further study. The decision maker must consider all reasonable alternatives and can not consider alternatives not discussed in the EIS.

MEPA (*Minnesota Rules*, part 4410.2300, subpart G) states that an alternative may be excluded if "it would not meet the underlying need for or purpose of the Project; it would likely not have any significant environmental benefit compared to the Project as proposed; or another alternative, of any type, that will be analyzed in the DEIS would likely have similar environmental benefits but substantially less adverse economic, employment, or sociological impacts."

In accordance with these requirements, the following screening criteria were used in evaluating the Tailings Basin closure cover options under consideration:

- Meet the Project's Purpose and Need
- Technically Feasible
- Economically Feasible (Practicable)
- Available (e.g., the land is available)
- Potentially Offer Significant Environmental or Socioeconomic Benefits
- Long-term Operation, Maintenance, and/or Treatment Requirements
- Uncertainty Regarding Long-Term Performance

The first five of these screening criteria are drawn from the DEIS. The last two criteria were added to more clearly differentiate among options the potential need for long-term operation, maintenance, and/or treatment requirements, as minimizing these is a goal of the Minnesota Permit to Mine. Finally, it became clear during our review that all of the options have some degree of uncertainty regarding performance when considering that the tailings basin would be in place indefinitely. We disclose our understanding of this uncertainty in this memo.

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4.0 SCREENING OF OPTIONS

Each of the options was evaluated using the screening criteria. At an early stage of the evaluation, the geomembrane clay liner (GCL) option (Option 6) was eliminated from further consideration because it was estimated to cost about 13-15% more (Pickarts, 8 August 2007; Schwanz, 5 November 2010) and provide no meaningful performance benefit versus the geomembrane option (Option 5). Further, recent regional experience with a coal ash landfill in Wisconsin found less success with conventional GCLs, which were damaged by cation exchange and dehydration, and better success with a laminated GCL (conventional GCL with a geomembrane bonded to one surface), which tends to further blur the distinction between a GCL and a geomembrane (Benson et al., 2007). For these reasons, the GCL option was eliminated from further consideration.

The remaining 5 options were evaluated using two screening level models. An oxygen transport and oxidation model was used to estimate sulfate and metal loads and concentrations in the seepage from the tailings basin as measured at the base of the PolyMet tailings (see model description in appendix A). Table 1 provides a summary of the model predictions for sulfate loads and concentrations given that sulfate is a critical contaminant. The model predictions for metals are comparatively the same across the tailings closure options (i.e., the option with the lowest sulfate load/concentration also has the lowest metals loads/concentrations). Appendix B provides the full results.

Table 1: Comparison of Screening Level Model Results

Option	Groundwater Seepage Volume	Sulfate Load*	Sulfate Concentration*
Wet Cover with bentonite side slope and pond amendment	1,421,000 m^3/yr	54 tpy	38 mg/L
Wet Cover with bentonite beach and pond amendment	1,450,000 m^3/yr	95 tpy	66 mg/L
Wet Cover with bentonite beach, side slope, and pond amendment	1,285,000 m^3/yr	36 tpy	28 mg/L
Dry Cover with bentonite surface amendment	794,000 m^3/yr	131 tpy	165 mg/L
Dry Cover with geomembrane	350,000 m^3/yr	70 tpy	200 mg/L

Source: John Chapman, SRK, 16 December 2010

* Load and concentration only from tailings oxidation. Loadings from other sources (e.g, process water, existing LTV tailings) not included in the screening level model. Concentrations at the toe of the existing LTV tailings basin are expected to be higher than those shown here. Loads based on metric tons.

As indicated in Section 1.0, a key component of this screening is whether the cover options are expected to meet the wild rice standard in Embarrass Lake. A preliminary mass balance calculation was conducted to determine the maximum “allowable” sulfate load from the PolyMet tailings basin to the Embarrass River watershed assuming that the sulfate load from all other sources (i.e., Babbitt/Biwabik WWTF, LTV tailings seepage from Cells 1E/2E and 2W, and other natural sources) remains constant and that sulfate in the Area 5 NW Pit was treated to achieve a concentration of 10 mg/L. Based on these assumptions, the mass balance calculations estimate the maximum allowable sulfate load from the NorthMet tailings to meet the wild rice standard in Embarrass Lake as approximately 95 tpy (see Table 2).

Table 2: Source Loadings to meet the Sulfate Standard at Embarrass Lake

	WWTF	**Area 5 Pit**	**LTV Cells 1E/2E**	**LTV Cell 2W**	**Natural Sources**	**NorthMet tailings**	**Embarrass Lake**
Sulfate (mg/L)	4.00	10	143	230	1.9	--	9.95
Flow (cfs)	0.47	2.56	2.01	1.99	100.39	--	107.10
Loading (tpy)	0.2	23.0	259.2	408.8	171.6	94.9	956.3*

Source: Greg Williams, email to Dave Blaha, 14 December 2010
* Numbers don't add up due to rounding.

Comparing this estimated 95 tpy "allowable" sulfate loading with the estimated sulfate loadings from each of the closure options (see Table 1), we observe the following:

- Wet Cover with Bentonite Side Slope and Pond Amendment – predicted to meet the wild rice standard in Embarrass Lake (54 tpy vs 95 tpy)
- Wet Cover with Bentonite Beach and Pond Amendment – may meet the wild rice standard in Embarrass Lake (95 tpy vs 95 tpy);
- Wet Cover with Bentonite Side Slope, Beach, and Pond Amendment – predicted to meet the wild rice standard in Embarrass Lake (36 tpy vs 95 tpy)
- Dry Cover with Bentonite Surface Amendment – predicted not to meet the wild rice standard in Embarrass Lake (131 tpy vs 95 tpy); and
- Dry Cover with geomembrane – predicted to meet the wild rice standard in Embarrass Lake (70 tpy vs 95 tpy).

Table 3 provides a comparison of the five options for a variety of other factors.

NorthMet Project Tailings Basin Cover Option Comparison - version 3 (correction) - prepared by PolyMet				
Factor	**Wet Cover with Bentonite Beach and Pond Amendment**	**Wet Cover with Bentonite Side Slopes, Beach, and Pond Amendment**	**Dry Cover with Bentonite Amendment**	**Dry Cover with Geomembrane**
Deposition				
- subaerial from perimeter	25%	25%	100%	100%
- subaqueous via diffuser	75%	75%	0%	0%
Contouring	generally sloped inward	generally sloped inward	generally sloped to East	generally sloped to East
Contingency Closure	can be implemented at any time	can be implemented at any time	contingency closure before year ~14 will not be able to be sloped to provide drainge to East so Partial Dry cover will be required.	contingency closure before year ~14 will not be able to be sloped to provide drainage to East so Partial Dry cover will be required.
Tailings Basin Pond				
- average operational area years 14-20 (acres)	920	920	200	200
Note on average operational area			A smaller pond will require longer beaches to provide volume to contain a storm event and maintain the freeboard required for dam safety.	
- estimated closure area (acres)	1030	1030	0	0
Beach Area				
- average operational area years 14-20 (acres)	440	440	1160	1160
Note on average operational area			A larger beach area will have more potential for a dust lift off event.	
- estimated closure (acres)	310	310	1340	1340
Embankment Area				
- estimated closure (acres)	315	315	315	315
Effectiveness				
- water barrier				
- estimated percolation at closure - pond (inches/year)	9.8	9.8	0	0
- estimated percolation - beach (inches/year)	3.58	3.58	3.58	0.3
- estimated percolation - embankment (inches/year)	8	3.58	8	8
- percolation - pond closure (gpm)	521	521	0	0
- percolation - beach closure (gpm)	57	57	248	21
- percolation - embankment closure (gpm)	130	58	130	130
- percolation - closure (gpm)	709	637	378	151
- GW seepage at closure (gpm)	419	376	223	89
- SW seepage at closure - south (SD026) (gpm)	290	261	155	62
- Need for treatment of SD026 water	Likely No	Likely No	Likely Yes	Likely Yes
- mass saturated (near zero oxidation) long term	Base	Slightly less than Wet Cover with Bentonite Beach and Pond Amendment	Less than Wet Covers	Less than Dry w/ Bentonite
- oxygen barrier				
- depth of oxidation zone below pond	Limited by advection of dissolved oxygen in water.	Limited by advection of dissolved oxygen in water.	No pond, see beach area below	No pond, see beach area below
- depth of oxidation zone below beaches	Partially oxygenated due to oxygen entry from sides, limited vertical oxygen penetration through bentonite.	Limited oxygen penetration through bentonite (beaches). No oxygen penetration to beach areas from sides (see below).	Same as partial dry. Applies to entire top surface of basin.	Partially oxygenated due to oxygen entry from sides. Vertical oxygen entry only through membrane defects, which are also preferential flowpaths for water.
- depth of oxidation zone in from sides	No barrier to oxygen penetration from side, estimated at 600 ft.	Barrier to oxygen penetration from side.	Approximately same as Wet Cover with Bentonite Beach and Pond Amendment	Approximately same as Wet Cover with Bentonite Beach and Pond Amendment
- mass subject to oxidation - closure - narrative	Narrative deleted because scoping model results now available			
- seepage sulfate concentrations in closure narrative	Narrative deleted because scoping model results now available			
- seepage sulfate concentrations in closure (mg/L)	65.5	27.9	165	199

NorthMet Project Tailings Basin Cover Option Comparison - version 3 (correction) - prepared by PolyMet

Factor	Wet Cover with Bentonite Beach and Pond Amendment	Wet Cover with Bentonite Side Slopes, Beach, and Pond Amendment	Dry Cover with Bentonite Amendment	Dry Cover with Geomembrane
- seepage sulfate load in closure (T/yr)	94.9	35.8	131	69.9
Slope Stability (Critical Section)				
- projected operational minimum (ESSA); minimum allowable	projected 2.63 ; must be ≥ 1.50	projected 2.63 ; must be ≥ 1.50	projected ≥ 2.63	projected ≥ 2.63
- projected operational minimum (USSA); minimum allowable	projected 1.64 ; must be ≥ 1.30	projected 1.64 ; must be ≥ 1.30	projected ≥ 1.64	projected ≥ 1.64
- projected operational minimum (USSA Liquefied); minimum allowable	projected 1.10 ; must be ≥ 1.05	projected 1.10 ; must be ≥ 1.05	projected ≥ 1.10	projected ≥ 1.10
- projected closure minimum (ESSA); minimum allowable	projected ≥ 2.63	projected ≥ 2.63	projected >> 2.63	projected >>> 2.63
- projected closure minimum (USSA); minimum allowable	projected ≥ 1.64	projected ≥ 1.64	projected >> 1.64	projected >>>1.64
- projected closure minimum (USSA Liquefied); minimum allowable	projected ≥ 1.10	projected ≥ 1.10	projected >> 1.10	projected >>> 1.10
Note on Slope Stability	Only Wet Cover with Bentonite Beach and Pond Amendment operational modeled. All other situations have pond farther from dam crest and/or reduced surface water infiltration because of better covers both of which will drive safety factors higher (ie better)			
Closure Prep.				
- pond water volume to remove (gallons) (100 acre in yr 20 x 20ft deep)	0	0	750,000,000	750,000,000
- pond dewatering - infrastructure - to Area 5 Pit	0	0	$200,000	$200,000
- pond dewatering - pumping ($/1000 gals)	0	0	$0.33	$0.33
- pond dewatering - pumping cost	0	0	$247,500	$247,500
- total closure prep	0	0	$447,500	$447,500
Closure Cost (Initial Capital)				
- Pond (/acre)	$14,900	$14,900	NA	NA
- Beaches (/acre) - min	$16,700	$16,700	$16,700	$100,000
- Beaches (/acre) - max	$34,000	$34,000	$34,000	$150,000
- Top cover material	tailings	tailings	tailings	soil
- Seeding - Beaches (/acre)	inc in above	inc in above	inc in above	inc in above
- treatment plant (if needed) for SD026	Likely 0	Likely 0	Likely $5 million	Likely $3 million
- total initial capital - min	$20,500,000	$25,800,000	$27,400,000	$137,000,000
- total initial capital - max	$25,900,000	$36,600,000	$50,600,000	$204,000,000
Note on Closure	Only after end of operations.	Bentonite application during operations as embankments are constructed, application on beaches & pond after end of operations.	Only after end of operations.	Only after end of operations.
Postclosure Care Cost (Ongoing Maintenance)				
- dam/pond monitoring (annual)	Highest	Highest	Lowest	Lowest
- PRB for sulfate mitigation (partial=base - others ratioed to sulfate load)	$8,000,000	$3,000,000	$11,000,000	$5,900,000
- water quality monitoring/project mgt (annual)	Same for All	Same for All	Same for All	Same for All
- woody species control (annual)	Lowest	Medium	Highest	Highest
- seepage pumping (gallons, annual)	152,000,000	137,000,000	81,000,000	32,000,000
- erosion control (annual)	Lowest	Medium	Highest	Highest
- dust control (annual) - not significant once vegetation estabilished	Lowest	Lowest	Highest	Highest
- treatment of SD026 ($/1000 gal)	$0.00	$0.00	$4.00	$4.00
Note on treatment cost			Unit cost is uncertain; cost is dependent on water quality.	
- pumping of SD026 ($/1000 gal)	$0.33	$0.33	$0.33	$0.33
- annual SD026 pumping and treating	$50,000	$45,000	$351,000	$139,000
- long term SD026 pumping and treating	$1,670,000	$1,500,000	$11,700,000	$4,630,000
Closure Cost (prep+initial capita+postclosure-wetlands mitigation) - max	$34,300,000	$39,900,000	$73,700,000	$148,000,000 - $215,000,000
Wetland Considerations				
Potential Wetland Mitigation Acres	250 (preliminary will depend on final design and COE discussions)	250 (preliminary will depend on final design and COE discussions)	0	0
Value of Mitigation Acres (assume $5000/acre savings)	$1,250,000	$1,250,000	0	0

NorthMet Project Tailings Basin Cover Option Comparison - version 3 (correction) - prepared by PolyMet				
Factor	**Wet Cover with Bentonite Beach and Pond Amendment**	**Wet Cover with Bentonite Side Slopes, Beach, and Pond Amendment**	**Dry Cover with Bentonite Amendment**	**Dry Cover with Geomembrane**
Wildlife Habitat Considerations				
- Wetland and Pond Habitat	upland meadow -plus- mitigation wetlands and pond will provide significant waterfowl habitat as evidenced by current ponds on Cell 1E and 2E	upland meadow -plus- mitigation wetlands and pond will provide significant waterfowl habitat as evidenced by current ponds on Cell 1E and 2E	upland meadow	upland meadow
Surface Water Discharge Considerations				
- runoff from beach areas (inches/yr)	5.5	5.5	5.5	8.9
- spring runoff from beach areas (inches)	2.4	2.4	2.4	3.9
- annual flow from beach areas to receiving water bodies (gpm)	surface water to interior pond at closure, discharge only during extreme events	surface water to interior pond at closure, discharge only during extreme events	380	620
- spring flow from beach areas to receiving water bodies (gpm)	surface water to interior pond at closure, discharge only during extreme events	surface water to interior pond at closure, discharge only during extreme events	2,000	3,200
- potential geomorphic impacts from discharge	none	none	Annual flow from beach areas is >30% of average annual flow in Spring Mine Creek. Snowmelt flow from beach areas is similar to existing snowmelt flow in Spring Mine Creek (i.e. stream flow would double).	Annual flow from beach areas is >50% of average annual flow in Spring Mine Creek. Snowmelt flow from beach areas is larger than existing snowmelt flow in Spring Mine Creek (i.e. stream flow would more than double).
Stormwater Management Considerations				
- stormwater management system	NA - all to interior	NA - all to interior	Sed. basin off facility to east, discharge routed to Area 5NW pit.	Sed. basin off facility to east, discharge routed to Area 5NW pit.

4.1 Wet Cover using a Bentonite Side Slope and Pond Amendment

This option would meet the Project's purpose and need, is already acknowledged by PolyMet as being economic, and is available. This option is the current PolyMet Proposal so is used as a baseline for comparing the environmental consequences of the other options.

This option is probably technically feasible, but some concerns have been raised regarding the feasibility of applying the bentonite, especially under the tailings pond. The original proposal from PolyMet was to apply it using a hollow tined rake, which has been used successfully in agricultural applications, mounted on a barge. Concern has been raised as to whether this would result in the relatively uniform distribution necessary to achieve the predicted performance. Barr (Radue, 6 December 2010) states that there are methods available to mechanically mix the bentonite into the tailings to achieve a relatively uniform distribution in the pond (e.g., various dosing, injection, and dredging techniques). In terms of the applying bentonite to the outer side slopes as proposed in this option, the bentonite could be blended with the LTV tailings and incorporated into the outer side slopes during construction of the embankment lifts and thereby provide more uniform mixing and offer water quality benefits during operations as well in closure. There is a paucity of studies on field methods for blending bentonite into soil or tailings, but the scientific literature does indicate that to act continuously as a lower permeability layer, the bentonite must be covered by a soil layer thick enough (~>0.75 meter cover layer thickness; Egloffstein, 2001) to protect it from freeze-thaw cycles and desiccation.

It may be necessary during drought years to pump water to maintain the pond's surface area and avoid exposing tailings to oxidation. Vegetation management will also be required to ensure woody plant roots don't create preferential flow paths through the bentonite. In terms of long-term performance, the primary uncertainty is the ability of the bentonite to tolerate freeze-thaw and wet-dry cycles. As discussed above, these problems can be avoided by ensuring the bentonite is applied at sufficient depth to protect it. There is also the potential for cation exchange that could reduce the effectiveness of the bentonite by as much as 70%, depending on the amount of calcium and magnesium in the seepage.

4.2 Wet Cover using a Bentonite Beach and Pond Amendment

This option is identical to PolyMet's Proposal except the bentonite would be applied to the beach area rather than the side slopes, in addition to the pond area. This option would meet the Project's purpose and need, is already acknowledged by PolyMet as being economic, and is available.

This option is probably technically feasible, but shares the same concerns as the PolyMet Proposal above regarding the feasibility of applying the bentonite to the pond area.

Applying bentonite to the beach area is probably more difficult than to the side slopes because it would be applied after deposition of the tailings has been completed rather than during construction as would be the case for the side slopes. The preferred method to achieve uniform mixing would be to blend the tailings and bentonite in a pug mill or similar device (Benson, 27 November 2010). Barr (Radue, 6 December 2010) states that there are other methods available to mechanically mix the bentonite into the tailings to achieve a relatively uniform distribution on the beach area (e.g., Kreiselgrubber KG, Residue Solutions "Mudmaster"). As indicated above, the scientific literature suggests that the bentonite should be covered by a soil/tailings layer thick enough (~>0.75 meter cover layer thickness) to protect it from freeze-thaw cycles and desiccation.

The modeling predicts that this alternative would result in greater seepage flow and increased sulfate load and concentrations in the seepage relative to the PolyMet Proposal. The mass balance modeling predicts that this alternative may be able to meet the wild rice standard in Embarrass Lake, but there is little room for uncertainty or error in the predictions. To the extent this option results in, or contributes to, an exceedance of the wild rice standard for sulfate, this option could require active management and possibly long term treatment via the Area 5 treatment plant or a passive permeable reactive barrier (PRB). In terms of other environmental considerations (e.g., wetlands creation in the tailings pond), this option would be expected to have similar effects as PolyMet's Proposal. This option is expected to have a similar or slightly worse geotechnical stability factor of safety since it would not apply bentonite to the side slopes, but it is still predicted to have an acceptable factor of safety for geotechnical stability.

It may be necessary during drought years to pump water to maintain the pond's surface area and avoid exposing tailings to oxidation. Vegetation management will also be required to ensure woody plant roots don't create preferential flow paths through the bentonite. In terms of long-term performance, the primary uncertainty is the ability of the bentonite to tolerate freeze-thaw and wet-dry cycles. As discussed above, these problems can be avoided by ensuring the bentonite is applied at sufficient depth to protect it. There is also the potential for cation exchange that could reduce the effectiveness of the bentonite by as much as 70%, depending on the amount of calcium and magnesium in the seepage.

4.3 Wet Cover using a Bentonite Surface, Side Slope, and Pond Amendment

This option is identical to the PolyMet Proposal, except that bentonite would also be added to the Tailings Basin beach area, in addition to the side slopes and pond area. This option would meet the Project Purpose and Need, is believed to be economic as it involves modest additional cost relative to the PolyMet Proposal, and is available. It would have the same technical feasibility questions as the PolyMet Proposal regarding the application of bentonite to the side slopes, beach, and pond areas as described for the previous two options, but these issues appear to be manageable.

This option appears to offer significant environmental benefits – a 33% reduction in sulfate load, a 26% reduction in sulfate concentration, and corresponding reductions in metal loadings/concentrations in groundwater and surface seepage as compared with the PolyMet Proposal. This option is predicted to comply with the wild rice standard at Embarrass Lake. In terms of other environmental considerations (e.g., wetland creation in the tailings pond), this option would be expected to have similar effects as PolyMet's Proposal.

It may be necessary during drought years to pump water to maintain the pond's surface area and avoid exposing tailings to oxidation. Vegetation management will also be required to ensure woody plant roots don't create preferential flow paths through the bentonite. In terms of long-term performance, the primary uncertainty is the ability of the bentonite to tolerate freeze-thaw and wet-dry cycles. As discussed above, these problems can be avoided by ensuring the bentonite is applied at sufficient depth to protect it. There is also the potential for cation exchange that could reduce the effectiveness of the bentonite by as much as 70%, depending on the amount of calcium and magnesium in the seepage.

4.4 Dry Cover using a Surface Bentonite Amendment

This option would eliminate the surface pond at closure and instead would provide a dry cover with a surface bentonite amendment over the entire surface of the Tailings Basin (side slopes are not included in this option). Based on the data in Table 1, it is clear that this option is the least desirable – it is predicted to result in the highest sulfate load, increased sulfate concentrations, increased concentrations of various metals, and is not predicted to meet the wild rice standard at Embarrass Lake, as well as other secondary issues (e.g., loss of wetland mitigation opportunity) relative to the PolyMet Proposal. This option would eliminate the wet cover and thereby improve the geotechnical factor of safety, but the wet cover offers an acceptable factor of safety, so this option does not provide a meaningful benefit. For these reasons this option is eliminated from further consideration.

4.5 Dry Cover using a Geomembrane

The Dry Cover with Geomembrane Option would meet the Project Purpose and Need, is Technically Feasible, and Available. The geomembrane is very effective in both reducing water percolation and oxygen diffusion – it would reduce the predicted seepage volume by approximately 75% relative to PolyMet's Proposal, and almost eliminate oxidation diffusion below it. In fact, the predicted sulfate and metals loading from the Tailings Basin under this option are primarily a result of oxygen diffusion from the exposed outer side slopes. This oxidation, combined with the significant reduction in seepage volume (i.e., dilution), is predicted to result in significantly higher sulfate concentrations (i.e., ~200 mg/L sulfate vs ~38 mg/L for the PolyMet Proposal) and to generate a 30% higher sulfate load. The geomembrane option is also expected to result in the following:

- Surface water quality exceedances at Second Creek - even under the geomembrane option, some seepage is still expected from the Tailings Basin to Second Creek (this is believed to be a permanent seep), and this seepage does not currently meet water quality standards (e.g., hardness, conductivity) and is not predicted to under this option. Under the current Draft Alternative and the Cliffs Erie LLC Consent Order, this seepage would be pumped back to the tailings pond during both operations and closure. Under the geomembrane option, the tailings pond would be eliminated during the later years of mine operation and would not be present in closure. Therefore, there would not be a location to pump this seepage and it would likely require treatment (e.g., proposed Area 5 treatment plant, new treatment facility near the Plant Site, or via a passive reactive barrier or PRB). Without the option of dilution through the Tailings Basin Pond, this seepage would likely require long-term treatment.
- Water quality exceedances north of the Tailings Basin – similar to the situation at Second Creek, the predicted seepage flow (~133 gpm) and quality during closure could result in exceedances of groundwater quality standards downgradient of the Tailings Basin for sulfate and possibly some metals (e.g., aluminum, arsenic).
- Lose the opportunity to create wetlands at the Tailings Basin – the elimination of the tailings pond would eliminate the opportunity to achieve some on-site wetland mitigation.
- Improve geotechnical stability – the geomembrane option would result in a lowering of the phreatic surface, which would improve the geotechnical factor of safety.

As mentioned above, much of the sulfate and metal loadings from the Tailings Basin under the geomembrane option result from oxygen diffusion through the outer side slopes, which could be mitigated to a large extent by the addition of bentonite to the outer side slopes. This would likely minimize the potential for groundwater quality exceedances north of the Tailings Basin, but may have little effect on surface water exceedances at Second Creek.

The capital cost for the geomembrane cover is significant. The estimated cost for the geomembrane alone is $50 million (Schwanz, 5 November 2010). Total costs, which include importing appropriate material for subgrade and cover material, range from $148 million to as high as $215 million (Table 3). PolyMet claims that even at the low end of this cost range that this option is not economic for the NorthMet Project.

As with the PolyMet Proposal, this option also requires vegetation management to protect the geomembrane from root damage. In terms of long-term performance, the primary uncertainty is the unknown life expectancy of geomembranes (currently estimated at between 50 and 300 years). There is the potential for differential settlement to cause tears in the geomembrane, but this issue should be avoided with proper subgrade design.

4.6 Summary

Table 4 provides a comparison of the Tailings Basin Closure options against the screening criteria.

Table 4: Tailings Basin Closure Options Comparison Summary

Options	Meet the Project Purpose and Need	Technically Feasible	Economically Feasible (Practicable)	Available	Potentially Offer Significant Environmental or Socioeconomic Benefits	Long-term O/M/T Requirements	Uncertainty regarding Long-term Performance
Wet Cover with bentonite side slope and pond area amendment	Yes	Yes	Yes Total Closure Cost ~$27 M (PolyMet est)	Yes	NA – baseline for comparison	Will require on-going vegetation mgt and potentially pumping to maintain water levels	Subject to freeze-thaw and wet-dry cycles and cation exchange that can affect bentonite
Wet Cover with bentonite beach and pond area amendment	Yes	Yes	Yes Total Closure Cost ~$34 M (PolyMet est)	Yes	Seepage sulfate load – 76% increase Seepage sulfate concentration – 74% increase Seepage volume – 2% increase Second Creek seepage quality – slightly better Groundwater quality - slightly worse Geotechnical stability – slightly worse On-site wetland creation – no change	May require long-term treatment of seepage. Will require on-going vegetation mgt and potentially pumping to maintain water levels	Subject to freeze-thaw and wet-dry cycles and cation exchange that can affect bentonite
Wet Cover with bentonite side slope, beach, and pond amendment	Yes	Yes	Yes Total Closure Cost ~$40 M (PolyMet est)	Yes	Seepage sulfate load – 33% reduction Seepage sulfate concentration – 26% reduction Seepage volume – 10% reduction Second Creek seepage quality – slightly better Groundwater quality - better Geotechnical stability – slightly better On-site wetland creation – no change	Will require on-going vegetation mgt and potentially pumping to maintain water levels	Subject to freeze-thaw and wet-dry cycles and cation exchange that can affect bentonite
Dry Cover with Bentonite Surface Amendment	Yes	Yes	Probably Total Closure Cost ~$74 M (PolyMet est)	Yes	Seepage sulfate load – 143% increase Seepage sulfate concentration – 334% increase Seepage volume – 44% decrease Second Creek seepage quality – slightly worse Groundwater quality - worse Geotechnical stability - better On-site wetland creation – lose opportunity	Will likely require long-term treatment of seepage. Will require on-going vegetation management	Subject to freeze-thaw and wet-dry cycles and cation exchange that can affect bentonite
Dry Cover with Geomembrane	Yes	Yes	Uncertain (PolyMet says it is uneconomic) Total Closure Cost $148-215 M (PolyMet est)	Yes	Seepage sulfate load – 30% reduction Seepage sulfate concentration – 426% increase Seepage volume – 75% decrease Second Creek seepage quality – slightly worse Groundwater quality - worse Geotechnical stability - better On-site wetland creation – lose opportunity	May require long-term treatment of seepage to Second Creek and will require on-going vegetation management	Geomembrane life expectancy unknown (estimated at between 100 – 300 years) and some susceptibility to differential settlement.

5.0 RECOMMENDATION

5.1 ERM Recommendation

Based on a thorough review of tailings basin closure options, ERM recommends that the Wet Cover with Bentonite Side Slopes, Beach, and Pond Area Amendment (hereafter referred to as the Recommended Alternative) be included as the Tailings Basin closure system in the Lead Agencies' Draft Alternative. This option is the same as the PolyMet Proposal except that bentonite would also be placed in the beach area. The model results indicate that this addition of bentonite to the beach area would result in significant environmental benefits – a 33% reduction in sulfate load, a 26% reduction in sulfate concentration, and corresponding reductions in metal loadings/concentrations in groundwater and surface seepage as compared with the PolyMet Proposal. Although the PolyMet Proposal is predicted to meet the wild rice standard at Embarrass Lake, we believe the incremental improvement represented by the Recommended Alternative is warranted considering that the planned probabilistic modeling will identify a range of values. Further there is some degree of uncertainty regarding the application of bentonite and the measures necessary to ensure its long term performance. We believe the incremental benefit of the Recommended Alternative is warranted as a "buffer" against the uncertainty represented by the use of the bentonite amendment. In terms of other environmental considerations (e.g., wetland creation in the tailings pond), this option would be expected to have similar effects as PolyMet's Proposal.

An argument can be made for including the geomembrane cover as an alternative in the SDEIS so that a full range of alternatives can be considered pursuant to NEPA guidance. But based on the discussion above, it appears clear that a geomembrane cover:

- Would offer worse performance in terms of sulfate and metals loads and concentrations than the Recommended Alternative;
- Does not represent common practice; and
- Would cost significantly more.

The only benefits that the geomembrane cover offers relative to the Recommended Alternative are:

- Significantly less seepage, although this seepage would have higher sulfate and metal loads and concentrations than the Recommended Alternative;
- a potential improvement in the geotechnical factor of safety associated with a dry versus a wet cover, but the Recommended Alternative offers an acceptable factor of safety, so this option does not provide a meaningful benefit; and
- higher degree of certainty regarding its performance, but the proposed capture wells as part of the Draft Alternative provides an engineering "backup" in case there are any problems with the bentonite application.

5.2 Rationale

It is important to put the NorthMet Tailings Basin into some context. Based on the analysis from the DEIS, the current PolyMet Proposal (i.e., referred to as the Tailings Basin Alternative in the DEIS) was predicted to generally meet groundwater standards with the primary exception of sulfate. The other two drivers for this evaluation as identified in Section 1.1 are:

- Desire to avoid or minimize the need for any long-term operation, maintenance, or treatment of groundwater seepage from the Tailings Basin – this driver is again related to sulfate since no long-term operation, maintenance, or treatment would be needed for the Tailings Basin as currently modeled for any other parameter because they are predicted to meet groundwater standards; and
- Need to provide an adequate "factor of safety" from a geotechnical perspective – but as mentioned above, the PolyMet Proposal has been determined to already provide an adequate factor of safety, so although a higher factor of safety may be desirable, it really is not meaningful.

So with this basis, the question is what is the best way to manage sulfate in the tailings? The screening level modeling conducted for this evaluation predicted that the Wet Cover with Bentonite Side Slope, Beach and Pond Amendment would have relatively low sulfate loads and concentrations. This result is not surprising as a wet cover is widely recognized as an effective way to minimize oxidation of sulfide tailings. In fact, a quick literature survey identified several examples of the successful use of wet covers to control sulfate and metals in tailings basin seepage from sulfide mines in Canada, including the Denison Mine (Laliberte et al., 2003), Falconbridge Mine (Hall, 1999), Louvicourt Mine (Julien et al., undated), and the Solbec Mine (Amyot, 1999). So the use of wet covers is well established and accepted practice, especially for sulfide tailings. On the other hand, a similar quick literature survey failed to find any examples where a geomembrane was used as a tailings basin cover.

A key question is whether the bentonite can be applied with sufficiently uniform mixing to achieve the oxygen diffusion and water infiltration reductions predicted and at sufficient depth to protect it from freeze-thaw (a key issue in Northern Minnesota), desiccation, and root penetration. There are some legitimate questions regarding the technical feasibility of achieving these goals, but we have been convinced that it is feasible. We distinguish among the three areas where bentonite could be applied: the beach, the pond, and the outer side slopes:

- Beach – this could be the most difficult area to apply bentonite at sufficient depths. There appears to be equipment available that can mix the bentonite relatively uniformly (e.g., the Kreiselgrubber KG and Residue Solutions "Mudmaster"), but studies demonstrating effective blending of bentonite into soil were not identified in the peer-reviewed literature in a mining application. We assume that sufficient depth can be accomplished by using this equipment, applying the bentonite and placing more tailings above it, or adding a cover material to achieve the desired depths.

- Pond – in the tailings pond, the bentonite is not needed to reduce oxygen diffusion, the water serves that function. The bentonite is only needed to reduce percolation sufficiently to maintain the desired pond elevation/surface area. To achieve this purpose, the bentonite probably does not need to be at depth (less chance of freeze thaw under the pond except at the shallow margins) and it is less critical if it is uniformly mixed as long as it achieves the desired percolation rate. Further, water from various sources (e.g., Colby Lake, Area 5 treatment plant, Second Creek seep) would be available for many years into closure to supplement the pond if necessary while more bentonite is added to achieve the desired percolation rate/water balance.
- Outer Side Slopes – this may be the easiest place to apply bentonite as it could be mixed with the LTV tailings and applied when each lift of the embankment is constructed. Applying bentonite during embankment construction offers water quality benefits during operations as well in closure. As with the surface application, the bentonite would need to be placed deep enough to avoid drying and root penetration.

For these reasons, we believe the use of bentonite could be accomplished successfully and any questions regarding technical feasibility can be addressed. There is also a concern that cation exchange could reduce the effectiveness of the bentonite, depending on the amount of calcium or magnesium in the percolating water. If it is determined at a later date that the predicted performance is not being achieved, then additional bentonite could be added until performance expectations are met.

In comparison with the geomembrane option, the Wet Cover option would also retain the tailings pond, which would accept continued pumping of Second Creek seepage and allow on-site wetland mitigation. Although probably not as effective as the geomembrane option, the Recommended Alternative, which includes applying bentonite to the side slopes, would reduce surface water infiltration and keep the embankment drier, potentially improving slope stability. The Recommended Alternative would likely require slightly more maintenance than a geomembrane cover, but it would not be onerous (e.g., potential pumping of water to maintain the tailings pond surface area during droughts).

6.0 LITERATURE CITED

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APPENDIX A
OXYGEN TRANSPORT AND OXIDATION MODELING
Source: SRK

The modelling was undertaken on the basis that the oxidation rates measured in the laboratory scale kinetic tests can be scaled to reflect the rates in the field for the as placed tailings. The premise is that the rate of sulphide mineral oxidation is controlled by oxygen supply to the reaction sites. Further, that the solute release rates measured in the kinetic tests can be related to the oxidation of the sulphide minerals, and that these release ratios hold true for field conditions.

Since the tailings are fine grained a relatively homogenous, the oxygen transport into the tailings can be described by Fick's Law. For the scoping level calculations the oxidation of the sulphide minerals was assumed to be zero order with respect to the oxygen concentration. This means that the oxidation rate will proceed at a fixed rate irrespective of the atmospheric oxygen concentration; i.e. the oxidation rate of the sulphide minerals are the same for an oxygen concentration of 21% and 0.1%. Only when the oxygen is depleted does oxidation cease. Since zero order kinetics are assumed, the oxidation of the tailings proceeds in layers. The first layer represents the initial depth of penetration of oxygen by diffusion, and the oxidation rate is constant with depth to the point where oxygen is depleted. This means that the sulphides near the surface oxidise at the same rate as the sulphides at the deepest edge of the layer and thus the sulphides will be depleted simultaneously at the surface and at depth. Once this occurs the next layer starts to oxidise. Oxygen supply to the second layer has to diffuse through the first, depleted. Layer therefore the rate of oxygen supply will be less than for the first layer. As a result sulphate production and solute release from the second layer will be less than for the first layer and so on.

The rate of diffusion is dependent on the effective diffusion coefficient and is dependent on factors such as the porosity of the tailings and the degree of saturation. The effective diffusion constant is calculated using the relationship presented by Elberling et al. (1993), which is the same procedure adopted in the previous modelling.

Assumptions that were adopted include:

All solutes generated are released and no selective flow paths form.
Oxidation rate corrected for temperature (Lab 20 ^{O}C to field 10 ^{O}C); the Arrhenius equation is used for this correction.

- Freezing conditions restrict oxidation for about 4 months of the year.
- The potential effects of the phreatic surface extending away from the pond were disregarded
- Oxygen entry to tailings beneath the pond was assumed to be limited to dissolved oxygen present percolating water only. The dissolved oxygen was assumed to be constant at 8 mg/L

- Levels of saturation within the tailings were assumed to be the same as those adopted during the previous modelling; these were derived from unsaturated flow modelling.

It is important to note that the calculations only represent loadings generated by oxidation within the new or proposed construction for the PolyMet (POM) tailings. These include the LTV tailings used in the construction of the embankment and the newly placed POM tailings. Contributing loads such as those from process water have not yet been included in these calculations. Therefore the loads and concentration estimates are effectively released from the newly constructed/placed tailings storage facility (TSF). These are incremental to the existing LTV facility.

Calculated Depth of Oxidation Diffusion

The effective depth of oxygen diffusion below the surface of the tailings for the various closure conditions are as follows:

- Coarse LTV Tailings (no mitigation) – up to 69 m or 225 ft
- Coarse LTV Tailings (18 " Bentonite amendment) – up to 7 m or 26 ft
- POM tailings (Bulk) (no mitigation) – up to 36 m or 118 ft
- POM tailings (Bulk) (18 " Bentonite amendment) – up to 5 m or 16 ft
- POM tailings (Bulk) (Geomembrane 1 cm diameter perforations, 8 perforations per acre) – effectively 14 mm or 0.56 inches across the base of the membrane.

APPENDIX B
OXYGEN TRANSPORT AND OXIDATION MODELING DATA

This data is provided in a separate Excel spreadsheet attachment.