October 16, 2017 VIA EMAIL

Commissioner Tom Landwehr
MN Department of Natural Resources
ATTN: PolyMet NorthMet Project
500 Lafayette Road N, Box 45
St. Paul, MN 55155-4045

Dear Commissioner Landwehr,

Thank you for the opportunity to submit comments for the NorthMet Draft Dam Safety Permits Nos. 2016-1380 and 2016-1383. These permits are a mere eight pages, but the length of the permits belies a basic truth about the proposed NorthMet Mining Project: by design, these dams are expected to hold back mine waste forever. To reiterate: earthen berms rising 250 feet above the surrounding area and constructed on top of 50 year old mine waste slurry are expected to contain 225 million short tons of powdered rock and water, and to do so indefinitely without unreasonably risking the public's health, safety, or welfare.

No mining company has ever constructed a copper-nickel tailings facility in the U.S. that did not release mine waste into the surrounding environs.[1] If history is any guide, the NorthMet facility will be no different. Nor will it be any different from the existing tailings basin on which it is to be constructed, which currently leaks 3.5 million gallons of mine-impacted waters a day to local rivers and streams.[2] The question is not if it will leak, but when. The agency's role in this question is to mitigate the risk to the public as much as possible, and to deny the permits if the risk cannot be reduced. These permits do not do that. These permits allow the use of outdated, dangerous construction techniques like upstream dam construction and fail to incorporate the current, prudent engineering practices learned from mining disasters like Mount Polley. If copper-nickel mining is to occur in Minnesota, it is irresponsible to do so at the expense of future generations. We cannot finance the jobs of today by contaminating the water of our grandchildren. We urge you to deny these permit applications or, at a minimum, incorporate permit conditions that require current best practices in mine engineering, including but not limited to a condition that requires a tailings storage design that reflects the Best Available Technologies recommended by the Mount Polley Expert Review Panel, which includes the elimination of surface water from the impoundment, the promotion of unsaturated conditions in the tailings with drainage provisions, and the achievement of dilatant conditions throughout the tailings deposit by compaction.

[1] Letter from Thomas Tidwell, Chief of Forest Service to Neil Kornze, Director of Bureau of Land Management, U.S. Forest Serv. File Code 2670 (Dec. 14, 2016), attached as Exhibit 1.
[2] Final Environmental Impact Statement, NorthMet Mining Project and Land Exchange, Minn. Dep't of Nat. Res., U.S. Army Corps of Eng'rs, U.S. Forest Serv., 5-7 (Nov. 2015) [herinafter "PolyMet FEIS"].

Please note that we are submitting individual comments from three of our consultants: Jim Kuipers, David Chambers, and Michael Malusis. Those comments are attached to this letter as Exhibits 2, 3, and 4, and are hereby incorporated by reference. We ask that they be considered together with the comments of the undersigned organizations.

1.0 The Proposed Tailings and HRF Dams Pose Unreasonable Risks to the Public, And Are Inconsistent with Current, Prudent Engineering Practices Approved by the Mount Polley Independent Expert Review Panel

It is difficult to overstate how significant the Mount Polley tailings dam failure was to the industry as a whole, and how critical it is for our state to learn the lessons of that tragedy. The disaster occurred in an area with decades of experience in non-ferrous mining regulation, and it happened despite being designed and inspected by leading engineering firms.[3] We believe that the Department understands this significance, and it does not escape our notice that the Department consulted with a member of the Mount Polley Expert Review Panel ("Mount Polley Panel") in evaluating dam safety permit application materials for the NorthMet project. Which is why it is equally significant to us that the draft dam safety permits in many ways do not incorporate the recommendations of the Review Panel. Minnesota law is clear that permit decisions on a new dam or enlargement must be based on a determination that the proposal complies with "prudent, current environmental practice throughout its existence."[4] The recommendations of the Mount Polley Expert Review Panel clearly constitute prudent, current practices for mining, and therefore the Commissioner must either deny the permits or modify them to require compliance with the recommended practices of the Review Panel.

1.1 Wet Closure of the Tailings Facility Poses an Unreasonable Risk to the Public

The Flotation Tailings Dam that is the subject of Draft Permit 2016-1380 will contain 11.27 million short tons of slurry pumped from PolyMet's Beneficiation Plant every year.[5] PolyMet proposes a wet closure for the tailings basin, with a permanent pond on the surface that will (if successful) limit the infiltration of oxygen through the mine waste.[6] Indeed, the proposal depends on wet tailings for it to function as expected. Bentonite amended layers only function properly when saturated to a certain degree, and the long-term maintenance of the dams involves routine inspection to ensure the bentonite amended tailings are not becoming dried out.[7] These inspections and other

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[3] *See* Jim Kuipers, "Review of NorthMet Mining Project Dam Safety Permit", KUIPERS & ASSOCIATES, (Sept. 30, 2017) [hereinafter "Kuipers Dam Safety Permit Comments"], at 12, attached as Exhibit 2.
[4] Minn. R. 6115.0410, subp. 8.
[5] NorthMet Dam Safety Permit Application: Flotation Tailings Basin, prepared for PolyMet Mining, Inc., Barr Eng'g Co., 1 (May 2017) [hereinafter "PolyMet FTB Permit Application"].
[6] NorthMet Project Flotation Tailings Management Plan, PolyMet Mining, Inc., Appendix A 39 (May 15, 2017).
[7] *Id*. at 40.

long-term maintenance activities on the dam will extend into perpetuity, and if the project performs as expected, the FTB dam will impound slurry waste and a tailings pond forever.[8]

Put most simply, storing mine waste wet is risky. These risks most often come in two forms: the risk of an outright dam failure such as occurred at Mount Polley, or the risk that water treatment of mine-impacted water will be required in perpetuity, often at taxpayer expense. While the former is a low-probability, high-consequence type event, the latter is a very high-probability event with variable consequences, depending on the constituents discharged from the tailings facility.

The collapse of a tailings dam is possibly the most devastating impact that could occur at a mine site, resulting in widespread impacts that could travel and diffuse for tens or even hundreds of miles when waste spills into moving water. Many Minnesotans were uncomfortably introduced to tailings dam failures in 2014 when the impoundment at the Mount Polley dam failed catastrophically, releasing a four square kilometer sized tailings pond into Hazeltine Creek and Quesnel Lake, a drinking water source for area residents.[9] The sudden deluge scoured trees from Hazeltine Creek and turned what was a four-foot wide stream into a raging river 150-feet wide.[10] Water sampling showed that the tailings spill contaminated Quesnel Lake with copper, iron, aluminum and phosphorus.[11] But the Mount Polley mine was no fly-by-night operation. It failed despite top-notch engineering design and regulatory oversight. The dam that failed was designed by Knight Piesold, a well-respected engineering firm, and was developed using the observational method recommended by DNR's consultants in this matter.[12] At the time of failure, the impoundment was only 124 feet high, far lower than the proposed 250+ feet for the NorthMet FTB dam.[13] Despite these precautions, an investigatory review panel determined that hidden unstable layers that were not discovered during the dam's design and construction rendered the dam vulnerable to collapse.

The central lesson of the episode, then, is that there is no amount of planning or design that can eliminate the risk of dam failure. That risk is present no matter how many pages of engineering documents exist to assert the dam's safety. It also shows, however, that well-respected engineering

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[8] *Id.* at 41.
[9] Justine Hunter, B.C. Didn't Inspect Mount Polley Mine in 2010, 2011, The Globe and Mail, (Oct. 14, 2014).
[10] Mount Polley Tailings Pond Situation Update, BC Gov News (Aug. 8, 2014), https://news.gov.bc.ca/stories/friday-aug-8---mount-polley-tailings-pond-situation-update.
[11] Impact Assessment Monitoring in the Quesnel Lake Watershed After the Mount Polley Mining Company Tailings Dam Breach, BC Ministry of Environment (2014), http://www2.gov.bc.ca/assets/gov/environment/air-land-water/spills-and-environmental-emergencies/docs/mt-polley/sample-monitor/moe_impact_assessment_monitoring_in_quesnel_lake.pdf.
[12] See Knight Piesold Letter to Mount Polley Mining Corporation, February 10, 2011, attached as Exhibit 5.
[13] Independent Expert Engineering Investigation and Review Panel, Report on Mount Polley Tailings Storage Facility Breach, MT. POLLEY INDEP. EXPERT INVESTIGATION AND REV. REP. 5 (Jan. 30, 2015), https://www.mountpolleyreviewpanel.ca/sites/default/files/report/ReportonMountPolleyTailingsStorageFacilityBreach.pdf [hereinafter "Mount Polley Panel Report"], attached as Exhibit 6; Flotation Tailings Basin North Dam Typical Cross Section Drawing No. FTB-009, NorthMet Project Flotation Tailings Basin Permit Application Support Drawings, Flotation Tailings Management Plan, Barr Eng'g, Attachment A (May 15, 2017).

can be overcome by mismanagement at the actual dam site. When Knight Piesold, the engineer of record, withdrew from ongoing operations in 2011, it warned the mine operator that the tailings pond was "getting large."[14] This warning was apparently ignored, as government regulators repeatedly advised the mine operator in subsequent years that effluent levels were too high.[15]

The failure of the Mount Polley dam in 2014 is perhaps the most well-known of its type, particularly in Minnesota, though it was overshadowed by the even more devastating Samarco disaster that occurred a year later. When the tailings dam at the Samarco iron mine failed in 2015, the rushing river of mine waste over 30 feet high laid ruin to the surrounding countryside, killing 19 and destroying villages. A year later, the river still runs red from mine contamination.[16] The tragedy has hit the mining companies hard: Samarco failed to make payments on debt and requested debt restructuring,[17] while BHP Billiton, one of the mine's owners, announced a record loss of $6.4 billion.[18] The mine owners and operator have signed an agreement with the Brazilian government for socioeconomic and environmental recovery work worth over $6.5 billion over 15 years.[19]

Perhaps most relevant to the instant permits, however, is the investigation into the cause of the disaster. An expert panel (including Steve Vick, who also served on the Mount Polley expert panel) concluded that structural damage to the starter dike resulted in increased saturation of the tailings and the encroachment of saturated slimes underneath the impoundment.[20] This saturated state precipitated a liquefaction event that rendered the dam unstable. Seismic shocks prior to the collapse may have been a contributing factor.[21]

These features are of course present in the dam design noticed for permitting by the DNR. The proposal would construct a dam with the upstream method on top of existing LTVSMC slimes (see discussion below). The proposal's efficacy is dependent on the proper functioning of the bentonite layer at closure, to prevent saturation of the tailings underneath the impoundment. As described below, that efficacy has not been demonstrated. Permitting a dam when the central determinants of its safety are unknown is clearly not protective of the public health, safety and welfare. It is for these reasons that wet closures are increasingly recognized as inherently risky. Mine

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14 Exhibit 5.
15 Mount Polley Tailings Pond Situation Update, BC Gov. News (Aug. 8, 2014), https://news.gov.bc.ca/stories/friday-aug-8---mount-polley-tailings-pond-situation-update.
16 Dom Phillips, Samarco Dam Collapse: One Year On From Brazil's Worst Environmental Disaster, The Guardian (Oct. 15, 2016), https://www.theguardian.com/sustainable-business/2016/oct/15/samarco-dam-collapse-brazil-worst-environmental-disaster-bhp-billiton-vale-mining.
17 *Id.*
18 *Id.*
19 *Id.*
20 See Demonstrative Animation, The Fundao Tailings Dam Investigation, Fundao Investigation, (Aug. 29, 2016), http://fundaoinvestigation.com/demonstrative-animation/.
21 *Id.*

experts "are concerned that flooded impoundments may create a risky legacy,"[22] primarily because conventional slurry tailings impoundments fail at a rate of 2 to 5 "major" failure incidents per year.[23]

1.2 Wet Closure Does Not Reflect Current, Prudent Environmental Practice

As detailed in the attached comments of Jim Kuipers and David Chambers, for the reasons identified above, the Mount Polley Panel identified underground or backfilling of pits and filtered tailings technology as the Best Available Technology (BAT) for tailings storage facilities, and specifically cautions against wet closures.[24] For the closure of active impoundments, the Panel recommended adoption of three design principles: no surface water; unsaturated conditions in the tailings, with drainage; and compaction of drained tailings to achieve a long-term, static stability condition.[25] The report is clear that anything less is a hazard: "Mount Polley has shown the intrinsic hazards associated with dual-purpose impoundments storing both water and tailings."

These conclusions represent the culmination of several decades of knowledge regarding the long term safety of tailings facilities. Maintaining the stability of an impoundment of slurry over hundreds of years is simply too great an engineering and financial challenge:

> The more traditional closure configuration for tailings impoundments has been to draw down water ponds as completely as possible, to reduce the potential for dam failure by overtopping or erosion. To raise water levels in impoundments formed by high dams could present considerable long term risk. One of the reasons that closed tailings impoundments have traditionally proven to be generally more safe, from the physical stability perspective, than operating impoundments is the relatively more "drained" condition of closed impoundments that do not include a large water pond. The flooded closure scenario represents an "undrained" condition that does not allow this improvement in physical stability to develop, so the risk does not decrease with time.[26]

As a result, the current, prudent environmental practice is either filtered tailings storage or subaqueous disposal. Mine experts are unequivocal: "the surest, safest and most cost-effective solution to prevent [acid rock drainage] is sub-aqueous disposal in a lake or the ocean."[27] If that

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[22] Michael Davies, et al. Design of Tailings Dams and Impoundments, 5 (2002), http://www.infomine.com/library/publications/docs/Davies2002b.pdf [hereinafter "Davies et al. 2002"], attached as Exhibit 7.
[23] Michael Davies & Stephen Rice, An Alternative to Conventional Tailing Management – "Dry Stack" Filtered Tailings (2004), http://www.infomine.com/library/publications/docs/Davies2004.pdf [hereinafter "Davies & Rice 2004"], attached as Exhibit 8.
[24] Mount Polley Panel Report at 121-122 (Exhibit 6).
[25] *Id.* at 121.
[26] Davies et al. 2002 (Exhibit 7).
[27] *Id.*

option is not available, slurry tailings must at a minimum be drained and compacted at closure to minimize risk to the public.[28]

Although Minnesota regulations do not define what constitutes "current, prudent engineering practice," (or "prudent, current environmental practice"[29]) our laws do make clear that alternative technologies offering significant environmental benefits may not be rejected solely for economic reasons.[30] These laws establish that "current, prudent engineering practice" and the Best Available Technology as determined by the Mount Polley Expert Panel are one and the same.[31] And it is amply evident that dry stack tailings storage offers considerable environmental benefits, in terms of both discharges of mine-impacted water and in terms of long-term tailings stability.

> Dry stacked tailings facilities have some tremendous potential environmental advantages over impounded slurried tailings largely because the catastrophic physical failures that define tailings management to non-supporters of the industry cannot occur. Moreover, leachate development is extremely limited due to the very low seepage rates possible.[32]

Dry stacking also offers the best chance of eliminating the need for perpetual water treatment, as seepage is greatly reduced if not eliminated.[33]

As the Mount Polley panel noted, technical feasibility is no impediment to filtered tailings storage. It is a "demonstrated technology . . . well-known in the industry."[34] The process involves dewatering tailings before storage, which allows it to be compacted to enhance stability:[35]

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[28] Mount Polley Panel Report at 121-122 (Exhibit 6).
[29] For the purposes of this section, the two terms are used interchangeably.
[30] Minn. Stat. § 116D.04, subd. 6, for instance, prohibits the state from taking any action, including issuance of a dam safety permit, that significantly affects the quality of the environment or from issuing a permit that "is likely to cause pollution, impairment, or destruction of the air, water, land or other natural resources located within the state," unless there is "no feasible and prudent alternative to issuance of the permit consistent with the reasonable requirements of the public health, safety, and welfare and the state's paramount concern for the protection of its air, water, land and other natural resources from pollution impairment or destruction. Economic considerations alone shall not justify such conduct." *See also* Minn. Stat. § 116B.04 (establishing that "economic considerations alone shall not constitute a defense" to a claim under the Minnesota Environmental Rights Act).
[31] See 33 U.S.C. 1314(b)(2)(B) (describing "best available technology" as taking into account "the age of equipment and facilities involved, the process employed, the engineering aspects of the application of various types of control techniques, process changes, the cost of achieving such effluent reduction, non-water quality environmental impact (including energy requirements), and such other factors as the Administrator deems appropriate").
[32] Exhibit 8 at 3.7.
[33] Michael Davies, Filtered Dry Stacked Tailings – The Fundamentals, Proceedings Tailings and Mine Waste, Vancouver, BC, Nov. 6-9, 8 (2011) http://www.infomine.com/library/publications/docs/davies2011.pdf [hereinafter "Davies 2011"], attached as Exhibit 9 (noting that "if there is proper compaction and maintenance of target moisture contents, seepage is negligible.").
[34] Mount Polley Panel Report at 122 (Exhibit 6).
[35] *Id.*

> Filtered tailings emerge from the process facility within a prescribed range of moisture contents . . . The tailings are then transported by conveyor or truck and then placed, spread and compacted to form an unsaturated, dense and stable tailings "stack" (often termed a "dry stack") requiring no dam for retention with no associated tailings pond.[36]

The process has been used for tailings quantities well in excess of the roughly 27,000 cubic yards of in-place mine waste that will be produced by the NorthMet project every day.[37] Some new operations will be producing filtered tailings at a rate of about 35,000 cubic yards a day.[38]

Filtered tailings are particularly appropriate for cold climates, where water handling is very difficult in winter, and in situations when the operating and closure liabilities exceed the incremental cost increase of developing a dry stack.[39] For the NorthMet project, water treatment costs at the mine's closure are upwards of $400 million.[40] We find it very concerning that the company would choose not to utilize dry stacking due to a larger upfront expense,[41] when the alternative is a literal eternity of extremely expensive water treatment. Like many others, we assume that this choice reflects an alarming assumption that those long-term costs will somehow never materialize, or at least never materialize for the company receiving permits.

Aside from increased stability and a quicker steady state condition, filtered tailings storage offers significant benefits at the mine's closure. Because the tailings have already been dewatered, there is no need for water treatment at closure:[42]

> The lack of a tailings pond, very low (if any) appreciable seepage from the unsaturated tailings mass and general high degree of structural integrity allows dry stacks to present the owner/operator with a comparably straight forward and predictable facility closure in comparison with most conventional impoundments.[43]

And because the end product more closely resembles typical terrain, "one of the main advantages of dry stack tailings over other tailings management options is the ease of progressive reclamation and closure of the facility."[44] This benefit is significant, as it allows "re-vegetation of the tailings slopes

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36 Davies 2011 at 3 (Exhibit 9).
37 PolyMet FTB Permit Application at 1.
38 Mount Polley Panel Report, supra note 13, at 122 (Exhibit 6) (please note that conversion from metric tonnes to cubic yards is an estimate, as the exact conversion rate is not provided in the report itself).
39 Davies 2011 (Exhibit 9).
40 See NorthMet Permit to Mine Application, prepared for PolyMet Mining, Inc., Foth Infrastructure & Env't, LLC & Barr Eng'g Co., Appendix 15, Tbl. 1 (Nov. 2016) (reflecting costs for Wastewater Treatment Facility Pit Flushing Costs and Wastewater Treatment Plant Gallons Treated Costs).
41 Presumably, since no explanation for the decision has ever been given by the company, to our knowledge.
42 Davies 2011 at 8 (Exhibit 9) (noting that "if there is proper compaction and maintenance of target moisture contents, seepage is negligible.").
43 *Id.*
44 *Id.*

and surface as part of the annual operating cycle."[45] Filtered tailings storage also allows for the use of less stable foundation conditions, because the dewatered and compacted tailings stack is inherently more stable than a saturated impoundment.[46] This would therefore solve the problem identified by DNR's consultants, whereby the existence of peat at the buttress foundation would raise the risk of dam failure.[47]

But perhaps most significantly, filtered tailings storage would eliminate the possibility of a catastrophic dam failure of the type that occurred at Mount Polley. "Filtered tailings placed in dry stacks are essentially immune to catastrophic geotechnical 'failure' and can be readily designed to withstand static and seismic forces."[48] Indeed, filtered tailings storage would eliminate the need for an impoundment of any kind. Dry stack tailings are frequently (if not always) capped at closure with a cover material to resist erosion, prevent water infiltration and to provide a growth media for vegetation during reclamation.[49] The end state of reclamation for dry stack tailings, therefore, is a more natural landscape that minimizes oxidation of mine waste and the need for water treatment, while the end state for the proposed tailings facility is a saturated pile of mine waste topped with a pond and held in place by an earthen berm for eternity.

Even if dry stack tailings storage were to prove unfeasible due to mine waste characteristics, partial dewatering of the mine waste offers a significant proportion of the benefits of dry stacking. The reduction in the amount of water stored behind the impoundment substantially reduces the risk of dam failure. As the Mount Polley Panel noted, the quantity of water impounded by a tailings dam is directly correlated with the amount of tailings released during a breach event. The Mount Polley Report notes that "[h]ad there been less water to sustain [fluvial processes], the proportion of the tailings released from the TSF would have been less than the one-third that was actually lost."[50] It is conversely true that the reduction of water impounded during operations and at closure produces a corresponding drop in the amount of tailings that would be released during a dam breach. In the case of Mount Polley, the level of water impounded may have been the difference between disaster and what could have been a less serious event. As the report notes, "Had the water level been even a metre lower and the tailings beach commensurately wider, this last link [in the chain of failures] may have held until dawn the next morning, allowing timely intervention and potentially turning a fatal condition into something survivable."[51]

In short, the regulatory directive that dam safety permits must be based on current, prudent engineering and environmental practice, when viewed in light of statutes related to environmentally preferable alternatives, requires that the NorthMet FTB and HRF facilities utilize the Best Available

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[45] *Id.*
[46] *Id.*
[47] Review Team Comments Memorandum from Dick Van Zyl, Steve Gale, Cecilio Olivier, and Stuart Grubb to Jason Boyle, May 15, 2017, at 4.
[48] Davies & Rice 2004 (Exhibit 8).
[49] *Id.*
[50] Mount Polley Panel Report at 137 (Exhibit 6).
[51] *Id.*

Technology for tailings storage. Drawing on the hard lessons of past mining disasters, expert panels of mine engineers have concluded that this Best Available Technology is dry tailings storage, not conventional slurry impoundments. By dewatering and compacting the tailings, a redesigned facility would eliminate the risk of catastrophic tailings dam failures and eliminate the need for water treatment in perpetuity.

1.3 The Department Unreasonably Refused to Consider Dry Stack Tailings as an Alternative to Wet Closure with Slurry Dams

The Department has long known that wet closures are inherently risky. DNR's Dam Safety Engineers have for years warned that wet closures pose serious risks to the public and to the taxpayer:

> [The] Dam Safety [Division] has numerous concerns with this project because the tailings dams must function properly for an extended period of time – we've heard on the order of 900 years. Our first concern is whether the PolyMet tailings will form a structurally sound base to support the perimeter dams. Our second concern is that the proposed wet cap will significantly increase the potential for a dam failure, and will result in costly monitoring and maintenance over the life of the project (including monitoring costs to DNR for 900 years).[52]

These concerns were shared by DNR's consultants, who urged the serious consideration of environmentally preferable alternatives to wet closure. Spectrum Engineering Engineer Don Sutton expressed his concerns to DNR's Dam Safety Engineers in an email:

> If seepage collection or treatment is or might be necessary for an indefinite time with a wet closure, then what is the benefit of wet closure? The wet closure is riskier, has more uncertainties, and may be more expensive because it will require more perpetual care and maintenance than a dry closure. I suggest that PolyMet investigate some alternatives . . . I don't like wet closure, because it is not a permanent closure. I believe it will eventually fail and release the sulfates.[53]

Mr. Sutton urged an exploration into the comparative economics of the long term costs associated with wet vs. dry closures:

> I share [the Dam Safety Engineer's] wet closure concern and have additional concerns related to the long term tailings wet closure uncertainties and risks . . . If there is a reasonable risk that wet closure won't prevent oxidation or sulfates for 900 years and if perpetual water collection and treatment will be needed, then why not investigate some dry closure options and compare the long term O&M costs and long term risks of each alternative? Perhaps there is a dry closure alternative that is

[52] DNR Dam Safety Senior Engineer Dana Dostert, Geotechnical/Geochemical Questions Related to PolyMet Tailings, January 31, 2012, attached as Exhibit 10.
[53] Email of Don Sutton to Dana Dostert, January 23, 2012, attached as Exhibit 11.

> more economical and less risky when perpetual maintenance O&M are considered. At some point, the cost of the risk will need to be assessed . . . I envision that PolyMet's reclamation plan could work for a while, but don't see how it will function forever without falling apart unless it is continuously maintained; which is a major leap of faith . . . I don't like the wet closure, because it is not a permanent closure. I believe it will eventually fail and release the sulfates.[54]

Despite the fact that Spectrum was hired by DNR to provide technical consultation on a matter with which it did not have any experience,[55] these very clear recommendations appear to have been ignored by the Department.

Mr. Sutton's email was written before the Mount Polley disaster. Since then, the investigation into that disaster persuaded the Expert Review Panel to conclude that wet closures were inherently risky (see discussion in section 1.1). When those conclusions were published during the environmental review process, citizens and advocacy groups (included the undersigned organizations) urged the Co-Lead Agencies to consider dry stacking as an alternative to the proposed slurry impoundment, specifically referring the Agencies to the very clear-cut recommendations of the Mount Polley Review Panel. This suggestion was summarily dismissed in a single paragraph. The Agencies responded that dry stacking would require a basin liner, which would not be feasible on the existing LTVSMC tailings basin.[56] The Agencies did not clarify why they believed the existing tailings basin was a stable site for a new dam, but not for a basin liner, especially since their technical consultants have suggested that lining the existing tailings might be feasible.[57] The response also presupposes that the LTVSMC site is the only suitable location for dry stacking, and there is no indication that a search for alternate sites was undertaken, despite the clear statutory mandate to do so.[58] The Agencies responded also that dry stacking would require a new location, which would increase footprint effects of the project, and that dry stacking would not address the legacy water quality issues associated with the existing LTVSMC tailings basin.[59]

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[54] *Id.*

[55] Dana Dostert, Exhibit 10 ("Dam Safety has experience with tailings dams that are constructed from the residue from the taconite industry, but has no experience dealing with tailings that will be derived from minerals in the Duluth Complex.").

[56] See PolyMet FEIS at Appendix A, Response to Comments on the DEIS for the NorthMet Mining Project and SDEIS for the NorthMet Mining Project and Land Exchange, A-315 (Nov. 2015).

[57] *See* Exhibit 11 (Sutton-Dostert email) ("Perhaps, rather than trying to prevent oxidation, there might be a way to accelerate the oxidation to minimize the collection and treatment time. Consider installing a leachate collection system in the taconite tailings basin before the new tailings are added. This might entail putting the bentonite on the existing surface and installing some type of under drain collection system before the tailings are placed on top.").

[58] See Minn. Stat. § 103G.297, subd. 3 (permit for control or use of waters for copper-nickel mining may be granted only if the commissioner determines that other feasible and economical methods of mining are not reasonably available); Minn. R. 6115.0410, subp. 8 (approval or denial of dam permits shall be based on a showing of lack of other suitable feasible and practical alternative sites, and economic hardship which would have a major adverse effect on population and socioeconomic base of the area affected).

[59] *Id.*

These responses are borderline *non sequiturs*. An independent panel of mine engineers concluded that, based on the historic tragedies of tailings dam failures, it was an unreasonable risk to impound slurry waste in perpetuity, but the Agencies would not consider a dry alternative because it would increase the footprint of the proposed project. It should go without saying that the environmental impact of a dry stacked facility's footprint and the impact of a conventional slurry tailings impoundment failure are not the same (setting aside the even more obvious fact that filtered tailings result in a lesser footprint than conventional slurry tailings impoundments).[60] Furthermore, the impacts of a dry stacked footprint could potentially be minimal. Unlike an open-pit mine, where some impacts on wetlands, streams and other natural features may be unavoidable due to the precise location of a mineral deposit, a dry-stack tailings facility has more flexibility when it is sited. The Department is in fact required to investigate potential sites for a dry-stack facility that could minimize impacts.[61] Such possibilities could include the excavated pits or other brownfield sites near the LTVSMC plant. They could also include the currently proposed HRF site, which could be expanded to accommodate the filtered tailings in addition to the hydromet process residues. One of the virtues of dry stacking is that dewatered tailings may be transported by truck.[62]

Moreover, it is unreasonable to eliminate a vastly preferable alternative because it would not address another company's legacy pollution. The very purpose of dry stacking is to avoid turning a private company's pollution into public legacy pollution by reducing or even eliminating the need for perpetual water treatment after the mine has closed, and yet the Agencies refused to consider this alternative due to a concern that another company's legacy pollution would not be cleaned up.[63] In effect, in choosing PolyMet's proposal to treat the LTVSMC legacy pollution with seepage controls, the Agencies vastly increased the risk that PolyMet's new facility will become a legacy liability requiring perpetual water treatment. Rather than trade one form of pollution for another, the Department should require responsible mining that eliminates the need for perpetual water treatment through dry stacking.

1.4 Upstream Dam Construction – Particularly On Top of a Unpermitted Legacy Tailings Site – Is Inherently Unsafe and Threatens the Public Safety and Welfare

The method that PolyMet has proposed to use to construct its Flotation Tailings Basin, namely the upstream construction method, is the riskiest but cheapest possible option. The collapse or major breach of the tailings dam has the most potential to cause widespread destruction of all mining operations. Recent reports demonstrate that the risk of a tailings dam collapse is not nearly as remote as PolyMet suggests. Two hundred and fourteen tailings dams have had failures or accidents

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60 *See, e.g.,* Davies & Rice 2004 (Exhibit 8) (noting that filtered tailings are a promising candidate for storage options where space is limited, "as filtered tailings result in a lesser footprint than for slurried tailings.").
61 Minn. Stat. § 103G.297, subd. 3; § 116D.04, subd. 6; Minn. R. 6115.0410, subp. 8.
62 Davies 2011 (Exhibit 9).
63 We note also that PolyMet would still take possession and legal responsibility for permitting at the LTVSMC site. Discharges from the tailings basin would be required to meet state water quality standards and other state and federal environmental laws regardless of whether PolyMet uses it as a disposal site in any event.

since 1940.[64] Since 1960, "serious" and "very serious" tailings dam failures have occurred with greater frequency.[65] As copper grades have dropped over time, with a corresponding increase in mine waste and decrease in profit margins, the frequency of tailings dam failures has increased dramatically.[66] Very large releases of mining waste occur even at relatively small mines, such as during the Mount Polley mining disaster.[67] Many of these failures occur at facilities using upstream dam construction techniques. Upstream dams are considered "unforgiving structures," and represent up to 66% of global tailings dam failures.[68] Moreover, the cost of cleanup for a catastrophic failure averages $543 million.[69] This dollar value is beyond the capacity of most mining companies to cover. Furthermore, it is not required that the risk of a tailings dam collapse be included in the financial assurance package.[70]

Recent studies and articles discuss how critical the process of statistical analysis of tailings dam failures is when evaluating the potential for a collapse at any given mine:

> Having something more like "actuarial data" to refer to is important in understanding the potential magnitude of loss from an individual dam or a permitting districts portfolio of dams and TSFs [Tailings Storage Facilities]. With such low frequency high severity losses we can never assign risk to an individual TSF based on its design and receiving environment parameters. Unless it has an identified flaw that puts it at near certain risk of imminent failure, we can't say whether a given dam "will" fail. We can only say what the consequence would be in economic terms if it failed.[71]

Minnesota statutes and administrative rules call for certain factors to be taken into account by both the permit applicant and the permitting agency; the primary purpose of these regulations is to "best provide for public health, safety, and welfare."[72] Namely, the permit application must be based on substantial evidence[73] and the dam must be "reasonable, practical, and . . . adequately protect public

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64 Lindsay Newland Bowker & David Chambers, The Risk, Public Liability, and Economics of Tailings Storage Facility Failures, 4 (2015) [hereinafter, "Bowker & Chambers 2015"], attached as Exhibit 12.
65 *Id.* at 4.
66 Lindsay Bowker and David Chambers, *In the Dark Shadow of the Supercycle: Tailings Failure Risk & Public Liability Reach All Time Highs*, August 17, 2017, attached as Exhibit 13.
67 *Id.* at 2.
68 Flavio Fonseca do Carmo, et al., Fundao tailings dam failures: the environment tragedy of the largest technological disaster of Brazilian mining in global context. 15 Perspectives on Ecology and Conservation 145-151 (July 2017) [hereinafter "Fonseca do Carmo, et al. 2017"], attached as Exhibit 14.
69 *Id.*
70 Minn. R. 6132.1200 (financial assurance must include funds for "reclamation activities" and "corrective action . . . if noncompliance with design and operating criteria in the permit to mine occurs."). Although the draft permits state that environmental liability insurance shall be acquired to cover dam failure, no policy has been procured and thus nothing can be said about the adequacy of such insurance coverage.
71 Bowker & Chambers 2015 at 4 (Exhibit 12).
72 Minn. R. 6115.0300; see also Minn. Stat § 103G.315, subd. 6.
73 Minn. Stat. § 103G.315, subd. 2.

safety and promote public welfare."[74] The permit applicant bears the burden of proving the dam will protect the public.[75] Finally, that "[a]pproval or denial [of the permit] shall be based on the potential hazards to health, safety, and welfare of the public and the environment including probable future development of the area downstream."[76]

There is a plethora of evidence that upstream dam construction is unsafe and unsound, posing a very high risk to surrounding communities and the environment.[77] This form of dam construction has been banned in other countries because of its tendency towards failure.[78]

Dr. David Chambers states the following on this matter:

> Safety should be the prime consideration in the design, construction, operation, and closure of a dam, whether this be a water supply reservoir or a tailings dam . . . Centerline and downstream-type construction, even though it is also done in stages like upstream, depends only on materials that are sized, placed, compacted, and subsequently tested for support of the sequential stages. When tailings are hydraulically spigotted into the impoundment, their placement and water content are not uniform. There is no practical way to test the characteristics of the tailings material to assure that it is subsequently drained of excess water after hydraulic placement, and that is has the consistency and density assumed by the design modeling.[79]

Perhaps more worrisome is the fact that

> [i]n tailings dam accidents we do not see a preponderance of one or two failure causes dominating. What we see is that the number and distribution of failure type is remarkably similar. That is, overtopping, seismic failure, foundation issues, internal seepage, slope instability, and structural failure all have similar number-of-failure profiles for both active and inactive tailings dam failures (Bowker & Chambers 2016).[80] This strongly suggests there is something more fundamental than the inability to deal with the causes of one or two failure types.[81]

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[74] Minn. Stat. § 103G.315, subd. 3.
[75] Minn. Stat. § 103G.315, subd. 6.
[76] Minn. R. 6115.0410, subp. 8 (emphasis added).
[77] See, e.g., Mount Polley Panel Report (Exhibit 6); David Chambers, "Comments on the Final Environmental Impact Statement (FEIS) NorthMet Mining Project and Land Exchange", CTR. FOR SCIENCE IN PUB. PARTICIPATION, (Dec. 2015) [hereinafter "Chambers FEIS Comments"], attached as Exhibit 15.
[78] Chambers FEIS Comments at 8 (Exhibit 15).
[79] Chambers, "Comments on Draft Dam Safety Permit Numbers 2016-1380, Flotation Tailings Basin, and 2016-1383, Hydrometallurgical Residue Facility", CTR. FOR SCIENCE IN PUB. PARTICIPATION, 1 (Oct. 4, 2017) [hereinafter "Chambers Draft Dam Safety Permit Comments"], attached as Exhibit 3.
[80] Lindsay Newland Bowker & David M. Chambers, Root Causes of Tailings Dam Overtopping: The Economics of Risk & Consequence, INT'L SEMINAR ON DAM PROTECTION AGAINST OVERTOPPING, PROTECTIONS 2016, Ft. Collins, CO (Sept. 2016), attached as Exhibit 16.
[81] Chambers Draft Dam Safety Permit Comments at 2 (Exhibit 3).

He supplements these concerns by saying that "[t]he only reason to use both centerline and upstream construction, over a conventional downstream-type approach, is to save money."[82] The Mount Polley Independent Expert Review Panel ("the Panel") has clearly stated that cost should not be the determining factor in constructing a tailings basin.[83]

Jim Kuipers notices that some of these shortcomings come from the way the regulations are written, and that by not taking into account many of the factors other states and countries have into their approaches to safety in construction and operation, the proponents of such facilities fall short of the engineering safety standards.[84] This increases the risk for dam failure and the potential for catastrophic destruction. We suggest, therefore, that the term "prudent, current environmental practice" must include more stable alternatives to upstream construction.

As noted above, wet closure heightens concerns posed by upstream construction and increases the risk of dam failure. First, existing water means that the tailings, an integral part of the proposed foundation, will be saturated either partially or fully, and thus will have little to no "weight-bearing capacity under seismic loading."[85] Thus, the stability will be very weak, and the distribution will be uneven. Second, "water remaining on and in the tailings acts as a deadly mobilizing agent should a catastrophic failure occur."[86] This means that the tailings will escape much quicker and cause more damage in a shorter period of time than if they were dry.

1.4.1 Slimes used in the dam liner:

The proposed dam construction violates rules of prudent engineering and environmental practice because the dam is underlain with slimes and fine tailings. As he discusses the dangerous nature of the type of the upstream tailings basin, Dr. David Chambers references an article authored by three experts on tailings basins. This article lays out ten rules for constructing a tailings basin – he includes the following excerpt in his comments:

> It is also important to note that these rules are not options and are not interchangeable with alternative concepts of soil mechanics. These rules exist based on the fundamentals of soil behavior, the experience of numerous tailings dam failures and the experience of well-managed facilities that perform better than intended. Of the 10 rules, a "score" of 9/10 will not necessarily have a better outcome than a 2/10, as any omission creates immediate candidacy for an upstream tailings dam to join the list of facilities that have failed due to ignoring some or all of the rules.[87]

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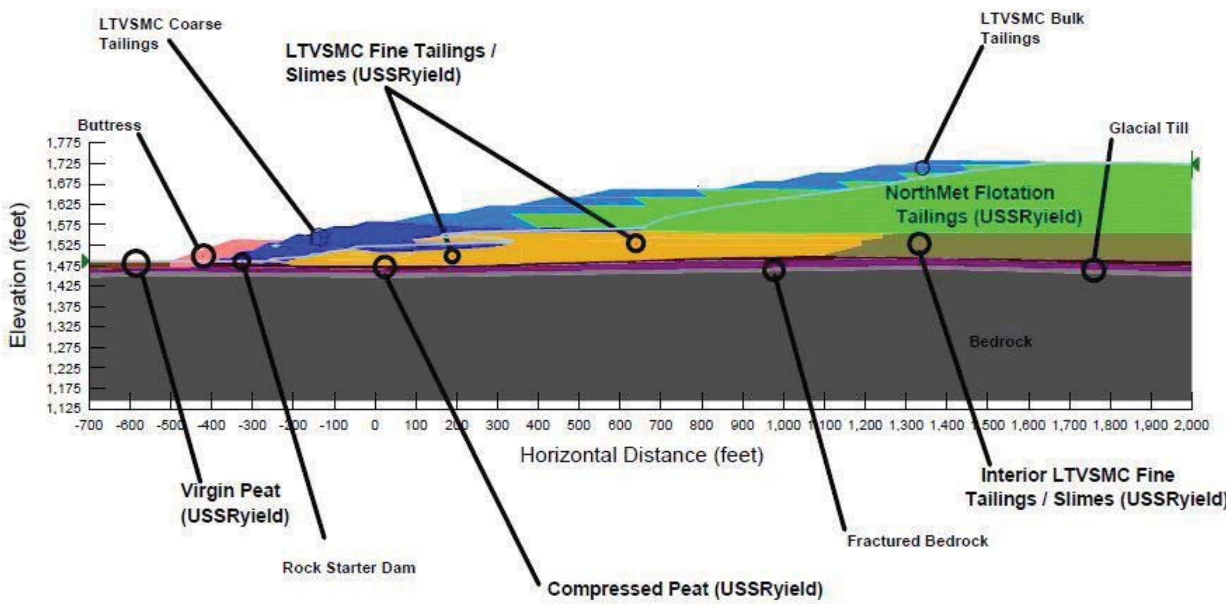
[82] *Id.* at 1.
[83] Mount Polley Panel Report at 125 (Exhibit 6).
[84] Kuipers Dam Safety Permit Comments at 2 (Exhibit 2).
[85] *Id.*
[86] *Id.*
[87] Chambers FEIS Comments at 8 (Exhibit 15).

Dr. Chambers says that because the proposed PolyMet FTB dam plans to incorporate tailings slimes in its liner, it violates rule number two, which states that "[t]he dam slope must not be underlain by tailings slimes . . ."[88]

As seen in the figure below, from the Geotech Data Package, the NorthMet dam will be built on a foundation of LTVSMC slimes and fine tailings. This scenario was a contributing factor to the devastating tailings dam collapse at the Samarco mine in Brazil, which killed 19 people. The Samarco Expert Panel Report concluded that after placing the "embankment directly over the previously-deposited slimes," the "slimes beneath the embankment were responding to the increasing load being placed on them by the rising embankment," thereby creating "all of the necessary conditions for liquefaction triggering."[89]



Large Figure 12. Cross-Section F Schematic of USSA Conditions

Reproduction of Large Figure 12 from Geotechnical Data Package Vol. 1 – Flotation Tailings Basin, Appendix B to May 5, 2017 Dam Safety Application for Flotation Tailings Basin Dam.

As noted below, DNR staff has expressed this same concern for years, but this risky design feature persists, in clear violation of the law's directive that dam safety permits be based on substantial evidence.

88 *Id.*
89 *Report on the Immediate Causes of the Failure of the Fundao Dam*, Fundao Tailings Dam Review Panel, at ii [hereinafter "Fundao Panel Report"], attached as Exhibit 17.

1.4.2 Dam Classification:

Both the FTB and the HRF should be classified as Class I dams. Dr. Chambers states that because both facilities' dams pose a very high risk and with regard to "environmental and economic destruction" should either of them fail, they both need to be "classified at the highest hazard category of risk."[90]

Jim Kuipers notes that hazard classifications aside, there are a number of things that the dam classifications do not take into account. Among them are the proximity to population centers, and the number of people that can potentially be displaced or harmed if the dam were to fail.[91] This skews the hazard classification of these facilities; not many people tend to live in close proximity of these facilities, and thus the potential impact that dam failure might have on the number of people displaced or killed is lower.[92] This in turn lowers the hazard classification; thus it is "often necessary to be on the conservative side when applying dam classifications."[93] Furthermore, he says that the work that he and his group conducted found the explanation PolyMet gave, namely that "[t]he FTB dams can be categorized as Class I or Class II dams[]"[94] "highly concerning".[95] Mr. Kuipers says that this conclusion

> [S]uggests the design engineer has not taken into account all failure modes that can cause a catastrophic dam breach, many of which are independent design factors of safety. Similarly, the recent Mount Polley and Samarco (Brazil) TSF catastrophic failures were considered to "unlikely," if not impossible, until they occurred. In our experience and professional judgment a more accurate portrayal would be to consider all potential failure modes and identify TSF failure as "possible" and would likely lead to highly significant safety, environmental and economic consequences, and for that reason the TSF should be classified as Class I.[96]

Each of the dams has the potential to cause widespread environmental destruction should either of them fail. This potential harm exists addition to the potential harm facility failure could bring to the people living within the immediate proximity of each of the facilities, or those living downstream. As a result of this potential, both facilities should be classified as Class I.

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90 David Chambers Draft Dam Safety Permit Comments at 3 (Exhibit 3).

91 Kuipers Dam Safety Permit Comments at 3 (referencing work conducted by the Canadian Dam Association) (Exhibit 2).

92 *Id.*

93 *Id.* at 4.

94 Kuipers Dam Safety Permit Comments at 16 (Exhibit 2) (quoting NorthMet Dam Safety Permit Application: Flotation Tailings Basin, prepared for PolyMet Mining, Inc., BARR ENG'G CO. (May 2017) (emphasis added).

95 Kuipers Dam Safety Permit Comments at 10 (Exhibit 2).

96 *Id.* at 16.

1.5 PolyMet conducted an insufficient Dam Break Analysis contrary to regulatory requirements.

The Dam Break Analysis prepared by Barr Engineering for PolyMet is grossly inadequate. Minnesota statutes and rules require the permit application to be based on "substantial evidence";[97] as is explained below, PolyMet has not met this burden, especially with its thirteen-page Dam Break Analysis (only seven-and-a-half of which comprises the actual analysis).[98] For a project of this stature, such an analysis needs to be more detailed and use current information.

1.5.1 PMP and PMF values:

In the course of determining the potential for heavy rainfall and possible flooding, Barr Engineering conducted hydrologic models using the Probable Maximum Precipitation (PMP) and Probably Maximum Flood (PMF). The model "computed runoff from the 72-hour Probable Maximum Precipitation (PMP) storm event." [99] This event was chosen because it allows for the "estimation of worst-case flooding in Trimble Creek," which is a tributary of the St. Louis River.[100]

The PMP is described as follows:

> PMP values are, in principle, most dependent upon atmospheric moisture, transport of moisture into storms, persistent upward motion, and strong winds where orographic uplift is important. . . . The general approach, using data and physical judgment, is to estimate the precipitation that would occur if all the relevant factors in a particular place and situation achieved their optimum values simultaneously and remained in place for the specified duration over the basin area.[101]

The assumed PMP used is "32.2 inches for the 10-square mile watershed, based on the Hydrometeorological Report number 51 . . . ."[102] Furthermore, the storm runoff from the FTB was calculated using this same method, but "the volume of runoff from the storm event was not routed downstream." PolyMet added, "[s]ince the FTB was designed to hold runoff from the 72-hour PMP event, it was assumed that the total runoff volume from the FTB direct watershed was added to the open water in the FTB and there was no discharge downstream."[103] This assumption is problematic looking to the future as climate change intensifies and changes some of the precipitation patterns.

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[97] Minn. Stat. § 103G.315, subd. 2.
[98] Dam Break Analysis, NorthMet Dam Safety Permit Application: Flotation Tailings Basin, prepared for PolyMet Mining, Inc., BARR ENG'G CO., ATTACHment H (May 2017) [hereinafter "FTB Dam Break Analysis").
[99] *Id.* at 3.
[100] *Id.*
[101] Kenneth E. Kunkel, et al., Probable Maximum Precipitation and Climate Change, 40 GEOPHYSICAL RESEARCH LETTERS 1402, 1402 (2013), http://onlinelibrary.wiley.com/doi/10.1002/grl.50334/epdf, attached as Exhibit 18.
[102] *Id.*
[103] *Id.*

Scientists expect that this rise in global temperature will result in a rise in evaporation and atmospheric water vapor content.

> A probable consequence is the intensification of the hydrologic cycle and PMP over land and ocean. The effect of this intensification on changes in PW_{max} [maximum precipitable water] values over land was investigated by analyzing future (2041-2070 and 2071-2100) and control (1971-2000) simulations from the Coupled-Model Intercomparison Project phase 5 (CMIP5) archive . . . The analysis reveals projected increases across all grid cells, indicating general global moistening of the atmosphere . . . The increases in PW_{max} are a robust result in the model simulations and have a strong theoretical basis, the Clausius-Clapeyron equation, linking the increases to increasing temperature. The PW_{max} increases are large and, if incorporated into PMP estimates, would have major implications for design of dams and other long-lived and critical runoff control structures.[104]

This projection is concerning, especially seeing that this region has already seen episodes of disproportional rainfall; in particular in June of 2012. Much of the St. Louis River and these parts of St. Louis County and Carlton County suffered unprecedented rainfall and catastrophic flooding, which wiped out whole towns, bridges, and roads. As a dam stands in perpetuity, such events must be a part of the evaluation and modeling in order to have a complete safety analysis. Jim Kuipers notes that facilities such as the FTB "are built during the development and operation of mines and remain as part of the landscape becoming a permanent feature that must perform as designed after the closure if the mine indefinitely."[105] Thus, the potential impacts of climate change and a generally warmer and more precipitous atmosphere need to be taken into consideration and such projections included in modeling when determining the strength and stability of the dam.

Such precipitous events also beg the question of adequate drainage. This issue has been raised by the United Nations Environment Programme, particularly in regard to areas with more saturated soils:

> The filter under-drainage system is a critical facility that has often been overlooked in the past, resulting in dangerously high phreatic surfaces within the body of the tailings dam. As is well known, the outer slopes of a tailings dam are very sensitive to the level of the phreatic surface. Capillary rise above the measured position of the phreatic surface can make the tailings in this zone to be close to full saturation. This condition can produce unexpectedly large rises of the phreatic surface from remarkably small amounts of rainfall.[106]

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104 Exhibit 18 at 1404 (emphasis added).

105 Kuipers Dam Safety Permit Comments at 2 (Exhibit 2).

106 Tailings Dams Risk of Dangerous Occurrences: Lessons Learnt from Practical Experiences, Bulletin 121, U.N. ENVT'L PROGRAMME, 17 (2001), http://www.unep.fr/shared/publications/pdf/2891-TailingsDams.pdf., attached as Exhibit 19.

The concern that historical precipitation patterns may paint a misleading picture of the risk to tailings dams was also poignantly highlighted by DNR's consultant, Spectrum Engineering. Don Sutton wrote to DNR's Dam Safety Engineers that:

> The climate is changing in unpredictable ways that makes it difficult to predict the water balance. For example, at the Zortman and Landusky sites in north central Montana, we have experienced three plus 100 year events in the last 10 years. In 2011, we experienced an event believed to be the 200 or 500 year event that overwhelmed all our water management and water treatment facilities and caused a waste dump to collapse and destroy a water capture and pump back station. The average precipitation for the last 2 years is 100% above average.[107]

We have already seen dramatic changes in precipitation in Minnesota as a result of climate change. Over the last 50 years, the amount of precipitation falling in heavy events has increased 37%, more than any other region in the U.S. except New England.[108] Compare to 1961-1970, the decade from 2001-2010 saw a 71% increase in severe storms of 3 inches or more, one of the largest increases in storm frequency in the country (note that PolyMet's reference data for precipitation is from 1978).[109] This "tendency towards precipitation extremes," along with higher average annual precipitation overall, is projected to continue unabated into the future.[110]

Even assuming that the levels of precipitation do fall within these parameters, the Dam Break Analysis does not address the issue of discharge back into the watershed. This lack of downstream impacts is discussed further below.

1.5.2 Inflow Design Flood

> The Inflow Design Flood (IDF) is the most severe inflow flood for which a [tailings storage facility] TSF or associated facilities are designed and should be considered applicable to the construction, operation, and transition phases. In selecting an IDF the risks of hydrologic failure of a TSF should be balanced with the potential downstream consequences.[111]

This is the approach recommended by the Federal Emergency Management Agency; importantly, "FEMA notes that no single approach to selection of an IDF is adequate given the unique situations of each site," and recommends four approaches to an IDF analysis.[112] These four approaches are the Prescriptive Approach, Site-Specific PMP Studies (Refinement of the Prescriptive Approach),

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[107] Exhibit 11.
[108] Minnesota Dep't of Health, Minnesota Climate and Health Profile Report 2015, at 20, attached as Exhibit 20.
[109] *Id.* at 21.
[110] *Id.* at 32.
[111] Kuipers Dam Safety Permit Comments at 10 (referencing recommendations by the Canadian Dam Association) (Exhibit 2).
[112] *Id.* at 10.

Incremental Consequence Analysis, and Risk-Informed Decision Making.[113] The descriptions as given by Mr. Kuipers are as follows:

> Prescriptive Approach – In this initial phase, a planned dam is designed or an existing dam is evaluated for a prescribed standard based on the hazard potential classification of the dam. This approach is intended to be conservative to allow for efficiency of resource utilization while providing reasonable assurance of the safety of the public. It is not intended to assure that there is an economical marginal benefit from designing for a conservative IDF.
>
> Site-specific PMP Studies (Refinement of the Prescriptive Approach) – The prescriptive approach relies upon determination of a PMF for high hazard dams which requires assessment of the PMP. The most common sources of the PMP information are the regional HMRs published by the NWS. These reports provide generalized rainfall values that are not basin-specific and tend to represent the largest PMP values across broad regions. Most of these reports have not been updated to reflect current state-of-the-art knowledge and technology. A site-specific study of the PMP/PMF using current techniques can result in a more appropriate estimate of the PMF for consideration as the IDF.
>
> Incremental Consequence Analysis – The volume of many reservoirs may be small in comparison to the volume of the hydrologic events to which they may be subjected. In these cases, the IDF can be established by identifying the flood for which the downstream consequences with and without failure are not significantly different.
>
> Risk-informed Decision Making – This method allows a dam owner or regulator to consider the risk associated with hydrologic performance of dams relative to other dam safety risks at the same dam, across a portfolio of dams, or in comparison to societal risks in general. In this method, the IDF is selected as the design flood which assures that a given level of "tolerable risk" is not exceeded. The strengths of this method include providing dam owners and regulators the ability to assess the marginal value of increasing levels of flood protection, balancing capital investment in risk reduction across a number of different failure modes, and prioritizing risk reduction actions across a portfolio of dams.[114]

As can be seen by the outline of this program, the analysis conducted for the NorthMet TSFs are inadequate and do not use the most recent, most accurate information available (see "PMP and PMF analysis" subsection above). These types of anticipatory analyses are inherently limited as they are calculations conducted with limited empirical records, and only provide an estimate.[115] Therefore, the most recent, accurate records must be provided, and multiple assessments using different approaches must be conducted.

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[113] *Id.*
[114] Kuipers Dam Safety Permit Comments at 10 (emphasis added) (Exhibit 2).
[115] *Id.* at 10-11.

1.5.3 Hypothetical Dam Failure Scenarios

The other issue present in this analysis is the fact that only one scenario was selected as the cause of the dam break for the study. "Piping" was selected in this analysis, and is explained as follows:

> Piping is the process whereby seepage through the dam is of sufficient velocity to initiate erosion and downstream transport of soils from the structure of the dam. Failure resulting from overtopping the dam was not considered because the dam is designed to not be overtopped even with the volume of the 72-hour PMP event.[116]

As stated above, this analysis does not take into account any precipitation patterns in the area from any point in the last 40 years. It also does not address any other number of potential events that could initiate dam failure, such as liquefaction of soil, and the role that may play in a sudden collapse of a dam wall. By way of comparison, the Mount Polley panel identified "four classes of failure mechanisms [that] required consideration . . . [b]ased on the experience of the Panel with both water and tailings dams . . . ."[117] In addition to piping, the Panel assessed cracking, human intervention, overtopping, and foundation failure.[118] Based on the tragedy that occurred at Mount Polley, anything less than preparing for what they assessed is irresponsible.

1.5.4 Lack of downstream analysis:

The primary purpose behind conducting the Dam Break Analysis was to supplement the Emergency Action Plan – in other words, to address what would happen to the 34 properties within the path of potential flooding should the dam breach or fail entirely on the north side. Furthermore, the Dam Break Analysis does not mention how many structures exist on those properties or how many lives on those identified properties would be at risk in the case of a dam breach.[119] While it is important to have a plan in action for the residents of the area should the dam breach, this is not the only thing that the Dam Break Analysis should (or as mentioned earlier, is required) to address.

To address some of these shortcomings, Mr. Kuipers makes the following recommendation:

> For the dam break analysis to be truly conservative, current industry guidance and experience suggests additional consideration should be given to the analysis. The CDA (2013) recommends the evaluation address initial hydrologic conditions for the following:
>
> - Sunny day failure – A sudden failure that occur during normal operations such as may be caused by internal erosion, piping, earthquakes, mis-operation leading to overtopping, or another event.

116 FTB Dam Break Analysis at 5.
117 *See* Mount Polley panel Report at 9 (Exhibit 6).
118 *Id.*
119 Kuipers Dam Safety Permit Comments at 21 (Exhibit 2).

- Flood induced failure – A TSF failure resulting from a natural flood of a magnitude that is greater than what the dam can safely pass.

> The incremental environmental consequences are often worse for a sunny day failure than a flood induced failure because of the large amount of process water and solids that are contained by TSFs (CDA 2014). The CDA (2013) recommends that simple and conservative procedures be applied to obtain a first approximation and that if necessary more detailed analysis should be conducted.[120]

Minnesota statutes require that public health and safety, in addition to the welfare of the public and the environment, need to be considered when a permit is issued.[121] This Dam Break Analysis does not take into account the potential hazards to the environment and surrounding waterways and water bodies should the dam fail. There is no analysis as to how to stop the flooding or escape of hazardous material should it find its way into a tributary of the St. Louis River, and flow downstream. Moreover, only one side of the dam was analyzed for the Dam Break Analysis – the side that faces the structures – which happens to be the north end of the dam.[122] The other sides, or the potential waterways or natural features they could affect, were not analyzed. DNR's staff has previously expressed concern that an eastern breach could reach Colby Lake through Wyman Creek, and PolyMet's only response was to flatly state that "a breach to the east would not reach Colby Lake."[123] Unsubstantiated denial, however, cannot constitute the "substantial evidence" required by law.

PolyMet conceded that other specific analyses (including but not limited to "evaluat[ion] [of] flotation tailings deposition after the breach" or "flow properties of the liquefied flotation tailings") were not included.[124] PolyMet claims that "[s]uch analysis is not warranted given the objective of this dam break analysis, which is to serve as an aid in development of the facility Emergency Action Plan."[125] Exclusion of a downstream analysis and the impacts on the surrounding waterways is contrary to the regulatory requirements and as such is inadequate.

1.6 PolyMet should incorporate a Failure Modes Effects Analysis (FMEA).

A FMEA "assist[s] in the TSF design and identification of other key aspects such as operational and closure requirements to ensure TSF safety."[126] The utilization of such analyses has become widespread, and is now considered a typical form of risk management. [127] According to experts in this field,

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120 *Id.*
121 Minn. Stat. § 103G.315, subd. 3.
122 See FTB Dam Break Analysis, supra note 95; see also Kuipers Dam Safety Permit Comments at 21 (Exhibit 2).
123 DNR Dam Safety Review Comments on NorthMet Project Flotation Tailings Basin Management Plan v. 2, Dec. 2012, attached as Exhibit 21.
124 FTB Dam Break Analysis at 7.
125 *Id.*
126 *Id.* at 19.
127 *Id.*

an effective risk management program must include the following elements:

- Identification of all failure modes and the factors that contribute to the likelihood of occurrence of that failure mode.
- A realistic assessment of the probability and consequences – yielding a risk rating.
- A program that mitigates the risks to reduce either probability (likelihood) or consequences to tolerable levels.
- An Action Plan and Management that implements the Action Plan.[128]

The design engineer for the PolyMet project did not conduct one of these, and it is recommended that one should be conducted, followed by a risk mitigation assessment and periodic MFEA reassessments.[129]

1.7 An accurate Probabilistic Seismic Hazard Analysis requires full dynamic modeling accounting for the Maximum Credible Earthquake and increased target factors of safety for slope stability in construction, operation, and transition phases in the seismic assessment.

The permit application as it stands presents two major issues with how the FTB has been proposed by PolyMet. The first is the seismic design event. The Probabilistic Seismic Hazard Analysis (PSHA) anticipates that a 2,475-year return seismic event is the largest seismic event that the dam potentially will experience. As laid out in Geotechnical Data Package Volume 1 (Section 6.5.3.3), the seismic liquefaction screening evaluation states that "the seismic design event . . . would not trigger liquefaction in any FTB materials . . . [so] no additional seismic triggering analyses were necessary."[130] Dr. Chambers notes that the use of the 2,475-year event renders a less accurate assessment of potential seismic activity, and that the PSHA should have used the Maximum Credible Earthquake (MCE) as the design earthquake.[131] It does not reflect the accepted current best practice.[132] With the MCE, there is a 10,000-year recurrence interval.[133] Dr. Chambers notes that this kind of an event has the potential to occur anywhere, and that its inclusion in such an analysis is vital for two reasons: (1) a structure like a tailings dam must stand in perpetuity, and thus must be designed to withstand something like the MCE, and (2) there are many active faults that have never

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128 *Id.*

129 *Id.* at 19-20.

130 NorthMet Project, Geotechnical Data Package Vol. 1 – Flotation Tailings Basin, prepared for PolyMet Mining, Inc., BARR ENG'G. Ver. 7, Sec. 6.5.3.3 (July 11, 2016). [hereinafter "GDP Vol. 1 - FTB"].

131 Dr. David Chambers, "Comments on NorthMet Mining Project and Land Exchange Supplemental Draft Environmental Impact Statement, prepared by Minnesota Department of Natural Resources, United States Army Corps of Engineers, United States Forest Service, November, 2013", CTR. FOR SCIENCE IN PUB. PARTICIPATION, 15 (Mar. 14. 2014) [hereinafter "Dr. Chambers SDEIS Comments"], attached as Exhibit 22.

132 Kuipers Dam Safety Permit Comments at 22(Exhibit 2).

133 David Chambers SDEIS Comments at 15 (Exhibit 22).

been mapped, or active faults previously thought to be inactive, so the potential for an active fault to be near the dam site is higher than PolyMet's assessment accounts for.[134]

In addition, a full dynamic model needs to be conducted in order to truly anticipate the potential weaknesses in not only the actual dam structure itself, but the geologic layers on the proposed building site. According to Dr. Chambers, "PolyMet performed what might be termed a pseudostatic analysis."[135] For projects with such stature as the FTB Dam, a pseudostatic analysis is considered deficient and currently is not accepted by most U.S. regulatory agencies, including the Federal Energy Management Agency; an agency regularly analyzing dam safety and seismic stability.[136] In order to fully anticipate and mitigate the potential for a seismic event, full dynamic modeling needs to be conducted, and the resulting information incorporated into the final decision in whether or not to grant the permit.

Mr. Kuipers takes this into account in his comments; he references recommendations from the Canadian Dam Association (CDA), which suggests that "crest deformations could be much larger [on tailings storage facilities as] compared to conventional dams,"[137] and as such "'criteria should be established for suitable deformations of a mining dam and the appropriate analyses undertaken to demonstrate the effect of an earthquake on the dam and determine if the deformation criteria is met.'"[138] Mr. Kuipers also points out that other states, including Montana and New Mexico, and British Columbia in Canada require use of the MCE and higher target factors of safety as well.[139] He includes the following statement from CDA:

> A factor of safety of 1.3 may be acceptable during construction of a dam where the consequences could be minor and measures are taken during construction to manage the risk such as detailed inspection, instrumentation, etc. But, the factor of safety of 1.3 should not simply be adopted because it is "End of construction." A factor safety of 1.5 has typically been adopted for tailings dams because of the potential consequences of failure. Therefore, when setting the design criteria for the dam, these target levels can be considered, but the risks associated with instability of the dam also need to be considered.[140]

The CDA also provides a table which contains the loading conditions and the minimum factors of safety – this table shows that a pseudostatic loading condition (like the one PolyMet has employed in the PSHA) shows a minimum factor of safety of 1.0.[141] This is below the values recommended by the CDA.

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134 *Id.*
135 *Id.*
136 Dr. Chambers SDEIS Comments at 16 (Exhibit 22).
137 Kuipers Dam Safety Permit Comments at 6 (Exhibit 2).
138 *Id.* (quoting Canadian Dam Association).
139 *Id.* at 6-9.
140 *Id.* at 7 (quoting Canadian Dam Association).
141 *Id.* at 7, Tbl. 5 (quoting Canadian Dam Association).

1.8 The Barriers Proposed to Mitigate Harmful Seepage from the Tailings Facilities Are Inadequate and Unlikely to Prevent Contamination of Surrounding Ground and Surfacewaters

As detailed in the attached comments of Dr. Malusis (Exhibit 5), while the testing of bentonite amendment is a laudable goal, the draft permits and permit application materials contain only the barest conceptual information as to how this testing will be done. But the efficacy of the bentonite amendment is not some peripheral component of the mine design; it is a critical determinant of whether the mine complies with the law or not. The effectiveness of the bentonite affects whether the mine complies with Minn. R. 6132.2200, subp. 2(B)(2) and it also substantially influences the stability of the FTB dam. The bentonite testing, in other words, goes to the heart of the matter, and by issuing the permit as drafted, the Department would be permitting a mine with only the barest of details to decide whether the mine and its dams pose a risk to the public health, safety and welfare. As drafted, the permits do not contain sufficient information for the Department to comply with the 'substantial evidence' requirements of the dam safety regulations.

Dr. Malusis addresses this concern in detail, and we will not duplicate that effort here, but incorporate his comments by reference. We will note here, however, that Dr. Malusis is not alone in his concerns. DNR consultants themselves characterized the proposal to cover the tailings with bentonite to prevent infiltration of oxygen as a "hail mary."[142] Those consultants concluded that the bentonite seal "will exacerbate erosion and slope failure and will eventually fail."[143] This is in fact the majority opinion – the literature on mine design is clear that "[c]overs have been found to present the risk of long term cracking or erosion, and to be ineffective in excluding air, so are less favoured solutions than submergence from the geochemical standpoint."[144]

Adding to Dr. Malusis' concern is the fact that DNR's Dam Safety staff expressed a belief that the percolation rate of 6.5 inches per year was almost certainly too low. When staff commented that this number "appears to be very low for the bentonite-amended FTB pond bottom (especially given the uncertainties associated with accurate bentonite placement)," PolyMet's only response was that the infiltration rate had already been accepted by the Department.[145] This response is troubling, for it avoids the central question and does not answer the concern that the infiltration rate is most likely understated. It may be irrelevant that the DNR had already accepted 6.5 inches as the infiltration rate, as the concern may not have been raised at the time acceptance occurred. Even more troublingly, it was not only DNR's staff that suggested the infiltration was understated. The issue was also raised by EOR, DNR's technical consultants, who wrote that 6.5 inches/year "appears to be very low (especially given the uncertainties associated with this methodology)."[146]

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142 Memorandum from Spectrum Engineering to Jennifer Engstrom, Feb. 24, 2012, attached as Exhibit 23.
143 *Id.*
144 Exhibit 7.
145 DNR Dam Safety Review Comments for the NorthMet Project Flotation Tailings Basin Management Plan v. 2, Dec. 2012 (Exhibit 21).
146 See email from Michael Kunz to Michael Liljegren with attached comments from EOR, Oct. 15, 2012, attached as Exhibit 24.

Indeed, given the verbatim language, it appears as though this concern originated with DNR's consultants and was conveyed to PolyMet through DNR staff. For DNR to ignore this concern on the basis that the infiltration rate had been accepted prior to its consultants raising any questions about it, would clearly violate the substantial evidence requirement. This is an issue that goes to the heart of the regulations – DNR is without a basis to determine that this proposal will prevent the movement of substantially all water through mine waster as required by Minn. R 6132.2200 if the assumptions about the rate in which water moves through the tailings pile are significantly understated, as DNR's own consultants have indicated.

1.10 The utilization of the LTV Steel Mining Company (LTVSMC) tailings basin adds to the overall risks of the FTB – the basin was constructed before environmental review laws came into effect, and was built to hold a completely different set of substances.

The reclaimed LTV Steel holding pond that PolyMet is now proposing to turn into the FTB was constructed prior to the enactment of environmental review laws and requirements. In addition to the lack of environmental review, there is an inherent risk present in repurposing something for use for which it was not designed. The original LTVSMC dam was built for a different purpose; it was built to hold different volumes of different materials that interact in different ways with the natural environment and organic compounds. The FTB was not designed for what it is being repurposed for. Throughout the EIS process, it was touted as a more affordable and even efficient alternative because the site would be repurposed –there would be no new disturbance, per se, of the surrounding environment by having to clear land and construct a new tailings basin. The LTVSMC dam has experienced reclamation of sorts, but it still possesses taconite tailings and other waste from LTV Steel's former days.[147] The Mount Polley panel suggests that the BAT approach for both new mines and existing mines is to construct a new tailings basin specifically for the material being mined.[148] Using it as a tailings basin for mining waste that has potentially catastrophic implications for both the natural environment and public health does not meet the requisite burden laid out under state regulations.[149]

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[147] See, e.g. FTB Draft Permit at Attachment H.

[148] Mount Polley Panel Report at 125 (Exhibit 6).

[149] See Minn. Stat. § 103G.315, subd. 3 (requiring that the Commissioner shall grant the permit "[i]f the commissioner concludes that the plans of the applicant are reasonable, practical, and will adequately protect public safety and promote the public welfare . . ."); Minn. R. 6115.0300 (stating that the intent of the regulations is to regulate the construction, operation, maintenance, and transfer of ownership of any dam "in such a manner as to best provide for public health, safety, and welfare."); Minn. R. 6115.0410, subp. 8(D) ("Approval or denial [of the permit] shall be based on the potential hazards to the health, safety, and welfare of the public and the environment including probable future development of the area downstream or upstream. The applicant may be required to take measures to reduce risks, and the commissioner shall furnish information and recommendations to local governments for present and future land use controls to minimize risks to downstream areas. The commissioner shall determine if the proposal is adequate with respect to: The stability of the dam, foundation, abutments, and impoundment under all conditions of construction and operation, including consideration of liquefaction, shear, or seepage failure, overturning, sliding, overstressing and excessive deformation, under all loading conditions including earthquake. This determination must be

1.11 The parallels between the proposed flotation tailings basin and the tailings storage facility at Mount Polley need to be drawn and assessed – there is more at issue than just the slope of the embankments.

The Mount Polley Expert Panel assessed the use of the upstream dam model after the Mount Polley Dam collapse in August of 2014; they came to the conclusion that this model is inherently dangerous and as such should not be used in any new dams.[150] The little credence given to this opinion is addressed by PolyMet as being a very different project, despite overall similarity because of the angle of the proposed slope being more gradual and thus safer for the overall structure. Given the extensive damage resulting from the dam failure at Mount Polley, and the overall similarities described in further detail below, the report conducted by the Panel needs to be given more credence in the assessment of the dam safety permits for which PolyMet has applied. In light of the Mount Polley disaster, only one such catastrophic disaster that has occurred, the opinions of the experts reviewing the breach and its causation must be given ample weight. A conservative approach must be taken in each assessment of the dam safety permits when reviewing the permit and application materials.

One of the first things that the panel of experts note is that upstream dam construction is the least safe way to construct a dam surrounding a tailings basin.[151] This design is often chosen simply because it is the least expensive way to construct and operate a basin of such large stature.[152] The Panel urged in its findings on the breach that cost of construction should not be the determining factor.[153] Environmental destruction and public health risks aside, the remediation costs would almost certainly surpass any initial costs spent on preventative measures, including but not limited to a safer dam design. The Panel urges a BAT analysis in order to ensure security and stability in the dam once the mine begins operating.[154]

PolyMet claims that this FTB dam is much safer than the one that was constructed at Mount Polley mostly because Mount Polley is a mountainous region and the slope was much steeper than the one that is proposed for the FTB at the NorthMet site.[155] There is more at issue than just the slope of the embankments. As stated above, Dr. Chambers notes that the mere design of the dam, notwithstanding slope, is inherently unstable and unsafe.[156] Roughly half of the tailings storage facilities around the world are built in the upstream design, "however upstream dams are more

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based on current, prudent engineering practice, and the degree of conservatism employed must depend on hazards.").

150 Mount Polley Panel Report at 118-133 (Exhibit 6).

151 Chambers Draft Dam Safety Permit Comments at 1 (Exhibit 3).

152 Mount Polley Panel Report at 125 (Exhibit 6).

153 *Id.*

154 *Id.*

155 "Tailings Basin Stability and Environmental Protections", POLYMET MINING, INC. (May 1, 2015), http://polymetmining.com/wp-content/uploads/2015/05/Fact-Sheet-Tailings-Apr-2015-_2_.pdf.

156 Chambers Draft Dam Safety Permit Comments at 1 (Exhibit 3).

susceptible to liquefaction flow events and are solely responsible for all major static liquefaction events."[157] Certainly slope has a role to play in the overall equation of safety and stability, but the prevailing factor is the design itself; all subsequent factors stem from the design.

The primary issue with the slope at Mount Polley was the fact that during construction, the necessary materials to extend the slope outward (making it a more gradual rise) ran out.[158] Thus, a steeper sloped wall was constructed; the intention was for the wall to be temporary, and flattened out at a later date.[159] The mine began operation on time with the wall constructed, the result being a less sturdy wall, and monitoring and construction would be ongoing.[160] The Mount Polley disaster highlights the dangers of ongoing construction and testing that should have been completed in the pre-permit stages, before the mine began operating.

Jim Kuipers notes that when the Expert Panel was formed, they issued a set of recommendations that can be grouped in seven categories:

1. Implement Best Available Practices (BAP) and Best Available Technologies (BAT) using a phased approach,
2. Improve corporate governance,
3. Expand corporate design commitments,
4. Enhance validation of safety and regulation of all phases of a TSF,
5. Strengthen current regulatory operations,
6. Improve professional practice, and
7. Improve dam safety guidelines[161]

He describes the Panel's set of recommendations in each of these categories, and how other groups have responded to them (namely, the British Columbia regulatory revisions, and Montana's Metal Mine Reclamation Act (MMRA), and then how Minnesota's regulations stand in comparison.[162] In almost each circumstance, each of the other jurisdictions adopted many or most of the Panel's recommendations. Minnesota, however, did not adopt these provisions or adopted only part of the recommendations. This is problematic when assessing the safety and stability of a very similar project. This circles back to the importance of implementing very conservative designs, and using conservative data when making calculations or conducting modeling.

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157 Michael Davies et al., Mine Tailings Dams: When Things go Wrong, ASSOC. OF STATE DAM SAFETY OFFICIALS, U.S. COMMITTEE ON LARGE DAMS, 10 (2002), http://www.infomine.com/library/publications/docs/davies2002d.pdf, attached as Exhibit 25.
158 Mount Polley Panel Report at 61 (Exhibit 6).
159 *Id.*
160 *Id.*
161 Kuipers Dam Safety Permit Comments at 12 (Exhibit 2) (referencing the Mount Polley Panel Report).
162 *Id.* at 12-13.

1.12 The integrity of the liner system at the Hydrometallurgical Residue Facility (HRF) is something that has not been adequately addressed at previous junctures – the problematic material, namely old tailings, should be removed down to the bedrock in order to ensure stability.

Throughout the EIS process, comments on the liner of the HRF were continually ignored. Thus, the design for the liner of the HRF has not changed much since these early stages. Of primary concern are the old taconite tailings from LTVSMC, which PolyMet has proposed consolidate with sediments in order to stabilize the material prior to the construction of the dam at the HRF.[163] Dr. Chambers notes that this is an unwise way to approach dam stabilization.

First, he says that the previous tailings can be removed, and placed in the FTB.[164] The other sedimentary layers should also be removed down to the bedrock, which should serve as the foundation for the HRF.[165] If PolyMet were to take this approach, "not only would the subgrade be more stable, nut more room for hydrometallurgical residue would be gained. In the case of the Hydrometallurgical Residue Facility placing the liner on the granite bedrock is possible."[166]

Second, Dr. Chambers states that "safety, not cost" should be the driver in weighing different options for dam liner designs.[167] If bottom liners fail or need to be repaired at any point in time, they almost certainly cannot be fixed without emptying out the basin, which leads to trouble when dealing with mining waste.[168] In other words, it is far more cost effective and safe to ensure safety and stability on the front end.

Furthermore, Dr. Chambers notes that "[a]dequate factors of safety should be guaranteed by installing engineered facilities verified by quality control, when possible – not by modeling."[169] This can be more readily ensured by removing layers down to the bedrock.[170]

1.13 The analyses conducted by Barr Engineering for PolyMet regarding the Hydrometallurgical Residue Facility are inadequate; a full dynamic model needs to be conducted.

1.13.1 Probabilistic Seismic Hazard Analysis is Insufficient

Similar to the Flotation Tailings Basin, PolyMet employed a smaller (and less severe) Probabilistic Seismic Hazard Analysis than some experts recommend. PolyMet employed a 2,475-

163 Residue Management Plan, NorthMet Dam Safety Permit Application: Hydrometallurgical Residue Facility, 10 (May 15, 2017) [hereinafter "HRF Permit Application"].
164 Chambers FEIS Comments at 23 (Exhibit 15).
165 *Id.*
166 *Id.*
167 *Id.*
168 *Id.*
169 *Id.*
170 *Id.*

year return event, as opposed to the Maximum Credible Earthquake (MCE).[171] Dr. Chambers notes that the MCE "should be used for the design event for all permanent structures, both dams and waste rock. The Maximum Credible Earthquake is recommended to be a 10,000-year return period earthquake."[172] Similar to the FTB, the use of a 2,475-year return severely underestimates the potential effect that a significant seismic event could have on a structure like a dam, a tailings basin, or on waste rock itself.

PolyMet notes that "Northern Minnesota is not a highly active seismic zone."[173] The manner in which the risk for future events was calculated was based almost entirely on small, past events – namely the 20 small-to-moderate earthquakes that Minnesota has experienced and recorded[174] - and placed in a seismic risk calculator provided by the United States Geological Survey.[175] This information does not account for the risk of geologic layers moving and changing (see Mount Polley disaster), undiscovered or unrecorded fault lines, or previous fault lines once thought dormant, that have become active or may become active in the future. These are all aspects that engineers need to take into account in order to ensure stability, as dams are built to stand in perpetuity, and can be done so with a 10,000-year seismic event calculation.[176]

The results from PolyMet's own calculations – from the FEIS to the Geotechnical Data Package (Volume 2) – demonstrate the intensity of the acceleration as it increases from a smaller event to a potentially catastrophic event. The FEIS contains the information in Table 6-2: Summary of PSHA Results.[177] For example, a 975-year return event has a maximum acceleration of 0.025g, whereas a 2,475-year return event has a maximum acceleration of 0.055g.[178] This is over twice the size of the 975-year return event, and Dr. Chambers comments that this falls woefully short of demonstrating how a 10,000 year-return event could affect the dam or waste rock; the acceleration for such an event would be "significantly larger",[179] meaning that the impact of the event and subsequent damage would be as well.

Lastly, and arguably most importantly, Dr. Chambers stated the following in his comments: "Even if the legal requirement is only for a 2,745-year return design earthquake, from an engineering standpoint and safety standpoint PolyMet and its consultants should not accept the minimum required. They should do what safety and conservative management requires."[180]

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171 *Id.* at 25.
172 *Id.* at 23.
173 NorthMet Project Geotechnical Data Package, Vol. 2 – Hydrometallurgical Residue Facility, 13 (July 11, 2016) [hereinafter "GDP Vol. 2 - HRF"].
174 *Id.* Minnesota has recorded 20 small-to-moderate earthquakes since 1860.
175 *Id.*
176 Chambers SDEIS Comments at 15 (Exhibit 22); see also Chambers FEIS Comments, supra note 70 at 23 (Exhibit 15).
177 Chambers FEIS Comments at 25 (Exhibit 15).
178 *Id.*
179 *Id.*
180 *Id.*

1.13.2 Dam Break Analysis for the HRF is Inadequate

PolyMet has not shown that the dam as currently proposed is "reasonable, practical, and will adequately protect public safety and promote the public welfare. . ."[181] Simply put, PolyMet has not adequately addressed the possibility of dam failure and what mitigation factors will be implemented should such an event occur. PolyMet, as the dam applicant, has the burden of proving that such a structure is reasonable and practical,[182] and must show that the application itself is based on substantial evidence.[183] The "dam break analysis" that was conducted revealed no plausible scenarios for dam failure were identified.[184] In the Technical Memorandum, PolyMet supplied a few hypotheticals (which were labeled as hypotheticals in the memorandum), as the basis for their conclusion in that further analysis was not necessary. The three-and-a-half page memorandum concluded that the HRF dam failure hypotheticals all have a "low probability" of occurrence, despite being possible, and thus, "[a]dditional hydrologic and hydraulic modeling to detail the extent of inundation from an HRF Dam break is not warranted because no plausible HRF dam failure scenarios have been identified."[185] At no point was a full dynamic model said to have been conducted.[186]

Dr. Chambers identifies this as troublesome, and furthermore inadequate. He states that full dynamic modeling needs to be conducted in order to fully assess and appreciate the potential for a dam breach.[187] By intentionally not conducting a full dynamic modeling analysis and instead listing out a few hypotheticals in the dam break analysis, PolyMet has not met their burden, and a dam safety permit for the HRF should not be issued unless and until it has.

1.13.3 Liquefaction Analysis Has Not Been Completed

Dr. Chambers states that despite the fact that the HRF is proposed to be constructed in the downstream fashion, as opposed to the more fallible upstream design, the prosed construction material, as it stands in the application, is insufficient for stability and requires a more conservative approach in analysis and testing in order to ensure dam stability and safety. Liquefaction analyses were not conducted at either the SDEIS stage or the permit application stage. At each juncture,

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181 Minn. Stat. 103G.315, subd. 3, 6.
182 Minn. Stat. 103G.315, subd. 6.
183 Minn. Stat. 103G.315, subd. 2.
184 HRF Permit Application at 8.
185 HRF Dam Break Analysis, Hydrometallurgical Residue Facility, NorthMet Dam Safety Permit Application, prepared for PolyMet Mining, Inc., BARR ENG'G, Attachment L (May 2017).
186 *Id.*
187 David Chambers, "Comments on the Geotechnical Stability of the Proposed NorthMet Tailings Basin and Hydrometallurgical Residue Facility in light of the Failure of the Mt Polley Tailings Storage Facility", CTR. FOR SCIENCE IN PUB. PARTICIPATION, 4 (Apr. 30, 2015), attached as Exhibit 26.

PolyMet and its engineers stated that it was not applicable and thus was not performed.[188] Despite the changes from the SDEIS stage to the permit application stage, which designate more compact layers for the base of the dam, a liquefaction analysis is still necessary, and is required for the Commissioner's consideration and subsequent approval of any dam safety permit.[189] Furthermore, the updated layers of the base of the dam still include leftover tailings from the LTVSMC era; experts like Dr. Chambers have argued against the inclusion of these layers from the EIS stage of the process because of the lack of stability.[190] This is particularly troublesome because the dewatering calculations conducted on the Drainage Collection System in the HRF do not consider the potential for drainage through the taconite layers.[191] PolyMet concedes that "drawdown may be more rapid than modelled" for the maximum residue depth.[192] The estimated time for drainage to occur is 14 years, or 5,113 days.[193] A more rapid drawdown is surely going to have a heavier impact than calculated given the anticipated 20-year life of the mine.

The recommendation made by Dr. Chambers has been to remove the underlying original ground (still included in the permit application and updated Geotechnical Data Package Vol. 2),[194] peat and silty materials (even if they are "well-compacted"), and the taconite tailings waste, in order to ensure increased stability.[195] These materials should be removed down to the bedrock in order to ensure stability.[196] Ensured stability requires not only material replacement, but full dynamic modelling, including a liquefaction analysis for the HRF.

1.14 The need for independent review

Dr. Chambers and Mr. Kuipers both call for independent review of both the FTB and HRF dams in assessing the overall process. This is the recommendation of the Mount Polley Panel as well.[197] Dr. Chambers states that neither permit "require[s] an Independent Tailings Review Board."[198] Furthermore, Mr. Kuipers notes that "a truly independent review process must be undertaken that includes the participation of additional TSF expertise including nominees from public stakeholders."[199]

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188 NorthMet Mining Project and Land Exchange, Supplemental Draft Environmental Impact Statement, MINN. DEP'T OF NAT. RES., U.S. ARMY CORPS OF ENGRS., U.S. FOREST SERV., 5-575 (Nov. 2013); GDP Vol. 2 - HRF, at 47.
189 Minn. R. 6115.0410, subp. 8(D).
190 Chambers FEIS Comments at 23 (Exhibit 15).
191 GDP Vol. 2 - HRF at 47.
192 *Id*. at 50.
193 *Id*.
194 *Id*. at sec. 6.0.
195 Chambers FEIS Comments at 23 (Exhibit 15).
196 *Id*.
197 Mount Polley Panel Report at 129-130 (Exhibit 6).
198 Chambers Draft Dam Safety Permit Comments at 3-4 (Exhibit 3).
199 *Id*.

1.15 DNR Acknowledges that the FTB and HRF Dams Pose a Long-Term Threat to the Public Health, Safety and Welfare, Even if the Dams Are Effective for the 20-Year Life of the Mine

Over the last few years, the undersigned organizations have made no secret of our view that these proposed dams pose an unreasonable risk to the public. This view, however, is not simply a voice in the wilderness. DNR's own staff and consultants have for years raised alarms about the safety of these proposed dams. The Department has permit conditions available (Best Available Technology for tailings storage as recommended by the Mount Polley Expert Panel) that would alleviate these concerns, and yet it has failed to require alternative designs that would protect the public.

These concerns from DNR staff and consultants run the gamut, and should not be ignored. They include Edie Evarts, DNR's Area Fisheries Supervisor, who expressed her concern that the HRF facility posed a risk to fisheries:

> Fisheries' concern about the Hydrometallurgical Facility (HRF) is because it will hold waste from the metallurgical plant and will be dependent on a liner underneath and a wick drain system. This seems like it would function appropriately during operation of the mine and certainly our engineers and hydrologists have this covered for the review. My concern is about far into the future. How long does such a liner last and what happens when it inevitably degrades as nothing lasts forever? Even if it takes 200 years, the waste will still be there and in its location would be very susceptible to leaching into nearby wetlands and groundwater. [200]

Ms. Evarts' concerns for the long-term impacts of the proposed dams are well-founded, for the Department has been clear that it intends the dams to operate for a minimum of 1000 years.[201]

These concerns, in other words, go straight to the heart of the question of whether these dams as proposed are adequately protective of the public safety, health, and welfare. And those concerns have never been addressed. Despite the DNR's warnings that upstream construction is not a good method "for a dam that is required to last for centuries,"[202] that design element has never changed. Staff's warning was specific to the particularly vulnerable foundation of the proposed dam, clearly indicating what we have indicated here - constructing a slurry impoundment on top of fine tailings slimes is simply not safe:

> It is my understanding that the LTV tailings at depth are already in a semi-liquefied state. I remain concerned that if another 150 feet of tailings are added, and then

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200 Comments of Edie Evarts, DNR Fisheries Supervisor, Dam Safety Permits 2016-1383 and 2016-1380, attached as Exhibit 27.

201 See, e.g., DNR Dam Safety Review Comments on NorthMet Project Flotation Tailings Basin Management Plan v. 2, Dec. 2012 (Exhibit 21) (referring to the "900 year design" of the FTB dam); Dana Dostert, Geotechnical/Geochemical Questions Related to PolyMet Tailings, January 31, 2012 (Exhibit 10).

202 Email of Dana Dostert to Neil Schwanz, Oct. 1, 2010, attached as Exhibit 28.

> experience a major precipitation event such as last week's 14 inches in south central Minnesota, the loading will lead to liquefaction and an embankment failure. With EPA requiring cleanup of any spilled tailings, the cost to Polymet or the State of Minnesota would be in the tens of millions of dollars. Further complicating this issue is the use of upstream construction, which I don't think is a good method for a dam that is required to last for centuries.[203]

But the most serious concerns were raised by DNR's consultant from Spectrum Engineering, Don Sutton, discussed in more detail above. Spectrum, it should be noted, is a mine engineering firm with extensive experience in mine reclamation and remediation, and is therefore quite experienced in the regulation of mines at closure.[204] DNR obviously recognized this expertise when it retained Spectrum's services. In writing Dana Dostert, DNR's Senior Dam Safety Engineer, Mr. Sutton wrote that he shared Ms. Dostert's concerns with wet closure, but had additional concerns of his own "relating to the long term tailings wet closure uncertainties and risks."[205] Mr. Sutton believes that the bentonite amendment proposal is a 'hail mary,' and that if bentonite amendment doesn't work and perpetual water treatment is necessary, "why not investigate some dry closure options and compare the long term O&M costs and long term risks of each alternative?"[206] Although "PolyMet's reclamation plan could work for a while," he argued that he doesn't see "how it will function forever without falling apart unless it is continuously maintained; which is a major leap of faith."[207]

2.0 If Permitted, the Commissioner Should Require Dry Stack Tailings as a Permit Condition Or, At a Minimum, Drained, Compacted Tailings at Closure

As noted above, Minnesota law does not define the concept of "current, prudent engineering practice." But the law is clear that the state may not permit an impoundment of water for copper-nickel mining if an environmentally preferable alternative is feasible, prudent and reasonably available.[208] Such a permit may also be permitted only if the Department determines that the impoundment "will not substantially impair the interests of the public in lands or waters or the substantial beneficial public use of lands or waters except as expressly authorized in the permit and will not endanger public health or safety."[209] As we describe in Section 1.0 above, the environmental benefits of dry stack tailings are stark: the process eliminates the need for perpetual water treatment and it eliminates the risk of catastrophic tailings dam failures that would inundate local rivers, streams and residences with acidic mine waste. Not only is dry stacking therefore the best available technology for tailings storage, thus constituting the current, prudent engineering practice on which the dam safety must be based, it is also an environmentally preferable alternative that would render the draft permits unlawful under Minn. Stat. 116D.04, subd. 6 and 103G.297, subd. 3. As state law

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203 *Id.*
204 See Resume of Don Sutton, Spectrum Engineering, attached as Exhibit 29.
205 Email of Don Sutton to Dana Dostert (Exhibit 11).
206 *Id.*
207 *Id.*
208 Minn. Stat. § 103G.297, subd. 3; § 116D.04, subd. 6.
209 Minn. Stat. § 103G.297, subd. 3(2).

provides, "economic considerations alone shall not justify" the issuance of a permit that significantly affects the quality of the environment when there is a "feasible and prudent alternative."[210]

DNR's consultants were clear on this question: dry closures are the preferable alternative. Spectrum Engineering wrote to DNR's Dam Safety Engineers that:

> If seepage collection or treatment is or might be necessary for an indefinite time with a wet closure, then what is the benefit of wet closure? The wet closure is riskier, has more uncertainties, and may be more expensive because it will require more perpetual care and maintenance than a dry closure. I suggest that PolyMet investigate some alternatives . . . I don't like wet closure, because it is not a permanent closure. I believe it will eventually fail and release the sulfates.[211]

In an earlier email to DNR staff, Spectrum was unequivocal: wet closures are cheaper but riskier:

> PolyMet is proposing to build the tailings disposal system that has the lowest initial cost, but has more long term risks than other tailings disposal methods. There is risk associated with perching a lake full of saturated tailings on top of the existing tailings. It is difficult to quantify the probability of failure over a long time frame, but I think you can consider the consequences of failure and estimate the cost of cleaning up the failure, and then add the cost of operating the repaired facility forever. This cost can be compared to the additional cost of building a more stable facility initially.[212]

These conclusions of the technical consultants hired by DNR establish three critical things. They establish that wet closures of the kind proposed by PolyMet do not constitute the current, prudent environmental practice for mine design, which would prohibit the issuance of the permits as drafted.[213] They also establish that wet closures cannot be permitted unless the applicant has demonstrated that dry stacking is not feasible, prudent or reasonably available,[214] a demonstration that has not even been attempted, let alone made. And lastly, they establish that a known risk to the public health, safety and welfare may not be permitted solely because it is cheaper than mitigating that risk at the outset through safer tailings storage.[215]

Perhaps most importantly, all of these issues were expressly considered during the drafting of Minnesota's non-ferrous mining regulations, which effectively prohibit wet closures. Dry-stacking is therefore an alternative made reasonable by virtue of the fact that it is the only way that this mine can comply with Minnesota law. This rule states:

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210 Minn. Stat. § 116D.04, subd. 6.
211 Email of Don Sutton to Dana Dostert (Exhibit 11).
212 Email of Don Sutton to Jennifer Engstrom, June 15, 2011, attached as Exhibit 30.
213 Minn. R. 6115.0410, subp. 8(F).
214 Minn. Stat. § 103G.297, subd. 3; § 116D.04, subd. 6; Minn. R. 6115.0410, subp. 8.
215 Minn. Stat. § 103G.297, subd. 3; § 116D.04, subd. 6.

> B. A reactive mine waste storage facility must be designed by professional engineers registered in Minnesota proficient in the design, construction, operation, and reclamation of facilities for the storage of reactive mine waste, to either:
> (1) modify the physical or chemical characteristics of the mine waste, or store it in an environment, such that the waste is no longer reactive; or
> (2) during construction to the extent practicable, and at closure, permanently prevent substantially all water from moving through or over the mine waste and provide for the collection and disposal of any remaining residual waters that drain from the mine waste in compliance with federal and state standards.

Mine waste includes tailings. "Reactive mine waste" is defined as waste "that is shown through characterization studies to release substances that adversely impact natural resources." In other words, "reactive waste" is not limited to waste that creates acidic conditions. Heavy metals can leach from rock under many conditions, some of which do not involve a low pH; whenever those conditions result in a great enough release of metals to adversely affect natural resources, the rock is deemed "reactive." Thus the PolyMet tailings will be "reactive" even if they do not result in acid drainage, because they have been characterized (by PolyMet's modeling) to release (at a minimum) copper, nickel, lead, and arsenic at levels far above surface and/or groundwater quality standards.

Rule 6132.2200(2)(B) provides two possible means of handling reactive mine waste after closure. Either the waste rock, tailings, and exposed rock must be left in such a way that they are not "reactive" (i.e., they no longer leach heavy metals), or the facilities must be closed in a way that "permanently prevent[s] substantially all water from moving through or over" them. Taken together, the import of the regulations is that nonferrous mine waste and mine pits must be closed in a way that does not result in a significant amount of water that will have to be treated before it can be discharged to the environment.

The Statement of Need and Reasonableness for this rule makes it clear that the point of Rule 6132.2200(2)(B) was to preclude perpetual or long term water treatment as a closure option:

> [M]erely collecting contact water and treating it in order to meet water quality discharge standards, without a substantial effort to minimize the amount of water contacting the waste, has been rejected. While this method may provide acceptable results during active operations, when the permittee is present, the potential for long-term failure of such a system, when the operator is no longer available to correct the situation, is too great. Because of the necessity to provide a permanent solution to the water quality concerns related to reactive mine wastes, the two required methods of storing these wastes are the only reasonable methods currently available.[216]

The current plan for the tailings basin allows the tailings to remain reactive and allows a significant amount of water to move through the tailings. As noted above, the long-term infiltration rate is 6.5

[216] Rule 6132 Statement of Need and Reasonableness at 22, attached as Exhibit 31.

inches per year, or roughly 25% of annual precipitation (see section 1.8). And our consultants, DNR's consultants, and DNR's staff have all raised a concern that 6.5 inches per years seem very low, but this concern has never been addressed. It cannot be said that this mine proposal will prevent "substantially all" water from moving through the tailings if the company's own estimate, which the Department believes to be very low, is 25% of annual precipitation.[217]

The dam design thus does not meet the regulatory requirements. As Dr. Malusis concludes, "dry closure would be a much better approach for meeting the intent of Part 6132.2200 Subpart B(2)." This preference for dry closure is the same conclusion reached by Don Sutton, DNR's technical consultant from Spectrum Engineering, and Dana Dostert, the Senior Dam Safety Engineer for DNR (see section 1.15). The Department must accordingly require dry stacked and compacted tailings as the only suggested alternative that might meet the requirements of state law.

Dry stacking is also required by regulations directed specifically at Class I dams, such as the FTB dam in permit 2016-1380. Rule 6115.0410, subp. 8 requires the Commissioner to make a determination that the applicant has demonstrated "a lack of other suitable feasible and practical alternative sites, and economic hardship which would have a major adverse effect on population and socioeconomic base of the area affected." In other words, before dry stacked tailings may be lawfully rejected as an alternative to conventional slurry impoundments, the applicant must prove that dry stacking would impose such a severe economic hardship that it would adversely affect the area. No such showing has ever been attempted, and the Department is therefore prohibited by law from issuing the permits as drafted.

3.0 The Draft Permits Abdicate Critical Regulatory Responsibilities to a Later Date, Placing the Public's Safety and Welfare at Risk and Violating State Laws and Regulations

DNR's consultants addressed the issue identified by our consultants, namely, that building a new tailings facility directly on top of an older facility is not an engineering best practice. In its review, DNR's expert review team noted that the proposed dam will be built on top of the pre-existing tailings dam, which was constructed partially on top of peat layers. The existing dam itself was also built with layers of taconite slimes. Both the peat and the slimes have very low shear strength, "which could potentially contribute to a dam failure."[218] The review team concluded that the proposed dam could be designed to mitigate the risks of failure posed by the peat and slimes, but that to do so, the "areas with peat and slimes must be well-defined and tested . . . additional data should be gathered on the peat layers and slime layers."[219]

Presumably in response to these concerns, the draft permits state that construction may not commence until DNR has approved "additional strength and permeability testing of existing fine

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217 Michael Malusis, Comments on Draft Dam Safety Permits, attached as Exhibit 4; NorthMet Project Adaptive Water Management Plan, Barr Eng'g, v. 10, 92 (July 11, 2016).
218 Memorandum from EOR, PolyMet Dam Safety Permit Application Review, 3 (May 15, 2017).
219 *Id.*

tailings and bulk tailings in the tailings basin to confirm that the material properties used in the various seepage and stability models in the Flotation Tailings Basin Geotechnical data Package are still applicable."[220] In short, DNR's consultants have notified it that certain features of the dam proposed for permitting may "contribute to a dam failure," but the draft permit does not contain any conditions which might alleviate that risk. Instead, the permit simply kicks that can down the road, and says only that additional approvals of dam stability data are required before construction may begin.

But Minnesota law does not allow permit authorizations to be sequentialized in this way. The Rules require approval or denial of "final" designs.[221] That final design "shall include . . . analytical determinations, such as seepage and underseepage studies, stability, deformation and settlement analysis; analytical and design details of facilities, such as dam, foundation, impoundment, [or] abutments."[222] The rules do allow for alterations of the approved designs, but they do not contemplate the sort of piecemeal permitting approach that the Department has taken here. There is a great deal of difference between approving final designs and modifying them if it becomes necessary, and approving only the mere concept of a tailings dam and allowing critical components of its design to be approved at a later date. Not only does this approach circumvent the permitting regulations, it effectively insulates key aspects of the project from public review and comment, in violation of open governance laws.[223]

The project designs for which the Department's approval is deferred to a later time are not trivial or incidental aspects of the project. They are in fact the essence of the proposal, and the primary determinants in whether the project is done responsibly or whether it results in an environmental and financial burden on future generations. DNR's consultants concluded that the foundation of the buttress, for instance, must be investigated further to determine whether it is a suitable and stable foundation for the tailings dam.[224] But this buttress design is not approved by the draft permits. DNR's consultants also described the bentonite amendment plan as a "hail mary," but the bentonite amendment testing is not approved by the draft permits. They have also concluded that the existence of taconite slimes in the pre-existing tailings dam could pose a risk of dam failure, but rather than address that concern the draft permits require only that further materials testing be done.[225] The results of those tests, and the implications that they might have for future dam stability, will not be available for public comment. The list does not end there. The draft permits also defer

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220 Draft Dam Safety Permit No. 2016-1380, Permit Condition No. 29.
221 Minn. R. 6115.0410, subp. 6.
222 Minn. R. 6115.0410, subp. 6.
223 See, e.g. Minn. Stat. § 14.001 ("The purposes of the Administrative Procedure Act are: (1) to provide oversight of powers and duties delegated to administrative agencies; (2) to increase public accountability of administrative agencies; (3) to ensure a uniform minimum procedure; (4) to increase public access to governmental information; (5) to increase public participation in the formulation of administrative rules; (6) to increase the fairness of agencies in their conduct of contested case proceedings; and (7) to simplify the process of judicial review of agency action as well as increase its ease and availability.").
224 Technical Review Team Comments on PolyMet Dam Safety Permit Application Review, May 15, 2017, at 4.
225 *Id.* at 3.

approval of the water management plan, the contingency action plan, and the operation and maintenance plan.[226]

The deferred approvals, therefore, are absolutely essential components of the project's design, and critical determinants of the project's impact on the environment and public safety. When the Mount Polley disaster occurred, the investigation concluded that the "dominant contribution to the failure resides in the design."[227] And yet, despite this clear lesson from past mine failures, the draft permits for the tailings basin and HRF dams do not contain any conditions whatsoever concerning the buttress design, water management, materials strength testing, bentonite testing, contingency action plan, or the operations and maintenance plan. To be clear: the Mount Polley panel found that foundation investigations failed to identify a particularly vulnerable layer that was susceptible to undrained failure. Here, DNR's consultants have identified similar concerns with the foundation of the flotation tailings basin dam, and yet the draft permit contains no approvals or conditions concerning the foundation of the buttress. The draft permits are a shell, and the design details required by law are simply missing.

As noted above, Minnesota law does not allow for this kind of piecemeal sequencing of permit approvals. But they go further than that. Minnesota Statute § 103G.315, subd. 6 states that the applicant has the burden of proving that the proposed project is reasonable, practical, and will adequately protect public safety and promote the public welfare." The Commissioner's decision on the application "must be based upon findings of fact made on substantial evidence."[228] Minnesota Statute § 103G.297, subd. 3 is just as clear: a permit for the control of waters of the state for mining copper-nickel ore "may be granted only if the commissioner determines that" the proposal "will not endanger public health or safety."[229] It is impossible and therefore unlawful for the Commissioner to issue the dam safety permits as drafted, when critical design details and approvals are missing from the permits. The applicant cannot meet its burden of proving the project is reasonable and safe when the permit itself states that further data on the strength of the materials used in the dam must be gathered, or that the efficacy of the bentonite cover (which is itself a regulatory requirement of Minn. R. 6132.2200, subp. 2(B)(2)) must be proved at some later date. Similarly, the Commissioner cannot determine on the basis of substantial evidence that the dam proposal is adequate with respect to stability of the foundation and abutments[230] when the permit expressly states that the very design of the foundation and abutments remains to be seen, once further investigations are completed.[231] Such a sequential, piecemeal approach is simply not allowed by law.

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226 Draft Dam Safety Permit No. 2016-1380, Permit Condition Nos. 28, 32, and 33.
227 Mount Polley Panel Report, supra note 13, at iv (Exhibit 6).
228 Minn. Stat. § 103G.315, subd. 2.
229 See also Minn. Stat. § 103G.315, subd. 3 ("If the commissioner concludes that the plans of the applicant are reasonable, practical, and will adequately protect public safety and promote the public welfare, the commissioner shall grant the permit.").
230 See Minn. R. 6115.0410, subp. 8(D).
231 Draft Dam Safety Permit No. 2016-1380, Permit Condition No. 30.

But this deferral of regulatory responsibility is not only unlawful, it is unsound policy. The U.S. and Canada have a long regulatory record to draw lessons from, and the pattern of that history is one of regulatory pullback during times of low commodity prices. In periods of low prices, between 30% and 52% of all copper mines become inactive.[232] These are the economically marginal mines that cannot produce sufficient revenue except in boom times, and historically regulators will not enforce permit controls at marginal mines:

> It is generally recognized within the industry that a widespread "cleansing" is both needed and well underway post supercycle metals price peak in 2011. Regulators meanwhile continue to avoid enforcement and duck corrections at these marginal mines hoping for a return of prices that will allow problems to be addressed out of mine revenues that are not likely to ever come again. They fear that enforcement actions may trigger bankruptcy, as occurred at the short-lived re-opening of the Yellow Giant Mine.[233]

But the pattern of cycling marginal mine operations from active to inactive with commodity boom-bust cycles is the very cause of the "trend to ever increasing severity and frequency of catastrophic tailings storage facility failures."[234] Indeed, Mount Polley itself was one of those marginal mines, having reopened in 2005 after a four year period of inactivity.[235] In other words, it is the financial vulnerability of the mines itself that underlies the proximate cause of tailings dam failures. The final precipitating event – the seismic, structural, or hydrological catalyst – is but the final event in a chain beginning with the mine's fragile and marginal economics.

> Overall the association derives from one of the global fundamentals of metallic mining:
>
> Over the past 100 years, the key dynamic of metallic mining globally for all metals has been declining grades and declining prices punctuated by a few short term supercycles. As grades fell across all metals for discoveries, reserves and head grades, economic feasibility and the possibility of profit has turned mainly on the economics of ore production made possible through open-pit mining.[236]

As ore grades and prices have declined over time, the increasing quantities of tailings has interacted with increasingly narrow profit margins to produce mines that effectively need to cut corners in order to make money.[237] Not surprisingly, these cut corners on marginal projects, during a time period when mine waste quantities have been increasingly exponentially, have produced an alarming rise in serious tailings failures, see Figure 1 below.

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232 Bowker and Chambers 2017 (Exhibit 13).
233 *Id.* at 8.
234 *Id.*
235 *Id.*
236 *Id.* at 9.
237 *Id.*

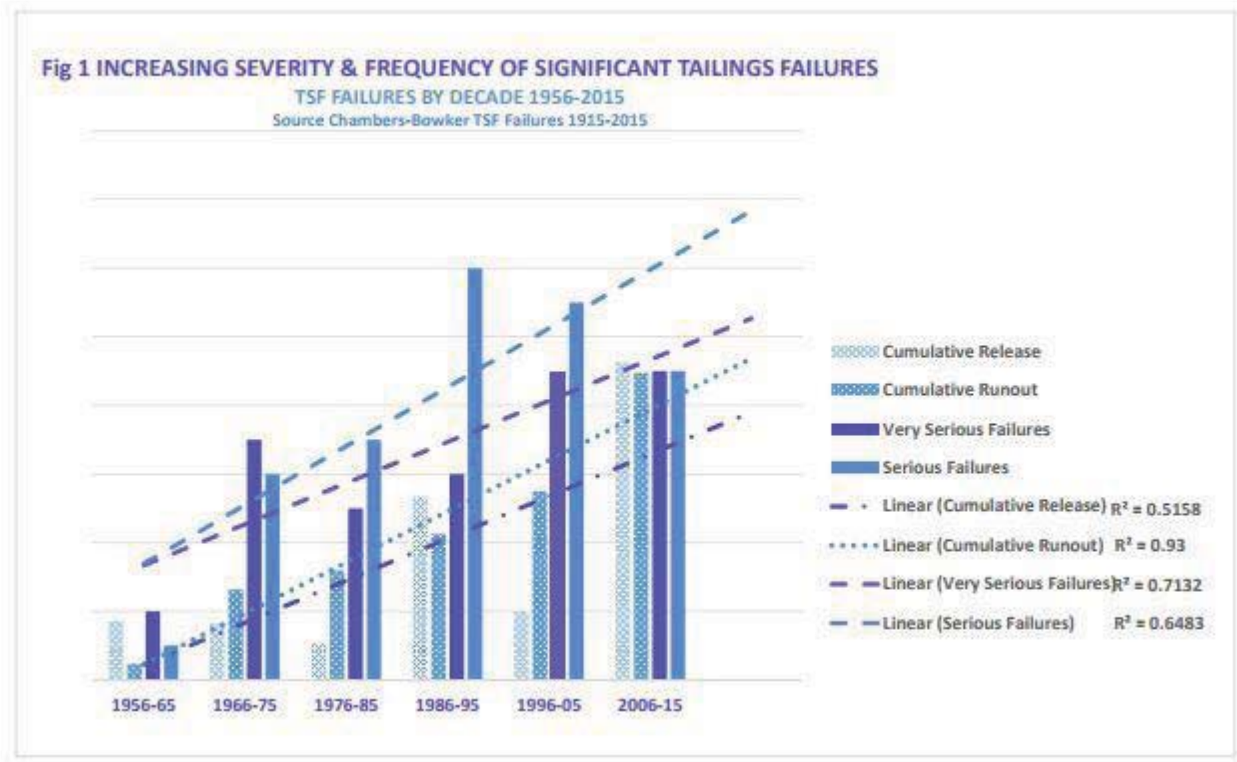

Figure 1 from Bowker & Chambers 2017.

But this relationship goes beyond a broad association. It is also possible to identify mine-level characteristics that are likely indicators of tailings dam failure risk. The volume of ore production and the grade of the copper ore at particular mines is a very strong predictor of serious and very serious tailings failures.[238] The ore grade is particularly predictive of physical problems manifesting at tailings facilities:

> A grade advantage is a critical determinant of ability to survive serious technical flubs. As a norm for all metals, this means that smaller, lower grade mines will suffer more and have more physical manifestations of their economic stress than larger, higher grade mines. Very simply, smaller, lower grade mines operated by junior and midsize miners have less cushion. They have to ride too close to the edge of financial viability viz. global metals markets and major producers to try to stay in production. They also have less access to high quality capital markets, paying more and operating under more onerous terms of credit than the top producers.[239]

These data suggest that tailings failures are a direct function of ore grade, a conclusion that has obvious significance for the Northmet mine project. The "key backstory at Mt. Polley," for example, was one of economic feasibility continually challenged by "poor vetting, shoestring

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[238] *Id.* at 9-10.
[239] *Id.* at 13.

economics and production schedules ahead of safety."[240] The life of mine average copper grade for Mount Polley was 0.38, less than what was expected and far less than the global average of 0.70.[241] The expected ore grade for the NorthMet project is 0.28%.[242]

In the briefest form possible, the point is this: global trends in copper mining show declining ore grades, increasing quantities of mine waste, and narrowing profit margins that put most mines on the knife edge of economic viability. These trends have caused a corresponding increase in serious tailings dam failures such as the Mount Polley and Samarco disasters, as mine operators have increasing difficulty meeting unforeseen technical challenges and adapting to changing circumstances at the tailings site. But amidst these worrying trends, Minnesota stands on the verge of permitting its very first copper-nickel mine, and in permitting one of the most critical safety features of the mine – the tailings and HRF dams – it has noticed a draft permit that fails to include any approvals or permit conditions concerning water management, additional materials testing to establish stability of the dams, the design of the buttress, the contingency action plan, operation and maintenance plan, or the proposal to cap the tailings dam with bentonite. It would also allow the operation of an impoundment to contain slurry mine waste in perpetuity. This approach to permitting invites disaster:

> There is a clear consensus among the world's top mining analysts that we have crossed the threshold into a new and as yet unclear era of mining. If it is understood at all, the industry, its regulators and even its key investment analysts have not publicly recognized that present discovery and as milled grades have reached levels that are beyond presently known technology that had previously worked to create economic viability for low grade large scale mines. No regulatory agency known to us has recognized the need to reexamine the large scale low grade mining projects like KSM, Pebble, and Polymet that were originated in the frenzy of the supercycle on assumptions that were never proven in the first instance, and which are very clearly no longer true. No regulatory agency known to us has recognized that the supercycle was a time of pushing marginal mines and their existing infrastructure beyond design capacity and that, as at Mt. Polley and Samarco, those are practices in which failure incubates and matures.[243]

We respectfully urge the DNR to decline to follow that well-trod path and to take actions to protect the public, now and in the future, by modifying the draft permits to require dry stack tailings or to otherwise deny those permits.

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240 *Id.*
241 *Id.* at 14.
242 Updated NI-43-101 Technical Report on the NorthMet Deposit, Minnesota, USA, AGP Mining Consultants Inc., at 25-3 (Jan. 14, 2013), attached as Exhibit 32.
243 Bowker & Chambers 2017 at 17 (Exhibit 13).

4.0 Contested case request

Minnesota law allows the DNR the discretion to order a Chapter 14 contested case proceeding for dam safety permits. Minnesota Statute § 103G.311 states that a hearing must be conducted unless waived on application.[244] We respectfully submit that the legal and factual issues raised in these comments warrant the DNR's exercise of discretion to order a contested case hearing pursuant to its statutory authority.

Because the legal and factual issues raised in these comments are so intertwined with issues covered in separate permits, however, we also suggest that efficient use of stakeholder resources would require at a minimum that the same fact-finder oversee contested cases on the dam safety permits and the permit to mine. As but one example, as noted above, the most significant predictors of tailings dam failures are econometric. In short, economically marginal mines, with higher volumes of ore production and lower grades of ore, are much more likely to suffer tailings failures. This pattern "suggests a significant public interest in giving independent authoritatively verified economic feasibility a specific and prominent place in mine and mine expansion approval, and in life-of-mine and life-of-facility regulatory oversight."[245] This poses a conundrum for the DNR in this matter. One of the key determinants of whether these proposed dams can operate safely and protect the public health and welfare is a feature of the mine plan that is addressed in a separate permit proceeding – the permit to mine. It is in the permit to mine that financial assurance is determined, hopefully based on updated economic feasibility studies that will specify whether this is a financially marginal project that is more likely to fail, or whether it is a financially robust project that can survive technical difficulties and price fluctuations.[246] Accordingly, we respectfully request that the Department exercise its discretion to order a contested case hearing for the dam safety permits, and that the legal and factual issues common to multiple permits (such as the dam safety permits and the permit to mine) be decided by the same fact-finder.

5.0 Contents of the Record

MCEA submitted a Data Practices Act request to obtain the administrative record for the dam safety permits noticed for comment. We received Phase 1 production of that record on September 27, 2017, and Phase 2 production on October 12, 2017. Our review of that record is currently ongoing, but will not be complete prior to the end of the comment period on October 16, 2017. Accordingly, we incorporate by reference the contents of the Department's response to that data practices act request to ensure it is made part of the administrative record for the Department's dam safety permit decisions. Because these documents originated with the DNR, they are before the Department and available to it. However, if you require a hard copy of those records to ensure they are made part of the record for this matter, please let us know and we will provide it to you.

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244 Minn. Stat. § 103G.311, subd. 1, 4.
245 Bowker & Chambers 2017 at 12 (Exhibit 13).
246 *Id.* at 12.

6.0 Conclusion

For the foregoing reasons, the undersigned organizations respectfully request that you deny the permits, or, in the alternative, issue a permit containing a condition that requires a tailings storage design that reflects the Best Available Technologies recommended by the Mount Polley Expert Review Panel, including the elimination of surface water from the impoundment, the promotion of unsaturated conditions in the tailings with drainage provisions, and the achievement of dilatant conditions throughout the tailings deposit by compaction. Failing either of those options, we urge you to adopt the recommendations of Mr. Kuipers, who argues that a managed risk approach proposed by the company must be approved only after receiving the informed consent of those people whose lives and livelihoods would be impacted by a failure of either of the proposed impoundments.

Thank your for your consideration of these important matters.

Kevin P. Lee
Senior Staff Attorney
Minnesota Center for Environmental Advocacy
26 E. Exchange St., Suite 206
St. Paul, MN 55101
klee@mncenter.org

Marc Fink
Senior Attorney
Center for Biological Diversity
209 East 7th St
Duluth, MN 55805
mfink@biologicaldiversity.org
218-464-0539

Lori Andresen
President
Save Our Sky Blue Waters
P.O. Box 3661
Duluth, MN 55803
andres01@charter.net
218-340-2451

Jane Reyer
Advocacy Director
Friends of the Boundary Waters Wilderness
401 N. Third St., Suite 290

Minneapolis, MN 55401-1475
jane@friends-bwca.org

Margaret Levin
State Director
Sierra Club North Star Chapter
2327 E. Franklin Ave., Suite 1
Minneapolis, MN 55406

LeRoger Lind
President
Save Lake Superior Association
P.O. Box 101
Two Harbors, MN 55616
llind@yahoo.com
218-834-6137

Bob Tammen
President, Wetlands Action Group
23 6th Ave.
Soudan, MN 55782
bobtammen@frontiernet.net

Duluth for Clean Water
11 E. Superior Street, Suite 563
Duluth, Minnesota, 55802
(218) 464-4203
duluthforcleanwater@gmail.com

John Crampton
President
Minnesota Division Izaak Walton League of America
2233 University Ave. W., Ste. 339
St. Paul, MN 55114
651-221-0215
ikes@minnesotaikes.org

Friends of the Cloquet Valley State Forest
P.O. Box 3674
Duluth, MN 55803
Friendscvsf.org

CENTER for SCIENCE in PUBLIC PARTICIPATION
224 North Church Avenue, Bozeman, MT 59715
Phone (406) 585-9854 / Fax (406) 585-2260 / web: www.csp2.org / e-mail: csp2@csp2.org
"Technical Support for Grassroots Public Interest Groups"

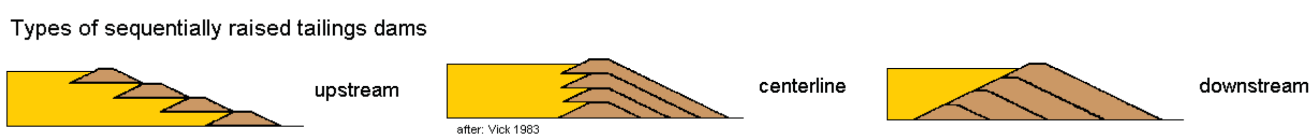
February 23, 2018

Re: PolyMet Mining, Permit to Mine Application, NorthMet Project, December 2017

A. Comments on the Flotation Tailings Basin

1. The permit allows upstream-type construction to continue.

Safety should be the prime consideration in the design, construction, operation, and closure of a dam, whether this be a water supply reservoir or a tailings dam. However, unlike water supply reservoir dams, which are typically of concrete arch-type or downstream-type construction, tailings dams can use centerline-type and upstream-type construction, each of which is inherently less safe than downstream-type dam construction.



As can be seen from the illustrations, upstream-type dam construction uses the tailings themselves for support for most of dam construction stages. Centerline and downstream-type construction, even though also built in stages like upstream, depend only on materials that are sized, placed, compacted, and subsequently tested for support of the sequential stages. When tailings are hydraulically spigotted into the impoundment, their placement and particle size distribution are not uniform. There is no practical way to test the characteristics of the tailings material at a sampling interval sufficient to assure that it is subsequently drained of excess water after hydraulic placement, and that it has the consistency and density assumed by the design modeling.

This lack of control of the underlying tailings introduces a level of uncertainty into upstream-type construction that does not exist with centerline and downstream-type dam construction. This does not mean that upstream-type dams cannot be safely designed and constructed, but it does mean there is more risk inherent in the upstream approach. Moreover, upstream-type tailings dam construction has proven to be the most risky and problematic type of dam construction.

The only reason to use upstream construction, over more conventional centerline or downstream-type approaches, is to save money. At best, it might be argued that safety and cost carry equal weight in tailings dam considerations, but today for most design, operation, and closure tailings dam considerations cost carries more weight than safety. The impoundment proposed by PolyMet is a good example of this imbalance.

The Mt Polley Expert Panel, which was convened by the Province of British Columbia after the Mt Polley tailings dam failure, was asked to analyze the failure mechanisms at Mt Polley and to make recommendations on preventing such failures in the future.

The Panel noted:

> *"Mount Polley illustrates that dam safety guidelines intended to be protective of public safety, environmental and cultural values cannot presume that the designer will act correctly in every case."* (Expert Panel 2015, p. 133)

In tailings dam accidents we do not see a preponderance of one or two failure causes dominating. What we see is that the number and distribution of failure type is remarkably similar. That is, overtopping, seismic failure, foundation issues, internal seepage, slope instability, and structural failure all have similar number-of-failure profiles for both active and inactive tailings dam failures (Bowker & Chambers 2016). This strongly suggests there is something more fundamental than the inability to deal with the causes of one or two failure types. It suggests we have failed to recognize and address something that is affecting all of these failure types. I suggest one fundamental problem is that safety is not being given clear priority over cost in the design, construction, operation, and closure of tailings dams. This affects not only the design of tailings dams, where cost plays a dominant role, but also operational management of dams, where there is too much incentive to cut corners when times get tough. Because of these factors, we are not seeing a decrease in the rate of failures for catastrophic tailings dam failures (Bowker & Chambers 2016).

The tailings dams at NorthMet could be built using a centerline-type construction with cycloned tailings. Finger drains beneath the impoundment would aid in draining the tailings post-closure. This approach would provide a much safer design than the upstream-type construction presently proposed.

2. **Closure cover requirement.**

Minnesota Administrative Rule 6132.2200, Reactive Mine Waste, requires:

"*for the storage of reactive mine waste, to either:*

(1) *modify the physical or chemical characteristics of the mine waste, or store it in an environment, such that the waste is no longer reactive; or*

(2) *during construction to the extent practicable, and at closure, permanently prevent substantially all water from moving through or over the mine waste and provide for the collection and disposal of any remaining residual waters that drain from the mine waste in compliance with federal and state standards.*"

Minnesota Administrative Rule 6132.0100, Definitions, delineates *"Reactive mine waste"* as "*waste that is shown through characterization studies to release substances that adversely impact natural resources.*"

Because sulfate release potentially affects wild rice in this area, it is a contaminant that 'adversely impacts natural resources.' The flotation rougher tailings contain enough residual sulfide minerals to continue to produce sulfate for the foreseeable future. Even if these sulfides do not cause widespread acidic conditions in the FTB, localized metal release could occur, and at a minimum the tailings will continue to produce sulfate.

Since the waste is still physically and chemically 'reactive', part (2) of the rule requires that the operator must "*… permanently prevent substantially all water from moving through or over the mine waste…*"

PolyMet plans to amend the surface of the tailings dams (sides of the impoundment) and the top of the closed facility. According to the revised permit application, "*... the bentonite layer will limit oxygen infiltration into the contained Flotation Tailings. The amendment will also reduce rainwater infiltration into the dams, which has a benefit in terms of increased slope stability safety factor*." In addition, "*The bentonite amendment will entail addition of granulated bentonite (approximately 3% by dry weight) to an*

18-inch thick layer of the dam construction material, overlain by an additional 30-inch layer of dam construction material." (PolyMet 2017, p. 271)

A pond/lake will remain on top of the liner. This water is not necessary to prevent acid generation. It is not necessary to maintain the oxygen barrier at this facility, although in other closure designs saturation of the bentonite/clay layer is required to prevent oxygen penetration. If it were necessary at NorthMet, then the barrier would not be effective on the sides of the dam/impoundment, or on the beach areas that will remain exposed.

It is not clear what the allowable conductivity of the FTB bentonite-enhanced liner will be, or whether the liner effectiveness has been verified under dry conditions.

> "*The Permittee must prepare a bentonite amendment of tailings pond liner workplan for DNR review and approval no later than 90 days following permit issuance. The workplan must include any bench or field scale work, sampling, and analyses necessary to demonstrate to the DNR that the tailings amendment with bentonite for the pond bottom will perform as intended to meet all applicable standards, statutes and regulations to be protective of natural resources, and function in perpetuity.*" (MDNR 2018, p. 11)

By leaving final design considerations until after the permit is issued, there is a real possibility the final design parameters and configurations will be driven by considerations for " ... *to the extent practicable* …", rather than "… *permanently prevent substantially all water from moving through or over the mine waste* …" (Rule 6132.2200)

3. The permit will allow water to be permanently impounded.

One of the key recommendations of the Mt Polley Expert Panel is:

> *"The goal of BAT (*Best Available Technology*) for tailings management is to assure physical stability of the tailings deposit. This is achieved by preventing release of impoundment contents, independent of the integrity of any containment structures. In accomplishing this objective, BAT has three components that derive from first principles of soil mechanics:*
>
> *1. Eliminate surface water from the impoundment.*
>
> *2. Promote unsaturated conditions in the tailings with drainage provisions.*
>
> *3. Achieve dilatant conditions throughout the tailings deposit by compaction."*
>
> (Expert Panel 2015, p. 121)

By allowing water to pond on the tailings post-closure, the tailings facility proposed by PolyMet violates all of the recommendations listed above.

The danger is leaving water on top of the tailings is two-fold. First, water means partial or full saturation of the tailings below. If the tailings are saturated, they have essentially no weight-bearing capacity under seismic loading. This means that any structure built on top of saturated tailings, like an upstream-type tailings dam, is susceptible to failure under seismic shaking. The permit requires further testing of the in-place tailings to confirm assumptions used in the modeling upstream dam safety calculations. However, at best, these are only interrupted samples, as opposed to an engineered structure that is required of downstream-type and centerline-type dams. It is too expensive to sample on a density that would truly provide enough data to prove that the model assumptions are accurate. In addition, if the sampling shows that the modeling assumptions are incorrect, from a cost and technical perspective it is probably too late to mitigate these issues with post-deposit drains or rock buttresses.

Second, water remaining on and in the tailings acts as a deadly mobilizing agent should a catastrophic failure occur. Dry tailings can be mobilized if support is removed, but the distance they will move is orders of magnitude less than tailings saturated with water. The Mt Polley Expert Panel recognized this by remarking:

> *"Mount Polley failure shows why physical stability must remain foremost and cannot be compromised. ... No method for achieving chemical stability can succeed without first ensuring physical stability: chemical stability requires above all else that the tailings stay in one place."* (Expert Panel 2015, p. 124)

4. **The permit does not specify dam hazard classification.**

The permit specifies:

> *"The Permittee understands the hazard classification of this dam could change ..."* (MDNR 2017, p. 4)

Not only do we not know the hazard classification being assigned to the tailings dam, but the wording also suggests that the anticipated hazard classification is either starting with something less than the highest risk (Class I), or that an initial Class I designation could be lowered in the future.

Because of the size of this dam, and environmental and economic destruction it could cause if it failed catastrophically, it should be designated as a Class I classification.

5. **The earthquake used for seismic design is inadequate.**

a. The Probabilistic Seismic Hazard Analysis (PolyMet 2011) considers the 2,475-year return seismic event to be the largest earthquake the dam will experience. This is not the largest seismic event the dam is likely to experience in its design lifetime.

The design earthquake should represent the ground motions or fault movements from the most severe earthquake considered at the site. Since a tailings dam must stand in perpetuity, the design earthquake should be the largest seismic event that the site could experience. The estimated largest earthquake that could occur at any given location is called the Maximum Credible Earthquake. The Maximum Credible Earthquake is defined as the greatest earthquake that reasonably could be generated by a specific seismic source, based on seismological and geologic evidence and interpretations. The Maximum Credible Earthquake is most often associated with a recurrence interval of 10,000 years (Wieland 2008).

Using the 2,475-year event will not only underestimate the horizontal acceleration that the dam will experience, but will also greatly increase the probability the dam will experience the design seismic event. The probability of experiencing a 2,475-year return seismic event in 2,475 years is 63%. The probability of experiencing a 2,475-year return seismic event in 10,000 years is 98%. Another way to look at this is that if the Maximum Design Earthquake is a 2,475-year return seismic event, it is virtually guaranteed that a tailings dam that must stand in perpetuity will experience a seismic event large enough to break it.

b. The mean distance to the nearfield earthquake is 100 miles (PolyMet 2011, Table 1). Probabilistic determination for the size of the largest earthquake is appropriate, but the assumption of 100 miles for nearfield is going to make the horizontal acceleration used to design the dam lower than what it should be.

The further away the tailings dam is from the location of the earthquake, the less energy the tailings dam will need to withstand in order to maintain its structural integrity. The closer the location of the earthquake to the tailings dam, the higher the cost of building the dam, because the closer the earthquake the more energy the dam will have to withstand.

Seismologists know there are many active faults that have not been mapped or have been mapped inaccurately, that some faults believed to be inactive may actually be active, and that many inactive faults that may become active again. Because of these considerations, probabilistic methods are the most conservative way to determine the magnitude of a Maximum Credible Earthquake for dam analysis.

For tailings dams the most conservative choice for the location of the Maximum Credible Earthquake would be what is sometimes referred to as a 'floating earthquake' on an undiscovered fault that passes underneath the site of the dam. This is a way of recognizing that we do not know the present, future, and even the past locations of significant faulting, and associated earthquakes (NRC 1985). The conservative choice for a Maximum Design Earthquake would be a Maximum Credible Earthquake that ruptures the ground surface on which the dam is built.

6. The permit does not require independent tailings review.

The permit does not require independent tailings review. The use of an Independent Tailings Review Board oversight board is a recommendation of the Mt Polley Expert Review Panel.

Independent review also the recommendation of virtually every major post-Mt Polley review conducted by regulatory bodies, for example British Columbia (BC Code 2017) and Montana (MT SB0409 2015), and professional organizations, for example the Mining Association of Canada (MAC 2017) and the International Council on Mining and Metals (ICMM 2016).

B. Comments on the Hydrometallurgical Residue Facility

1. The permit does not require independent tailings review.

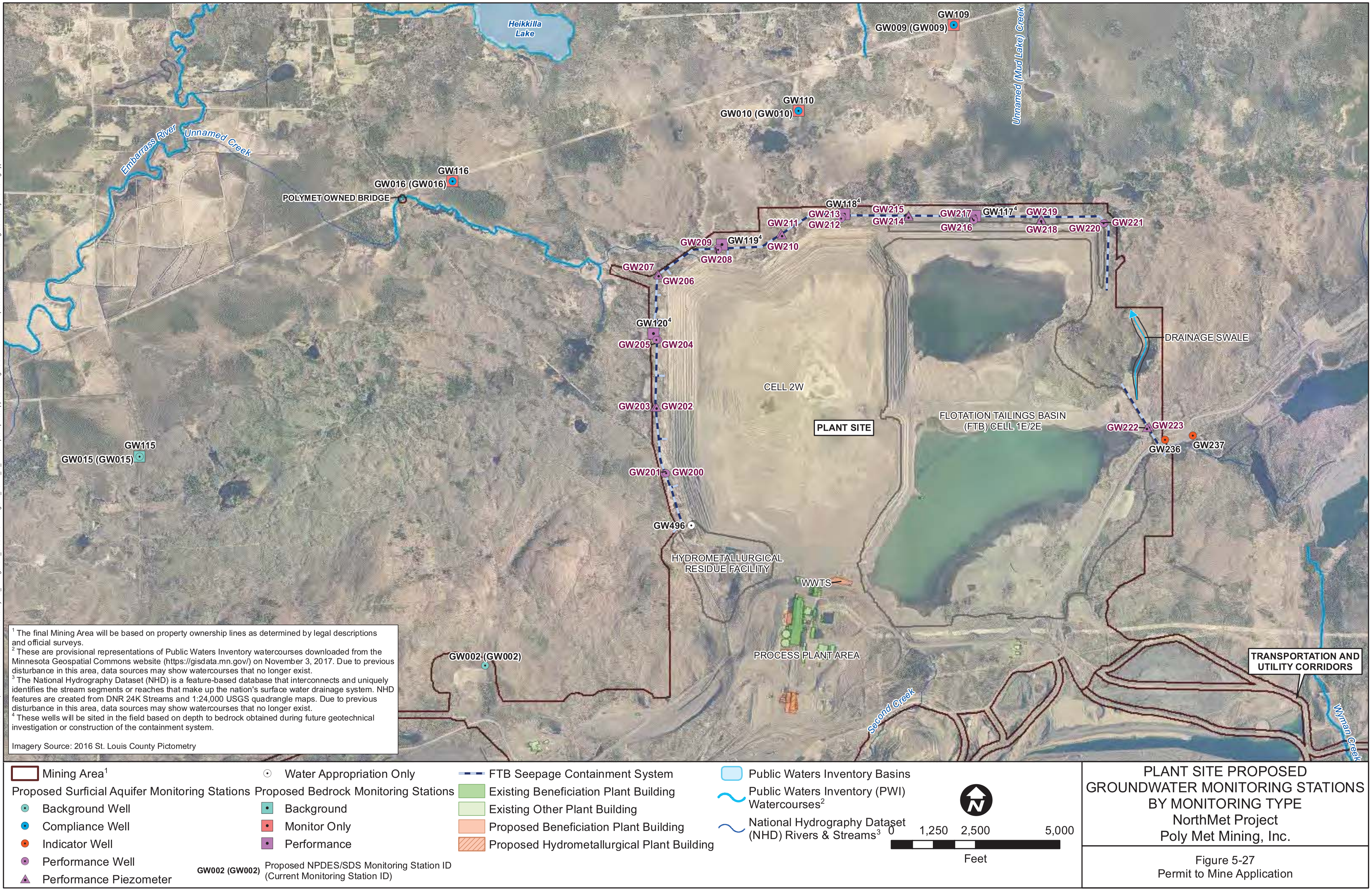
As noted for the flotation tailings basin, there is no independent tailings review oversight required. It would be simple to require independent tailings review that would review both facilities.

2. The monitoring wells proposed for the Hydrometallurgical Residue Facility are insufficient

Even though the Hydrometallurgical Residue Facility will have a double liner with leak detection, it cannot be assumed that the liner system could not be ruptured by a shift in the subsurface, or a seismic event. Monitoring wells should be located to detect unexpected seepage, since the material in this facility will be so toxic.

Presently the monitoring wells planned are shown in Figure 1 - FTB Groundwater Monitoring Wells. The surface groundwater flow pattern is shown in Figure 2 - FTB Groundwater Contours.

Figure 1 - FTB Groundwater Monitoring Wells



[1] The final Mining Area will be based on property ownership lines as determined by legal descriptions and official surveys.
[2] These are provisional representations of Public Waters Inventory watercourses downloaded from the Minnesota Geospatial Commons website (https://gisdata.mn.gov/) on November 3, 2017. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.
[3] The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. NHD features are created from DNR 24K Streams and 1:24,000 USGS quadrangle maps. Due to previous disturbance in this area, data sources may show watercourses that no longer exist.
[4] These wells will be sited in the field based on depth to bedrock obtained during future geotechnical investigation or construction of the containment system.

Imagery Source: 2016 St. Louis County Pictometry

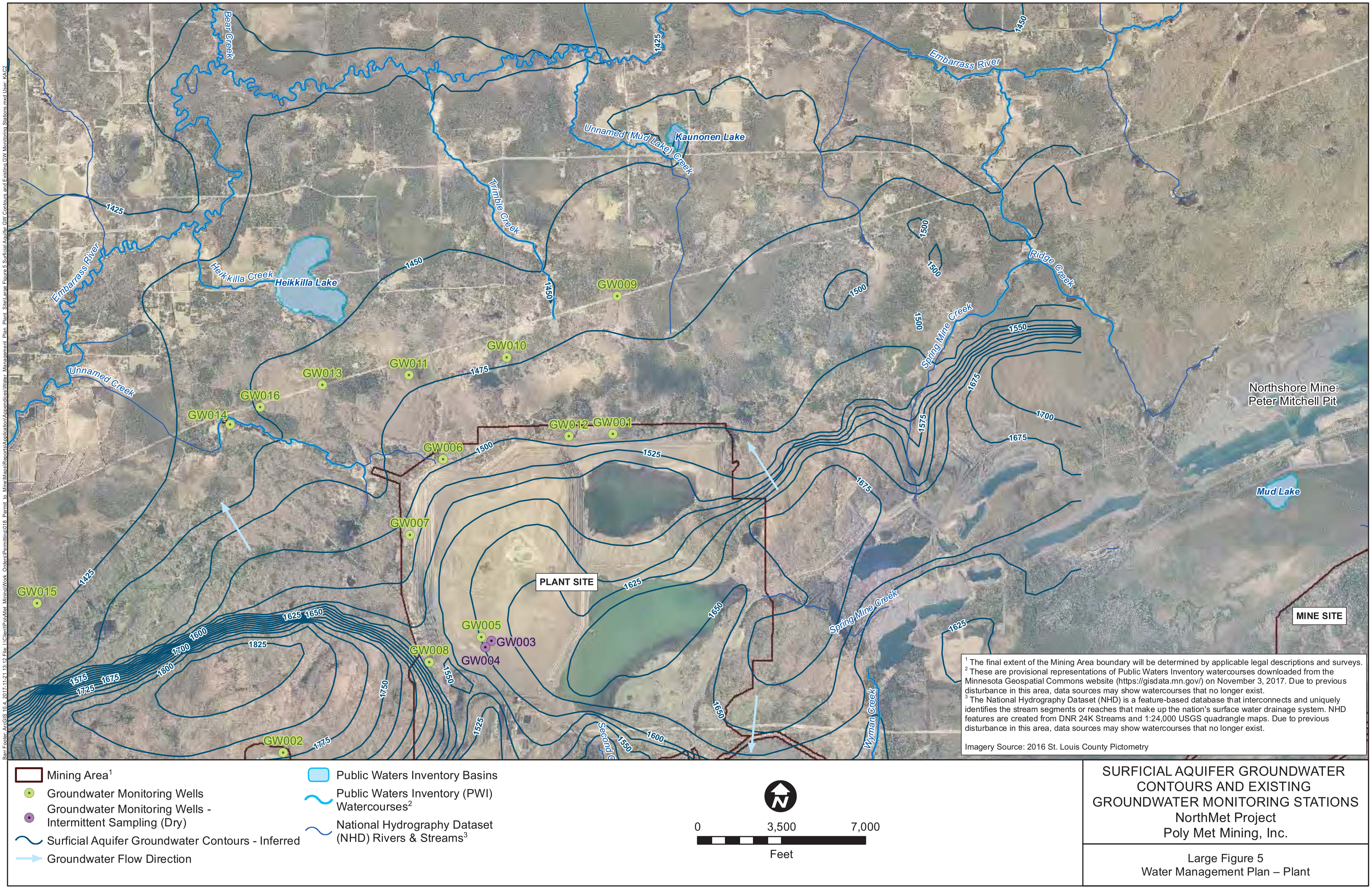
PLANT SITE PROPOSED GROUNDWATER MONITORING STATIONS BY MONITORING TYPE
NorthMet Project
Poly Met Mining, Inc.

Figure 5-27
Permit to Mine Application

Barr Footer: ArcGIS 10.4, 2017-11-20 14:52 File: I:\Client\PolyMet_Mining\Work_Orders\Permitting\018_Permit_to_Mine\Maps\Reports\Application\Figure 5-27 Plant Site Proposed Groundwater Monitoring Stations by Monitoring Type.mxd User: KAC2

Joint Petition Ex. 2

Figure 2 - FTB Groundwater Contours



Existing well GW008 (Figure 2) might be an appropriate location for a monitoring well northeast of the Hydrometallurgical Residue Facility, but there is no appropriate existing or planned well located south/southeast of the Hydrometallurgical Residue Facility. Monitoring wells are needed for the Hydrometallurgical Residue Facility.

Thank you for considering these comments.

Sincerely;

David M Chambers

David M Chambers, Ph.D., P. Geop.

REFERENCES

BC Code 2017. Health, Safety and Reclamation Code for Mines in British Columbia – Permitting, Reclamation and Closure Part 10, revised February 28, 2017

Bowker & Chambers 2016. Root Causes of Tailings Dam Overtopping: The Economics of Risk & Consequence, Lindsay Newland Bowker and David M. Chambers, International Seminar on Dam Protection Against Overtopping, Protections 2016, Fort Collins, CO, September 2016

Expert Panel 2015. Report on Mount Polley Tailings Storage Facility Breach, Independent Expert Engineering Investigation and Review Panel, Province of British Columbia, January 30, 2015

ICMM 2016. Position Statement on Preventing Catastrophic Failure of Tailings Storage Facilities, International Council on Mining & Metals, December, 2016

MAC 2017. A Guide to the Management of Tailings Facilities, Third Edition, The Mining Association of Canada, Version date: October 2017

MDNR 2017. Draft Dam Safety Permit, Permit Number 2016-1383, Minnesota Department of Natural Resources, 18Sep17

MDNR 2018. Permit to Mine Draft Special Conditions (Draft), Minnesota Department of Natural Resources, 6Feb18

MT SB0409 2015. An Act Revising Metal Mine Reclamation Laws; Establishing Standards for Tailings Storage Facilities; Establishing a Fee; Defining Terms; Creating Independent Review Panels; Providing for Reviews and Inspections; Providing Enforcement – Montana Senate Bill 409, signed by the Governor 05/04/2015

NRC 1985. Safety of Dams, Flood and Earthquake Criteria, Committee on Safety Criteria for Dams, Water Science and Technology Board, Commission on Engineering and Technical Systems, National Research Council, National Academies Press, Washington, D. C. 1985

PolyMet 2011. NorthMet Project Geotechnical Data Package, Volume 1 – Flotation Tailings Basin Probabilistic Seismic Hazard Analysis, Version 1, PolyMet Mining, September 23, 2011

PolyMet 2017. Permit to Mine Application, NorthMet Project, PolyMet Mining, December 2017

Wieland 2008. Large Dams, the First Structures Designed Systematically Against Earthquakes, Martin Wieland, ICOLD, the 14th World Conference on Earthquake Engineering, Beijing, China, October 12-17, 2008

James Kuipers, PE
Principal Consulting Engineer
jkuipers@kuipersassoc.com

Kuipers & Associates, LLC

PO Box 145
Wisdom, MT 59761
406-689-3464

February 23, 2018

To: Kevin Lee, Minnesota Center for Environmental Advocacy

From: Jim Kuipers PE, Kuipers & Associates

Re: **PolyMet NorthMet Mine Application Review Comments**

Please find the following comments pertaining to the PolyMet NorthMet Permit to Mine Application dated December 2017 and submitted to Minnesota DNR as well as subsequent Permit to Mine Draft Special Conditions. At your request the comments have focused on aspects relating to water treatment, financial assurance, and tailings.

1. Water Treatment

PolyMet's original application contained two sections relating to their proposal to transition from mechanical to non-mechanical water treatment as part of its Reclamation, Closure and Postclosure Maintenance Plan. According to **Section 15.7 Acceptable Reclamation Research** (p. 378) "The PTM Regulations allow alternative activities to be implemented in certain circumstances, including after operations cease, based upon acceptable research and findings. Minnesota Rules, part 6132.0100, subpart 2 defines "acceptable research" as "research approved by the commissioner that is site-related and is reasonably designed for the purpose of demonstrating that reclamation can be achieved by alternative methods." PolyMet intends to undertake several test projects during operations to evaluate alternative methods for reclamation"" including "Non-Mechanical Treatment Systems."

According to Section 15.8 Plans to Transition from Mechanical to Non-Mechanical Water Treatment (p. 446-47) "An important objective of the Project is to provide water treatment for as long as necessary to meet applicable regulatory standards at groundwater and surface water compliance points. The Project includes long-term mechanical treatment (reverse osmosis or equivalently performing technology) at the WWTS with a goal of transitioning to a non-mechanical treatment technology requiring less maintenance over the long term. This goal is consistent with the closure and post-closure maintenance requirements of the PTM Regulations, including the regulatory goals of minimizing and eventually eliminating the need for maintenance." The section goes on to describe a conceptual plan for transitioning during the 20-year mine life based on evaluations including data collection and pilot studies to demonstrate the ability to transition to non-mechanical water treatment. They describe the evaluation process as potentially being started and implemented during operations in four steps:

1. collecting site-specific information (e.g., hydrology and influent water quality),
2. laboratory testing,
3. pilot-scale testing, and
4. designing a system for full scale implementation.

However, the permit application goes on to suggest that it would be delayed due to aspects related to pit flooding and ultimately pit lake water quality as well as facility discharges. The permit application suggests that as a result the evaluation steps would be conducted during the reclamation period (approximately Mine Years 25 – 28) and the technology would be implemented "a few years" after the West Pit has been flooded (approximately Mine Year 55).

It is notable that PolyMet did not use water models to estimate when water treatment could be ended, or when a transition from mechanical to non-mechanical water treatment might occur. The application instead suggests the process will rely on actual monitoring result and performance of the proposed engineering controls.

Appendix 17.4 of the permit application contains a draft report by ARCADIS dated October 12, 2016 titled **Engineered Wetlands, Pilot Scale Testing Work Plan**. The work plan, which was removed from the 2017 revised application, describes two conceptual non-mechanical treatment approaches: 1) biological sulfate reduction and 2) constructed wetlands. The report suggests a conceptual field-scale pilot system utilizing an engineered wetland and also describes an engineered wetland pilot test. The design assumptions for the pilot test include a flow of 2.0 gpm (gallons per minute) and is "based on the average sulfate concentration at SD026 (183 mg/L), and a sulfate reduction rate based on the goal of reducing sulfate concentrations to 100 mg/L or less. The target sulfate reduction rate is 0.04 moles per day per square meter of substrate. Based on flow and loading calculations (Table 3), the dimensions of the pilot scale engineered wetlands are approximately 70 feet in length, 50 feet in width, and 4 feet of substrate depth (total wetland depth of approximately 7 feet). This sizing includes a 10% volume allowance for blending of inorganic amendments such as zero valent iron if bench testing indicates this step is necessary."

The **Permit to Mine Draft Special Conditions** issued by MDNR in January 2018 included two conditions specific to the Non-Mechanical Water Treatment System Plan as follows:

> 64. The Permittee's reclamation plan includes mechanical treatment. To further evaluate the goal of non-mechanical water treatment, the Permittee must develop a plan for investigation, design, and pilot testing of non-mechanical water treatment systems. The Permittee must provide this plan to the DNR for review and approval prior to Mine Year 1.
> 65. Upon DNR approval of the non-mechanical water treatment system plan, the Permittee must provide financial assurance sufficient for the DNR to implement the plan to evaluate non-mechanical water treatment in the event of unplanned closure.

The December 2017 **Revised PolyMet Mining NorthMet Project Permit to Mine Application** Financial Assurance estimate (Appendix 15) for the project assumes the cost of mechanical treatment for the entire period of 100 years used as the duration for the estimate, with no allowance for the potential application of future non-mechanical treatment methods.

A. Discussion

The objective of using non-mechanical treatment to meet discharge standards is laudable as ultimately it could result in less cost for long-term treatment, which is ultimately likely to be the responsibility of future taxpayers, as the present approach to financial assurance would ultimately result in the use of the available funds over the period of 200 years, albeit under idealized circumstances (e.g. no change in inflation, costs and/or technology). However, whereas mechanical treatment methods are widely regarded as proven based on their continued use for treatment of discharges for more than 30 years, non-mechanical methods, while promising, are as yet unproven except in particular applications, and ultimately may have certain limitations such as for flow rates and removal of low concentrations of contaminants, that result in it not being applicable to many site-specific situations such as the NorthMet PolyMet project.

For clarification it is important to note that the scientific literature frequently uses the term "active treatment" as an alternative to "mechanical treatment," and "semi-passive treatment" as an alternative to "non-mechanical treatment." The term "passive treatment" is also sometimes used to describe "non-mechanical treatment."

Gusek (2002) defined non-mechanical treatment as: ".... a process of sequentially removing metals and/or acidity in a natural-looking, man-made bio-system that capitalizes on ecological and geochemical reactions. The process does not require power or chemicals after construction, and lasts for decades with minimal human help." However, as noted by MEND (1999), "No 'passive treatment' or non-mechanical treatment system is truly passive. All systems require monitoring and replacement of consumed alkalinity or organic based nutrients for bacteria. Also, metal precipitates need to be removed and in some jurisdictions sludge falls under "hazardous waste" regulations and disposal may be a significant challenge." In our experience, even in the best of circumstances, significant activity is required to operate non-mechanical systems, and for that reason the use of the term "semi-passive" is more appropriate than "passive" to describe non-mechanical water treatment systems.

The proponent has proposed to ultimately use wetlands treatment to address very large flows (>2,000 gpm) and in a challenging climate. The climate in Minnesota is relatively similar to that of much of Canada. As noted by MEND (1999):

> "Passive treatment of acid mine drainage has a future in Canada, but is limited to applications where:
> - flows are of relatively constant volume
> - water temperature is greater than 7°C (e.g. mine water or embankment seepage)
> - water chemistry of low to medium strength acidity and metal concentration
> - low concentrations of aluminum and iron
> - low sensitivity of the receiving environment to upsets in the passive treatment system.
>
> Further research and field experience is needed to more precisely specify passive treatments for AMD in Canada to ensure that metal mining liquid effluent regulations are met all the time."

According to the findings of MPERG (2010) "Bioremediation and passive treatment…, because they involve life sciences are inherently unpredictable. As a consequence, passive treatment must prove itself through years of research." Given the inherent uncertainties and limitations with respect to site-specific application of non-mechanical treatment technologies, the only way of proving their effectiveness is to build a full-scale system and prove its ability to meet objectives over a significant period of time. Otherwise, even after pilot scale testing, performance of the system is speculative at best.

B. Recommendations

MDNR has proposed conditions to the permit that requires the proponent to submit a plan for investigation, design, and pilot testing of non-mechanical water treatment systems and provide financial assurance sufficient for the DNR to implement the plan to evaluate non- mechanical water treatment in the event of unplanned closure. The proponent has also included financial assurance for mechanical treatment for a period of 100 years in the current financial assurance estimate. These measures treat non-mechanical treatment as a contingency rather than the primary method of treatment, and in general reflect good practice with respect to the potential use of unproven techniques or approaches in the development of existing reclamation and closure plans and financial assurance.

The main concern that we have is that the demonstration of non-mechanical treatment for post-mining water discharges cannot be achieved until closure occurs and actual post-mining water quality is known and has equilibrated, together with a significant period of demonstration of the treatment approach. This could require a period well beyond the 100 years used to estimate the cost of mechanical water treatment. Additionally, while non-mechanical treatment is demonstrated at full-scale, it will be necessary to continue to operate mechanical treatment as a polishing step or to maintain it on stand-by until the non-mechanical treatment consistently meets standards on its own. Given the nature of changing ecologic conditions and other factors this suggests that if an actual full-scale demonstration is conducted at some point in the future, a period of at least 30 years for demonstration be allowed and continued use of mechanical treatment should be assumed for that period in the financial assurance cost estimate. MDNR should specify the demonstration period and performance criteria such as flow and water quality standards that must be met in order for the use of non-mechanical treatment to be determined as having demonstrated technical viability. In making this determination MDNR should further ensure that it must be demonstrated that the use of non-mechanical treatment does not present any additional risk to the environment and/or to future taxpayers.

One of the primary concerns with the requirement for water treatment is the potential for changes in the applicable water quality standard, for sulfate in particular, which is largely responsible at the PolyMet NorthMet site for driving the need for proven mechanical/active treatment methods versus potential non-mechanical/semi-passive treatment methods, which while generally unproven, are particularly unproven with respect to meeting more stringent water quality standards for sulfate and other potential contaminants of concern. While this is one of the potential consequences of any regulatory system, the project proponent could voluntarily agree to impose “anti-backsliding” provisions or agree to that condition separately. This ensures that the proposed project would use the best available technology and practices to minimize the discharge of contaminants of concern, regardless of potential changes to regulatory standards, and instead as a matter of corporate commitment to responsible and sustainable mining practice. Were the proponent to provide a guarantee of this nature it should be possible for all parties to agree that the ultimate use of non-mechanical treatment, once adequately demonstrated, would be in the best interest of all parties today and in the future.

2. Financial Assurance

A. Revised Financial Assurance Estimate

In December 2017 a revised PolyMet Mining NorthMet Project Permit to Mine Application was submitted and the following comments are provided concerning the revised Reclamation, Closure and Postclosure Financial Assurance (Appendix 15).

The revised application provided two estimates: Pre-mining financial assurance for existing conditions, and reclamation costs for Mine Year 1. The Mine Year 1 costs are based on the activities described in the Reclamation, Closure and Postclosure Plan.

Consistent with our previous review of the financial assurance for this project, it is important to note that this review has not included a critique of or recommendations addressing the adequacy of the Reclamation, Closure and Post-Closure Plan submitted by the proponent.

i. Discussion

- Overall the financial assurance estimate was conducted in a manner consistent with professional engineering practice and represents an accurate representation of the cost based on the assumptions that were used, however it relies heavily on customized engineering estimates and contractor quotations as noted later in these comments, which is not consistent with current typical financial assurance cost estimation practice.

- Instead of involving SRK and using the SRCE (Standard Reclamation Cost Estimator) Excel spreadsheet program to generate the estimate, together with a Minnesota specific cost database, the revised application provides a custom spreadsheet-based estimate that relies on estimates from the project's contractors to provide the material take-offs, task descriptions, and costs for the various tasks. This approach is not standard and a comprehensive and detailed review of the cost estimate would be necessary, and should be performed by the Minnesota regulatory agencies in order to ensure that the estimate has been conducted in an accurate manner consistent with financial assurance cost estimate practice.

    - In previous circumstances where this approach was used it was typical for contractor-based estimates to be 25-50% less than for estimates based on standard industry wide references such as are used in the SRCE model[1]. There is an inherent bias for contractors to underestimate costs in favor of potential clients unless the costs they are providing are an actual offer for services, and for that reason, except for cost estimation of specialty tasks, the use of standard references for cost data is preferred in financial assurance cost estimation. In this particular case some level of custom estimation is necessary due to the issue of legacy demolition tasks and tasks particular to the given site, however many of the tasks described by and for which costs were estimated by Barr Engineering and Ames Construction for example, could have been performed using SRCE and/or standard cost estimation references.

    - The departure from the initial use of SRCE, which incorporates standard cost references, to a custom method which relies on contractor estimates, is unprecedented in our experience. The Nevada Department of Environmental Protection together with the Bureau of Land Management (BLM), which have allowed for the use of contractor estimates since 1989, were instrumental in the development of the SRCE estimate beginning in approximately 2002 and its use of standard cost references, in part due to

[1] Standard references for reclamation costs include Caterpillar Performance Handbook (Caterpillar Inc., Peoria, IL 61629 [www.cat.com]); Products and services by CostMine (MineInfo USA, CostMine, 1120 N. Mullan Rd. Suite 100, Spokane Valley, WA 99206 (http://costs.infomine.com/)); R.S. Means Site Work & Landscaping Cost Data and R.S. Means Heavy Construction Cost Data (R.S. Means, 63 Smiths Lane, Kingston, MA 02364-9988 (http://www.rsmeans.com/index.asp)); EquipmentWatch's Cost Reference Guide and Rental Rate Blue Book for Construction Equipment (Penton Media, Inc., EquipmentWatch, 1735 Technology Drive, Suite 410, San Jose, CA 95110-1333 (http://www.equipmentwatch.com/))

issues raised with the prevalent use of contractor estimates for financial assurance in Nevada. During the period of 1997-1999 a number of mines went bankrupt in Nevada and the regulatory agencies discovered that contractors were not willing to back up the quotations. The agencies noted that without extensive review they were not able to verify the accuracy of custom contractor-based estimates and the use of this approach required an almost equal level of effort to review and verify by the agencies and therefore the SRCE was developed, which typically requires a reviewer less than a day to review and determine a relatively high level of confidence in an estimate specifically made for financial assurance cost estimation purposes.

- The revised financial assurance cost estimate does include a number of improvements with respect to important assumptions in the estimates that directly relate to our previous comments and recommendations which include the following:

    - Indirect costs were estimated as 5% of direct costs in the initial estimate as compared to typically 29% to +80% in those cases where agency guidance has been developed (see MINE CLOSURE AND RECLAMATION COST ESTIMATION GUIDELINES: INDIRECT COST CATEGORIES, Alaska Department of Natural Resources, 2015).[2] The revised plan includes 21.5% in indirect costs (Contingency 10%, Adaptive Management 2%, Engineering Redesign 2%, Performance Bond 1%, Prime Contractor Markup 2.5%, Mobilization 4%) related to capital expenditures and 20.5% in indirect costs (Contingency 15%, Adaptive Management 2%, Prime Contractor Markup 2.5%) related to long-term monitoring and O&M (operation and maintenance) costs. The costs also include DNR agency costs of $32.5M over 100 years so could be considered to approach 25-30%, which is still significantly below that of most other state and federal regulatory agency guidance for financial assurance indirect cost estimation.

    - The duration for long-term costs was increased from 50 years in the initial estimate to 100-years in the revised estimate. Consistent with the previous estimate the long-term costs include costs for active treatment (reverse osmosis) for the entire projected 100-year period with no allowance for the potential application of future semi-passive treatment methods such as wetlands. While the duration is less than the 500-year period we recommend consistent with BLM requirements, the use of a 100-year period makes the estimate consistent with most other state and federal guidance and practice for estimation of long-term trust funds.

    - The discount rate used to calculate the present value was decreased from 6.9% to 2.9%. The 6.9% represented an unrealistic and ill-advised investment scenario for the investment of a trust fund for long-term financial assurance whereas 2.9% is more consistent with most other state and federal guidance and practice for estimation of long-term trust funds.

- Overall, the revised financial assurance resulted in a decreased estimate for reclamation capital costs from $146M to $114M, or a reduction of $32M, and an increased estimate for long-term monitoring, operations and maintenance costs from $583M to $1,100M, or an increase of $517M. Indirect costs increased from $29M to $208M. Based on a net present value of 2.9%,

[2] http://dnr.alaska.gov/mlw/mining/largemine/rcindirects_dowlreport20150407.pdf

the overall amount of financial assurance for the project increased from $311M to $544M, or an increase of $233M, or 75% more than the initial financial assurance estimate. While the amount is still less than what could be considered ideal and should be reviewed by the agencies and further revised prior to finalization, it does represent a significant improvement from the initial estimate and was responsive to most of our recommendations.

ii. Recommendations

- Given the custom methodology used by PolyMet for the NorthMet Project financial assurance cost estimate we strongly recommend that it be reviewed in detail by both Minnesota DNR and by their previously retained financial assurance consultants. The review should be performed in a manner as to essentially develop an independent cost estimate using factors and assumptions familiar to the reviewers employed by MDNR and/or using the SRCE model with a Minnesota specific cost database, the latter of which is our preferred methodology. We recognize in making these recommendations that there are many highly site-specific variables which might require custom estimate methods to be used for example as “user input” for SRCE, however this is not adequate reason to rely on the estimate provided by PolyMet on its own.

- Concerns have been raised with respect to both lowering of existing water quality standards and/or the use of constructed wetlands as an alternative to active water treatment as presently proposed and included in the financial assurance estimate. As the actual post-mining water treatment requirements in terms of quality and quality as well as associated discharge standards cannot be known with a high degree of confidence until mine operations are closed, both from a predictive and legislative perspective, and the demonstration of a constructed wetlands approach might require decades given their nature, we recommend Minnesota DNR include as a condition of the financial assurance that the provision and costs for active treatment be included in the estimate until a period of at least 50 years following closure during which time a constructed wetlands approach must be demonstrated to be continuously successful at achieve applicable water quality standards.

- As demonstrated by the amount of financial assurance determined in this latest estimate to exceed $500 million, which would be among the highest for a hardrock mine in the U.S. or elsewhere, the cost of reclaiming and in particular addressing long-term monitoring, operations and maintenance at hardrock mines where potential water quality and other issues exist can be significant. The ability of the insurance and banking industry to have an appetite for, much less provide, financial assurance for projects of this level is uncertain. Depending on the cost of the financial assurance, particularly if some level of cash outlay is required up front, could easily impact the economic feasibility of the project. Given the project’s inherent sensitivity to ever fluctuating commodity prices and operating costs it would be important to consider the impact of the actual reclamation and closure costs as well as the cost of providing financial assurance in any future project feasibility study performed by PolyMet- the present financial assurance associated outlays and costs were not considered in prior economic analysis for the project.

Based on a database of financial assurance cost estimates for mine sites in the U.S. that we maintain, the total financial assurance estimated for the proposed project of $544M - $588M for reclamation and closure is among the highest of any hardrock mine site in the U.S. Obtaining and retaining a financial assurance instrument of this magnitude will entail both challenges and risks.

B. Permit to Mine Draft Special Conditions

The **Permit to Mine Draft Special Conditions** issued by MDNR in January 2018 included a number of provisions specific to financial assurance contained in Attachment 2 to Draft Special Conditions. These included provisions for independence of financial institutions providing financial assurance (Condition 2) and that no single financial institution may hold more than 34% of the total required financial assurance coverage (Condition 3). They have also defined acceptable financial assurance instruments to include (i) Irrevocable Letter of Credit (ILOC); (ii) Surety or Reclamation Bonds; and (iii) Cash. In addition, the Permittee will be required to establish and fund a Trust Fund for long-term treatment. (Condition 4) Finally, the specific terms of each financial assurance instrument must be acceptable to the MDNR prior to becoming effective (Condition 5). Additional requirements for surety bonds (Condition D), irrevocable letters of credit (Condition E) and Trust Funds (Appendix B) are also included in the permit special conditions.

iii. Discussion

Requiring that no single financial institution provide more than 34% of the total financial assurance is a progressive requirement by MDNR that helps to reduce the risk of exposure to bankruptcy by the financial institution itself. It may also help to address the fact that more than one financial assurance institutional provider may be necessary given the large financial assurance amount. While this will result in additional administrative requirements for both the agency and the proponent we recognize this as a good practice.

The purpose of financial assurance is to protect the taxpayer in the event the company fails to perform reclamation and closure. In most cases historically, this has occurred as a result of bankruptcy of the responsible company. However, financial assurance may be considered property of the company, particularly if it is in the form of cash or its equivalent, which may attract the attention of bankruptcy trustees and courts who might use it to repay creditors. And financial guarantees in the form of corporate or self-guarantees have no value in the event of bankruptcy. Therefore, it is critical with respect to financial assurance that corporate or self-guarantees are not allowed under any circumstances, and that forms of financial assurance be constructed so as to provide the best available protections from bankruptcy court claims.

Gorton (2009) describes the legal issues that create conflict between the Bankruptcy Code which is intended to give the company a "fresh start" and maximize the recovery of creditors versus laws meant to protect the environment. According to Gorton "Frequently in bankruptcies, debtor companies and their secured creditors attempt to sell attractive assets to maximize the dollar recovery but ignore and attempt to leave behind their environmental reclamation obligations. It is not unusual for a Trustee who is unfamiliar with the extensive regulatory structure surrounding the mining industry to actually sell the mineral resources in the ground without permits and related reclamation obligations associated with them in order to maximize the recovery of funds for the creditors and his/her commission."

As a result of their experience with financial assurance and bankruptcy many states have more explicit requirements for financial assurance. Montana, which as a state may have the most experience with actually obtaining financial assurance in the event of bankruptcy as a result of the Pegasus Gold bankruptcy in 1998 affecting seven mines that were ultimately reclaimed and closed, and continue to be managed by the State (and paid for by State taxpayers), for example, requires that proponents use only the state's form for surety bonds (See Attachment A). This resulted after the state was forced to negotiate with the bonding company and was fortunate to receive the majority of the funds owed due to discrepancies in the bond form.

EPA has developed guidance and forms for financial assurance for use in Superfund settlements and orders that should also be considered by MDNR. Information including example financial assurance mechanisms are available on EPA's Cleanup Enforcement Model Language and Sample Documents webpage (https://cfpub.epa.gov/compliance/models/).

iv. Recommendations

Based on the specific provisions provided in Conditions D, E and Appendix B, MDNR has taken provisions to ensure it is paid cash prior to any settlement in bankruptcy court and otherwise attempted to protect the financial assurance from other parties such as creditors. It is recommended that the Conditions and ultimate forms of financial assurance proposed by the proponent be reviewed by a highly qualified attorney with expertise in both contract and bankruptcy law to see if further protections can be asserted.

3. Tailings Treatment and Storage Technologies

While there was recognition of the potential for TSF failure to occur in less regulated jurisdictions, two recent TSF catastrophic failures (Mount Polley and Fundao) defied the previous assumption that failures were unlikely to occur where a higher standard of engineering and regulation exists. However, both of these recent significant TSF failures demonstrate that minimization and/or prevention of catastrophic consequences requires detailed and strict attention to not only design, but also other factors such as operations, and that most failures result from a series of events and not just one singular event as is typically assumed.

Comments were previously provided dated October 16, 2017 to MCEA and submitted to MDNR on the NorthMet Mining Project Dam Safety Permit (see Attachment B). The following comments further elaborate on the difference in characteristics and risks between conventional slurry tailings (aka wet tailings) and filtered tailings (aka dry stack tailings), and the feasibility of filtered tailings disposal on existing conventional slurry tailings impoundments.

A. Risk from Conventional Slurry Tailings

As described in Kuipers 2015, conventional milling processes produce a tailings slurry depending on the process with a solids content ranging from 30-50 percent. The tailings slurry may be thickened up to 60 percent solids. The tailings slurry is transported by pipeline either by gravity or by pumping and discharged to a TSF where it is deposited on "beaches" or into a pond. The solids settle leaving supernatant process water that forms a surface pond. The water is typically recycled and reused in the milling process. Deposition of tailings slurry is often by spigot (discharge via a pipe nozzle) from single or multiple points around the perimeter of the containment basin. Spigot tailings form a shallow beach slope (1 to 2 percent) as the tailings solids drop from solution and the excess water flows down the beach and forms a settling pond at the low point of the basin. This excess water (also known as supernatant water) can be recycled to the process plant using a barge or decant pumping system in order to reduce fresh water make-up requirements. Excess water may also be treated and released back into the environment.

As is discussed at more length in our comments on the Dam Safety Permit, potential failure modes related to conventional slurry tailings impoundments can include both structural (geotechnical) failure modes (sliding, overtopping, internal erosion, etc.) and other modes that are non-structural in nature and are related to environmental protection. UNEP's, 2001, Tailings Dams Risk of Dangerous Occurrences, Bulletin 121 is frequently cited as a reference with respect to TSF failure modes. They identified slope stability as being the primary failure mode of TSFs, followed by earthquake (seismic) and overtopping. They also identify foundation failures, seepage, structural, erosion and mine subsidence as failure modes.

The consequences of conventional slurry tailings impoundment failures are significant. CDA (2014) notes the following:

- Environmental losses are often the most significant aspect of a mining dam failure. Specific studies may be required to predict the degree of environmental loss.
- Mining dam failures can result in loss of site infrastructure such as roads, pump stations, power lines, and pipelines.
- Mining dams can also have the special case where the failure could threaten employees of the mine working downstream of the mining dam, such as in an open pit mine. In this instance, the training of the mine staff can be considered with respect to evacuation procedures and the potential for reducing the potential for loss of life.
- The economic losses to a mining company can be substantial and may be much larger than the direct financial burden associated with a failure. Failures of mining dams can result in lost production, have a negative impact on the market capitalization of a company, and limit the ability of the company to engage in other mining projects.

In addition, typical to any catastrophic failure, loss of human life is also a distinct risk, specific to those who live downstream from any conventional slurry tailings impoundment.

B. Characteristics of Filtered Tailings

As described in Kuipers (2015), filtered tailings, or dry stack tailings, are an unsaturated (e.g. not truly dry) tailings product that cannot be pumped. Filtration in mineral processing has been utilized for hundreds of years for purposes such as concentrate dewatering and separation of filtrate containing dissolved metals from solid materials, such as in cyanide leach processing. The applications have tended to be relatively smaller scale, generally less than 1,000 tpd (tons per day). In the modern mining era, there are a limited but notable number of mines where filtration has been utilized, including in the U.S. at the Greens Creek Mine, Alaska, Mineral Hill Mine, Montana and Pogo Mine, Alaska, all of which are relatively small-scale mines (less than 5,000 tpd). In addition, filtration has been identified as the preferred option for the proposed Rosemont mine in Arizona, which would have a capacity of 60,000 tpd, making it one of the world's largest tailings filtration operations.

Tailings and other filtration requirements in mineral processing are typically performed using three different types of equipment:

- **Disc and drum filters** are well developed technology that has traditionally been used for filtering concentrates. They consist of a rotating disc or drum with a filter medium (typically cloth) that strains the liquid from the solids under vacuum followed by pulling air through the cake and finally releasing the cake from the filter using pressure. Disc and drum filters have a high surface unit area to unit volume processed and with fine (clay or slimes) material commonly have issues with blinding of the filter pores.

- **Vacuum belt filters** have horizontal surfaces that are covered by a continuous rotating filter cloth, with a vacuum applied below to remove water. The advantage is that relatively high capacities can be achieved, however the disadvantage is that the pressure differential to drive the filtering process is limited by atmospheric pressure. This characteristic normally limits the moisture content achievable on a vacuum belt filter to typically 20 percent moisture (80 percent solids). These high moisture contents may limit the application of this technology if compaction is required.
- **Pressure filters** consist of a large number of vertically mounted plates with filter media attached to the plate surface. The filtered material is pumped into a chamber between two plates, when the chamber is full, compressed air is used to dry the filter cake, and an opening mechanism pulls the plates apart allowing material to drop onto a conveyor belt below. The plates may also be shaken and washed prior to the press being closed (normally by hydraulic piston) and the cycle beginning again. High differential pressure of 3 to 5 atmospheres drive the drying process to achieve typical filter cake moisture content in the range of 18 to 20 percent. An additional step can be added to the filter process, in that expandable membranes on the surface of the filter plates are pressurized with water or air and squeeze residual water out of the chamber before the cake blow cycle. This additional process is costlier, but can decrease the retained moisture content by an additional 2 to 5 percent. The disadvantage of pressure filters is that they are typically a batch process, however automation of the process design together with hybridization with vacuum belt filters, such as the Larox filter, have resulted in the production of equipment with higher capacity.

Multiple options are available for filtered tailings stacking systems and vary depending on processing rates, characteristics of the material, topography of the area to be stacked, and the shape of the final TSF. Filtered tailings are typically transported by truck or conveyor to the tailings storage facility where they are then placed, spread and compacted. The intent is to form an unsaturated, dense and stable tailings stack with no dam required for tailings retention. Davies (2011) notes that while the term “dry stack” is used, the filtered tailings are not “dry” but instead are unsaturated, so the preferred term is filtered tailings.

The environmental risk related to catastrophic failure is minimized with filtered tailings because there is no water present to either cause a dam breach or transport tailings farther downstream of the impoundment.

In general, filtered tailings will display similar geochemical and potential mine influenced water (MIW) discharge characteristics to that of other tailings treatment methods but at a significantly reduced level. No segregation together with compaction and the ability to perform concurrent reclamation, including installation of cover liners if necessary, results in the least potential for the formation and discharge of MIW as compared to the other methods. Filtered tailings can be lined. At closure because there is no supernatant or draindown water, and the TSF using filtered tailings is constructed as a stable landform, there are no transition, active or passive closure phases or associated MIW discharges involved in closure. In addition, lime or other materials to increase neutralization potential can be mixed with filtered tailings, and because the tailings are compacted, infiltration will be reduced, and if necessary cover liners can be installed immediately upon closure, reducing the terminal drain-down discharge quantity.

Filtered tailings are conducive to concurrent reclamation during the operational life cycle. As noted by Davies (2011), filtered tailings storage facilities can be developed to their final reclamation configuration as there is negligible deformation post-placement versus conventional tailings experiencing consolidation settlement over a potentially very long period of time. Concurrent reclamation may include interim measures but typically includes the final resloping or reshaping of the compacted tailings materials, installation of permanent stormwater run on and run-off features, and construction of covers and revegetation and/or engineered covers for infiltration control as part of on-going operations. This approach minimizes final reclamation requirements for filtered TSFs. There is no transition period from active to post-closure care and any long-term requirements are significantly decreased.

C. Feasibility of Filtered Tailings Disposal on Existing Conventional Slurry Tailings

It is technically feasible to place filtered tailings on top of conventionally placed slurry tailings. Similar to the requirements for the design of any TSF, it requires understanding the potential failure modes and addressing them in the design, construction, operational and closure processes over the life-cycle of the project.

Lupo and Musse (2014) identified water management as a critical issue relative to consumption and efficient use leading to greater industry interest in filtered dry stack tailings. It should be noted that this was prior to the Mount Polley Independent Engineering Review Panel (IERP) identifying filtered tailings as best available technology (BAT) for reasons related to stability (see comments Section IV). Lupo and Musse cite advantages for filtered tailings in terms of consumption, handling, concurrent reclamation versus the disadvantage of up-front capital costs and operating costs. They also identify challenges such as impoundment access and equipment working on top of tailings noting that it "… is a function of tailings mechanical and hydraulic properties, drainage conditions within the impoundment, deposition history/management and time." Impoundment characterization must be performed with respect to geotechnical, hydrogeologic and geochemical aspects, dependent on site specific conditions and the level of uncertainty allowed, and can range from very extensive to minor.

The advantages to the placement of filtered tailings on top of conventional slurry tailings include the ability to store additional filtered tailings within a given footprint area, the use of the filtered tailings combined with dewatering of the underlying tailings to stabilize the underlying tailings by consolidation, and improved conditions for installation of source control measures such as covers.

- The ability to place tailings with stable slopes of as steep as 3:1 (H:V) using filtered tailings results in a significant reduction in the required storage footprint. Some additional area is required for filtered tailings facilities and process water storage but in most cases, depending on the amount of process water that is stored, it will not offset the reduced tailings storage footprint. Other advantages include placement of tailings in a relatively dense state, meaning more solids per unit volume, and in most cases per unit area of the storage facility, including use of valley slopes (Davies 2011).
- Filtered tailings can be used to aid in densification of the underlying tailings accompanied by dewatering to form a stable landform, resulting in both minimization of risk from new tailings and ultimately from the old wet tailings – using filtered tailings to consolidate underlying unconsolidated tailings to achieve dilatant/stable conditions is the approach that most ideally achieves the recommendations of the Mount Polley Independent Engineering Review Panel in terms of Best Available Technology (BAT) and Best Available Practice (BAP).

- The addition of source control covers such as bentonite or other materials over unconsolidated tailings is problematic because the tailings are still subject to further densification over decades in the future resulting in surface expressions that in most cases are highly uneven, impact drainage, and compromise cover integrity whereas filtered tailings are typically compacted as they are placed and subject to no further settling.

The primary disadvantages in the case of the NorthMet TSF are inherent to the production of filtered tailings, so include reliability at the scale proposed, and cost. Additionally, the placement of filtered tailings on top of conventional slurry tailings is complex and requires a high-level of care and diligence relative to the use of the observational process. However, overall it is no more onerous than the construction and operation requirement or for closure to achieve dilatant conditions might otherwise be for a conventional slurry TSF.

D. Recommendations

The following recommendations were provided on the Dam Safety Permit in our October 16, 2017 comments to MCEA and are re-iterated herein relative to tailings methods and technologies:

- Minnesota's existing dam safety regulation, Minnesota Rule 6115.0410, is intended for water storage dams and does not specifically address tailings storage facilities. In addition, the requirements rely on "current, prudent engineering practice" and "prudent, current environmental practice" rather than on current accepted industry engineering performance standards as is common to nearly all other regulatory jurisdictions in the U.S. and internationally. We would encourage consideration by all parties as to the critical need to revise or modify Minnesota's approach to dam safety and to incorporate statutes, rules and guidance specifically for TSFs that are consistent if not better than those recently enacted and/or developed by Montana and British Columbia.

- Performance standards for TSFs should be specifically required and should include a hazard classification system based on TSFs similar to that recommended by the CDA (Table 1), seismic criteria requiring 1/10,000 year or Maximum Credible Earthquake (MCE), geotechnical minimum Factors of Safety (FOS) and Inflow Design Flood (IDF) consistent with CDA and other guidance.

- If Minnesota DNR's intention is to consider the actual recommendations of the Mount Polley IERP, then at a minimum additional consideration must be given to the IERPs recommendations for BAT. Our recommendation would be for a Multiple Accounts Analysis (MAA) to evaluate BAT for both operation and closure of the proposed TSF and alternative approaches to the TSF including filtered dry stack tailings and closure of the TSF to achieve dilatant conditions. It is notable that the Mining Association of Canada (MAC) in their recently published Guide to the Management of Tailings Facilities (2017) makes clear reference to and provides an Appendix on the use of MAA to address the assessment of tailings management alternatives. According to MAC (2017):

  > "A process to assess alternatives for the location of a potential tailings facility, and the site-specific BAT for tailings management, should be implemented at the project conception and planning phase of the life cycle. Selection of BAT and facility location lay the foundation for all subsequent decisions and activities related to the tailings facility,

including risk management. Decisions at this phase of the life cycle have profound and often irreversible implications throughout the life cycle.

Alternatives for closure and long-term closure objectives and post-closure land use are essential considerations in the initial selection of location and technology, and may also need to be reassessed at other phases throughout the life cycle. Alternatives may also need to be assessed at other phases throughout the life cycle in the event of a mine-life extension and the need for a new or expanded tailings facility."

- Minnesota should also consider the IERPs recommendations and undertake to:
  - Require TSF operators to commit to an equivalent program of tailings management, including the audit function, as is required by members of the Mining Association of Canada;
  - Expand corporate design commitments and require a failure modes effects analysis, BAT cost-benefit analysis, and Quantitative Performance Objectives (QPOs);
  - Require the use of formal Independent Review Boards (IRBs) and use QPOs in regulator evaluations of TSF safety;
  - Require that inspections be performed at all existing TSFs to ascertain whether they may be a risk and require appropriate actions due to specific failure modes: filter adequacy; water balance adequacy; undrained shear failure of silt and clay foundations; and,
  - Develop guidelines that would lead to improved site characterization for tailings dams with respect to the geological, geomorphological, hydrogeological and possibly seismotectonic characteristics.

- PolyMet should conduct further TSF analysis including a multi-stakeholder FMEA to consider all potential failure modes and their consequences as well as mitigating measures together with the development of an AMP to ensure that means to mitigate potential failures are developed and triggered appropriately.

- PolyMet should also appoint a formal IRB for the TSF and involve them in the final design, construction, operation and reclamation through final closure and during post-closure if necessary. The IRB should be robust and include at least three representatives. The IRB process should complement the Engineer of Record's process but at the same time be transparent and involve public representatives in a capacity that would allow them to ensure and report on the outcome of the overall process. We have been involved at several other sites as a technical representative to IRBs or have served on similar panels and would be glad to advise DNR and the NGO community on processes to achieve this recommendation.

- It is our professional opinion that the ultimate determination of acceptability of risk, if a wet tailings approach such as the NorthMet TSF is proposed, should lie with the public members whose lives would be at risk in the event of a catastrophic breach. NorthMet's analysis shows that the proposed TSF represents significant risk of loss of life in the event, however unlikely, of a catastrophic failure. For that reason, we recommend that the inundation analysis together with the proposed emergency response plan be presented to both the responding regulatory agencies but also to the potentially affected public, through a very intentional process to engage and take their opinions wholly into account, <u>prior to approval of the dam safety permit or the Permit to Mine.</u> The DNR otherwise would be making a decision to put those persons at risk without their input or potentially even their knowledge.

- Our recommendations and opinions should not be seen as exclusive of the possibility that the proposed wet tailings approach, at least during the operational period, might be considered as a reasonable risk by the parties most at risk and otherwise involved. For that reason, we also take the opportunity at this time to recommend in that event, in addition to the involvement of a formal IRB and transparent technical process, that PolyMet, DNR and the EOR undertake to:

  - Develop a corporate TSF management strategy similar to that recommended by Mining Association of Canada (MAC) (2011).
  - Develop a TSF operations, maintenance and surveillance (TOMs) manual similar to that recommended by the MAC (2012).
  - Conduct a technology development program together with modifications to the TSF reclamation and closure design to achieve a final stable landform design.

- In the absence of any of our above recommendations and in particular informed public consent, it is our professional opinion that the Mount Polley IERP recommendations for BAT for new tailings (e.g. filtered dry stack tailings) should be required for the NorthMet TSF and as a requirement of the dam safety permit. If the decision is to allow for a wet tailings facility during operations, then at the least the dam safety permit and the Permit to Mine should specify closure to meet dilatant landform conditions so as to avoid the threat of a catastrophic failure in perpetuity.

References

CDA. 2014. *Technical Bulletin: Application of Dam Safety Guidelines to Mining Dams*. Canadian Dam Association. www.cda.ca

Davies, M. 2011. *Filtered Dry Stacked Tailings – The Fundamentals*. Proceedings Tailings and Mine Waste 2011Vancouver, BC, November 6 to 9. http://www.infomine.com/library/publications/docs/davies2011.pdf

Gorton 2009. Gorton, W., *Understanding the Reclamation Surety Relationship Before and After Operator Default*. Rocky Mountain Mineral Law Foundation Special Institute on Mine Closure, Financial Assurance and Final Reclamation, Westminster, Colorado, November 2009.

Gusek 2002. Gusek, J., *Sulphate-Reducing Bioreactor Design and Operating Issues: Is This the Passive Treatment Technology for Your Mine Drainage?* National Association of Abandoned Mine Land Programs, September 15-18, 2002, Park City, UT.

Kuipers 2015. Kuipers, J. *Mine Tailings Fundamentals: Current Technology and Practice for Mine Tailings Facilities Operations and Closure, Part 1 – Mine Tailings Facility Design and Operations*, U.S. EPA Contaminated Site Clean-Up Information Webinar Series May 19-20, 2015.

Lupo and Musse 2014. Lupo, J. and M. Musse, *Converting Slurry Tailings Facilities to Filtered Dry Stacks – A Case History*, Paste 2014 Vancouver, Canada, June 8-12, 2014.

MEND 1999. *Review of Passive Systems for Treatment of Acid Mine Drainage*, MEND Report 3.14.1, Revised 1999.

MPERG 2010. *Evaluation of the Effectiveness of Biological Treatment of Mine Waters*, Laberge Environmental Services, Mining and Petroleum Environment Research Group (MPERG) Report 2010-4, Yukon, Canada.

UNEP. 2001. *Tailings Dams Risk of Dangerous Occurrences, lessons learnt from practical experiences*. Bulletin 121. http://www.unep.fr/shared/publications/pdf/2891-TailingsDams.PDF

Attachment A
Montana Surety Bond Form

MONTANA DEPARTMENT OF ENVIRONMENTAL QUALITY
ENVIRONMENTAL MANAGEMENT BUREAU
PO BOX 200901
HELENA MT 59620-0901
PHONE:(406)444-2461 FAX:(406)444-1499

U.S.D.I. BUREAU OF LAND MANAGEMENT
BLM ADDRESS AND PHONE #;S

HARD ROCK RECLAMATION SURETY BOND

BOND NO. PROVIDED BY SURETY COMPANY

MINING COMPANY OR INDIVIDUAL'S NAME, as Principal, and FULL NAME OF SURETY, a corporation organized and existing under the laws of the State of __________________________ and duly authorized to transact business in the State of Montana, as Surety, are held and firmly bound to the State of Montana, acting through the Department of Environmental Quality and the United States of America acting through the U. S. Department of Interior, Bureau of Land Management, in the penal sum of TYPE OUT ENTIRE DOLLARS AND CENTS AS WORDS $NUMERIC DOLLARS AND CENTS (USD) DOLLARS, for the reclamation performance bond required by the Metal Mine Reclamation Act, for the payment of which sum, well and truly to be made, we bind ourselves, and each of our legal representatives, executors, administrators, successors and assigns, jointly and severally, firmly by these presents.

WHEREAS, the Principal holds or has applied for a license/permit from the Department of Environmental Quality and a plan of operations (POO) from the U.S.D.I. Bureau of Land Management to conduct exploration/mining operations on the following premises, to wit:

All lands permitted pursuant to Operating Permit # PROVIDED BY DEQ

NOW, THEREFORE, the conditions of this obligation are such that if the above bonded Principal shall, in conducting such mining operations faithfully perform the requirements of the license/permit, the reclamation plan and Title 82, Chapter 4, Part 3, MCA and the plan of operations and 43 CFR Section 3809 relating to mining and the Rules and Regulations adopted pursuant thereto, then this obligation shall be exonerated and discharged and become null and void; otherwise to remain in full force and effect. The requirements assured by this bond include those requirements imposed on Principal as a result of those activities that occurred prior to issuance of this bond and before the date the bond is canceled or released or substitute bond is approved. If this bond is forfeited, the State of Montana and the U.S.D.I. Bureau of Land Management shall be entitled to the entire amount of this bond without regard to actual damages. Reasonable attorneys' fees and costs shall be awarded to the prevailing party in an action to enforce the terms of the bond.

If the Principal fails or refuses to fulfill its obligations pursuant to any section of its operating permit, the Department of Environmental Quality and the U.S.D.I. Bureau of Land Management shall declare this surety bond to be forfeited and the surety shall pay to the Department of Environmental Quality and the U.S.D.I. Bureau of Land Management, within thirty (30) days after receipt of notice of forfeiture by certified mail, ten (10) per cent of the bond amount with any interest on the amount accruing to the Department of Environmental Quality and U.S.D.I. Bureau of Land Management for use in interim reclamation activities pending payment in full of the entire bond amount by the surety. Interest accruing on all principal paid by the surety to the Department of Environmental Quality and U.S.D.I. Bureau of Land Management shall be the sole and exclusive property of the Department of Environmental Quality and U.S.D.I. Bureau of Land Management and shall not be refunded to the surety.

Line items prepared by the Department of Environmental Quality and U.S.D.I. Bureau of Land Management to determine the total amount of the surety bond required are not limitations on how the Department of Environmental Quality and U.S.D.I. Bureau of Land Management may spend any of the bond proceeds paid by the surety.

PROVIDED, however, the Surety shall not be liable under this bond for an amount greater in the aggregate than the sum designated in the first paragraph hereof, and shall not be liable as respects any obligation related to mining operations performed after the expiration of ninety (90) days from the date of the mailing by the Surety of a cancellation notice directed to the Principal and the Department of Environmental Quality, Helena, Montana and the local U.S.D.I. Bureau of Land Management office. The bond shall remain in full force and effect as respects any obligations related to mining operations performed prior to the effective date of such cancellation, even if mining operations continue after the effective date of such cancellation, unless the principal files a substitute bond, approved by the Department of Environmental Quality and U.S.D.I. Bureau of Land Management, or unless the Department of Environmental Quality and U.S.D.I. Bureau of Land Management shall otherwise release the Surety.

Signed, sealed and dated this ____________ day of ______________________________, ______________.

MINING COMPANY OR INDIVIDUAL'S NAME
Principal

Signature: Principal

SAME AS ONE ON DEQ'S PERMIT APPLICATION
Mailing Address

Title

City, State, Zip

Telephone No.

FULL NAME OF SURETY
Surety

Signature: Surety

Mailing Address

Title

City, State, Zip

Telephone No.

(Surety Seal Here)

Approved on ______________________________, ______________.
U.S.D.I. Bureau of Land Management

By: ______________________________
Signature: BLM

Title

SAMES AS USED AT TOP RIGHT CORNER OF PAGE 1
Mailing Address

Telephone No.

City, State, Zip

Approved on ______________________________, ______________,
Department of Environmental Quality

By: ______________________________
Signature: DEQ

Title

PO BOX 200901
Mailing Address

(406) 444-2461
Telephone No.

HELENA, MT 59620-0901
City, State, Zip

Attachment B
Review of NorthMet Mining Project Dam Safety Permit

James Kuipers, PE
Principal Consulting Engineer
jkuipers@kuipersassoc.com

Kuipers & Associates, LLC

PO Box 145
Wisdom, MT 59761
406-689-3464

September 30, 2017

To: Kevin Lee, Minnesota Center for Environmental Advocacy

From: Jim Kuipers PE, Kuipers & Associates

Re: **Review of Northmet Mining Project Dam Safety Permit**

Please find the following comments related to the Northmet Mining Project Dam Safety Permit. The comments address four specific areas, all of which relate to engineering best practice as currently recognized by the mining industry for tailings storage facilities (TSFs). The first area of comment is with respect to Minnesota's current regulations for dam safety and their adequacy with respect to tailings storage facilities; with the exception of Montana which has enacted more current regulations in response to the Mount Polley Independent Expert Review Panel (IERP) recommendations most states in part or in whole rely on regulations specific to water storage dams which differ significantly from tailings storage facilities. The second area of comment is with respect to the current criteria which the Minnesota Department of Natural Resources (DNR) considers in approving a dam safety permit to address public safety; the requirement for clearly defined and specified design performance criteria is evident in most regulatory approaches. And the third area is with respect to how DNR considered what happened at Mount Polley in its review. Finally, the fourth area is with respect to the actual engineering analysis and reviews that have been performed for the Northmet TSFs.

The comments provided are based on more than 35 years of professional experience which has included significant levels of involvement in tailings storage facility design, permitting, operations, reclamation and closure, and long-term monitoring, maintenance and operations, as well as financial assurance for tailings storage facilities and associated requirements such as supernatant and seepage water capture and treatment. I was the government appointed Technical Liaison for the Mount Polley IERP and the tailings dam re-stabilization engineering effort on behalf of the primary affected First Nations, and was responsible for assisting them in understanding and responding to the reports and recommendations related to those activities. I was also involved in the development of the 2015 Montana tailings dam safety regulations and have spent significant time assessing and directly participating at a number of mine sites in current industry best practice for tailings storage facilities. The overall objective of these comments is to lend my professional expertise to the determination by the State of Minnesota and its citizen's in how best to address public safety and environmental issues with respect to the storage of tailings from mining activities.

The comments provided are intentionally thorough and include numerous citations and references to professional and governmental regulations and guidance identifying current best practice for TSFs. In many cases the references are not available to the public and regulators, in particular the Canadian Dam Association reports cited herein. In addition, clarifying information is provided as to the views of the Mount Polley IERP that should be acknowledged if their work is to be cited relative to Dr. van Zyl's involvement at a TSF evaluation. The objective of including this level of information is to ensure that both regulators and the public are informed as to current best practice as well as ongoing controversy as to in particular the application of Best Available Technology (BAT).

1. Dam Safety and Tailings Storage Facilities

In most jurisdictions nationally and internationally, mining TSFs are regulated in terms of stability and hydrology based on requirements designed and intended for water storage dams. In some cases, those regulations may include practices applicable to mining TSFs, however only one U.S. state, Montana, has enacted regulations specific to mine TSFs. Mining TSFs are different from water storage dams in the following ways (sources, Martin et al 2002, CDA 2014):

- TSFs are constructed, operated and closed by mine owners focused on extraction for a profit and not necessarily for public benefit or on TSF safety.
- TSFs are designed to retain solids (that may or may not be contaminated) and/or process solutions (that may or may not be contaminated).
- TSFs can contain large quantities of fluids and solids that if released can cause significant environmental damage and result in loss of human life.
- TSFs are built during the development and operation of mines and remain as part of the landscape becoming a permanent feature that must perform as designed after closure of the mine indefinitely (e.g. in perpetuity).
- TSFs, if they contain contaminated substances (fluids and/or solids), have no minimum size where the consequences of failure would be generally acceptable.
- Many TSFs are built in stages over the mine life, rather than built in a single stage prior to decommissioning.
- The condition of TSFs is continually changing so safety must be continually re-evaluated rendering TSF management more onerous as a steady-state condition is only achieved some time after the mine operations cease.
- TSF decommissioning cannot be accomplished by breaching and removal but instead typically requires a transition period and long-term monitoring and maintenance.
- TSFs are not generally viewed as an asset but instead as a liability and thus may warrant a lower standard of care from their owners.
- TSF owners typically rely on consultants rather than in-house expertise leading to the potential for poor communication and project continuity.

As discussed further in these comments, Minnesota's existing dam safety statutes, RSM 6115.0410, are intended for water storage dams and do not specifically address tailings storage facilities. In fact, because the requirements rely on "current, prudent engineering practice" and "prudent, current environmental practice" rather than on current accepted industry engineering standards it is questionable as to whether Minnesota's existing dam safety statutes are consistent with accepted standards for water storage facilities, much less TSFs.

2. Dam Safety Performance Standards

a. Hazard Classification

Minnesota classifies existing and proposed dams into three hazard classes (RSM 6115.0340):

those dams where failure, misoperation, or other occurrences or conditions would probably result in:

A. Class I: any loss of life or serious hazard, or damage to health, main highways, high-value industrial or commercial properties, major public utilities, or serious direct or indirect, economic loss to the public;

B. Class II: possible health hazard or probable loss of high-value property, damage to secondary highways, railroads or other public utilities, or limited direct or indirect economic loss to the public other than that described in Class III; and

C. Class III: property losses restricted mainly to rural buildings and local county and township roads which are an essential part of the rural transportation system serving the area involved.

Minnesota's classification system is consistent with the recommendations of the Federal Emergency Management Agency (FEMA), which is responsible for federal dam safety requirements. FEMA (2013a) notes that significant variations of the dam classification system are in use which is problematic and therefore suggests the following hazard potential classes for dams in Table 1.

Table 1: Recommended Dam Classification System Based on Hazard Potential (FEMA 2013a)

Hazard Potential Classification	Loss of Human Life	Economic Loss, Environmental Loss, and/or Disruption of Lifeline Facilities
High	Probable (one or more expected)	Yes (but not necessary for this classification)
Significant	None expected	Yes
Low	None expected	Low and generally limited to owner

Although the Minnesota regulations do not specifically require it, in practice, dam break and inundation studies are used to support assessment of the consequences of potential failure of dams in order to use a dam classification system. However, the Canadian Dam Association (CDA 2014) notes that the science of predicting tailings dam breaches and flows is relatively new, and techniques therefore limited. Additionally, the lethality of failures from TSFs may be different than for conventional dam breach flooding. For example, because the supernatant fluid and/or solids in a TSF are frequently contaminated, the incremental environmental consequences may be worse for a sunny day failure than a flood induced failure.

The CDA (2014) recommends a more detailed approach to dam classification for dams and mentions the following specifically for TSFs:

- Since many mining dams are remote from population centers, the potential for loss of life is often not as prevalent as it is for conventional dams. There could be occasions where there are people in the area downstream of the dam temporarily due to seasonal cottages, roads and highways, rail corridors, and recreational activities.
- Mining dams can also have the special case where the failure could threaten employees of the mine working downstream of the mining dam, such as in an open pit mine. In this instance, the training of the mine staff can be considered with respect to evacuation procedures and the potential for reducing the potential for loss of life.
- Environmental losses are often the most significant aspect of a mining dam failure. Specific studies may be required to predict the degree of environmental loss.
- The economic losses to a mining company can be substantial and may be much larger than the direct financial burden associated with a failure. Failures of mining dams can result in lost production, have a negative impact on the market capitalization of a company, and limit the ability of the company to engage in other mining projects.

- Mining dam failures can result in loss of site infrastructure such as roads, pump stations, power lines, and pipelines.

The CDA recommends a dam classification approach that also can be used to provide guidance on the standard of care expected of dam owners and designers. As loss of life is difficult to predict, it considers both population at risk as well as loss of life. It also separately considers environmental and cultural values from infrastructure and economics. The approach is presented in Table 2.

The CDA notes that:

- Because of the difficulty in predicting the environmental and ecosystem effects from accidental releases, it is often necessary to be on the conservative side when applying dam classifications.
- The owner must also consider the other consequences, as described above that the dam presents to their operation when establishing the risk profile and although this may not change the classification, the risk profile could have a bearing on the surveillance activities and design criteria

By definition, because the catastrophic failure of TSFs can result in the loss of life and is considered a serious hazard, TSFs are generally considered to be in the highest hazard category, or Class I in the case of Minnesota's classification system. Minnesota should consider revising its requirements to reflect current practice for TSF by adopting a more detailed and specific hazard classification system such as that recommended by the CDA, including a requirement for inundation studies using methods consistent with, and in consideration of further aspects specific to TSFs as provided in CDA (2014) guidance.

b. Performance Standards

Minnesota addresses dam safety in subpart 8. Performance standards which follows:

Subp. 8. Permit standards. Approval or denial shall be based on the potential hazards to the health, safety, and welfare of the public and the environment including probable future development of the area downstream or upstream. The applicant may be required to take measures to reduce risks, and the commissioner shall furnish information and recommendations to local governments for present and future land use controls to minimize risks to downstream areas.

The commissioner shall determine if the proposal is adequate with respect to:

A. For Class I, a showing of lack of other suitable feasible and practical alternative sites, and economic hardship which would have a major adverse effect on population and socioeconomic base of the area affected.

B. For Class II, a showing of lack of other suitable feasible and practical alternative sites and that the dam will benefit the population or socioeconomic base of the area involved.

C. The need in terms of quantifiable benefits.

D. The stability of the dam, foundation, abutments, and impoundment under all conditions of construction and operation, including consideration of liquefaction, shear, or seepage failure, overturning, sliding, overstressing and excessive deformation, under all loading conditions including earthquake. This determination must be based on current, prudent engineering practice, and the degree of conservatism employed must depend on hazards.

E. Discharge and/or storage capacity capable of handling the design flood based on current, prudent engineering practice and the hazard classification.

F. Compliance with prudent, current environmental practice throughout its existence.

Table 2: CDA TSF Dam Classification (Source: CDA 2013, 2014)

Dam class	Population at risk [note 1]	Incremental losses		
		Loss of life [note 2]	**Environmental and cultural values**	**Infrastructure and economics**
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary only	Unspecified	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes
High	Permanent	10 or fewer	Significant loss or deterioration of *important* fish or wildlife habitat Restoration or compensation in kind highly possible	High economic losses affecting infrastructure, public transportation, and commercial facilities
Very high	Permanent	100 or fewer	Significant loss or deterioration of *critical* fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances)
Extreme	Permanent	More than 100	Major loss of *critical* fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances)

Note 1. Definitions for population at risk:

None—There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.

Temporary—People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

Permanent—The population at risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 2. Implications for loss of life:

Unspecified—The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

In our experience the federal agencies and most state agencies use a more prescriptive, standards based approach to dam safety performance standards. The CDA (2013) describes the traditional standards-based approach as follows:

"Established practice in safety assessment of dams relies mainly on a standards-based approach deterministic concept, largely because it is computationally straightforward; provides the reassurance of a well-known method; and uses numerical measures, such as safety factors. The deterministic approach requires the determination of stability or stress state for a critical region the dam or its foundation. These states are typically analyzed for a set of usual, unusual, and extreme load combinations. The deterministic loads and resulting stresses are then related to the deterministic ultimate stability and failure criteria. The quantitative definitions of the factors of safety are determined primarily by empirical evidence, experience, and engineering judgment.

A deterministic design or assessment of unique structures is typically based on either (i) worst case values for the input variables or (ii) nominal values with a safety factor applied to the results Thus, the approach accounts for uncertainty by

- Assuming conservative (extreme) values for the loads
- Assuming conservative (safe) values for resistance variables
- Applying conservative safety factors

The usual (normal), unusual, and extreme cases can be considered from the perspective of exceedance probability. The most critical loads-seismic and hydrotechnical-are to some extent characterized on the basis of statistics, reliability theory, and probability. In this way, the deterministic approach has been gradually transformed to a semi-probabilistic concept. The calibration and numerous simplifications introduced in the final format of a standards-based procedure are often hidden in the background, and thus the deterministic method may be called prescriptive.

It should be noted that a particular factor of safety is physically meaningful only with respect to given design assumptions and equations. Engineering guidelines or regulations may provide precise instructions for calculation of the factor of safety. This ensures a certain uniformity of approach on the part of different designers. However, practising engineers must have a full understanding of the actual reliability assessment methods and meanings of factors used to express the safety, durability, and serviceability of structural components."

i. Seismic Criteria

Table 3, from CDA's *Application of CDA Dam Safety Guidelines to Mining Dams* provides suggested target levels that can generally be applied to the Construction, Operation, and Transition Phases of a TSF. CDA suggests that these are intended for consideration and consultation between the owner and regulator, and that the owner may adopt, or regulations may require, more stringent criteria. The CDA also notes that for TSFs, crest deformations could be much larger compared to conventional dams, and result in release of contents. They suggest that "criteria should be established for suitable deformations of a mining dam and the appropriate analyses undertaken to demonstrate the effect of an earthquake on the dam and determine if the deformation criteria is met."

Table 3: Target Levels for Earthquake Hazards, Standards-Based Assessments, for Construction, Operation, and Transition Phases (For Initial Consideration and Consultation Between Owner and Regulator) (From CDA 2014)

Dam Classification	Annual Exceedance Probability – Earthquakes (note 1)
Low	1/100 AEP
Significant	Between 1/100 and 1/1,000
High	1/2,475 (note 2)
Very High	1/2 Between 1/2,475 (note 2) and 1/10,000 or MCE (note 3)
Extreme	1/10,000 or MCE (note 3)

Notes:

Acronyms: MCE, Maximum Credible Earthquake; AEP, annual exceedance probability

1. Mean values of the estimated range in AEP levels for earthquakes should be used. The earthquake(s) with the AEP as defined above is(are) then input as the contributory earthquake(s) to develop the Earthquake Design Ground Motion (EDGM) parameters as described in Section 6.5 of the *Dam Safety Guidelines* (CDA 2013).
2. This level has been selected for consistency with seismic design levels given in the National Building Code of Canada.
3. MCE has no associated AEP.

ii. Geotechnical

CDA (2014) recommends target levels related to slope stability for static and seismic conditions in Tables 4 and 5.

Table 4: Target Factors of Safety for Slope Stability in Construction, Operation, and Transition Phases - Static Assessment (From CDA 2014)

Loading Condition	Minimum Factor of Safety	Slope
During or at end of construction	> 1.3 depending on risk assessment during construction	Typically downstream
Long term (steady state seepage, normal reservoir level)	1.5	Downstream
Full or partial rapid drawdown	1.2 to 1.3	Upstream slope where applicable

Table 5: Target Factors of Safety for Slope Stability in Construction, Operation, and Transition Phases - Seismic Assessment (From CDA 2014)

Loading Condition	Minimum Factor of Safety
Pseudo-static	1.0
Post-earthquake	1.2

The CDA (2014) notes that "A factor of safety of 1.3 may be acceptable during construction of a dam where the consequences could be minor and measures are taken during construction to manage the risk such as detailed inspection, instrumentation, etc. But, the factor of safety of 1.3 should not simply be adopted because it is "End of construction." A factor of safety of 1.5 has typically been adopted for tailings dams because of the potential consequences of failure. Therefore, when setting the design criteria for the dam, these target levels can be considered, but the risks associated with instability of the dam also need to be considered."

The CDA (2014) also notes the following unique aspects of TSFs with respect to geotechnical design:

- The design, construction, and operation of tailings dams often use the observational method due to the long construction period and opportunities to review actual conditions.
- Loading on a dam shell from an upstream tailings beach needs to be accounted for in stability assessments.
- Liquefaction of tailings upstream of the dam needs to be considered in stability assessments.
- Mine waste is often used in the structural portion of a mining dam and this requires special care with respect to the design of filters and transition zones to protect the seepage control elements of the dam.
- Geochemical processes (often acid rock drainage or metal leaching) can clog filters and drains through precipitate accumulation. While this can also occur with conventional dams, it is more prevalent in mining dams that contain materials with acid rock drainage generation potential. The rate of clogging and the time that the drains are required to operate may greatly exceed those typical of conventional water storage dams. Cementing of soil into a "hard pan" can affect the seepage conditions in a dam.
- Decant structures and/or pipes embedded in embankments in general are potential pathways for seepage. The deterioration of pipes through dams is a well-known cause of several mining dam failures. Development of preferential seepage paths and arching zone(s) are also notable safety hazards. For decant pipes with intermittent discharge, frost action can also create seepage pathways around the pipes. Hence, these structures need to either be avoided or designed and constructed with a high level of care, including redundant protective measures.
- Mining dams are often located near other infrastructure such as open pits and underground workings. The consequences of failure of such mining dams require careful consideration. Also, the potential interaction of the mining operations (i.e. blasting or large waste rock dumps) on the mining dams must be assessed.
- Subsidence of ground beneath a mining dam can occur due to underground workings that may not have been detected prior to the design and construction of the dam.
- Piping can occur into underground workings with caving occurring upward into the tailings.
- Design for thickened tailings discharge facilities.
- Geosynthetics are often considered for mining dams because of limited construction materials, but these must be used judiciously when considering structures that will have to last a long time.
- Design should be flexible to accommodate variability and availability of construction materials throughout the life of a tailings dam.
- Instrumentation monitoring, recording between raises, damage to instrumentation during construction or mine operations.
- The use of impervious membranes for lined ponds that also require measures to prevent wildlife from getting trapped in the ponds and causing damage to the liners.
- Vandalism, particularly recreational vehicles that can cause damage to closed site dams.

iii. State and Other Approaches

Montana and New Mexico provide two examples of prescriptive state requirements for seismic and geotechnical performance standards for TSFs, as do requirements for the province of British Columbia. The requirements for Montana and British Columbia were formulated based in part on the recommendations of the Mount Polley Independent Engineering Review Panel (IERP). The requirements are shown in Table 6.

Table 6: Seismic and Geotechnical Requirements – Montana[1], New Mexico[2], British Columbia[3]

State	Design Criteria	
	Minimum Seismic Event	Factor of Safety – Static
Montana	1-in-10,000-year event, or the maximum credible earthquake, whichever is larger	During Construction, 1.3 Normal Operating, 1.5 Post-Earthquake, 1.2 (loss of containment) Post-Earthquake, 1.0 (no loss of containment)
New Mexico	Dams classified as high hazard potential other than flood control structures shall be designed for the maximum credible earthquake or for a 1% probability of exceedance in 50 years (approximately 5000-year return frequency).	End of Construction, 1.3 Operational Drawdown, 1.5 Rapid Drawdown, 1.3 Steady-state Long-term, 1.5
British Columbia, CAN	minimum seismic design criteria shall be a return period of 1 in 2475 years for dam classification of low-high, ½ between 1/2475 and 1/10,000 or MCE for dam classification of very high to extreme.	End of Construction, 1.5 Long-term, 1.5 Full or Partial Drawdown, 1.5

iv. Hydrology

1. Inflow Design Flood

Surface water estimation related to flood flows (e.g. most extreme event) is presently performed using either deterministic approaches or based on risk analysis. The deterministic, or traditional standards-based approach is based on historic meteorological data and computational approaches to establish precipitation estimates, including Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) estimates, as well as estimates based on various return intervals (5, 10, 25, 100, 500 year). The

[1] Montana's Metal Mine Reclamation Act (MMRA) amended 2015. §82-4. Section 5. http://leg.mt.gov/bills/mca_toc/82_4_3.htm
[2] New Mexico Office of State Engineer, Part 12 Dam Design, Construction & Dam Safety (2010). §19.25.12.11 http://www.ose.state.nm.us/DS/Regs/19-25-12-NMAC-2010%202016-05-27.pdf
[3] British Columbia Health, Safety and Reclamation Code, Part 10 Revisions (2016). §10.1.8 http://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/health-safety/health-safety-and-reclamation-code-for-mines-in-british-columbia

risk analysis approach uses either a quantitative or qualitative or risk assessment technique. Quantitative risk assessment mathematically calculates estimates of risk, but it requires data upon which to estimate risk, is highly complex, and the current state-of-knowledge is limited (CDA 2013). Qualitative risk assessment characterizes uncertainty in more general terms and uses methods for indexing, scoring and ranking risk factors. The most common example used in TSF design is the MAA process. Robertson (2012) and others have long advocated for the use of various alternatives analysis assessment methods which has resulted in the development and widespread adoption of the Multiple Accounts Analysis (MAA) process for TSF sites, and more recently TSF technology and design selection. Today the process is both well-defined and in common use, particularly in Canada where it is required. Environment Canada's *Guidelines for the Assessment of Alternatives for Mine Waste Disposal*[4] summarizes the MAA process as it would apply to TSF selection. The deterministic approach is the most accepted approach for dam design and assessment, however the use of a risk-based approach is becoming more widely used and is recommended where appropriate as noted in the following section.

The Inflow Design Flood (IDF) is the most severe inflow flood for which a TSF or associated facilities are designed and should be considered applicable to the construction, operation, and transition phases (CDA 2014). In selecting an IDF the risks of hydrologic failure of a TSF should be balanced with the potential downstream consequences. Current practice is described in FEMA's Federal Guidelines for Selecting and Accommodating Inflow Design Floods for Dams which was first published in 1986 and most recently updated in 2013. FEMA (2013) notes that no single approach to selection of an IDF is adequate given the unique situations of each site, and therefore recommends the following approaches:

Prescriptive Approach – In this initial phase, a planned dam is designed or an existing dam is evaluated for a prescribed standard based on the hazard potential classification of the dam. This approach is intended to be conservative to allow for efficiency of resource utilization while providing reasonable assurance of the safety of the public. It is not intended to assure that there is an economical marginal benefit from designing for a conservative IDF.

Site-specific PMP Studies (Refinement of the Prescriptive Approach) – The prescriptive approach relies upon determination of a PMF for high hazard dams which requires assessment of the PMP. The most common sources of the PMP information are the regional HMRs published by the NWS. These reports provide generalized rainfall values that are not basin-specific and tend to represent the largest PMP values across broad regions. Most of these reports have not been updated to reflect current state-of-the-art knowledge and technology. A site-specific study of the PMP/PMF using current techniques can result in a more appropriate estimate of the PMF for consideration as the IDF.

Incremental Consequence Analysis – The volume of many reservoirs may be small in comparison to the volume of the hydrologic events to which they may be subjected. In these cases, the IDF can be established by identifying the flood for which the downstream consequences with and without failure are not significantly different.

Risk-informed Decision Making – This method allows a dam owner or regulator to consider the risk associated with hydrologic performance of dams relative to other dam safety risks at the same dam, across a portfolio of dams, or in comparison to societal risks in general. In this method, the IDF is selected as the design flood which assures that a given level of "tolerable risk" is not exceeded. The strengths of this method include providing dam owners and regulators the ability to assess the marginal

[4] https://ec.gc.ca/pollution/default.asp?lang=En&n=125349F7-1&offset=2&toc=show

value of increasing levels of flood protection, balancing capital investment in risk reduction across a number of different failure modes, and prioritizing risk reduction actions across a portfolio of dams.

2. Prescriptive Approach

FEMA (2013a) recommends prescriptive IDF criteria corresponding to the hazard potential classification described in Table 1 in Table 7.

FMEA (2013a) notes that, "When selecting an IDF based on either probabilistic or PMP concepts, it should be recognized that these values are derived using limited information. Accordingly, such estimates are not fixed but inherently have a margin of uncertainty. As science evolves and additional data is collected, precipitation estimates and frequency of floods can change. The occurrence of events greater in magnitude than had been previously recorded in a specific location or region can cause such estimates to increase. This uncertainty in the foundation data is combined with the uncertainty inherent in modeling a postulated, rather than actual, event. Practitioners should be aware of this and, when possible, select IDFs that consider this reality. In all cases, an appropriate IDF selection should be performed, or directed and reviewed by a registered professional engineer experienced in hydrology and hydraulics."

Table 7: IDF Requirements for Dams Using a Prescriptive Approach (FEMA 2013a)

Hazard Potential Classification	Definition of Hazard Potential Classification	Inflow Design Flood
High	Probable loss of life due to dam failure or mis-operation (economic loss, environmental damage, or disruption of lifeline facilities may also be probable, but are not necessary for this classification)	PMF[1]
Significant	No probable loss of human life but can cause economic loss, environmental damage, or disruption of lifeline facilities due to dam failure or mis-operation	0.1% Annual Chance Exceedance Flood (1,000-year Flood)[2]
Low	No probable loss of human life and low economic and/or environmental losses due to dam failure or mis-operation	1% Annual Chance Exceedance Flood (100-year Flood) or a smaller flood justified by rationale

(1) Incremental consequence analysis or risk-informed decision making may be used to evaluate the potential for selecting an IDF lower than the prescribed standard. An IDF less than the 0.2% annual chance exceedance flood (500-year flood) is not recommended.

(2) Incremental consequence analysis or risk-informed decision-making studies may be used to evaluate the potential for selecting an IDF lower than the prescribed standard. An IDF less than the 1% annual chance exceedance flood (100-year flood) is not recommended.

Based on CDA's use of five hazard potential classifications as shown in Table 2, the CDA (2014) recommends target levels for the inflow design of TSFs described in Table 8. CDA also suggests that "…the dam classification and the associated target levels shown…" in Table 2 "…should be considered when developing the design criteria. In addition, the mining dam owner will want to factor in other risks and may choose to adopt more stringent design criteria than suggested by the classification alone."

Table 8: Target Levels for Flood Hazards, Standards-Based Assessments, for Construction, Operation, and Transition Phases (CDA 2014)

(For Initial Consideration and Consultation Between Owner and Regulator)

Dam Classification	Annual Exceedance Probability – Floods (note 1)
Low	1/100
Significant	Between 1/100 and 1/1,000 (note 2)
High	1/3 Between 1/1,000 and PMF (note 3)
Very High	2/3 Between 1/1,000 and PMF (note 3)
Extreme	PMF (note 3)

Notes:
Acronyms: PMF, Probable Maximum Flood; AEP, annual exceedance probability
1. Simple extrapolation of flood statistics beyond 10^{-3} AEP is not acceptable.
2. Selected on basis of incremental flood analysis, exposure, and consequences of failure.
3. PMF has no associated AEP.

3. Mount Polley Independent Expert Review Panel Findings

In August 2014, the Mount Polley Mine tailings facility breached, resulting in a catastrophic release of tailings that was previously considered unlikely due to the circumstances of it occurring in what is touted as one of the more progressively regulated jurisdictions (British Columbia - BC) at a mine operated by a rising and supposedly highly capable Canadian based mining company (Imperial Metals) and designed and inspected by leading engineering firms (Knight Piésold and AMEC). The event was considered by the industry and associated engineering consultants as a highly significant event. The need for conservative and proactive measures for the design, operation and closure of tailings facilities has since been further reinforced by the even more catastrophic failure that occurred at the Samarco tailings facility in Brazil in November 2015.

The Mount Polley Independent Expert Review Panel (IERP), consisting of three leading experts in the geotechnical stability of mine tailings facilities, was convened by the BC Government to address the minimization and elimination of the risk of similar failures from tailings facilities. The Panel Report was issued in January 2015 and included recommendations that can be grouped into the following seven areas:

1. Implement Best Available Practices (BAP) and Best Available Technologies (BAT) using a phased approach,
2. Improve corporate governance,
3. Expand corporate design commitments,
4. Enhance validation of safety and regulation of all phases of a TSF,
5. Strengthen current regulatory operations,
6. Improve professional practice, and
7. Improve dam safety guidelines

Table 9 summarizes the Panel recommendations and the British Columbia regulatory revisions. For comparison purposes, Table 1 also includes the revisions made to Montana's Metal Mine Reclamation Act (MMRA) in 2015 intended to address the Panel recommendations, and the existing Minnesota regulations.

a. Implement Best Available Practices (BAP) and Best Available Technologies (BAT) using a phased approach

The Panel recommended using Best Available Practices (BAP) to address existing TSFs, and recommended using Best Available Technology (BAT). They further recommended applying BAT principles to closure of active impoundments to eliminate risk. The Panel identified the three principles of BAT as: no surface water; unsaturated conditions, and; achieve dilatant conditions by compaction. The Panel further identified backfilling of mined out pits or underground workings as being the most direct method, but otherwise identified "filtered tailings" technology as the primary BAT. In doing so, the Panel suggested that "There are no overriding technical impediments to more widespread adoption of filtered tailings technology" and "While economic factors cannot be neglected, neither can they continue to pre-empt best technology."

The BC Revisions define BAT as "the site-specific combination of technologies and techniques that most effectively reduce the physical, geochemical, ecological and social risks associated with tailings storage during all stages of operation and closure." The BC Revisions incorporate a "combination of technologies" to "reduce" risk during all stages of the TSF life-cycle. The BC revisions do not include or identify the BAT principles identified by the Panel, or filtered tailings as the prime BAT with cost as a secondary factor. The BC Revisions are not consistent with the Panel recommendations. They do not provide the underlying BAT principles or identify BAT technology to "prevent" or achieve zero risk of TSF failures, but instead the approach uses site specific technologies and techniques to "reduce" the risk of TSF failures.

It is important to note that subsequent to the Panel report, BC regulators had engaged in additional discussions with Dirk van Zyl, one of the three Panel members, whom has issued a letter suggesting he favors the approach being taken by BC regulators consistent with industry recommendations. In response, Steve Vick, another Panel member, has provided comments suggesting that the Panel recommendations were to achieve zero risk by the use of primary BAT and that any compromise will result in further avoidable TSF failures. Those communications are attached as Appendix A to these comments in the interest of ensuring that the views of the IERP and Dr. van Zyl are available for consideration by the public and the regulators that may otherwise depend on them to be representative of the IERPs views.[5]

The MT MMRA Revision requires "an evaluation indicating that the proposed tailings storage facility will be designed, operated, monitored, and closed using the most applicable, appropriate, and current technologies and techniques practicable given site-specific conditions and concerns" and defines "practicable" as "available and capable of being implemented after taking into consideration cost, existing technology, and logistics in light of overall project purposes." The MMRA revisions do not include or identify the BAT principles identified by the Panel, or filtered tailings as the prime BAT. The MT MMRA Revisions do not appear to be consistent with the Panel recommendations in that they do not provide the underlying BAT principles or identify BAT technology to "prevent" or achieve zero risk of

[5] Communications can be provided.

TSF failures, but instead present the approach favored by industry which is to use site specific technologies and techniques to "reduce" the risk of TSF failures.

Minnesota's regulations, typical to most if not all other U.S. State regulations with the exception of Montana's recent revisions, do not address either BAP or BAT or the need to evaluate them to either reduce or prevent risk of catastrophic failures.

b. Improve corporate governance

The Panel recommended that corporations operating TSFs should be required to be a member of the Mining Association of Canada (MAC) or be obliged to commit to an equivalent program for tailings management, including the audit function.

The MAC, in response to issues presented by TSFs worldwide owned by Canadian based corporations, developed guidelines for tailings management that are considered worldwide as best management practice (BMP). This includes: A Guide to the Management of Tailings Facilities; Developing an Operation, Maintenance and Surveillance Manual for Tailings and Water Management Facilities, and; A Guide to the Audit and Assessment of Tailings Facility Management.[6] The Tailings Management Protocol was updated in 2015 and an additional update is expected in 2016, in part implementing Panel recommendations for corporate governance.

The BC Revisions fall short of the Panel recommendations in that while they require the mine manager to "consider" the HSRC Guidance Document, it does not require they be a member of MAC or be obliged to commit to an equivalent program.

The MT MMRA Revisions require a description of proposed risk management measures. They fall far short of the Panel recommendation and require no obligation to a program equivalent to those required of MAC members. There are no equivalent U.S. based industry or professional groups that have developed equivalent tailings management guidance or that similarly oblige their members to commit to an equivalent program.

The Minnesota regulations address "measures to reduce risk" however typical to most if not all other U.S. State regulations including Montana's recent revisions, do not address or provide stringent and current requirements for tailings management similar to those contained in MAC guidance and member obligations.

c. Expand corporate design commitments

The Panel recommended that new TSFs "should be based on a bankable feasibility study and consider all technical, environmental, social and economic aspects of the project in sufficient detail to support an investment decision" and should contain a failure modes and effects analysis, cost/benefit analysis of BAT tailings and closure options with the caveat the cost/benefit should not super-cede safety considerations, and detailed and declared Quantitative Performance Objectives (QPOs).

The BC Revisions are for the most part consistent with the Panel's recommendations. They require risk assessment and management, an alternatives assessment of best available technology, and QPO's. The

[6] http://mining.ca/towards-sustainable-mining/protocols-frameworks/tailings-management

primary difference with the Panel recommendations is that the alternatives assessment does not specifically require that safety considerations must not super-cede cost/benefit considerations.

The MT MMRA revisions are for the most part consistent with the Panel's recommendations. They require a failure modes effects analysis, QPO's and risk management measures. The primary difference with the Panel recommendations is that the MMRA revisions do not specifically require that safety considerations must not super-cede cost/benefit considerations.

The Minnesota regulations do not require a failure modes effects analysis, BAT cost-benefit analysis, or QPOs, similar to most if not all other U.S. State regulations with the exception of Montana's recent revisions. Typical to water reservoirs, they do require analysis of a dam break flood as a result of dam failure.

d. Enhance validation of safety and regulation of all phases of a TSF

The Panel recommended that Independent Tailings Review Boards (ITRBs) be utilized together with QPOs to improve safety and regulation of all phases of TSFs.

The BC Revisions require an ITRB and the submission of the terms of reference and qualifications for board members for approval. The BC revisions also requires a report of the activities of the ITRB, confirmation and incorporation of ITRB recommendations, and assurance that the report is a true and accurate representation of their reviews. The BC Revisions do not address the use of QPOs to improve regulator evaluation of TSFs. The BC Revisions do not address the requirements for ITRB members to be independent of the proponent.

The MT MMRA Revisions require an ITRB and the submission and approval of board members. The MT MMRA Revisions do not require the submission and approval of the terms of reference for the ITRB. The MT MMRA revisions require that "The panel shall review the design document, underlying analysis, and assumptions for consistency with this part. The panel shall assess the practicable application of current technology in the proposed design. (9) The panel shall submit its review and any recommended modifications to the operator or permit applicant and the department. The panel's determination is conclusive. The report must be signed by each panel member." The MT MMRA Revisions do not address the use of QPOs to improve regulator evaluation of TSFs.

The Minnesota regulations do not address either ITRBs or use of QPOs in regulator evaluation.

e. Strengthen current regulatory operations

The Panel recommended that inspections be performed at all existing TSFs to ascertain whether they may be a risk and require appropriate actions due to specific failure modes: filter adequacy; water balance adequacy; undrained shear failure of silt and clay foundations.

The BC government required inspections to be completed and submitted by June 30, 2015 to comply with the Panel's recommendations.

The Montana MMRA Revisions do not require inspections for this purpose although the requirement for both annual EOR and independent audit inspections can be construed as requiring these failure modes be addressed. The Minnesota regulations do not require inspections specific to these failure modes.

f. Improve professional practice

The Panel encouraged the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) to develop guidelines that would lead to improved site characterization for tailings dams with respect to the geological, geomorphological, hydrogeological and possibly seismotectonic characteristics.

The APEGBC developed and published Site Characterization for Dam Foundations in BC in August 2016, including a section on seismotectonic conditions.

There are no equivalent U.S. or Minnesota based industry or professional groups that have developed equivalent site characterization guidance for either dams or TSFs.

g. Improve dam safety guidelines

The Panel, recognizing limitations of current Canadian Dam Association guidelines, recommended that dam safety guidance be developed specific to the conditions encountered with TSFs in British Columbia and incorporated as a statutory requirement. The Montana and BC dam safety regulations include prescriptive and specific design criteria requirements for TSFs. The Minnesota regulations rely on the consideration of alternative sites and the determination of dam safety by “current, prudent engineering practice.”

4. Northmet TSF Engineering Analysis and Reviews

The Northmet Dam Safety Permit Application (NDSPA) prepared by Barr and dated May 2017 addresses the classification of the TSF, dam break analysis, and performance standards.

a. TSF Classification

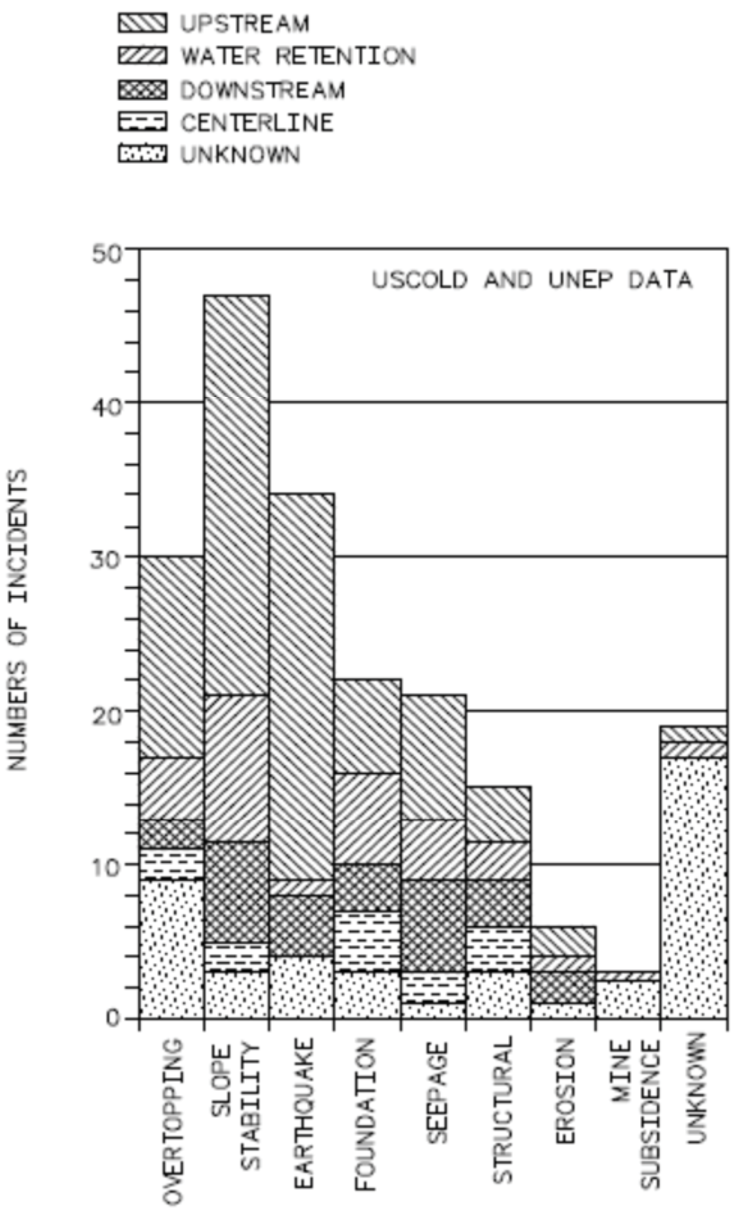
According to the NDSPA (p. 9), “The FTB dams have been designed to achieve necessary factors of safety, so a dam break is unlikely.” It goes on to say that “A dam break analysis was completed to understand the potential extent of flood inundation between the FTB and the Embarrass River in the unlikely event of a failure at the dam.” Based on these premises, the report concludes “The FTB dams can be categorized as Class I or Class II dams.”

We find this approach, particularly as it speaks for the assumptions used by the design engineer, to be highly concerning as it suggests the design engineer has not taken into account all failure modes that can cause a catastrophic dam breach, many of which are independent of design factors of safety. Similarly, the recent Mount Polley and Samarco (Brazil) TSF catastrophic failures were considered to be “unlikely,” if not impossible, until they occurred. In our experience and professional judgment, a more accurate portrayal would be to consider all potential failure modes and identify TSF failure as “possible” and would likely lead to highly significant safety, environmental and economic consequences, and for that reason the TSF should be classified as Class I.

Potential failure modes related to TSFs can include both structural (geotechnical) failure modes (sliding, overtopping, internal erosion, etc.) and other modes that are non-structural in nature and are related to operations and/or environmental protection. UNEP’s, 2001, Tailings Dams Risk of Dangerous

Occurrences, Bulletin 121 is frequently cited as a reference with respect to TSF failure modes. They identified (see Figure 1) slope stability as being the primary failure mode of TSFs, followed by earthquake (seismic) and overtopping. They also identify foundation failures, seepage, structural, erosion and mine subsidence as failure modes.

Figure 1: TSF Failure Incidents by Failure Mode and Design Type (UNEP 2001)



LePoudre (XXXX) provides a more comprehensive list of Failure Modes and Contributing Factors for TSFs, noting they are partial, which includes the following:

Physical / Structural Failure Modes

Slope Failure
- Raising of Dyke
- Placement of tailings
- Undercutting
- Poor construction materials
- Over-steepening
- Direct loading
- Seismic

Foundation Failure
- Undrained loading
- Sensitivity clays
- Seepage forces
- Strength loss
- Weak layers

Surface Erosion
- Overtopping
- Runoff
- Excessive inflow
- Insufficient outflow conveyance
- Inadequate rip-rap
- Landslide into impoundment

Internal Erosion
- Piping
- Lack of adequate filter
- Zoned dams
- Sinkholes
- Unprotected conduits
- Joints/seepage in foundation/abutments

Contributing Factors for Mode of Failure

Design /Construction
- Dam type
- Materials
- Hydrology/hydrogeology
- Construction
- Outlet Structures
- Freeboard
- Foundation/ Abutments
- Chemical processes
- Biological Processes

Operation /Maintenance
- Rate of deposition
- Water Management
- Inspection / Monitoring
- Maintenance

- Chemical processes
- Biological processes

External Factors

- Human Activity
- Climate/weather
- Seismic activity
- Earth movement
- Unforeseen

The CDA (2014) identifies the following Other Failure Modes for TSFs:

- Unplanned release of contaminated water via an emergency overflow spillway.
- Release of excessive contaminated seepage down gradient of the dam.
- Contamination of groundwater.
- Excessive seepage causing the loss of water cover required over a tailings deposit to inhibit sulphide oxidation.
- Excessive erosion by wind resulting in dust releases (in the case of mining dams constructed of tailings).

It appears that the design engineer has not conducted a formal Failure Modes Effects Analysis (FMEA) to assist in the TSF design and identification of other key aspects such as operational and closure requirements to ensure TSF safety. FMEA is a form of risk analysis and risk management that has become widely used for both typical water retaining dams and for TSFs. Figure 2 shows how risk analysis, risk assessment, and risk management relate to each other.

The U.S. ACOE (2014) notes that it has moved from a solely standards-based approach for its dam safety program to a dam safety risk management approach for dams within its portfolio. They provide an extensive example of application of the approach in their policies and procedures document.

Robertson (2012) describes risk assessment and management for TSFs as “The Balance Between Experience, Judgement and Science” and suggests that an effective risk management program must include the following elements:

- Identification of all failure modes and the factors that contribute to the likelihood of occurrence of that failure mode.
- A realistic assessment of the probability and consequences – yielding a risk rating.
- A program that mitigates the risks to reduce either probability (likelihood) or consequences to tolerable levels.
- An Action Plan and Management that implements the Action Plan.

He goes on to suggest the following stages in the performance of the risk management process.

STAGE 1 – PERFORM A FMEA

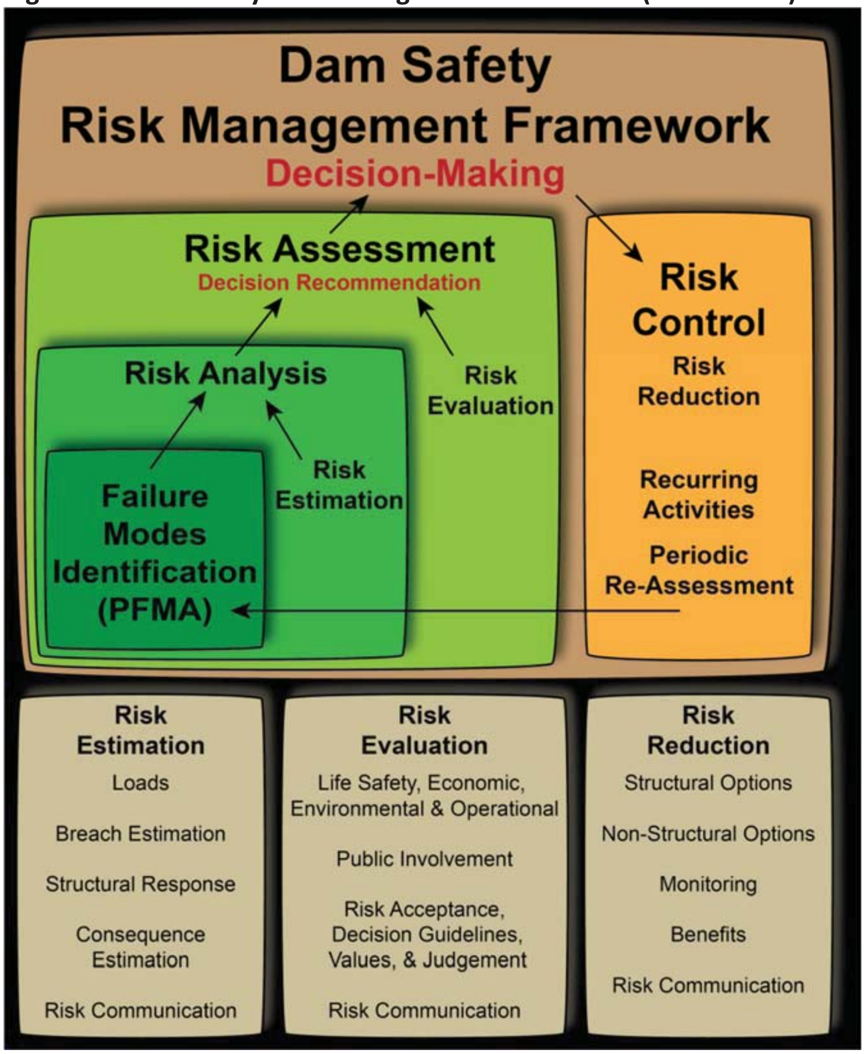
- Identify all significant failure modes
- For each: assess likelihood and consequences
- Determine Risk - see the following matrix
- Identify tolerable risk levels and failure modes with excessive risk – prioritize need for mitigation

- Identify mitigation measures that will reduce risks to tolerable limits

STAGE 2 – PERFORM RISK MITIGATION
- Develop an Action Plan, including schedule
- Implement Action Plan – Mitigate

STAGE 3 – PERFORM PERIODIC FMEA REASSESSMENTS
- Determine if Risks remain tolerable, and implement additional mitigation as required

Figure 2: Dam Safety Risk Management Framework (FEMA 2015)



b. Dam Break Analysis

According to the NDSPA (p. 9), “A dam break analysis was completed to understand the potential extent of flood inundation between the FTB and the Embarrass River in the unlikely event of a failure at the dam.” The report refers to the analysis in Appendix H but does not provide further information in support of the dam classification.

Appendix H of Attachment A of the NDSPA Flotation Tailings Basin Dam Break Analysis identifies the methodology. According to Appendix H (p. 4), “The dam break analysis focused on the north side of the FTB, because this is the section of the dam where a break would result in the shortest warning time for potentially affected downstream properties. A breach was not considered to the east or south of the FTB because a large portion of the perimeter ties into natural ground and/or no homes are within the respective downstream flow path.” The identification of “downstream properties” where a break was considered and “homes” where a breach was not considered, when it can be assumed that the downstream properties included residential homes where a breach was considered, appears to underplay the consequences of loss of life in the analysis. Appendix H (p. 5) goes on to identify piping as the selected cause of the dam break, suggesting that “Failure resulting from overtopping was not considered because the dam is designed not to be overtopped even with the volume of the 72-hour PMP event.” The Appendix (p. 6), while noting “Time to failure is a sensitive parameter for dam failure analysis,” chose to use a time to failure of three hours, suggesting that FERC’s recommendation of less than one hour seemed unrealistic based on the size of the dam and final configuration.” The Appendix (p. 8) concluded that “a dam break could increase flood elevations approximately 15 feet at the upstream end of Trimble Creek (near the FTB) and approximately 9 feet at the downstream end of Trimble Creek (at the Embarrass River)” and “that there are 34 properties along Trimble Creek or the breakout paths that could potentially be affected by a FTB dam break.” The analysis does not identify the actual number of homes on those properties or the number of lives that could be lost due to a TSF breach.

We appreciate the elements that were included in the analysis that were conservative as noted in the report (p. 7) and agree that for the type of failure analyzed “The actual extent of inundation and risk to residents and infrastructure can reasonably be anticipated to be lower than suggested by this analysis.” However, the report (p. 7) also suggests that additional analysis is not warranted “given the objective of this dam break analysis, which is to serve as an aid in development of the facility Emergency Action Plan.” An additional objective of the break analysis should be to assist in determination of the dam classification, as well as consideration of the consequence of failure in a FMEA as suggested in the preceding section.

For the dam break analysis to be truly conservative, current industry guidance and experience suggests additional consideration should be given to the analysis. The CDA (2013) recommends the evaluation address initial hydrologic conditions for the following:

- Sunny day failure – A sudden failure that occur during normal operations such as may be caused by internal erosion, piping, earthquakes, mis-operation leading to overtopping, or another event.
- Flood induced failure – A TSF failure resulting from a natural flood of a magnitude that is greater than what the dam can safely pass.

The incremental environmental consequences are often worse for a sunny day failure than a flood induced failure because of the large amount of process water and solids that are contained by TSFs (CDA 2014). The CDA (2013) recommends that simple and conservative procedures be applied to obtain a first approximation and that if necessary more detailed analysis should be conducted. The CDA (2013) suggests that TSF failure consequences should be evaluated for the following:

- Loss of Life

- Economic Losses
- Environmental Losses
- Cultural Losses
- Incremental and Total Consequences

As noted by Morgenstern et al (2015) the Mount Polley TSF failure was a blue sky or sunny day failure, and it occurred in a matter of minutes if not seconds. The failure was also compounded by process water levels that exceeded freeboard requirements and contributed significantly to the extent of the failure. And while it did not result in the loss of human life, that was only by coincidence. The Samarco TSF failure, which was also sudden, did result in significant loss of human life.

The Northmet TSFs breach analysis should include consideration of a sunny day failure that occurs within a short amount of time (minutes). It should further identify the number of homes and corresponding population and estimate the potential loss of life in the event of a worst-case TSF failure. This information should be used not only to inform the ERP, but also to inform the TSF design process, including a FMEA.

c. Permit Standards

According to the NDSPA (p. 10) the permit standards were previously submitted to DNR and a "Large Table" is referenced. The Large Table shows that ARM 6115.0410 (8)(D) is addressed in Geotechnical Data Package Volume 1 (Appendix B) Section 7.3, pages 102-115 and 6115.0410 (8)(E) is addressed in Flotation Tailings Management Plan (Appendix A) Section 3.3, page 20 and Attachment H.

i. Geotechnical

Geotechnical Data Package Volume 1 (Appendix B) Section 7.3 does not identify the source for the geotechnical design standards that were used for the Flotation TSF. Appendix B (p. 10) identifies the seismic design event as using a 2,475-year return period. Also, according to Appendix B (p. 93) "The proposed FTB dams have been configured to have safety factors equal to or greater than 1.5 for drained (ESSA) conditions, equal to or greater than 1.3 for undrained ($USSA_{yield}$) conditions, and equal to or greater than 1.1 for liquefied ($USSA_{liq}$) conditions.

The seismic design event using a 2,475-year return period does not reflect current best practice. As previously noted (see Table 6), Montana's MMRA requires a minimum seismic event for a 1-in-10,000-year event, or the maximum credible earthquake, whichever is larger and British Columbia requires that the minimum seismic design criteria shall be a return period of 1 in 2475 years for dam classification of low-high, ½ between 1/2475 and 1/10,000 or MCE for dam classification of very high to extreme. Given the significant potential for loss of human life without additional information we would suggest the TSF classification and corresponding seismic design event should be considered highly conservatively and consistent with the practice of those jurisdictions that have considered the recommendations of the Mount Polley IERP.

Notwithstanding the inadequacy of the seismic design criteria, the analysis does appear to consider Target FOSs equivalent to those recommended by the CDA and regulatory requirements such as for Montana and British Columbia. Review of the stability modeling results suggests that with the exception of the operations modeled FOS of 1.10, application of the recommended MCE is unlikely to result in any of the other FOS being below the Target FOSs.

ii. Hydrology

According to the Flotation Tailings Management Plan (Appendix A) (p. 7, 13, 20) the design incorporated the Probable Maximum Precipitation (PMP), the stability analysis considered the effects of the PMP event, and the dam break analysis was based on a 72-hour PMP event, which is consistent with current best practice.

5. EOR Review Team

EOR, Minnesota DNR's contractor, assembled a Review Team to supplement the review process, which is described in a memo titled PolyMet Dam Safety Permit Application Review and dated May 15, 2017. According to the memo (p. 1) "The review approach focused on key elements similar to tailings basin review panels required by law in Montana and other western states." The memo identifies Dirk van Zyl and Steve Gale, both professional engineers (PEs), as members of the review team but does not identify other participants either from EOR or DNR. The Review Team's scope consisted of review of documents, site visit and discussion with Polymet and TSF designers, Review meetings with DNR, and presentation of a Draft Report and preparation of a Final Report.

The EOR Review Team comments included the following:

- The EOR Team concluded that the permit application lacks the detail and description of contingencies for the Observational Method to be effective. If monitoring data indicate a potentially unsafe condition during construction, then the alternate construction methods and designs (contingencies) must be already in place so that they can be implemented immediately.

- 0The former LTV tailings basin was constructed over layers of peat in some areas. Layers of slimes (very fine-grained taconite tailings) were also included in the construction of the tailings basin dam. Both peat layers and slimes layers have very low shear strength, which could potentially contribute to a dam failure. The tailings basin can be designed to safely mitigate for these conditions, but the areas with peat and slimes must be well-defined and tested. The EOR Team commented that additional data should be gathered on the peat layers and slime layers, and that the design may need to be modified in the future in accordance with the Observational Method.

- As currently designed, a pond of water will be maintained on top of the tailings basin in perpetuity. The EOR Review Team recommended that a water pocket distance of less than 625 feet (or in direct contact with the tailings dam) be analyzed as an event/condition of the Observational Method approach.

- To minimize water seepage from the tailings basin, bentonite will be added to the soils at the top of the basin during the closure and reclamation process. The permit application only lists alternatives for placing the bentonite that will be pilot tested and field tested later. The EOR Review Team commented on specific elements that should be included in the field testing that would impact the permeability of the bentonite amended tailings. Once the preferred bentonite application method is selected, the EOR Review Team recommended developing material and installation specifications and a detailed protocol for both a laboratory and a field pilot study.

- EOR Review Team commented that some of the geotechnical test results (i.e. low coarse tailings friction angles) were excluded from the statistical analyses. Because of their importance in the overall stability of the basin, the EOR Review Team recommended that coarse tailings friction angles be considered as a variable condition in the Observational Method process. This would also provide a consistent and proper procedure for future analyses.

- Wet closure has ongoing costs like; maintaining water levels to prevent flooding and drying out, erosion repair, treatment of discharged water and on-going monitoring. Dry closure (no water ponding) requires a greater initial investment, but has much lower ongoing maintenance costs and less long-term environmental risk. The EOR Review Team did not proposed dry closure as a permit requirement at this time. The EOR Review Team recommended that if the wet closure is permitted, the DNR should require PolyMet to continually review the current state-of-the-practice for dry closure techniques prior to starting any tailings basin closure activities.

- HydroMet Residue Facility - The soft ground beneath the proposed residue facility consists of up to 30 feet of slimes, peat and tailings concentrate. This will not be an adequate foundation for the 80-foot-high basin. Three potential remediation alternatives have been considered:
  - Pre-loading the existing material with 50 feet of rock and soil to compress and consolidate the underlying material. This is the method currently proposed by PolyMet.
  - Installing wick drains that will allow water to flow out of the existing material, thereby increasing its shear strength.
  - Removing the existing material and any soft soils before constructing the basin.
  - The basin will have a geomembrane or geosynthetic liner. The liner could deform and fail if the existing underlying material cannot support the material added to the basin.

- The EOR Review Team commented that the proposed pre-load design should be re-evaluated to determine if it will adequately surcharge and compress the existing material.

The EOR Review Team recommended that the comments and issues be addressed pre-permit, post-permit and made a condition of the permit, or addressed pre-construction.

The inclusion of Dirk van Zyl as an EOR review team member is notable. He was one of the three Mount Polley IERP members, but as noted previously in Section 3.a., he has also chosen to distance himself from the findings of the IERP by advocating for a less conservative approach to TSF's than the IERP, particularly with respect to the recommendation for filtered dry stack tailings as BAT for new TSFs. In this case, he also advocates for a wet closure approach which also contradicts the recommendations of the Mount Polley IERP which advocated for dry closure - for existing TSFs the Panel identified the three principles of BAT as: no surface water; unsaturated conditions, and; achieve dilatant conditions by compaction. While we respect van Zyl's professional expertise and opinions and work with him in numerous forums, we find it necessary to note his difference of opinion from that of the IERP. It is our opinion that in order to ensure a balanced review and for it to be considered valid by the public in particular, a truly independent review process must be undertaken that includes the participation of additional TSF expertise including nominees from public stakeholders.

6. Summary of Conclusions and Recommendations

- Minnesota's existing dam safety statutes, RSM 6115.0410, are intended for water storage dams and do not specifically address tailings storage facilities. In addition, the requirements rely on "current, prudent engineering practice" and "prudent, current environmental practice" rather than on current accepted industry engineering performance standards as is common to nearly all other regulatory jurisdictions in the U.S. and internationally. We would encourage consideration by all parties as to the critical need to revise or modify Minnesota's approach to dam safety and to incorporate statutes, rules and guidance specifically for TSFs that are consistent if not better than those recently enacted and/or developed by Montana and British Columbia.

- Performance standards for TSFs should be specifically required and should include a hazard classification system based on TSFs similar to that recommended by the CDA (Table 2), seismic criteria requiring 1/10,000 year or Maximum Credible Earthquake (MCE), geotechnical minimum Factors of Safety (FOS) and Inflow Design Flood (IDF) consistent with CDA and other guidance.

- If Minnesota DNR's intention is to consider the actual recommendations of the Mount Polley IERP, then at a minimum additional consideration must be given to the IERPs recommendations for BAT. Our recommendation would be for a Multiple Accounts Analysis (MAA) (see Section 2.b.iv.1.) to evaluate BAT for both operation and closure of the proposed TSF and alternative approaches to the TSF including filtered dry stack tailings and closure of the TSF to achieve dilatant conditions.

- Minnesota should also consider the IERPs recommendations and undertake to:
    - Require TSF operators to commit to an equivalent program of tailings management, including the audit function, as are required by member of the Mining Association of Canada;
    - Expand corporate design commitments and require a failure modes effects analysis, BAT cost-benefit analysis, and QPOs;
    - Require the use of formal Independent Review Boards (IRBs) and use QPOs in regulator evaluations of TSF safety;
    - Require that inspections be performed at all existing TSFs to ascertain whether they may be a risk and require appropriate actions due to specific failure modes: filter adequacy; water balance adequacy; undrained shear failure of silt and clay foundations; and,
    - Develop guidelines that would lead to improved site characterization for tailings dams with respect to the geological, geomorphological, hydrogeological and possibly seismotectonic characteristics.

- Northmet should conduct further TSF analysis including a multi-stakeholder FMEA to consider all potential failure modes and their consequences as well as mitigating measures together with the development of an AMP to ensure that means to mitigate potential failures are developed and triggered appropriately.

- Northmet should also appoint a formal IRB for the TSF and involve them in the final design, construction, operation and reclamation through final closure and during post-closure if necessary. The IRB should be robust and include at least three representatives. The IRB process should complement the Engineer of Record's process but at the same time be transparent and involve public representatives in a capacity that would allow them to ensure and report on the outcome of the overall process. We have been involved at several other sites as a technical representative to IRBs or have served on similar panels and would be glad to advise DNR and the NGO community on processes to achieve this recommendation.

- It is our professional opinion that the ultimate determination of acceptability of risk, if a wet tailings approach such as the Northmet TSF is proposed, should lie with the public members whose lives would be at risk in the event of a catastrophic breach. Northmet's analysis shows that the proposed TSF represents significant risk of loss of life in the event, however unlikely, of a catastrophic failure. For that reason, we recommend that the inundation analysis together with the proposed emergency response plan be presented to both the responding regulatory agencies but also to the potentially affected public, through a very intentional process to engage and take their opinions wholly into account, prior to approval of the dam safety permit. The DNR otherwise would be making a decision to put those persons at risk without their input or potentially even their knowledge.

- Our recommendations and opinions should not be seen as exclusive of the possibility that the proposed wet tailings approach, at least during the operational period, might be considered as a reasonable risk by the parties most at risk and otherwise involved. For that reason, we also take the opportunity at this time to recommend in that event, in addition to the involvement of a formal IRB and transparent technical process, that Northmet, DNR and the EOR undertake to:

    - Develop a corporate TSF management strategy similar to that recommended by Mining Association of Canada (MAC) (2011).
    - Develop a TSF operations, maintenance and surveillance (TOMs) manual similar to that recommended by the MAC (2012).
    - Conduct a technology development program together with modifications to the TSF reclamation and closure design to achieve a final stable landform design.

- In the absence of any of our above recommendations and in particular informed public consent, it is our professional opinion that the Mount Polley IERP recommendations for BAT for new tailings (e.g. filtered dry stack tailings) should be required for the Northmet TSF and as a requirement of the dam safety permit. If the decision is to allow for a wet tailings facility during operations, then at the least the dam safety permit should specify closure to meet dilatant landform conditions so as to avoid the threat of a catastrophic failure in perpetuity.

7. References

CDA (Canadian Dam Association). 2013. Technical Bulletin: Dam Safety Guidelines. www.cda.ca

CDA. 2014. Technical Bulletin: Application of Dam Safety Guidelines to
Mining Dams. www.cda.ca

FEMA. 2013. *Federal Guidelines for Dam Safety: Selecting and Accommodating Inflow Design Floods for Dams.* FEMA P-94. August 2013. https://www.fema.gov/media-library/assets/documents/3898

FEMA. 2015. *Federal Guidelines for Dam Safety Risk Management.* FEMA P-1025. January 2015. https://www.fema.gov/media-library-data/1423661058965-58dfcecc8d8d18b7e9b2a79ce1e83c96/FEMAP-1025.pdf

LePoudre, D. 2015. *Examples, Statistics and Failure modes of tailings dams and consequence of failure,* REMTECH– OCT 15, 2015. http://www.esaa.org/wp-content/uploads/2015/10/15-LePoudre.pdf

MAC (Mining Association of Canada). 2011a. *A Guide to the Management of Tailings Facilities.* Second Edition. The Mining Association of Canada. http://mining.ca/sites/default/files/documents/GuidetotheManagementofTailingsFacilities2011.pdf

MAC. 2011b. Developing an Operation, Maintenance and Surveillance Manual for Tailings and Water *Management Facilities*. The Mining Association of Canada. http://mining.ca/sites/default/files/documents/DevelopinganOMSManualforTailingsandWaterManagementFacilities2011.pdf

Martin, T, Davies, M., Rice, S., Higgs, T., Lighthall, P. 2002. *Stewardship of Tailings Facilities.* Mining, Minerals and Sustainable Development April 2002 No. 20 http://pubs.iied.org/pdfs/G01027.pdf

Morgenstern, Norbert R., Steven G. Vick, and Dirk Van Zyl. 2015. *Independent Expert Engineering Investigation and Review Panel, Report on Mount Polley Tailings Storage Facility Breach.* Province of British Columbia. January 30. https://www.mountpolleyreviewpanel.ca/final-report

Province of British Columbia. 2016. Guidance Document, Health, Safety and Reclamation Code for Mines in British Columbia, Version 1.0 http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/mineral-exploration-mining/documents/health-and-safety/part_10_guidance_doc_10_20july_2016.pdf

Province of British Columbia. 2017. *Health, Safety and Reclamation Code for Mines in British Columbia.* Mines Act, [RSBC 1996] Chapter 293. Updated to February 28, 2017. http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/mineral-exploration-mining/documents/health-and-safety/code-review/health_safety_and_reclamation_code_2017.pdf

Robertson, A. M. 2012. *FMEA Risk Analysis: Failure Modes and Effects Analysis*, Seminaria 2012 Gestao De Riscos E Segiramca De Barragems De Rejeitos http://www.infomine.com/library/publications/docs/Robertson2012b.pdf

UNEP. 2001. Tailings Dams Risk of Dangerous Occurrences, lessons learnt from practical experiences. Bulletin 121. http://www.unep.fr/shared/publications/pdf/2891-TailingsDams.PDF

U.S. ACOE (Army Corps of Engineers). 2014. *Engineering and Design, Safety of Dams – Policy and Procedures*. ER 110-2-1156, 31 March. http://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1110-2-1156.pdf

Table 9 - Comparison of Mt Polley Expert Panel, Montana SB409 Revisions, British Columbia Part 10 HSRC Revisions, Minnesota RSM 6115.0410

Mount Polley Expert Panel Recommendations (2014)	Montana Metal Mine Reclamation Act Section 82-4 Revisions 7(SB 409) (2015)	British Columbia Health, Safety and Reclamation Code Part 10 Revisions (2016)	Minnesota Department of Natural Resources Section RSM 6115.0410 New Dams or Enlargements (2003)
Implement Best Available Technologies (BAT) using a phased approach: • Existing TSFs. Rely on best practices for the remaining active life. • New TSFs. BAT (filtered tailings) should be actively encouraged for new tailings facilities at existing and proposed mines. • At closure. BAT principles (no surface water, unsaturated conditions, achieve dilatant conditions) should be applied to closure of active impoundments so that they are progressively removed from the inventory by attrition.	**82-4-303. Definitions.** (25) "Practicable" means available and capable of being implemented after taking into consideration cost, existing technology, and logistics in light of overall project purposes. **Section 5**. **Tailings Storage facility - design document - fee.** (2) The design document must contain: (e) an evaluation indicating that the proposed tailings storage facility will be designed, operated, monitored, and closed using the most applicable, appropriate, and current technologies and techniques practicable given site-specific conditions and concerns;	**Definitions.** "best available technology" means the site specific combination of technologies and techniques that most effectively reduce the physical, geochemical, ecological and social risks associated with tailings storage during all stages of operation and closure. **Application Requirements. 10.1.3** The application shall include the following unless otherwise authorized by the chief inspector: (f) an alternatives assessment for the proposed tailings storage facilities that assesses best available technology,	*Not addressed.*
Improve corporate governance: Corporations proposing to operate a TSF should be required to be a member of the Mining Association of Canada (MAC) or be obliged to commit to an equivalent program for tailings management, including the audit function.	**Section 5**. **Tailings Storage facility - design document - fee.** (2) The design document must contain: (x) a description of proposed risk management measures for each facility life-cycle stage, including construction, operation, and closure;	**Governance. 10.4.2** (1) The manager of a mine with one or more tailings storage facilities shall: (a) develop and maintain a Tailings Management System that considers the HSRC Guidance Document and includes regular system audits	**Subp. 8. Permit standards.** The applicant may be required to take measures to reduce risks, and the commissioner shall furnish information and recommendations to local governments for present and future land use controls to minimize risks to downstream areas.

Table 9 - Comparison of Mt Polley Expert Panel, Montana SB409 Revisions, British Columbia Part 10 HSRC Revisions, Minnesota RSM 6115.0410 (Continued)

Mount Polley Expert Panel Recommendations (2014)	Montana Metal Mine Reclamation Act Section 82-4 Revisions (SB 409) (2015)	British Columbia Health, Safety and Reclamation Code Part 10 Revisions (2016)	Minnesota Department of Natural Resources Section RSM 6115.0410 New Dams or Enlargements (2003)
Expand corporate design commitments: Future permit applications for a new TSF should be based on a bankable feasibility that would have considered all technical, environmental, social and economic aspects of the project in sufficient detail to support an investment decision, which might have an accuracy of +/- 10-15%. More explicitly it should contain the following: • A detailed evaluation of all potential failure modes and a management scheme for all residual risk • Detailed cost/benefit analyses of BAT tailings and closure options so that economic effects can be understood, recognizing that the results of the cost/benefit analyses should not supersede BAT safety considerations • A detailed declaration of Quantitative Performance Objectives (QPOs).	**Section 5. Tailings Storage facility - design document - fee.** (2) The design document must contain: (n) a dam breach analysis, a failure modes and effects analysis or other appropriate detailed risk assessment, and an observational method plan addressing residual risk; (t) a list of quantitative performance parameters for construction, operation, and closure of the tailings storage facility. The quantitative performance parameters may be expressed as minimums or maximums for embankment crest width, embankment slopes, beach width, operating pool volume, phreatic surface elevation in the embankment and foundation, pore pressures, or other parameters appropriate for the facility and location. (x) a description of proposed risk management measures for each facility life-cycle stage, including construction, operation, and closure;	**Application Requirements. 10.1.3** The application shall include the following unless otherwise authorized by the chief inspector: (d) a mine plan including: (vii) designs and details for tailings storage and a description of proposed quantifiable performance objectives, (e) a program for the environmental protection of land and watercourses during the construction and operational phases of the mining operation, including plans for (i) prediction, identification and management of physical, chemical, and other risks associated with tailings storage facilities and dams, (f) an alternatives assessment for the proposed tailings storage facilities that assesses best available technology,[i] **Governance. 10.4.2** (1) The manager of a mine with one or more tailings storage facilities shall: (d) review annually the tailings storage facility risk assessment to ensure that the quantifiable performance objectives and operating controls are current and manage the facility risks,	**Subp. 6. Final design requirements.** Upon acceptance and agreement by the commissioner of the preliminary report, the applicant shall submit to the commissioner, for approval, a final design report, together with plans and specifications and the initial inspection fee. The final design report shall include, but is not limited to, the following: A. general description of the project, such as its service life, production rates, required storage and area(s); geological considerations such as physiography, topography, geology, seismicity, groundwater conditions, and maps; hydrologic studies such as physical features, climatology, design, storm and design flood characteristics, flood routing, water-material balance, free-board requirements, dam-break flood; geotechnical information, such as rock-soil sampling and logging, geophysical investigations, field and lab testing, instrumentation data; considerations of construction materials and their properties, such as quantities required, borrow and aggregate locations and volumes, field and lab work and investigations, concrete, waste materials generation and placement techniques, investigation of the stored waste materials such as generations, transportation, mechanical/chemical/special testing, disposal practice; B. analytical determinations, such as seepage and underseepage studies, stability, deformation and settlement analysis; analytical and design details of facilities, such as dam, foundation, impoundment, abutments, spillways (for the purpose of these rules, spillway means any facility appurtenant to the dam available to discharge excess water and/or waste from the impoundment) or decant facilities, diversions, outlet works, instrumentation; operational aspects, such as impoundment operating criteria, initial filling criteria, responsibility and coordination, emergency procedures and warning systems: air, water, and solid pollution controls, sedimentation, and erosion controls: operational and postoperational maintenance and abandonment considerations; surveillance and inspection programs; and C. a detailed cost estimate.

Table 9 - Comparison of Mt Polley Expert Panel, Montana SB409 Revisions, British Columbia Part 10 HSRC Revisions, Minnesota RSM 6115.0410 (Continued)

Mount Polley Expert Panel Recommendations (2014)	Montana Metal Mine Reclamation Act Section 82-4 Revisions (SB 409) (2015)	British Columbia Health, Safety and Reclamation Code Part 10 Revisions (2016)	Minnesota Department of Natural Resources Section RSM 6115.0410 New Dams or Enlargements (2003)
Enhance validation of safety and regulation of all phases of a TSF: • Increase utilization of Independent Tailings Review Boards. • Utilize the concept of Quantitative Performance Objectives (QPOs) to improve regulator evaluation of ongoing facilities.	**Section 6. Independent review panel - selection - duties.** (1) An independent review panel shall review the design document required by [section 5]. (2) The operator or permit applicant shall select three independent review engineers to serve on the panel and shall submit those names to the department. The department may reject any proposed panelists. If the department rejects a proposed panelist, the operator or permit applicant shall continue to select independent review engineers as panelists until three panelists are approved by the department. (3) An independent review engineer may not be an employee of: (a) an operator or permit applicant; or (b) the design consultant, the engineer of record, or the constructor. (4) The operator or permit applicant shall contract with panel members, process invoices, and pay costs. (5) A representative of the department and a representative of the operator or permit applicant may participate on the panel, but they are not members of the panel and their participation is nonbinding on the review. (6) The engineer of record is not a member of the panel but shall participate in the panel review. (7) The operator or permit applicant shall provide each panel member with a hard copy and an electronic copy of the design document and other information requested by the panel. (8) The panel shall review the design document, underlying analysis, and assumptions for consistency with this part. The panel shall assess the practicable application of current technology in the proposed design. (9) The panel shall submit its review and any recommended modifications to the operator or permit applicant and the department. The panel's determination is conclusive. The report must be signed by each panel member. (10) The engineer of record shall modify the design document to address the recommendations of the panel and shall certify the completed design document. The operator or permit applicant shall submit the final design document to the department pursuant to [section 5]. (11) For an expansion of a tailings storage facility for which the original design document was approved by the department, the operator shall make a reasonable effort to retain the previous panel members. To replace a panel member, the process in subsection (2) must be followed.	**Governance. 10.4.2** (1) The manager of a mine with one or more tailings storage facilities shall: (c) establish an Independent Tailings Review Board, unless exempted by the chief inspector, (2) The composition of an Independent Tailings Review Board established under subsection (1) (c) shall be commensurate with the complexity of the tailings storage facility in consideration of the HSRC Guidance Document. (d) review annually the tailings storage facility risk assessment to ensure that the quantifiable performance objectives and operating controls are current and manage the facility risks, (3) The manager shall submit the terms of reference for the Independent Tailings Review Board including the qualifications of the board members to the chief inspector for approval. (4) The terms of reference for the Independent Tailings Review Board shall be developed or updated as required in consideration of the review under subsection (1) (d). **Annual Reporting. 10.4.4** The owner, agent or manager shall submit one or more annual reports in a summary form specified by the chief inspector or by the conditions of the permit by March 31 of the following year on the following: (c) a report of the activities of the Independent Tailings Review Board established under section 10.4.2 (1) (c) of this code that describes the following: (i) a summary of the reviews conducted that year, including the number of meetings and attendees; (ii) whether the work reviewed that year meets the Board's expectations of reasonably good practice; (iii) any conditions that compromise tailings storage facility integrity or occurrences of non-compliance with recommendations from the engineer of record; (iv) signed acknowledgement by the members of the Board, confirming that the report is a true and accurate representation of their reviews	*Not addressed.*

Table 9 - Comparison of Mt Polley Expert Panel, Montana SB409 Revisions, British Columbia Part 10 HSRC Revisions, Minnesota RSM 6115.0410 (Continued)

Mount Polley Expert Panel Recommendations (2014)	Montana Metal Mine Reclamation Act Section 82-4 Revisions (SB 409) (2015)	British Columbia Health, Safety and Reclamation Code Part 10 Revisions (2016)	Minnesota Department of Natural Resources Section RSM 6115.0410 New Dams or Enlargements (2003)
Strengthen current regulatory operations: Utilize the recent inspections of TSFs in the province to ascertain whether they may be at risk due to the following potential failure modes and take appropriate actions: • Filter adequacy • Water balance adequacy • Undrained shear failure of silt and clay foundations	*No additional requirements for existing TSFs.*	Inspections required and completed. Final submissions received June 30, 2015. More information available at: http://www2.gov.bc.ca/gov/content/industry/mineralexploration-mining/dam-safety-inspections-2014	*No additional requirements for existing TSFs.*
Improve professional practice: Encourage the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) to develop guidelines that would lead to improved site characterization for tailings dams with respect to the geological, geomorphological, hydrogeological and possibly seismotectonic characteristics.	*No equivalent action has yet been performed by a professional organization located in the U.S.*	APEGBC developed and published Site Characterization for Dam Foundations in BC, August 2016. https://www.apeg.bc.ca/getmedia/34e1bb3f-cd39-450d-800e-614ac3850bc5/APEG_2016_Site-Characterization-for-Dam-Foundations_WEB_2.pdf.aspx	*No equivalent action has yet been performed by a professional organization located in the U.S.*

Table 9 - Comparison of Mt Polley Expert Panel, Montana SB409 Revisions, British Columbia Part 10 HSRC Revisions, Minnesota RSM 6115.0410 (Continued)

Mount Polley Expert Panel Recommendations (2014)	Montana Metal Mine Reclamation Act Section 82-4 Revisions (SB 409) (2015)	British Columbia Health, Safety and Reclamation Code Part 10 Revisions (2016)	Minnesota Department of Natural Resources Section RSM 6115.0410 New Dams or Enlargements (2003)
Improve dam safety guidelines: Recognizing the limitations of the current Canadian Dam Association (CDA) guidelines incorporated as a statutory requirement, develop improved guidelines that are tailored to the conditions encountered with TSFs in British Columbia and that emphasize protecting public safety.	**Section 5. Tailings Storage facility - design document - fee.** (g) a demonstration through site investigation, laboratory testing, geotechnical analyses, and other appropriate means that the tailings, embankment, and foundation materials controlling slope stability are not susceptible to liquefaction or to significant strain-weakening under the anticipated static or cyclic loading conditions, to the extent that the amount of estimated deformation under the loading conditions would result in loss of containment; (h) for a new tailings storage facility, design factors of safety against slope instability not less than: (i) 1.5 for static loading under normal operating conditions, with appropriate use of undrained shear strength analysis for saturated, contractive materials; (ii) 1.3 for static loading under construction conditions if the independent review panel created pursuant to [section 6] agrees that site-specific conditions justify the reduced factor of safety and that the extent and duration of the reduced factor of safety are acceptable; and (iii) 1.2 for postearthquake, static loading conditions with appropriate use of undrained analysis and selection of shear strength parameters. Under these conditions, a postearthquake factor of safety less than 1.2 but greater than 1.0 may be accepted if the amount of estimated deformation does not result in loss of containment. (i) for a new tailings storage facility, an analysis showing that the seismic response of the tailings storage facility does not result in the uncontrolled release of impounded materials or other undesirable consequences when subject to the ground motion associated with the 1-in-10,000-year event, or the maximum credible earthquake, whichever is larger. Any numeric analysis of the seismic response must be calculated for the normal maximum loading condition with steady-state seepage. The analysis must include, without limitation, consideration of: (i) anticipated ground motion frequency content; (ii) fundamental period and dynamic response; (iii) potential liquefaction; (iv) loss of material strength; (v) settlement; (vi) ground displacement; (vii) deformation; and (viii) the potential for secondary failure modes.	**10.1.8 (**1) Seismic and flood design criteria for tailings storage facilities and dams shall be determined by the engineer of record based on the consequence classification determined under section 10.1.7 of this code in consideration of the HSRC Guidance Document, subject to the following criteria: (a) for tailings storage facilities that store water or saturated tailings, (i) the minimum seismic design criteria shall be a return period of 1 in 2475 years, (ii) the minimum flood design criteria shall be a return period1/3rd of the way between the 1 in 975-year event and the probable maximum flood, and (iii) a facility that stores the inflow design flood shall use a minimum design event duration of 72 hours; (b) for tailings storage facilities that cannot retain water or saturated tailings, (i) the minimum seismic design criteria shall be a return period of 1 in 975 years, and (ii) the water management design shall include an assessment of tailings facility erosion and surface water diversions as well as measures to prevent impounded tailings from becoming saturated that consider the consequence classification as determined under section 10.1.7 of this code. (2) The environmental design flood criteria shall be determined by a Professional Engineer in consultation with other qualified professionals. **10.1.9** For a tailings storage facility design that has an overall downstream slope steeper than 2H:1V, the manager shall submit justification by the engineer of record for the selected design slope and receive authorization by the chief inspector prior to construction. **10.1.10** For a tailings storage facility design that has a calculated static factor of safety of less than 1.5, the manager shall submit justification by the engineer of record for the selected factor of safety and receive authorization by the chief inspector prior to construction.	**Subp. 8. Permit standards.** The commissioner shall determine if the proposal is adequate with respect to: A. For Class I, a showing of lack of other suitable feasible and practical alternative sites, and economic hardship which would have a major adverse effect on population and socioeconomic base of the area affected. B. For Class II, a showing of lack of other suitable feasible and practical alternative sites and that the dam will benefit the population or socioeconomic base of the area involved. C. The need in terms of quantifiable benefits. D. The stability of the dam, foundation, abutments, and impoundment under all conditions of construction and operation, including consideration of liquefaction, shear, or seepage failure, overturning, sliding, overstressing and excessive deformation, under all loading conditions including earthquake. This determination must be based on current, prudent engineering practice, and the degree of conservatism employed must depend on hazards. E. Discharge and/or storage capacity capable of handling the design flood based on current, prudent engineering practice and the hazard classification. F. Compliance with prudent, current environmental practice throughout its existence.

	(j) if a pseudo-static stability analysis is performed to support the design, a justification for the use of the method with respect to the anticipated response to cyclic loading of the tailings facility structure and constituent materials. The calculations must be accompanied by a description of the assumptions used in deriving the seismic coefficient.		

[i] BC HSRC for Mines Version 1.0, July 2016. The alternatives assessment for TSFs will consider BAT and will provide a comparative analysis of options considering the following sustainability factors: Environment; Society; Economics.

Appendix A – van Zyl and Vick Letters

UBC

UNIVERSITY OF BRITISH COLUMBIA
NORMAN B. KEEVIL Institute of Mining Engineering

tel: 604 822 2540 fax: 604 822 5599 517, 6350 Stores Road, Vancouver, BC V6T 1Z4 www.mining.ubc.c

Honourable Bill Bennett
Minister of Energy and Mines
PO BOX 9060, STN PROV GOVT
Victoria, BC V8W9E2

August 18, 2015

Dear Minister Bennett,

I have observed with interest the public dialogue around tailings management options following the Mount Polley tailings storage facility failure and would like to take this opportunity to provide you with some of my thoughts with respect to tailings management facility (TMF) design related to best available technology (BAT).

The Independent Expert Engineering Investigation and Review Panel identified three components to accomplish BAT and listed filtered tailings ("dry stack"), underground backfill and mined out pits as examples of potential management options.

The geology, topography and climate of British Columbia are diverse and varied. Considerations for selecting a tailings management option requires site specific measures to result in a stable and resilient tailings deposit; one size does not fit all. Structural integrity must be the number one priority of the design and management of every TMF.

Following the release of the Panel report, the Panel met in Prince George on March 20, 2015, as part of a discussion on tailings management involving government, First Nations and industry. There was further discussion about this topic, specifically risk management practices, including redundancies in design. It was emphasized that, like most technologies, there are variations for site specific tailings management that could satisfy BAT and there are opportunities for industry to explore new innovations with respect to tailings management.

In my opinion, BAT is not a single technology; its selection is based on a site-specific risk management process with the outcome of a stable and resilient tailings deposit. Thank you for the opportunity to provide you with my thoughts. Should you be interested, I would be pleased to discuss these ideas with you further.

Sincerely,

Dirk van Zyl.

Dirk van Zyl, Ph.D., P.Eng.
Professor, Chair of Mining and the Environment

UNIVERSITY OF BRITISH COLUMBIA
NORMAN B. KEEVIL Institute of Mining Engineering

tel: 604 822 2540 fax: 604 822 5599 517, 6350 Stores Road, Vancouver, BC V6T 1Z4 www.mining.ubc.ca

Honourable Bill Bennett
Minister of Energy and Mines
PO BOX 9060, STN PROV GOVT
Victoria, BC V8W9E2

September 14, 2015

Dear Minister Bennett,

This correspondence is intended to provide two important clarifications with respect to my letter of August 18, 2015 which presented some of my thoughts with respect to tailings management facility (TMF) design related to best available technology (BAT). The August 18, 2015 letter does not suggest that the overall goal of moving to zero TMF failures, as stated in the Independent Expert Engineering Investigation and Review Panel Report, can be reconsidered. It must remain the overall target.

Lastly, the August 18, 2015 letter represents my observations and comments and does not represent the opinions of the other Panel members.

Sincerely,

Dirk van Zyl.

Dirk van Zyl, Ph.D., P.Eng.
Professor, Chair of Mining and the Environment

Steven G. Vick

Geotechnical Engineer
42 Holmes Gulch Way
Bailey, Colorado 80421
USA
(303) 838-1443

April 22, 2016

MEND Secretariat
555 Booth Street
Ottawa, ON
K1A 0G1
attn: Gilles A. Tremblay
Manager, Mine Closure and Ecosystem Risk Management

Review comments
Draft Report for the State of Practice Assessment of Tailings Management Technologies

Dear Mr. Tremblay:

1.0 INTRODUCTION

This letter forwards the writers' review comments on the March 4, 2016 Draft Report for the State of Practice Assessment of Tailings Management Technologies by KCB. These comments represent exclusively the views of the writer. They have been prepared at your request and without compensation by or consultation with MEND or any interested party. In the remarks that follow, *report* and *study* refer to the above-referenced KCB document unless otherwise indicated. Similarly, page numbers, tables, or figures in brackets [ ] refer to the KCB report.

The writer has long advocated the need for better integration of dam safety and geochemical aspects of tailings management, so it is encouraging to see MEND sponsor this work. Both MEND and the report's authors should be complimented for undertaking this effort. The end product will serve as a primary resource for tailings management.

MEND's Terms of Reference[1] make it clear that the study is an outgrowth of the failure of the Mount Polley tailings dam in August, 2014 and consequent recommendations of the Mount Polley report[2] for preventing such failures elsewhere. But regrettably, events have overtaken this incident. November, 2015 saw the failure of the Fundao tailings dam owned by Samarco in Brazil,

1 MEND PROJECT - TERMS OF REFERENCE, Study of tailings management technologies
2 Independent Expert Engineering Investigation and Review Panel, 2015, Report on Mount Polley Tailings Storage Facility Breach, Province of British Columbia.

a company with corporate connections to Canada. As of this date, the failure has resulted in more than $40 billion in direct costs to Samarco and its parent companies, 22 fatalities, destruction of the town of Bento Rodriguez, and criminal homicide indictments of Samarco executives, engineers, and consultants. Samarco has changed the complexion of tailings dam failures, elevating their consequences to an entirely new level in contemporary experience. Both the report and these comments should be read in this light.

Even more regrettably, the Samarco experience is not unique. Tailings dam failures have cost more than 1800 lives worldwide since 1960, despite improvements in tailings management practices over this period[3]. This too is necessary for proper perspective on the report and the remarks forwarded here.

The statistical implications of these incidents can be understood from Appendix I of the Mount Polley report, using the subpopulation of tailings dams in British Columbia as a sample of tailings dams in Canada more broadly. The failure frequency for BC tailings dams is about $1.7\text{x}10^{-3}$/yr. At the time of the Mount Polley report, there were 120 active tailings impoundments at 60 mines in BC, or a ratio of 2:1. This same ratio would imply that the 177 mines in Canada [Table 1.1] have 354 tailings facilities of some kind. Of these, 20 use alternative tailings technology, leaving 334 conventional impoundments. Applying the BC failure frequency, it is easily shown that the annual probability of at least one failure of a conventional tailings facility in Canada is 0.43, or almost a 50/50 chance, and the average failure recurrence interval is about two years. Thus, absent substantive changes in current tailings management technology, tailings dam failures are and will continue to be an expected and statistically predictable occurrence in Canada. Only by appreciating this can informed decisions regarding tailings technology be made.

2.0 BAT

2.1 Definitions

The Mount Polley report defined BAT for physical stability according to the following three criteria:

1. Eliminate surface water from the impoundment.
2. Promote unsaturated conditions in the tailings with drainage provisions.
3. Achieve dilatant conditions throughout the tailings deposit by compaction.

This definition is cited in the report. Notwithstanding, the report advances its own definition of BAT, in the process traveling far afield from its Terms of Reference. It proposes that BAT should be enlarged to encompass not just physical stability, but geochemical stability as well:

3 Vick, S., 2011, The Consequences of Tailings Dam Failures, Cross Canada Lecture, Canadian Geotechnical Society

The chief goal of applying BAT is to achieve physical and geochemical stability for operations and closure [5].

It goes on to expand BAT's scope still further:

Therefore, BAT should be defined as processes and designs that are most suitable for a project and climate that enhance (reduce risk of) physical, geochemical, biophysical and social stability [8].

The reader then learns that BAT is even more broad:

Therefore BAT cannot be "one-size-fits-all" as it needs to be specific to the climate, geology, geomorphology and sensitivity of the downstream receptors of the tailings facility site, the tailings characteristics, and the social situation of the project [8].

And finally, BAT emerges as an all-encompassing array of technologies, management strategies, risks, and activities over every stage of the life cycle:

For purposes of this study the definition of Best Available Technology (BAT) means the combination of technologies and management strategies that most effectively reduce the economic, physical, geochemical, ecological and social risks associated with tailings during all stages of operation and closure. BAT includes site selection considerations, technologies and design features that provide a resilient and robust tailings facility during operations and post-closure. BAT should be implemented at every stage of the tailings life cycle [8].

Unlike those advanced in the Mount Polley report, these definitions contain no objective criteria by which they can be judged. As such, BAT is whatever you want it to be. And if everything is BAT, then nothing is BAT.

It would have been better had the report more faithfully adhered to its Terms of Reference.

2.2 Multiple Objectives, Tradeoffs, And Multiple Accounts Analysis

In its attempts to define BAT, the report becomes entangled in another problem. BAT now has multiple attributes, objectives it seeks to achieve. These include [iii]:

1. physical stability
2. geochemical stability
3. ecological stability
4. biophysical stability
5. social stability

and added to these [vi] is:

6. life cycle costs

While these are all worthy goals, the report recognizes that they may conflict and allows that risk tradeoffs among them will be necessary (i.e., geochemical risk for physical risk or vice-versa). But having raised the issue, it then begs the question of just how these tradeoffs should be made, leaving this task for government and industry [iii]. Later it allows that Multiple Accounts Analysis is the right tool for the job [66] but again does not elaborate.

The report frames physical stability as merely one desirable attribute among many. This is a false premise. No other objective can be achieved without first assuring physical stability. Restated in terms of the report's BAT objectives:

1. there can be no geochemical stability if the dam fails
2. there can be no ecological stability if the dam fails
3. there can be no biophysical stability if the dam fails
4. there can be no social stability if the dam fails
5. and there can be virtually immeasurable life-cycle costs if the dam fails

Hence, dam safety is not one among many competing objectives, but prerequisite to all of them. This is contrary to Multiple Accounts Analysis, which is predicated on a zero-sum decision rule. That is, any nonzero weighting factor assigned to one objective necessarily reduces the influence of some other objective in the decision outcome. And the more such objectives there are, the greater the dilution becomes.

But dam safety is a decision constraint, not a decision outcome. If tradeoffs of dam safety are acceptable, the result is to accept dam failures. It is inconceivable that failures like Mount Polley or Samarco could be rationalized by having traded off safety for something else.

3.0 DEWATERED TAILINGS VERSUS WATER COVERS

A continuing theme throughout the report is that physical risks are in conflict with geochemical risks, and the corollary that water covers eliminate ARD while dewatered tailings promote it [iii, 2, 21, 34, 39]. While this dichotomy exists at some level, the report tends to oversimplify and overstate it. For example:

... to limit oxidation and prevent Acid Rock Drainage (ARD) the best practice is to keep Potentially Acid Generating (PAG) tailings submerged with an appropriate water cover.[iii]

Standard practice with conventional PAG tailings is to limit oxidation and reduce the risk of ARD by maintaining greater than 85% saturation in the tailings with an appropriate pond or water cover (INAP 2014).[2]

...saturation of sulphidic tailings is the most successful method of controlling ARD...[20]

...to limit oxidation and prevent ARD, keeping PAG tailings submerged with an appropriate water cover, often greater than 1 m deep is recommended (INAP 2014) [21]

The writer can find no such references to best practice, standard practice, or recommended practice in Chapter 6 of INAP (2014)[4]. What Section 6.6.7 INAP actually says is:

Disposal of acid generating materials below a water cover is ***one of*** *the most effective methods for limiting ARD* ***generation***. [emphasis added]

In fact, water covers are only one of more than 28 control methods described in INAP (2014) and one of 14 such methods enumerated in the report itself [Table 1.3]. But as far as the writer can determine, the report devotes only two sentences to the entire category of dry covers [41]. And while sulphide flotation does receive some discussion [37], it later falls off the list of case histories without explanation. Water covers aside, the entire topic of geochemical control occupies only three pages of the 81 page report.

The above citation from INAP alludes to another overlooked factor. It is not simply generation, but transport of ARD reaction products that produces ARD consequences and risks. Water covers produce saturation and flow gradients that enhance transport of anionic constituents like SO_4 and Se that are very difficult and costly to treat, even in the absence of ARD reaction products. Indeed, the entire matter of contaminant transport that constitutes fully half the ARD problem receives no discussion at all. For example, the alternating cycles of oxidation and flushing that occur in cyclone sand dams are well known but receive no mention [49]. Neither is it noted that dewatered tailings are typically nonsegregated, with reduced conductivity to water and oxygen that retard both oxidation and transport. Dewatered tailings may also offer opportunities for sequential "cell" deposition and covering that serve the same ends, but this is not explored.

The Terms of Reference intend that the report promote informed decisionmaking about tailings technology. If so, the report needs to spend more time explaining how physical and chemical stability can be reconciled, and less time insisting that they cannot be.

4.0 FEASIBILITY AND COSTS

In a number of instances the report takes note of the limited tonnage for dewatered tailings applications to date. It is commonly claimed that scaleup difficulties make high-tonnage operations unfeasible, and the writer had looked forward to learning why. The report hints [Figure 6.4] that, to the contrary, there may be economies of scale for larger operations, but this important question remains unanswered.

As the Mount Polley report discussed, the cost of alternative technologies has been the chief factor in their adoption to date. The cost estimates provided in the report, while crude, are a first step in illuminating this factor. The more important question, however, concerns not so much

4 The International Network for Acid Prevention, 2014, Global Acid Rock Drainage Guide

the relative costs of these technologies compared to conventional methods, but their impact on the overall cost of the mine over the life of the operation. A followup study to evaluate the cost of alternative tailings technologies at actual operating mines—say a high tonnage open-pit operation, low-tonnage open pit, and an underground mine—would be a worthwhile undertaking for MEND to consider.

4.0 OTHER TOPICS

Most readers are likely to find, as did the writer, Section 5 on Case History Review of Tailings Management Technologies and Practices to be the most useful part of the report. It is surprising, however, that cyclone sand dams are introduced at this stage as an alternative technology when they are actually a well-established aspect of conventional technology that do not seem to warrant separate status.

And lastly, the report included a clarifying comment on the Mount Polley report by Professor Dirk van Zyl [6]. Having done so, it is obligated to also acknowledge both of the items in Dr. van Zyl's subsequent correspondence attached to this letter.

Thank you for the opportunity to share these ideas, and I trust you will find them useful.

Yours very truly,

Steven Vick

attachment: letter from Dirk van Zyl to Bill Bennett dated September 14, 2015

BUKA ENVIRONMENTAL
941 9th Street
Boulder, CO 80302 USA
303.324.6948/aamaest@gmail.com

Technical Memorandum

To: Kevin Lee, Minnesota Center for Environmental Advocacy
From: Ann Maest, PhD; Buka Environmental
Date: 27 February 2018
Re: Comments on PolyMet Mining's Permit to Mine: Water quality and geochemical issues at the proposed NorthMet Mining Site

Introduction

The comments contained in this technical memorandum are presented on behalf of the Minnesota Center for Environmental Advocacy and are in response to the Permit to Mine Application for the NorthMet Project (PolyMet Mining, 2017a). I present a summary of my major findings and then discuss technical comments, including errors in mine waste characterization, assumptions about acid drainage and contaminant leaching, the quality of water impacted by the waste stockpiles at the mine site, the reactivity of tailings, and state-of-the-art tailings management. Recommendations are presented at the end of each section. The documents relied on for my evaluation are listed in the References section of the memorandum.

Summary of Major Findings

- The number of samples analyzed for acid-base accounting, whole rock chemistry, and mineralogy is inadequate for the waste rock and ore that will be generated for this project. Only 84 samples were analyzed, and the total should have been over 250. The low number of samples indicates that the possible range, especially the upper range, of sulfide and metal content is not known and likely underestimated. Statements that Category 1 wastes will have a sulfide content under 0.12% are therefore unreliable.
- Waste rock and ore samples were not analyzed for neutralization potential (NP), which, in combination with the acid production potential (AP), is used to estimate the acid generation potential of a waste. An NP surrogate, percent total carbon, was measured but did not reflect the carbonate content of the materials. Neutralization potential measurements were conducted on all other mined materials (flotation tailings, LTVSMC tailings, metallurgical residue, overburden, and saturated overburden). The NP values of the waste rock and ore are important to know for internal consistency. The limited mineralogic results indicate that waste rock has

nearly no ability to neutralize acidic leachate, should it develop in the stockpiles or the pit.

- The consistent separation of Category 1 wastes from wastes and ore with higher sulfide content during operations will be difficult, if not impossible, leading to a greater potential for pollutants to be generated in the unlined Category 1 storage pile than PolyMet assumes.
- No adaptive management plan (AMP) exists for waste rock management. Given the uncertainties associated with separating the different waste categories and ore, and the potential adverse environmental consequences if more reactive materials are included in lower category wastes, an AMP is especially important for wastes reporting to the Category 1 stockpile, which has the lowest neutralizing potential of any waste and will sit on the land surface in perpetuity.
- Incorrect assumptions about acid drainage and contaminant leaching have led PolyMet to underestimate the potential impact of mine water on the environment at and around the mine and plant sites. The assumptions include that once wastes go acidic, the pH will "recover." In addition, the repeated and seasonal contribution of secondary salts to waste and ore leaching has been ignored, and release rates and concentration caps rely on incorrect conceptual models. For example, if the measured pH values of Category 1 HCT leachate were used to estimate the concentration cap for nickel, maximum nickel concentrations would be approximately 10 times higher than predicted by the site water quality model.
- If the pH range between 6.0 and 7.0 is considered, the maximum measured nickel concentration is 120 mg/L, almost 10 times higher than the maximum concentration cap.
- Mitigation measures for the Category 1 stockpile are unlikely to prevent the movement of contaminants to mine site groundwater and surface water. An alternative modeling effort shows that sulfate plumes from the Category 1 and 2/3 stockpiles will be created during operations and reach groundwater under the Partridge River. A synthetic liner and segmented leachate collection system should be installed under the Category 1 stockpile to minimize the release of contaminants to groundwater and help identify the location of leaks that do develop.
- The waste characterization results for the flotation and LTVSMC tailings demonstrate that they are reactive according to the Minnesota definition, which includes any waste that is shown through characterization studies to release substances that adversely impact natural resources. Based on this finding, the tailings facility should be lined with a geomembrane and leachate collection system, and alternative, state-of-the-art methods of tailings management should be considered, including removal of the LTVSMC tailings and the use of dry tailings deposition methods. Improved techniques for desulfurization of the tailings should be examined, and mineralogic analysis should be used to determine their effectiveness.

Technical Comments

1. Errors in Mine Waste Characterization

a. Inadequate Number of Characterization Samples

PolyMet has not characterized a sufficient number of samples to determine the project's potential to generate acid or leach other contaminants. Characterization samples should include waste rock, ore, tailings (flotation and LTVSMC), hydrometallurgical residue, and overburden, at a minimum. The total number of waste rock samples is just 82, and only three ore composite samples and 33 flotation tailings samples have been analyzed as part of the mine waste characterization program (PolyMet Mining, 2017b, p. 4 and 5).

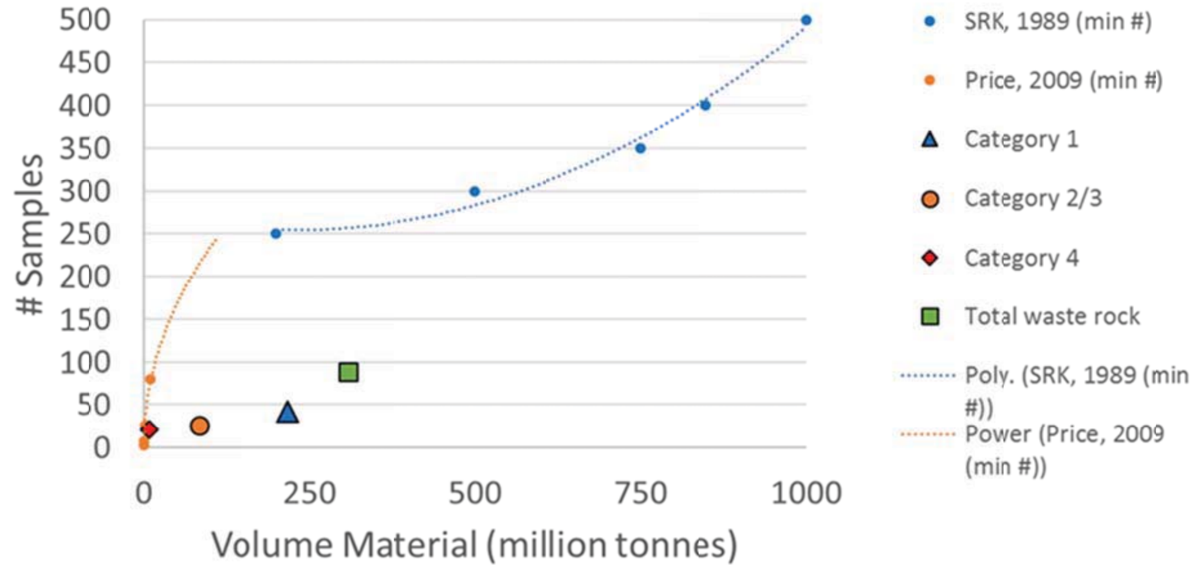
The volumes of waste rock are large (PolyMet Mining, 2017b, Table 2-1), especially for Category 1 wastes:

- Category 1 = 216,694,717 tons, 70.3% of all waste rock
- Category 2/3 = 82,782,343 tons, 26.7% of all waste rock
- Category 4 = 8,636,630 tons, 2.8% of all waste rock
- Total waste rock, all categories = 308,113,690 tons.

Figure 1 shows the recommended minimum number of geochemical characterization samples from two literature sources and the actual number of samples analyzed for each waste category and for the total amount of waste rock. Although no hard and fast rules exist, the number of samples analyzed for the NorthMet Project are well below recommended minimum values. Each sample should be run through the suite of geochemical tests, including acid-base accounting (ABA) and whole rock analysis, at a minimum. In addition, a smaller number of short-term leach tests, long-term kinetic tests, and mineralogy should be conducted on each sample.

PolyMet has chosen to sacrifice quantity for detail. Because of the involvement of the Minnesota Department of Natural Resources, in particular Kim Lapakko, an impressive number of very long-duration humidity cell tests (HCTs) have been run. Where the Project falls short is the number of ABA, whole rock, and mineralogic analyses. Instead of 84 samples, over 250 should have been tested for ABA and whole rock chemistry. Although the Rock and Overburden Management Plan touts its use of 38,000 assays to create the current mine site Block Model (PolyMet Mining, 2017c (Appendix 11.1, p. 39), the data for ore characterization are not publicly available. The block model is most commonly used to guide ore extraction and is built using target metal percentages (in the case of NorthMet, copper, nickel, cobalt, platinum, palladium, and gold) in the ore rather than the waste; this is

Figure 1. Recommended number of geochemical characterization samples vs. the actual number analyzed by PolyMet for each waste rock category and total waste.



Sources: For recommended minimum number of samples: SRK (1989), in Parbhakar-Fox, A. and Dominy, S.C. (2017) and Price (2009). For waste volumes: PolyMet Mining, 2017b, Table 2-1 and PolyMet Mining, 2015, Table 4-4. SRK (1989) points are fitted with a 2nd-order polynomial curve, and Price (2009) points are fitted with a power function and forecasted forward for 100 periods using Excel.

referred to as an *economic* block model. The NorthMet deposit block model is described in PolyMet Mining, 2017c, Appendix 11.1, Attachment A. In addition to ore assays, the NorthMet block model includes waste categories, waste units, %S, and whole rock metal concentrations. The block model has 133,000 blocks for ore and waste, and each block is given a metal concentration. However, only 82 waste rock samples were analyzed for metal content, as noted previously in this memorandum, so the accuracy of the block model for contaminant leaching of the wastes is quite limited. In addition, the total metal concentration in the rock does not necessarily relate directly to metal concentrations in waste leachate. Further, no information on neutralization potential is included in the block model. The decision on waste vs. ore is based on the metal content, and the separation of different waste categories is based on %S values. Because so few waste rock samples were analyzed for %S and metal content (a total of 82) and the only leach test results (HCTs) are not used to predict contaminant generation potential, the block model is a blunt tool for separating different waste categories according to their contaminant leaching or acid generation potential.

The available waste rock geochemical characterization data for whole rock chemistry and %S are included in SRK Consulting (2007a), Appendix D.4. But the results are categorized using the old definitions of reactive and nonreactive rather than the revised waste rock categories (1, 2/3, 4). To determine which results are for Category 1 waste rock, for example, one has to cross-reference the sample identifiers with those in Large Table 1 in

Polymet Mining (2015a), create a new table, and conduct statistical analyses. The summary statistics for whole rock chemistry of the revised waste rock categories are provided in PolyMet Mining, 2017b (Table 2-2), but the raw data are not. The lack of relevant raw data is a transparency issue and should be remedied.

b. Missing Analyses

In addition to analyzing an inadequate number of waste rock and ore samples, PolyMet failed to analyze the samples for their ability to neutralize acid. It appears that no measure of neutralizing ability was conducted for the waste rock or ore samples. This is a major shortcoming of the characterization program. Acid production potential (AP) and neutralization potential (NP) are two separate measures that are considered together to provide an indication of the potential for the development of low pH conditions.
During operations, mines commonly use static tests such as ABA to identify and separate potentially acid-generating (PAG) from uncertain or non-acid-generating materials quickly. The NP of a mined material is important to know because it provides an estimate of the amount of acid-neutralizing ability of a sample. Taken together, they are used to estimate the acid generation potential of the samples, using the NP:AP ratio, or NPR. The industry-sponsored GARD Guide (INAP, 2009) recommends that if the NPR is <1, the sample is potentially acid generating.

The reason PolyMet provides for analyzing the ore and waste rock samples for "carbonate" rather than NP was (SRK, 2007a, p. 28) is:

> Carbonate rather than neutralization potential was determined because neutralization potential determinations on rocks containing reactive silicates are ambiguous (Lapakko 1994a) and do not reflect field capacity to neutralize acid.

The method used to determine "carbonate" was not mentioned. PolyMet Mining (2017b, pgs. 4-7) lists "carbon" rather than carbonate as an analysis for all sample types, and I suspect this is what SRK, 2007a was referring to when they discussed "carbonate." Carbon measurements are a shortcut to estimating NP. A simple measurement from a Leco instrument will give a total carbon value, and equation (1) is given to convert to NP (INAP, 2009, Chapter 5b):

$$\text{NP (total C)} = \%\text{C} \times 83.3 \qquad (1)$$

This equation assumes that all the carbon is present as calcite (INAP, 2009, Chapter 5b). Although total carbon can be used as a surrogate for NP (INAP, 2009), the results are meaningless if they are not linked with mineralogic analyses showing that the carbon is associated with a neutralizing carbonate mineral such as calcite or dolomite. The percent total carbon (% Total C) results in SRK (2007a, Table 2-4) are low for all waste and ore samples, suggesting that the method was run to analyze samples for organic carbon rather than carbonate. I have found no documentation of any attempt to use carbon or "carbonate" to estimate the neutralizing potential of the waste rock or the ore.

Essentially all rocks associated with metal mines contain silicates, but their reaction rates are much slower than those for carbonates or sulfides (Sherlock et al., 1995). The Permit and associated documents repeatedly state that acid is neutralized by the dissolution of silicate minerals, but these minerals will only provide limited pH buffering near neutral pH and will not be able to keep up with the acid production once the pH drops. No method exists, short of detailed analysis of HCT results, to estimate the neutralizing ability of silicate minerals in mine waste. Although challenges exist with the measurement of NP, it is important to have internal consistency at a site for comparison of the relative ability to generate and neutralize acidity (INAP, 2009). While all other samples types were analyzed for NP (tailings, overburden, metallurgical residue, and saturated overburden; PolyMet Mining, 2017b, pgs. 4-7), the ore and waste rock were not, so internal consistency across waste types is not possible.

The lack of NP measurements for Category 1 wastes is important because these are the wastes that will remain on the surface in perpetuity. Although the sulfide content of Category 1 wastes is supposed to be ≤0.12%, the carbonate content is also very low. The mineralogy of the waste categories is summarized in PolyMet Mining (2017b, Table 2-4). It shows that Category 1 wastes have a maximum carbonate content of 2% (no minimum or average values are provided). All other waste categories (2/3, 4, and Virginia Formation) have maximum carbonate contents of 25%, with average values of 2, 5, and 10%, respectively. These results show that Category 1 waste rock has the lowest neutralizing ability of any of the waste categories.

c. Inability to Separate Category 1 from Ore and Category 2/3 and Wastes and Reactivity of Wastes

The consistent separation of Category 1 wastes from wastes and ore with higher sulfide content will be difficult, if not impossible, and this waste management challenge has important implications for water pollution at the mine site.

Category 1 and 2 wastes were previously combined in the waste management schemes described for the project; in fact, PolyMet originally considered waste rock “reactive” if the sulfide content was greater than only 0.05% S (discussed in SRK Consulting, 2007a, p. 23). According to SRK Consulting (2007a, p. ii), currently all waste categories are considered “reactive,” including what is now defined as Category 1 wastes:

> All of these categories are defined as “reactive” because drainage would be unsuitable for direct discharge. The concept of a category for which drainage would be suitable for direct discharge was evaluated but not found to be achievable because hardness-based water quality discharges standards for copper may not be met.

As noted in Section 1b of this memorandum, Category 1 waste rock has a very low neutralizing ability. If wastes with a higher sulfide content, or ore, are inadvertently included in the Category 1 stockpile, the Category 1 waste will not be able to neutralize the acid produced. In fact, although PolyMet states that the maximum %S for Category 1 waste rock is 0.12%, the maximum percent sulfide in the mineralogy summary table is 4% (PolyMet Mining, 2017b, Table 2-4 – average and minimum values are not provided). Table 2-5 in the same document shows that the most common sulfides in Category 1 wastes are either chalcopyrite or pyrrhotite. Using the formula weights for these minerals, a sample with 4% chalcopyrite would have a sulfur value of 1.4%, and one with 4% pyrite would have a sulfur value of 2.3% - both of which are much higher than the 0.12%S assumed for Category 1 wastes. This discrepancy is not explained in the text and suggests that higher sulfide values could be present in Category 1 wastes. In addition, an inadequate number of samples were analyzed for Category 1 wastes, and if more samples were analyzed, it is likely that the %S range would expand. The conclusion from these results is that if acid is generated from Category 1 wastes, it will not be neutralized and will instead be available to leach metals from sulfides and other minerals in the waste. In addition, oxyanions such as arsenic can leach from mine wastes under neutral and alkaline pH conditions (see, e.g., Al-Abed et al., 2006).

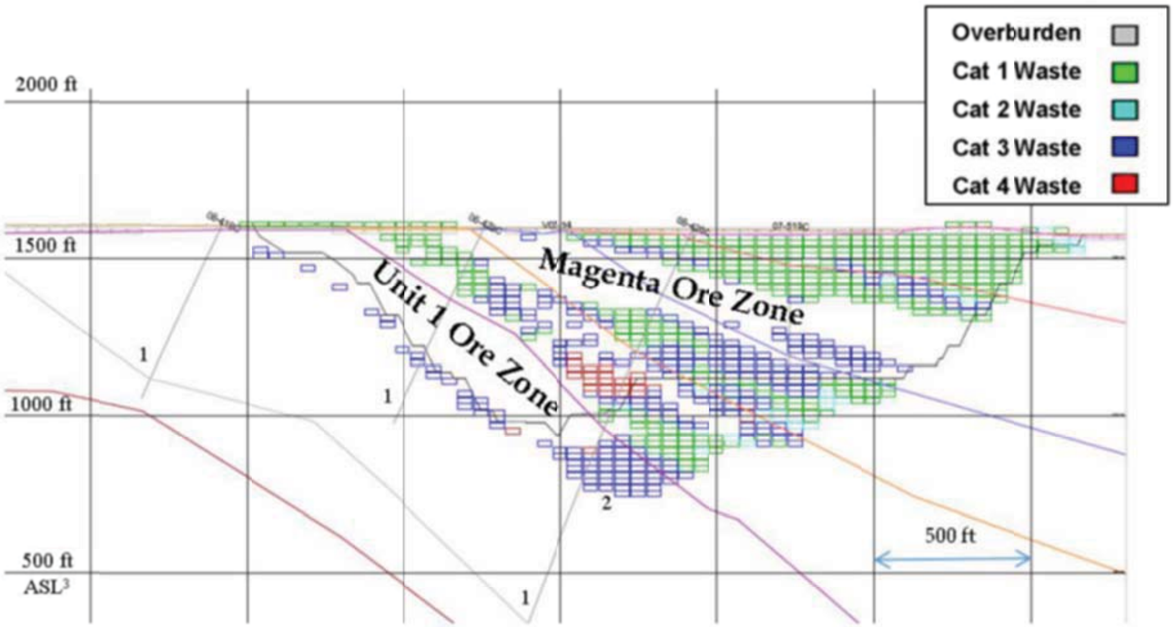
The Rock and Overburden Management Plan (PolyMet Mining, 2017c, Appendix 11.1, p. 40) discusses the plan for separating waste categories. In the beginning of operations, each blast hole will be assayed, but as mining progresses assaying will be conducted "less frequently." As the assaying becomes less frequent, errors in categorizing wastes in the field are bound to occur.

SRK Consulting (2007a, p. 92) discusses the difficulty in separating rocks with similar sulfur contents and the implications for environmental behavior in the field:

> Predictions of drainage chemistry from Category 2 rock are susceptible to the assumption that the overall conditions within the waste rock will remain non-acidic and the composition will reflect rock classified as Category 2 in the block model. Under operational conditions, these assumptions may be affected by the accidental inclusion of small amounts of Category 3 and 4 rock that could become localized sources of acidic water and leaching metals. The effect of these inclusions could be to contribute to metal leaching and lowering of pH resulting in higher concentrations of metals in the drainage. Category 3 and 4 rock could become incorporated into Category 2 rock by a number of routes which could include waste heterogeneity (i.e. small-scale inclusions of Category 3 and 4 rock in Category 2 rock) and operational errors. The latter are factors such as mistakes at the operating face and dumping location. These errors will be minimized by management practices but some level of operational mishaps can be expected.

Figure 2 shows that Category 1 waste in this example cross-section is most often close to Category 3 wastes and ore, especially along the upper edge of the Magenta Ore Zone. Ore has a higher sulfide content, and inclusion of ore, or any other waste category, will increase the acid drainage potential of the Category 1 stockpile.

Figure 2. Example cross-section through deposit showing waste rock categories.



[1]Drill Cores
[2]Block Size: 50x50x20 feet
[3]Above Sea Level

Source: PolyMet Mining, 2017c, Appendix 11.1, Figure 4-2.

The categorization of wastes for the NorthMet Project is based solely on sulfide content. In the past, copper concentrations in the wastes were also considered, but they are not currently. Descriptions of the pollution potential of mine wastes often focus solely on their acid generation potential, and acidity does increase the leaching of metals and other contaminants. However, the metal content of the waste rock is also a major concern. The total metal content of Category 1 wastes is not notably different than that of the other waste categories or ore, and in some cases, the concentrations are higher in Category 1 wastes.

As shown in Table 1, the mean nickel concentration in Category 1 wastes is similar to that in the other waste rock categories, and the maximum concentration is higher. Nickel is one of the major contaminants of concern for the NorthMet Project. Mean and maximum cobalt and manganese concentrations are higher in Category 1 than in the other waste categories. Category 1 zinc concentrations are similar to those in Category 2/3 wastes and higher than those in the ore. The %S content of Category 1 wastes, as proposed, is lower than the other wastes and ore, and Category 1 wastes have the lowest copper content, with the exception of the Virginia Formation, which is only 2.8% of all waste rock (see pg. 3). The whole rock data show that the potential exists to leach elevated concentrations of toxic metals from Category 1 wastes by themselves. The inadvertent mixing in of other wastes will only increase metal concentrations and acidity in the Category 1 stockpile leachate.

Table 1. Whole rock and %S summary results for some key constituents in waste rock and ore.

Constituent	Units	Category 1 (n=38) Mean	Category 1 (n=38) Range	Category 2/3 (n=25) Mean	Category 2/3 (n=25) Range	Category 4 (Duluth Complex; n=16) Mean	Category 4 (Duluth Complex; n=16) Range	Virginia Formation (n=3) Mean	Virginia Formation (n=3) Range	Ore (n=3) Mean	Ore (n=3) Range
Copper	%	0.025	0.005-0.095	0.084	0.010-0.295	0.088	0.020-0.152	0.017	0.015-0.021	0.360	0.323-0.422
Nickel	%	0.032	0.000-0.095	0.035	0.000-0.072	0.034	0.013-0.071	0.017	0.013-0.020	0.106	0.088-0.139
Cobalt	ppm	57	21-117	51	11-94	60	21-119	29	24-36	83	76-94
Manganese	ppm	864	351-1545	702	331-1325	451	151-1130	227	125-377	717	705-739
Zinc	ppm	78	33-136	84	33-200	120	47-324	575	252-918	74	71-76
Total Sulfur	%	0.05	0.02-0.12	0.29	0.14-0.59	1.44	0.68-4.46	3.82	2.00-5.68	0.87	0.86-0.90

Source: PolyMet Mining, 2017b, Table 2-2.

Given the uncertainties associated with separating the different waste categories and ore, and the potential adverse environmental consequences if more reactive materials are included in lower category wastes, it is critical to have an adaptive management plan (AMP) for waste rock. This is especially true for wastes reporting to the Category 1 stockpile, which will sit on the land surface in perpetuity. The only AMPs discussed in the Permit to Mine Application are for water quality and quantity and tailings dam stability (PolyMet Mining, 2017a, Section 3.6). An AMP for waste rock management should be similarly included and defined at this stage of the project. PolyMet Mining, 2017c, Appendix 11.1 (Section 6.0, p. 46) vaguely discusses adaptive management, but it does not appear to be related to stockpile composition. Section 6.2, although it is titled Adaptive Management, only discusses the capacity of the pits and the temporary stockpiles to hold waste rock. An AMP for waste rock management should include actions required if testing results indicate that wastes have been mixed, an evaluation of the impacts based on monitoring results, mitigation measures to be employed, mine company and agency responsibilities, timelines for actions, and an evaluation of the effectiveness of the mitigation measures employed.

Recommendations: Conduct ABA testing for more waste rock and ore samples, including NP, especially for samples identified as Category 1 wastes. Re-examine the assumption that the %S in Category 1 wastes will be ≤0.12%. Rerun the water quality predictions for discharge from the Category 1 stockpile assuming that a certain percentage of Category 2/3 wastes and ore will be included in the pile (use a range of percentages). Create an adaptive management plan for waste rock management.

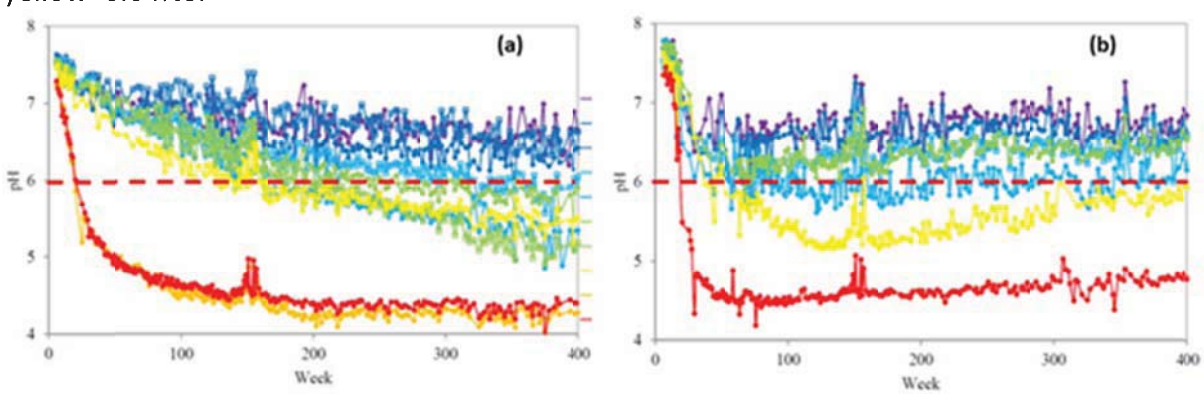
2. *Assumptions about Acid Drainage and Contaminant Leaching*

a. The pH recovers in samples that have gone acidic

SRK Consulting (2007a) and PolyMet Mining (2015a) have stated that in some cases, once the pH becomes acidic, the pH "recovers." SRK Consulting (2007a, p. i) stated that "the transition to acidic pHs takes many years" and the recovery occurred after "depletion of sulfide minerals." The Minnesota Department of Natural Resources (MDNR) reactor kinetic tests did show some recovery of pH values after the onset of acidification, as shown in Figure 3b for the samples with higher %S values. However, pH values were still acidic (pH<6) throughout the test. The minimal recovery was only seen in the MDNR reactor tests, where the sample and particles sizes were smaller than in the conventional HCTs (Figure 3a).

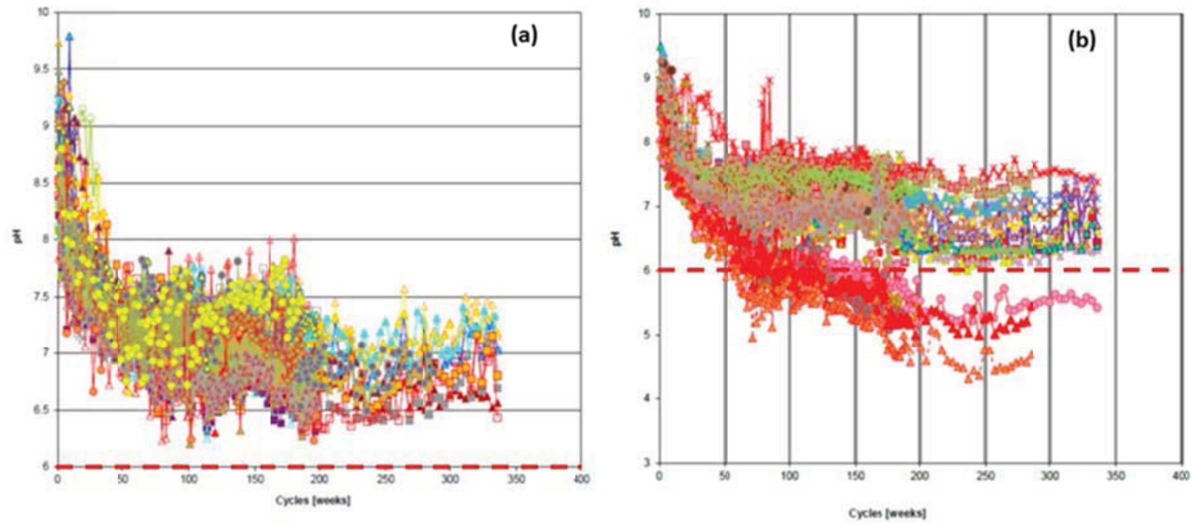
PolyMet Mining (2015a; Attachment 2, p. 2) stated that in some cases the pH recovered as oxidation rates decreased. Category 1 waste rock HCTs (Figure 3a) did not produce acidic conditions, but Category 2/3 waste rock did (Figure 4b). Some pH recovery occurred in the Category 4 waste rock HCTs (PolyMet Mining 2015a, Attachment 2, Figure 3; not shown), but in no case did pH values increase above 6.

Figure 3. The pH of long-term kinetic testing using (a) HCTs and (b) MDNR reactors.
HCT=1000g, d<6.35mm; MDNR reactors=75g, 0.053<d<0.149mm. Red=0.94%S, yellow=0.64%S.



Source: MDNR, 2013, Figure 7.

Figure 4. The pH of HCTs for (a) Category 1 and (b) Category 2/3 waste rock.



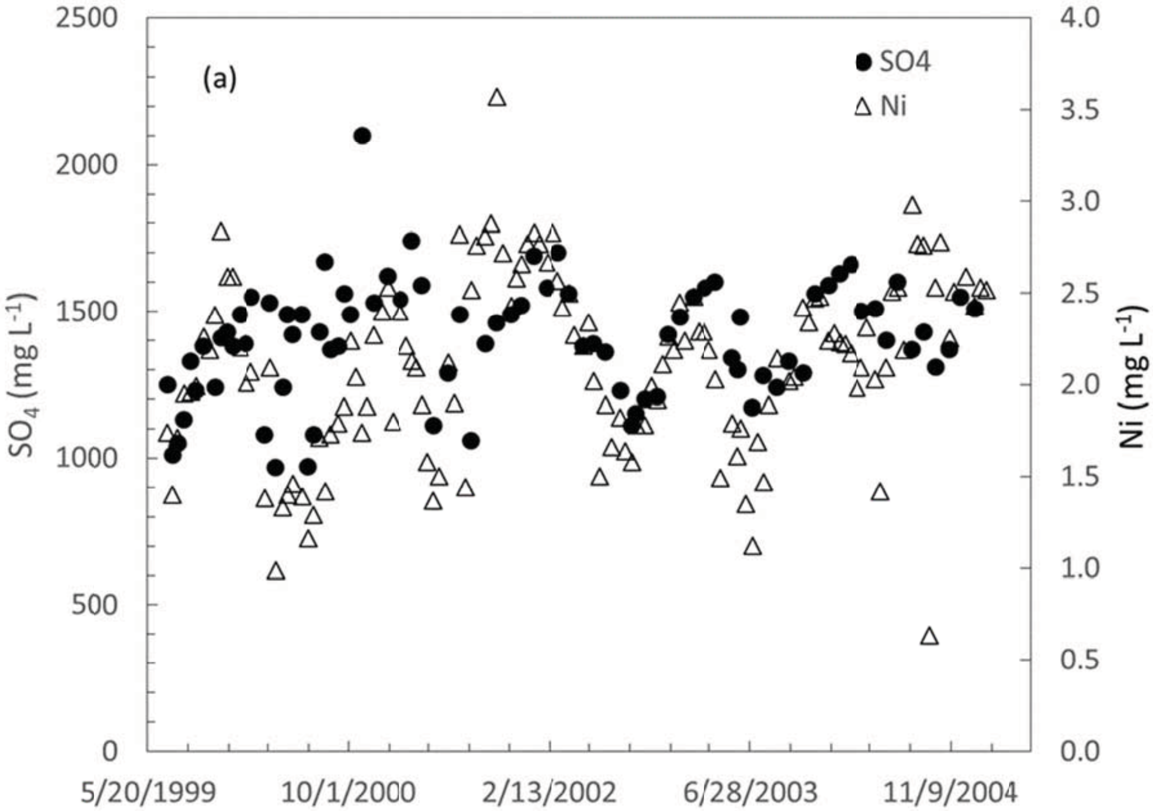
Source: PolyMet Mining, 2015a. Attachment C, Figures 1 and 2. Line at pH 6 added.

b. Release from secondary salts

One important distinction between HCTs and field conditions is the formation of secondary salts seasonally in aerially deposited waste rock piles. These hydrated metal-sulfate salts form from the oxidation of sulfide minerals and create crusts on the surface of mine wastes during periods of evaporation (Jambor et al., 2000). Under field conditions, some of these secondary salts (especially hydrated iron sulfate salts) can store acidity – and all store metals and sulfate – that can be readily released during rain or snowmelt events; the secondary minerals can form again as interstitial waters in the waste pile evaporate under drier conditions (Nordstrom, 1982; Hammarstrom et al., 2005). Under laboratory conditions, the dissolution of secondary salts occurs most notably during the first few weeks of kinetic testing, but these results are uniformly ignored (Maest and Nordstrom, 2017). In HCTs, the secondary salts are typically rinsed out during the first few weeks of testing – sometime purposefully – and these weeks often show the highest concentrations and release rates. The PolyMet HCTs used a higher volume of rinsate for the first week of testing (750 mL) than subsequent weeks (500 mL), so the first flush from the dissolution of soluble salts is diminished in the HCT results.

PolyMet took a different approach with the tailings and the waste rock regarding incorporating this "first flush" into release rates for water quality predictions at the NorthMet site. It is included for the tailings but excluded for the waste rock. This process clearly applies to waste rock, as seen in Figure 5 for the Dunka Road test piles. In the spring, concentrations of nickel and sulfate spike and then decrease as the sulfate salts that built up over the winter are dissolved.

Figure 5. Duluth Formation field leachate results. Sulfate and nickel concentrations over a 4.5-year period from 1999 to 2005 in Duluth Formation waste rock seeps, Dunka Road stockpile 8011.



Data source: Minnesota Division of Natural Resources, Division of Ecological & Water Resources. Electronic data deliverable. March 2014.

c. Release Rates and Concentration Caps

Overview

The methods used to build the GoldSim water quality model are described in PolyMet Mining, 2017b, Section 2.4. The results from the waste characterization program and other sources were used to develop the geochemical parameter inputs to the model. The primary reference for the inputs to the model is SRK Consulting (2011). The focus in this section will be on the development of model parameters for Category 1 waste rock because it is the only waste material that will remain on the surface forever.

SRK Consulting (2011) distinguishes between "release" and "leaching" as follows:

- Solute release = movement of the contaminant from the mineral or solid material source to solid, secondary weathering products
- Leaching = dissolution of weathering products by contact water and release to the environment.

Weathering products can be thought of as the metal sulfate salts produced from the oxidation and dissolution of primary minerals in the wastes or ore. For example, when sulfide minerals weather, they produce metal-sulfate salts. To estimate release rates, SRK used measured rates from the HCTs and metal:sulfur ratios in pyrrhotite[1] or olivine.[2]

One of the fallacies associated with this distinction is that HCT results actually include both processes, yet HCT results were only used for developing release rates. In addition, SRK (2011, p. 1) makes the following statement in their first paragraph: "The finite solubility of secondary minerals typically limits their dissolution so that leaching rates are lower than release rates on average." While this statement could be true for hydroxides, the opposite is the case for secondary metal-sulfate salts. Sulfate salts forming on weathered waste dissolve rapidly when contacted by rain water or snowmelt; in contrast, primary sulfide and aluminosilicate minerals weather relatively slowly (Maest and Nordstrom, 2017 and references contained therein). This assumption leads to underestimation of release rates that are used as inputs to the NorthMet water quality model.

To estimate leaching, SRK's main focus was on limiting concentrations (concentration caps) that could be present in leachate from waste rock. SRK used concentrations from short-term leach tests (SMWMP), theoretical mineral solubilities, and data from the AMAX test piles (only for nickel, and only from pH 7 to 8). These concentrations are the maximum values allowed to reach the environment after the contaminant is released from the weathering products by contact water (e.g., rain or snowmelt). Once in the environment, concentrations are limited further by adsorption onto soils or aquifer materials.

The approaches used by SRK to develop inputs to the water quality model are unnecessarily convoluted, inconsistent, unsupported, and opaque. Some of the limitations to SRK's development and use of release rates and leachate concentration limits (concentration caps) are discussed below.

Release Rates

Final methods for developing model distribution parameters for ore and waste rock release are shown in Tables 2-19 to 2-23 (PolyMet Mining, 2017b).

<u>Method 1: Fit to HCT Data</u>. For many constituents, release rates are based on *average* non-acidic release rates from HCTs.[3] Release rates for waste rock were initially developed as shown in Table 1 in SRK (2011). Discrepancies between this table and Large Table 2 in PolyMet Mining (2015a), which contains and relies upon the SRK (2011) memorandum, suggest that using whole rock or microprobe metal:S ratios for silver, arsenic, beryllium, lead, antimony, selenium, and vanadium and multiplying by the sulfate release rate was

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[1] Pyrrhotite, $Fe_{1-x}S$, is the primary iron sulfide mineral in the NorthMet deposit that is responsible for acid drainage formation.

[2] A rock-forming mineral containing iron, magnesium, and, in the case of the NorthMet deposit, trace amounts of nickel.

[3] For Category 1 waste rock this includes Ag, alkalinity, As, B, Be, Ca, Cr, F, K, Mg, Na, Pb, Sb, Tl, and V.

abandoned. Instead, <u>average</u> HCT release rates from non-acidic conditions earlier in the tests (referred to as Conditions 1 & 2) were used.

Although this approach seems reasonable on the face of it, there are two issues that will underestimate release rates for constituents using Method 1. First, the initial releases of contaminants (“first flush,” referred to as Condition 0) are never included (see SRK, 2011, pg. 7). Second, using average release rates dampens the higher release rates that should be considered for environmental protection. Figure 6a shows that the highest arsenic release rates for Category 1 samples occurred very early in the tests – in fact, some rates are so high they are excluded from the graph; however, these “Condition 0” first flush rates were excluded from the water quality model. Figure 3a also shows how using average release rates for the entire series of Category 1 HCTs (Category 1 HCT results were only labeled as Condition 1 or 2) would minimize release rates, especially by inclusion of rates beyond week 200.

A variation on Method 1 was used for sulfate. The HCT data from Conditions 1 & 2 were used, but the results were regressed against the %S values. Again, this approach eliminates the higher rates seen in Condition 0, or first flush, times in the tests, as shown in Figure 6b.

<u>Method 2: Use element ratios from solids – either using whole rock chemistry (aka aqua regia) or individual mineral results.</u> This approach was used for many of the important contaminant of concern, including copper, zinc, and nickel for Category 1 and 2/3 wastes and arsenic in Category 2/3 wastes.

A very brief description of the approach is given in SRK (2011, Section 2.4), but no data are provided to confirm that the approach makes sense for the constituents and samples evaluated. The following equations are provided in Section 2.1 of the same document; equation (2) is for metal and sulfur concentrations in pyrrhotite, and equation (3) is for metal and magnesium concentrations in olivine. Taken together, the implication is that to arrive at a release rate for metals using Method 2, the sulfate, magnesium, or potassium release rate from the HCTs is multiplied by the metal:major anion or cation concentration ratio in the solid. No information is given on the release rates used for sulfate, magnesium, or potassium. Is it an average of all the rates in the HCT? Is it the average of rates in a certain Condition (1, 2, or 3, for example)? Section 8.1.2.3 in PolyMet Mining (2015a) states that for metals using ratios from whole rock data (aqua regia results), 18,800 samples were used to develop distributions. However, those data are tied to HCT release rates from a limited number of samples (just those in a given waste Category). Are the metal:S ratios varying wildly, but the sulfate release rate from the HCTs is not? Samples with different metal and sulfur concentrations in the solid will presumably produce different sulfate and metal release rates, but this does not seem to be accounted for in the approach. No examples are provided to show how the results from this method relate to results, for example, from the AMAX test piles. We are apparently to take this on faith.

Figure 6a. HCT release rates for arsenic in Category 1 waste rock samples.

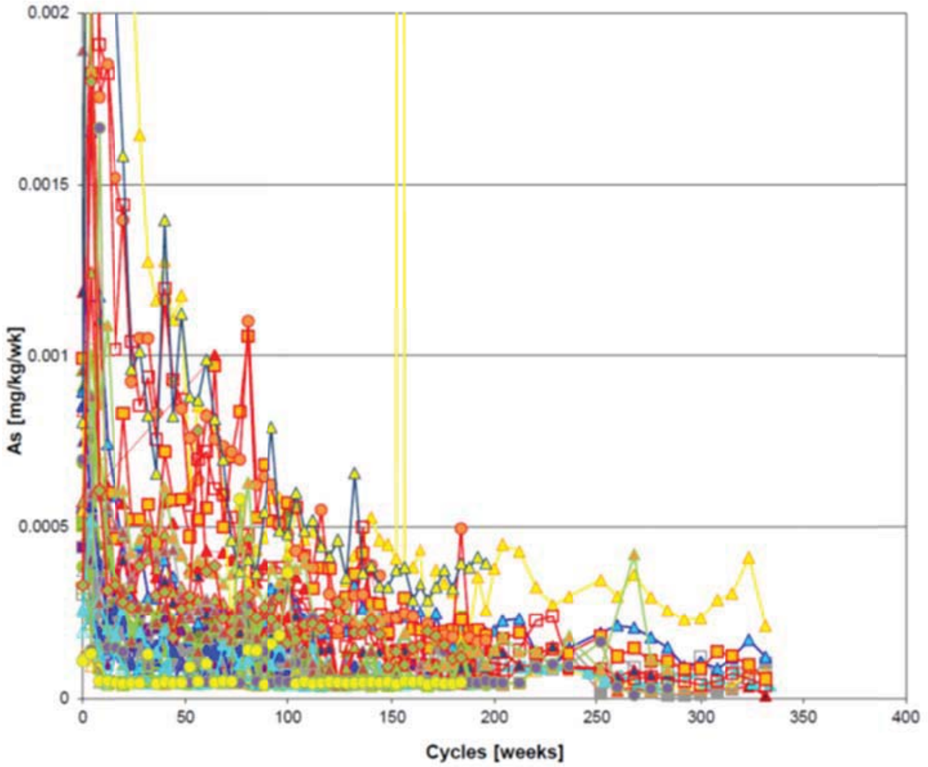
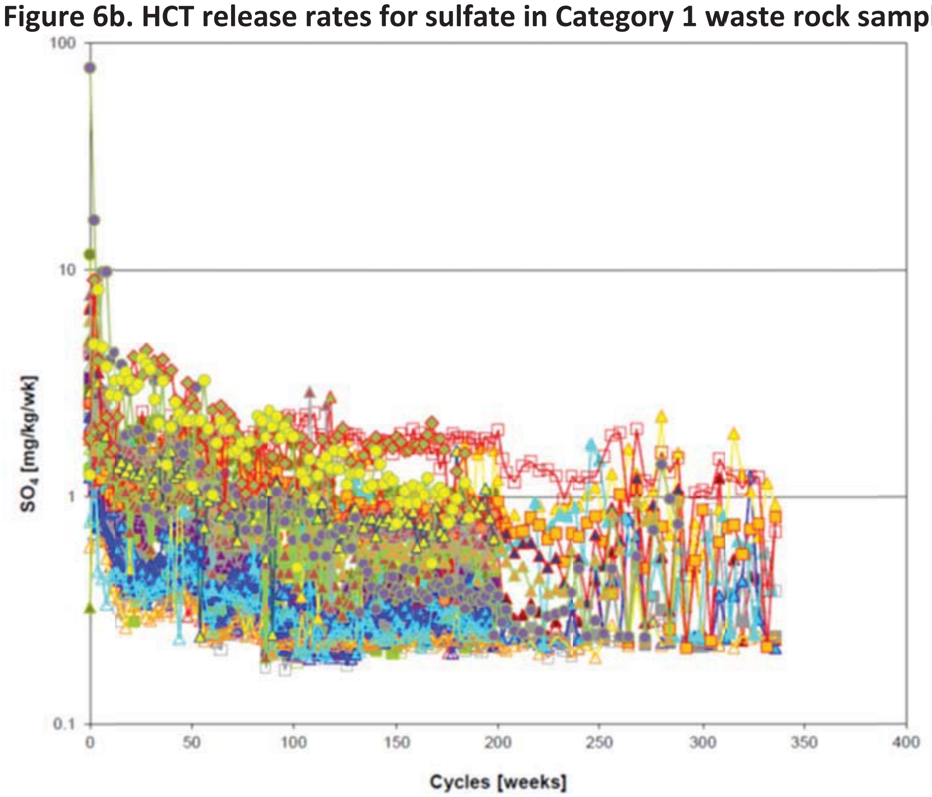


Figure 6b. HCT release rates for sulfate in Category 1 waste rock samples.



Source: PolyMet Mining, 2015a, Attachment C, Figure 1.

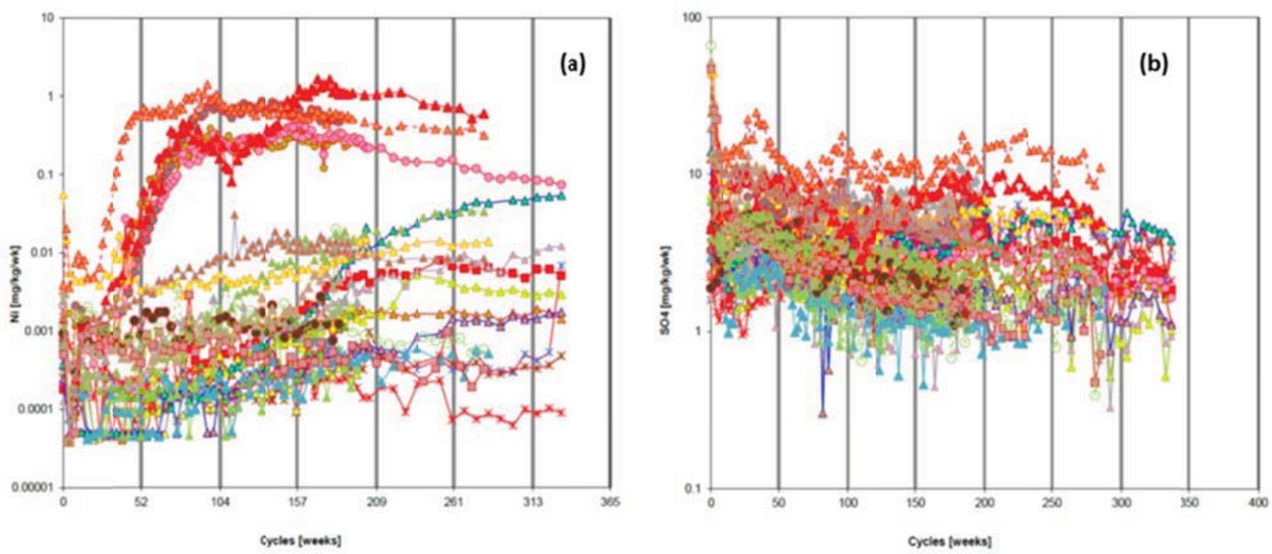
The math implied in equations (2) and (3) requires that the metal release rate will always be in lock step with the sulfate, magnesium or potassium release rate. However, we can see by looking at the HCT results that this is not the case. For example, the HCT release rate for nickel is tied to the HCT release rate for sulfate for Category 1 and 2/3 wastes. Figure 7 shows that trends in rates for these two contaminants do not mirror each other.

$$R_M = R_S \cdot \frac{[M]_{solid}}{[S]_{solid}} \qquad (2)$$

$$R_{metal} = R_{Mg} \cdot \frac{[M]_{solid}}{[Mg]_{solid}} \qquad (3)$$

The methods used to develop release rates for wastes and ore often underestimate potential release rates in the environment and do not hold true to the available data. In addition, the theories are unconvincing because they are not supported by comparison to actual laboratory or environmental data.

Figure 7. Comparison of rate trends for nickel (a) and sulfate (b) in Category 2/3 waste rock HCTs.



Source: PolyMet Mining, 2015a, Attachment C. Figure 2.

Scaling Factors and Concentration Caps

Scaling factors and concentration caps were used to limit input concentrations in the water quality model. Scaling factors will be discussed only briefly for Category 1 waste rock. The approaches have changed over the different versions, but the current approach for scaling laboratory to field results for Category 1 waste rock is to compare sulfate release rates from the Dunka Road stockpiles to sulfate release rates from MDNR reactor tests using rock from the Dunka Mine blast holes. For the laboratory tests, the first 71 weeks of testing were used, but results from the first five weeks were excluded (PolyMet Mining, 2017b, p. 13 and PolyMet Mining, 2015a, Section 8.2.8). This resulted in 17 *average* sulfate release rates as a function of sulfur content. The fact that results from the first five weeks were removed from the leach tests means that any "first flush" effects were also removed. In contrast, all flow and concentration data from the Dunka Mine stockpiles were used, which likely includes first flush data, as shown by the peaks in sulfate concentrations each spring (see Figure 4). However, the first flush concentrations and the high values during the remainder of the leach tests were essentially removed by using average annual sulfate release rates as a function of sulfur content.

A more protective approach to scaling for Category 1 waste rock would be to use the full range of non-acidic AMAX leachate data without averaging (i.e., using a scaling factor of 1.0) to account for uncertainties in the sulfur content of the stockpile (discussed in Section 1c of this memorandum). It is also important to keep in mind that the AMAX leachate data are from filtered samples, which ignores the potential for particulate metals to dissolve and increase mobile concentrations under varying field conditions.

Concentration caps are important because the Mine Site water quality model assumes that contaminants in the stockpile leachate will be entering the environmental at no higher than these concentrations. Concentration caps for Category 1 were used for nearly every constituent: alkalinity, aluminum, antimony, arsenic, beryllium, cadmium, cobalt, copper, iron, lead, manganese, nickel, potassium, selenium, silver, sodium, thallium, vanadium, and zinc (PolyMet Mining, 2017b, p. 15). Release rates units are mg/kg/wk, and concentration cap units are in mg/L.

In addition to the use of averaging and elimination of first flush values, a further shortcoming of the Category 1 concentration cap conceptual model is that pH values below 7.0 and above 8.1 are not considered; apparently this narrow range was based on results from short-term leach tests (SMWMP; SRK, 2011, p. 15), which are not reflective of longer term leaching. The entire Category 1 HCT pH range should instead be used. The pH range used for Category 1 metal concentration cap distribution values is 7.0 to 8.1 (PolyMet Mining, 2017b, Table 2-30), yet many Category 1 HCT pH values are below 7.0, including values from early in the tests (starting at ~25 weeks) to the end of the tests (~350 weeks), as shown in Figure 8a. When the pH drops, most metal concentrations increase, so the caps will underestimate leachate metal concentrations at pH values <7 for the Category 1 stockpile. Similarly, the higher pH values in Category 1 HCTs are between 9.5 and 10 (see Figure 7a). Concentrations of elements that form oxyanions such as arsenic, antimony, molybdenum, selenium and vanadium can increase at higher pH values, and higher arsenic concentrations are associated with higher pH values in Category 1 leachate (see Figures 6a, which shows arsenic rates that reflect concentration trends) and 8a (for pH). Examples of this behavior are shown for some of the oxyanions listed above in SRK's porphyry database (2011b, Attachment 3).

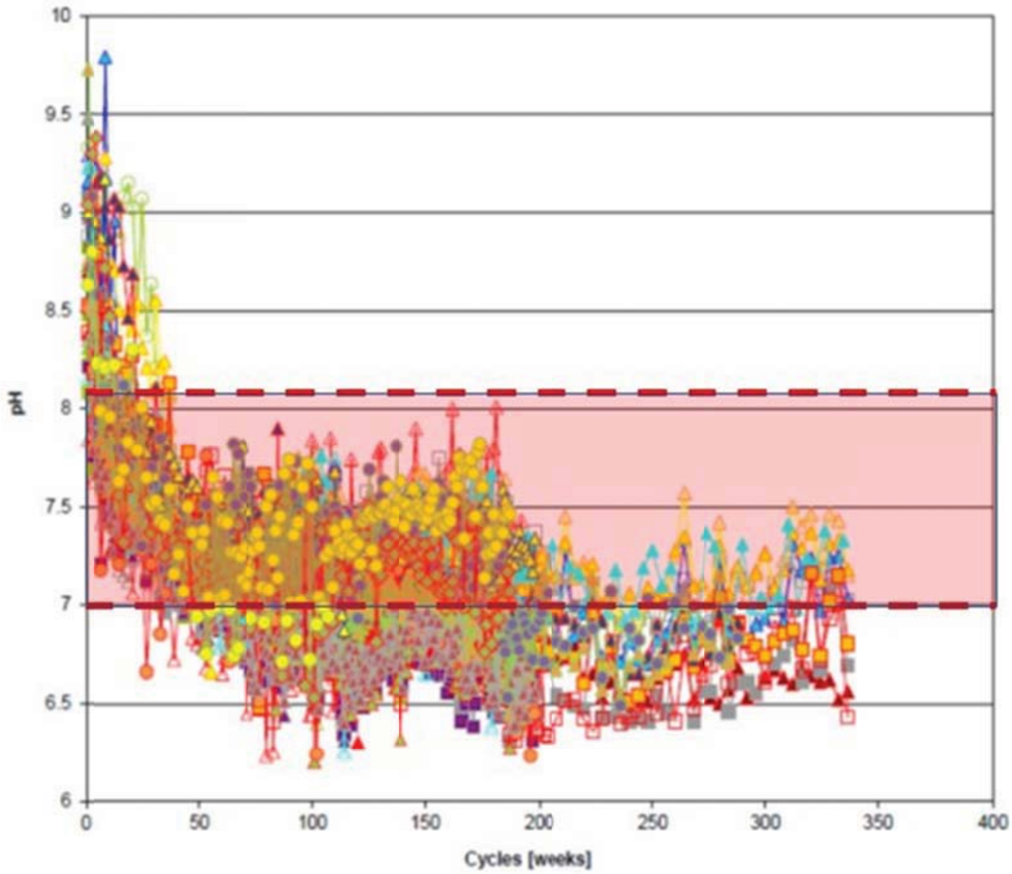
The AMAX test pile data were used to develop the concentration caps for most metals and for alkalinity (PolyMet Mining, 2017b, Table 2-30). Figure 8b shows the AMAX data for nickel as a function of pH. In the pH range considered for Category 1 waste rock concentration caps, the maximum measured nickel concentration is 67 mg/L. However, the maximum concentration cap allowed for nickel in Category 1 wastes is only 13 mg/L (PolyMet Mining, 2017b, Table 2-30). If the pH range between 6.0 and 7.0 is considered, the maximum measured nickel concentration is 120 mg/L, almost 10 times higher than the maximum concentration cap. Similar results are likely for other metals. For comparison, the cap for non-acidic leaching of Category 2/3, 4, and ore materials is only 32 mg/L at pH 6.0 (PolyMet Mining, 2017b, Table 2-31). These results show that the concentration caps for nickel and possibly other metals in all mined materials are too low and that their use in the mine site water quality model will underestimate concentrations of metals in leachate that reaches the environment.

These alternative results are based on a different conceptual model for the development of concentration caps:

- Concentration caps are unnecessary in a water quality model that could use a geochemical code to limit concentrations based on mineral solubility.
- If caps are to be used, they should include upper concentration values that were excluded by using averages and eliminating first flush concentrations.
- The full range of potential Category 1 pH values should be used, including values above 8 and below 7. Considering that the Category 1 stockpile will likely include higher %S wastes, acidic conditions could develop. Limiting pH values to 6.0 on the low end could underestimate maximum possible contaminant concentrations in Category 1 leachate. As an initial estimate, the pH range from Category 1 HCTs could be used (approximately pH 6-9.5)
- Using "median" sulfate concentration for gypsum solubility, estimated at 2,700 mg/L (SRK, 2011, pg. 11) and based on HCT results for a time in the test when gypsum is not likely dissolving (Condition 2), will underestimate possible sulfate concentrations for the Category 1 stockpile. A better approach would be to base limits on first flush HCT values or, even better, use a geochemical code that will take complexation into account.
- Concentrations of many elements, including sulfate, copper, nickel, selenium, iron and others are likely limited by the solubility of secondary sulfate salts, and a geochemical code with thermodynamic data for these phases should be employed. Inverse modeling could be used to evaluate potential phases (Maest and Nordstrom, 2017). SRK (2011b, pg. 9) notes that concentrations of sulfate, barium, selenium, and copper were likely limited by secondary mineral solubilities in the sequential short-term leach tests conducted on Category 1 wastes.

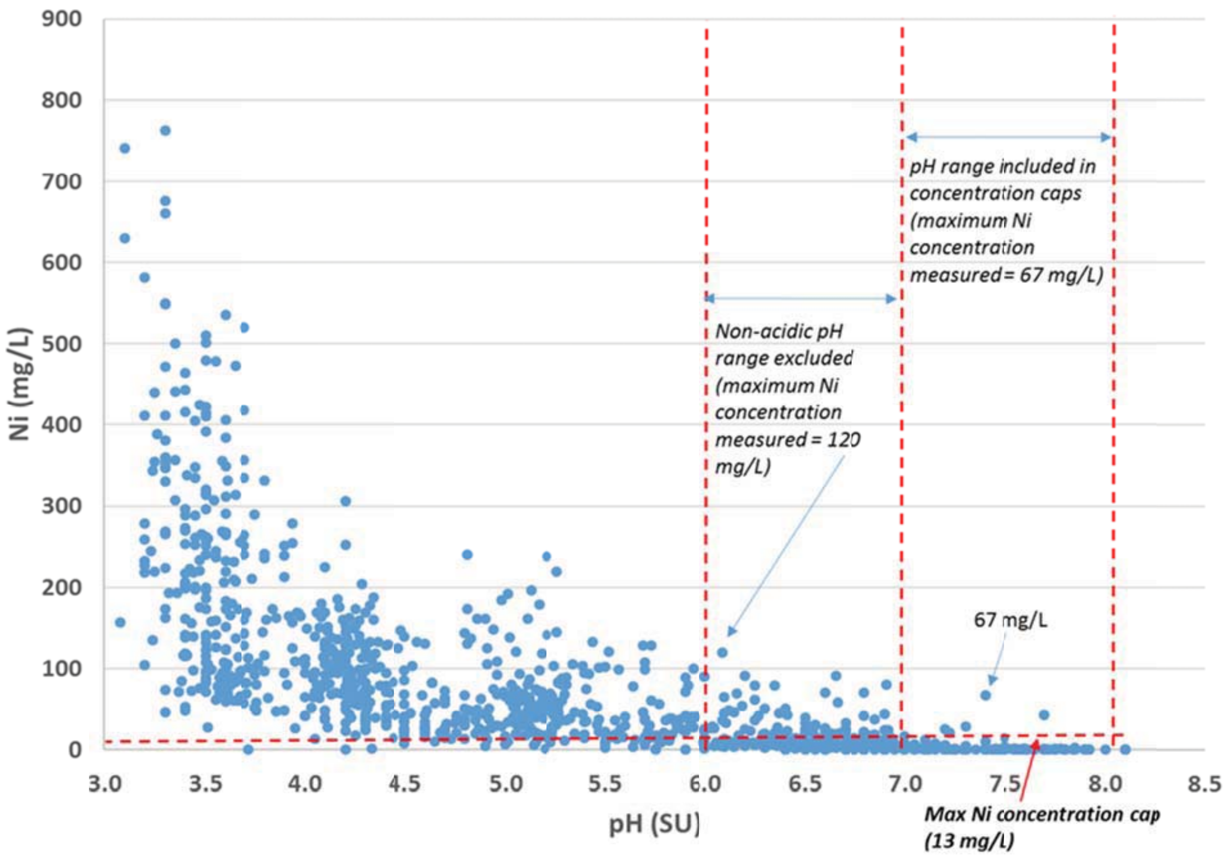
Recommendations: Incorporate the release of metals, acidity, and sulfate from secondary salts into release rates for waste rock and ore and then into water quality predictions. The release of contaminants from secondary salts has been ignored in water quality modeling for the mine site, yet these are important long-term, soluble sources. Using averages and ignoring inputs from secondary salts will underestimate the extent of contaminant plumes in the environment, and the use of a proprietary code (GoldSim) decreases transparency. Use the information to create seasonal changes in released concentrations that better mimic the releases observed from the Dunka Road/AMAX piles.

Figure 8a. Category 1 HCT pH values and the pH range considered for development of concentration caps.



Source: PolyMet Mining, 2015a, Attachment C, Figure 1.

Figure 8b. Nickel concentrations vs. pH in AMAX test pile, showing pH range considered for Category 1 concentration caps with maximum measured value (67 mg/L) and non-acidic pH range excluded (pH 6.0 to 7.0) and maximum measured value (120 mg/L) between pH 6.0 to 7.0. The maximum concentration cap for nickel in Category 1 waste rock is only 13 mg/L.

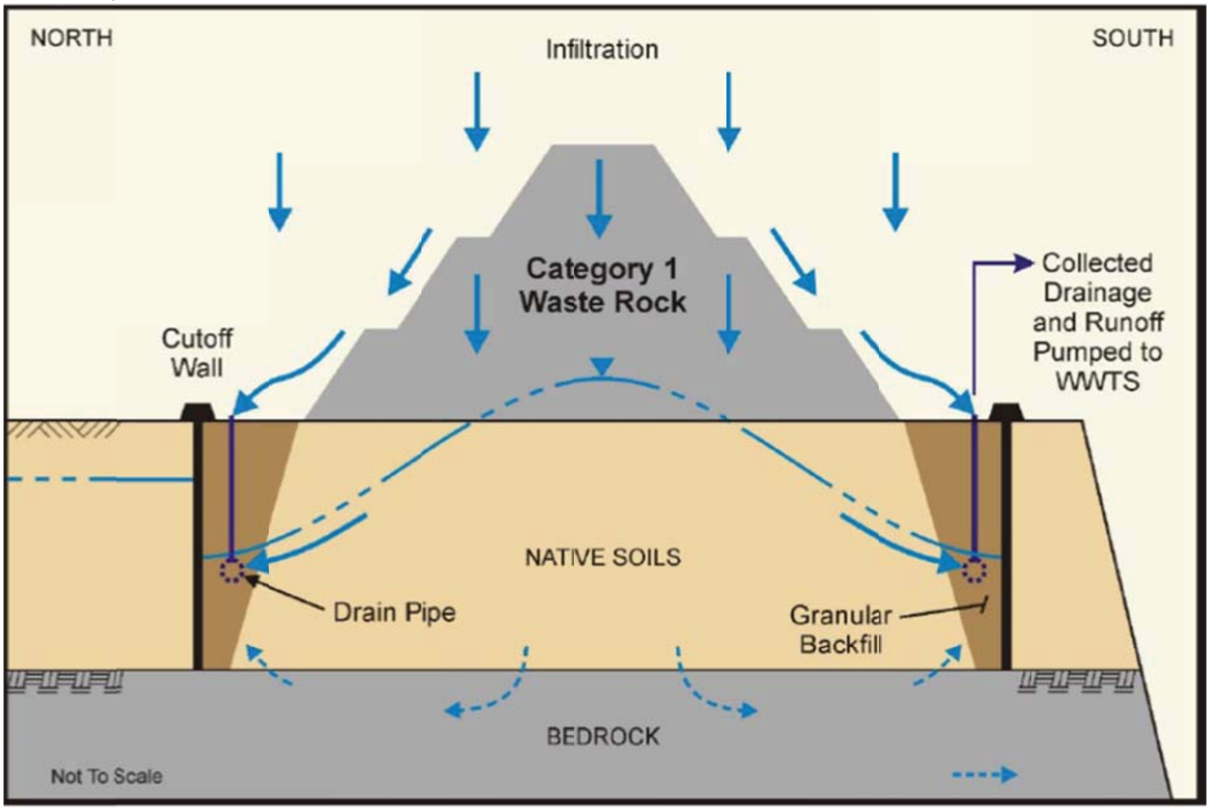


Data source: Minnesota Division of Natural Resources, Division of Ecological & Water Resources. Electronic data deliverable. March 2014.

3. The Quality of Water Impacted by Category 1 and Category 2/3 Stockpiles

If seepage collection from the waste rock stockpiles doesn't work as well as predicted during operations and closure, nearby groundwater and surface water resources will be threatened. Figure 9 shows the plan for management of seepage from the Category 1 stockpile. No liner is proposed for the facility, the groundwater between the cutoff walls is expected to contact the wastes, and contaminated drainage has the potential to escape capture and infiltrate to the bedrock aquifer. The stockpile cap is assumed to limit the infiltration of precipitation falling on the stockpile (although not the ingress of oxygen), but the cover will not be installed until Mine Year 14 and will take eight years to complete (PolyMet Mining, 2017c, Appendix 11.4, p. 20 and 39). This leaves one to two decades of weathering and leaching for contaminants in the stockpile.

Figure 9. Conceptual cross-sectional model of Category 1 stockpile drainage and containment system during operations. Note that no liner is proposed for the facility, the groundwater surface (blue dashed line with blue triangle at high point) between the cutoff walls is expected to contact the wastes, and contaminated drainage has the potential to escape capture and infiltrate to the bedrock aquifer (dashed blue lines with arrows in bedrock).



Source: PolyMet Mining, 2017c, Appendix 11.1, Figure 2-2.

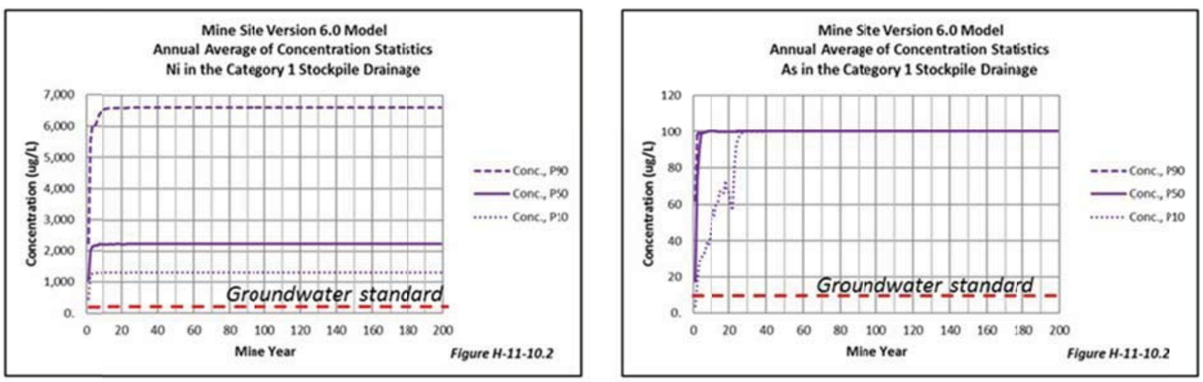
The Rock and Overburden Management Plan (PolyMet Mining, 2017c, Appendix 11.1, p. 15) states that groundwater could flow under the cutoff wall on all sides of the stockpile but the south side, but that groundwater recovery wells could be installed if this occurs. Allowing pollution and attempting to remediate the situation does not reflect a pollution prevention approach. Instead, the stockpile should be lined with a segmented leachate collection system (to help pinpoint the source of leaks) installed directly under the pile instead of in native soils that drain to bedrock.

Annual average (not maximum) nickel concentrations in the drainage are predicted to be at least 10 times higher than groundwater standards, and arsenic concentrations are predicted to be up to 10 times higher than the groundwater standard, as shown in Figure 10a. According to modeling conducted by Myers (2018, p. 17), Category 1 drainage will not be captured by dewatering of the West Pit but will instead flow toward the Partridge River south of the mine site (Figure 11a).

Similar results are found for drainage from the temporary Category 2/3 stockpile, which is predicted to have much higher copper and nickel concentrations than Category 1 drainage. Figure 10b shows that predicted concentrations of nickel and copper in the Category 2/3 stockpile drainage are up to 3,500 and 160 times higher than groundwater standards, respectively, during the 20-year life of the stockpile (groundwater standards for nickel and copper are 0.1 and 1 mg/L, respectively).

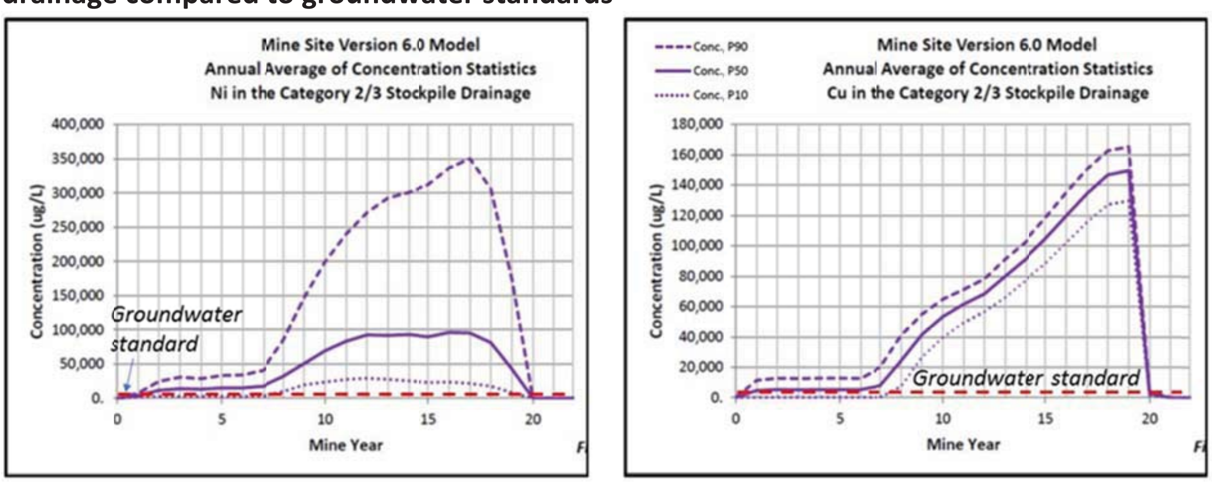
Discharge from the Category 2/3 stockpile will flow south a shorter distance than the predicted Category 1 plume toward the Partridge River (Figure 11b; Myers, 2018, p. 17). Surface water standards for nickel and copper are 0.158 and 0.0098 mg/L, respectively (using a hardness of 100 mg/L as $CaCO_3$, which is close to average values for points close to the mine site); predicted peak copper concentrations in Category 2/3 stockpile discharge are over 17,000 times higher than water quality standards for the Partridge River.

Figure 10a. Predicted concentrations of nickel and arsenic in Category 1 stockpile drainage compared to groundwater standards



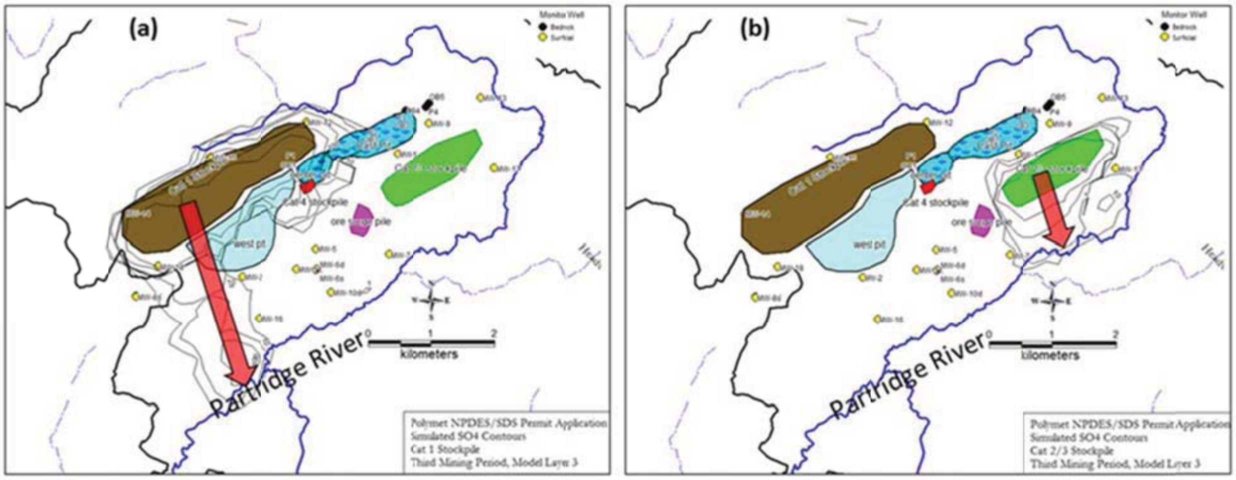
Source: Excel file received from MN DNR, GW_Conc_Timeseries_MineSite.xls (Note: these graphs were not included in PolyMet Mining, 2015b).

Figure 10b. Predicted concentrations of nickel and copper in Category 2/3 stockpile drainage compared to groundwater standards



Source: PolyMet Mining, 2015b, Fig. G-01-13.2 (Cu) and G-01-20.2 (Ni).

Figure 11. Predicted sulfate plumes and flow directions in groundwater for the (a) Category 1 and (b) Category 2/3 stockpiles during Mine Year 11



Source: Myers, 2018, Figures 21 and 22. Flow directions added.

PolyMet does not estimate the pH of stockpile drainage, but the HCT results suggest that pH values for the Category 1 stockpile will be between 6.5 and 7.5, and values for the Category 2/3 drainage will be acidic. If the Category 1 drainage does become acidic as a result of mixing with higher-sulfide materials (see Section 1c of this memorandum), the silicate minerals will not be able to buffer the acidity (see, e.g., King and McSween, 2005). A detailed examination of a PolyMet sample that did go acidic shows that when pH values are low and aluminosilicate minerals such as olivine are dissolving, the pH remained low (~pH 4) (Maest and Nordstrom, 2017).

The available information on stockpile drainage quality and groundwater flow directions strongly suggests that groundwater and the Partridge River will exceed water quality standards as a result of drainage transport. The Permit to Mine Application predicts that all metals and sulfate will be attenuated at the mine site before it reaches compliance locations. Nonconservative assumptions about contaminant fate and transport in groundwater result in this conclusion.

Modeling by SRK Consulting predicts that no mine-related contaminants will exceed water quality standards at the surface water and groundwater locations examined (Dunka Road, SW005, etc.). However, closer-in monitoring wells were not but should have been examined.

Recommendations: Commit to lining the Category 1 stockpile using a geomembrane and underlying it with a sectional leachate collection system. Rerun the water quality model for Category 1 releases using this new mitigation approach and assuming no adsorption onto aquifer materials as one end-member of the prediction.

4. Reactivity of Flotation and LTVSMC Tailings

The State of Minnesota defines "reactive" mine waste as follows (Minn. R. 6132.0100, subp. 28):

> “Reactive mine waste" means waste that is shown through characterization studies to release substances that adversely impact natural resources.

The definition implies that the “substances” refers to those that could potentially have an adverse impact on natural resources. For example, if the waste rock releases only magnesium, the waste rock would likely not be considered reactive, but if the waste rock releases copper, which has known adverse effects to aquatic biota, it would be. The goal of the definition is to prevent or minimize the effect of the releases on natural resources, so the definition of reactivity addresses the potential of the material to release contaminants. If a potential to release substances that could adversely affect natural resources exists, the mitigation measures in Minn. R. 6132.2200, subpart 2.B must be put in place to avoid the negative impact.

The characteristics of the NorthMet tailings, and all sulfidic tailings for that matter, are such that the “oxidation of residual sulfide minerals resulting in release of acidity, iron, sulfate and trace elements (copper and nickel)” is expected to occur, and an oxidation front is expected to develop and move through the tailings (SRK, 2007b; p. 15). This statement from PolyMet’s consultants, and the available data, clearly show that the tailings are reactive, will remain reactive for a long time, and need best practice mitigation measures to prevent an adverse effect on natural resources.

In addition to the NorthMet flotation tailings, pre-existing tailings from former iron ore processing, known as LTVSMC tailings, are also at the Plant Site. PolyMet plans to put NorthMet tailings on top of the LTVSMC tailings. Some of the LTVSMC tailings are saturated with water, and groundwater levels are currently above the former ground level (PolyMet Mining, 2017a, p. 83). The LTVSMC tailings were also examined using characterization methods that were similar to those used for the NorthMet flotation tailings.

A report on the NorthMet flotation tailings and hydrometallurgical residues is actually called “Reactive Residues Progress Report” (SRK, 2006a) suggesting that as early as 2006, PolyMet considered the tailings reactive. The primary iron sulfide mineral in the NorthMet ore, tailings, and waste rock is pyrrhotite, which is known to be more reactive than even pyrite (Nicholson and Scharer, 1994).

a. LTVSMC Tailings

Unlike the NorthMet tailings, the LTVSMC tailings currently exist, and water quality data from groundwater and seeps in and around the tailings basin are available (Barr Engineering, 2006). The description of the releases from these tailings limits the constituents to calcium, magnesium, iron, manganese, and alkalinity (SRK, 2007b, p. 15). However, the tailings area groundwater and seep quality data show that fluoride, manganese, and sulfate exceed state water quality standards applicable to the project in groundwater affected by the LTVSMC tailings (SRK, 2007b, Table 4-1). The elevated fluoride is believed to be related to the use of wet scrubbers for control of particulate emissions from the induration furnaces (SRK, 2007b. p. 12).

Leaching experiments with LTVSMC tailings show that the leachate exceeded NorthMet Project groundwater quality standards for fluoride, sulfate, and arsenic and had higher concentrations of these constituents and chloride, cobalt, copper, and manganese than leachate from the NorthMet tailings (SRK, 2007b, Appendix C.3). The LTVSMC tailings leachate also generally had higher pH and alkalinity and higher calcium and magnesium concentrations than the leachate from the NorthMet tailings. However, nickel concentrations were almost always higher in the NorthMet tailings leachate, indicating that nickel is a major contaminant of concern for the new project.

Several of the constituents in the LTVSMC tailings (SRK, 2007b, Appendix C.3) showed a flushing effect (initial higher concentrations), including sulfate, fluoride, chloride, cobalt, copper, nickel; sulfate, arsenic, boron, chloride, copper, lithium, magnesium, potassium, sodium, strontium, and molybdenum showed a flushing effect in the NorthMet tailings.[4] The results indicate that these constituents are associated with soluble salts in the tailings and could be released fairly rapidly upon contact with infiltrating waters.

b. NorthMet Flotation Tailings

The NorthMet tailings have sulfur values ranging from 0.09 to 0.24 %S (SRK, 2007b, Table 5-2), and eight of 13 samples had %S values higher than those for Category 1 wastes (0.12 %S). SRK (2007b, p. 39) predicts that tailings with sulfur values < 0.2% S would not produce acid. Only 13 tailings samples were analyzed for ABA, and three of 13 samples had sulfur values ≥0.2 %S (SRK, 2007b, Appendix B.3). However, as noted in the following paragraphs, leaching even under neutral conditions will increase the release of nickel and other metals. Results from only 13 tailings samples are presented in SRK (2007b), but PolyMet, 2017b (p. 5) states that 33 tailings samples were analyzed for total sulfur and NP. The complete results are not presented in any available document. According to sulfur testing of NorthMet flotation tailings, the average sulfur content of the tailings was 0.19 %S, and the composite tailings sample had a sulfur content of 0.2%, "closely representing the average" (SRK, 2006b, p. 1). These results indicate that, over time, the NorthMet tailings will likely produce acid.

SRK (2007b) uses geochemical modeling on the results from tailings kinetic tests and concludes that the leaching of nickel from secondary minerals in the tailings could generate concentrations of nickel from 2.2 to 2.4 mg/L at neutral pH (pH 6.5) under field conditions. SRK further concludes that the coarser NorthMet tailings can be expected to leach nickel after several months when the pH drops below 7, and that nickel concentrations below pH 7

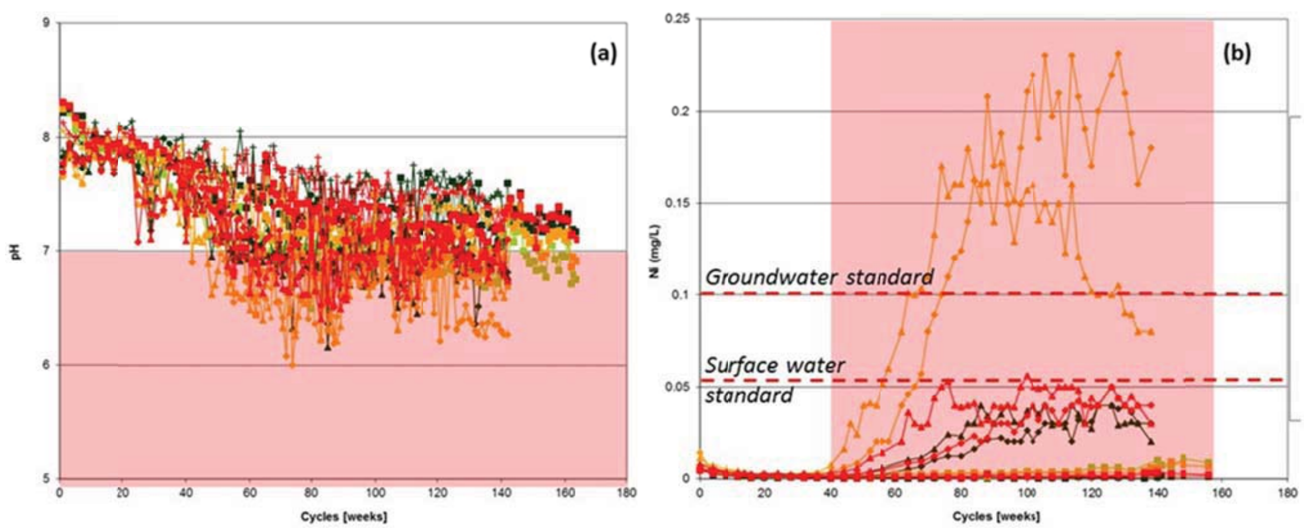
[4] Source: Minnesota Division of Natural Resources, Division of Ecological & Water Resources. Electronic data deliverable. March 2014. Excel file of tailings graphs, concentrations_Tailings_graphs.xls.

will be higher under field conditions than indicated in the kinetic testing results (SRK, 2007b, p. 46). The predicted leachate nickel concentrations are over 20 times higher than applicable groundwater quality standards, indicating that the NorthMet tailings do pose a water quality threat to underlying groundwater, and effective, best practice mitigation measures must be installed.

In terms of pH, a discrepancy exists between statements in reports and the leach test results. PolyMet Mining, 2017b (p. 10), which contains mine waste characterization summaries, states that the kinetic testing results for the flotation tailings show "no indication of trends below pH 7" or "with lowest pHs typically above 7." As shown in Figure 12a, many pH values are below 7, with values as low as pH 6.

Samples with pH values below 7 also show enhanced nickel leaching (Figure 12b) with cobalt and manganese concentrations following very similar trends. SRK (2007b, p. i) notes that kinetic testing by MDNR and PolyMet "on coarse (>200 mesh fraction) tailings has shown that nickel and cobalt leaching accelerates when pH falls below 7 due to re-leaching of weathering products formed at higher pH." These results indicate that the tailings are reactive even under non-acidic leaching conditions. According to PolyMet, 2017b (p. 10), the mineralogy of the flotation tailings is similar to that of Category 1 waste rock. If that is the case, Category 1 waste rock could also activate the release of nickel and cobalt if the pH drops below 7.

Figure 12. Flotation tailings humidity cell results for pH and nickel; (a) tests with pH values <7 in pink shading, (b) enhanced nickel leaching when pH values are <7 (pink shading) and applicable groundwater and surface water quality standards.



Source: Minnesota Division of Natural Resources, Division of Ecological & Water Resources. Electronic data deliverable. March 2014. Excel file of tailings graphs, concentrations_Tailings_graphs.xls.

The geochemical characterization results for the LTVSMC and NorthMet flotation tailings strongly indicate that these wastes are reactive and best management measures are needed to avoid environmental impacts at the Plant Site.

Recommendations: Commit to lining the entire tailings facility based on the reactivity of the new flotation and the older LTVSMC tailings. Consider removing the LTVSMC tailings and using for alternative purposes, potentially pit backfill.

5. State-of-the-Art Tailings Management

The NorthMet flotation tailings are reactive, especially in terms of their ability to leach metals that threaten surface water and groundwater quality. According to Minnesota regulation, reactive mine waste must be mined, disposed of, and reclaimed to prevent the release of substances that result in the adverse impacts on natural resources (Minn. R. 6132.2200, subpart 1.). The facility design must meet the following requirements (Minn. R. 6132.2200, subpart 2):

> B. A reactive mine waste storage facility must be designed by professional engineers registered in Minnesota proficient in the design, construction, operation, and reclamation of facilities for the storage of reactive mine waste, to either:
> (1) modify the physical or chemical characteristics of the mine waste, or store it in an environment, such that the waste is no longer reactive; or
> (2) during construction to the extent practicable, and at closure, permanently prevent substantially all water from moving through or over the mine waste and provide for the collection and disposal of any remaining residual waters that drain from the mine waste in compliance with federal and state standards.

The results from LTVSMC tailings area groundwater and seep samples (Barr Engineering, 2006) demonstrate that water is "moving through or over the mine waste" at the existing tailings basin and that the "remaining residual waters that drain from the mine waste" have not been adequately collected. PolyMet's plan is to deposit the NorthMet flotation tailings on top of the existing LTVSMC tailings at the Plant Site without the addition of a liner. PolyMet has stated publicly that the NorthMet Project will be a state-of-the-art mine, but their plan for tailings management does not comport with their statements.

Several recent governmental or industry organization documents have addressed the repeated failure of tailings dams around the world and recommended best practices for tailings management. In addition to addressing tailings dam breaches, these reports recommend innovative tailings management approaches that minimize environmental releases of contaminated leachate (see, e.g., Mining Association of Canada, 2017; United Nations Environment Programme and GRID-Arendal, 2017; INAP, 2009 (GARDGuide, Chapter 6, which is regularly updated); and European Commission, 2009).

The design of the flotation tailings basin (FTB) is described in PolyMet Mining (2017, Section 10.2.3). PolyMet plans to use the reactive coarse LTVSMC tailings to construct the FTB dam and maximize subaqueous disposal of tailings; Polymet is not considering adding a tailings impoundment liner or alternative use or management of the existing tailings.

In the past, PolyMet was considering using the LTVSMC tailings for pit backfill, and that is one of the best practice approaches recommended in INAP (2009, Chapter 6). Dry stacking or tailings filtration and dry closure are also recommended; dry closure is especially recommended for existing wet tailings facilities (UNEP and GRID-Arendal, 2017; IIERP, 2015). Tailings desulfurization is recommended to minimize the long-term acid drainage potential of tailings (INAP, 2009, Section 6.6.3.3). PolyMet has used copper sulfate to remove pyrrhotite (e.g., SRK, 2007b, p. 23), but the method only decreased the %S from 0.2 and 0.23% to 0.1 and 0.15%. The reduced percentages are still above the cutoff for Category 1 wastes, and both are above the former reactive values of 0.05 %S. In addition, no mineralogic analyses were conducted to examine if pyrrhotite had actually been removed. Desulfurization is also recommended by the Nordic Council of Ministers (2014, p. 56).

PolyMet should take a fresh look at its plans for tailings management for both the LTVSMC and the NorthMet materials to consider more protective options that are needed to effectively manage and meet the requirements for reactive wastes.

Recommendations: Re-evaluate the management of the flotation tailings to include lining the facility and an underlying, segmented leachate collection system. Evaluate alternative methods for removal of sulfides, especially pyrrhotite, from the tailings that will improve sulfide removal over that seen from the addition of copper sulfate. Examine the mineralogy of the tests, not just the %S. Consider using paste tailings or dry stack tailings to minimize the potential for leaching of contaminants from the facility.

References Cited

Al-Abed, S.R., Jegadeesan, G., Purandare, J., and Allen, D. 2006. Arsenic release from iron rich mineral processing waste: Influence of pH and redox potential. Chemosphere 66 #4, 775-782.

Barr Engineering Co. 2006. RS64 – Existing Tailings Basin Water Information. Technical Memo. prepared for PolyMet Mining Inc. February.

European Commission, 2009. Reference document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities. January 2009. European Commission (EC). 511 p. ftp://ftp.jrc.es/pub/eippcb/doc/mmr_adopted_0109.pdf

Hammarstrom, J.M., Seal II, R.R., Meier, A.L., and Kornfeld, J.M. 2005. Secondary sulfate minerals associated with acid drainage in the eastern US: recycling of metals and acidity in surficial environments. Chemical Geology 215, 407– 431. In: Geochemistry of Sulfate Minerals: A Tribute to Robert O. Rye. Paper 2. Available: http://digitalcommons.unl.edu/usgsrye/2.

IEEIRP (2015) Independent Expert Engineering Investigation and Review Panel (2015). The Report on the Mount Polley Tailings Storage Facilities Breach. Vancouver, Province of British Columbia. Available: https://www.mountpolleyreviewpanel.ca/sites/default/files/report/ReportonMountPolleyTailingsStorageFacilityBreach.pdf

The International Network for Acid Prevention (INAP), 2009. Global Acid Rock Drainage Guide (GARD Guide). Available: http://www.gardguide.com/ Access 2/8/2018. Link to ABA interpretation: http://www.gardguide.com/index.php?title=Chapter_5b#top

Jambor, J.L., Nordstrom, D.K., Alpers, C.N., 2000. Metal-sulfate salts from sulfide mineral oxidation. In: Alpers, C.N., Jambor, J.L., Nordstrom, D.K. (Eds.), Reviews in Mineralogy and Geochemistry, vol. 40. Mineralogical Society of America, Washington, D.C, pp. 303-350. Sulfate Minerals -- Crystallography, Geochemistry, and Environmental Significance, P.H. Ribbe, Series Ed.

King, P.L. and McSween Jr., H.Y., 2005. Effects of H2O, pH, and oxidation state on the stability of Fe minerals on Mars. J. Geophys. Res. 110. E12S10.

Maest, A.S. and Nordstrom, D.K. 2017. A geochemical examination of humidity cell tests. Applied Geochemistry 81, p. 109–131.

Mining Association of Canada, 2017. A Guide to the Management of Tailings Facilities. Third Edition. Available: http://mining.ca/sites/default/files/documents/MAC-Guide-to-the-Management-of-Tailings-Facilities-2017.pdf

Minnesota Department of Natural Resources (MDNR), United States Army Corps of Engineers, and United States Forest Service, 2013. NorthMet Mining Project and Land Exchange. Supplemental Draft Environmental Impact Assessment (SDEIS). November.

Myers, T., 2018. Technical Memorandum: Review of PolyMet Project NPDES/SDS Permit Application. Prepared for Minnesota Center for Environmental Advocacy. February 19.

Nicholson, R.V., Scharer, J.M., 1994. Laboratory studies of pyrrhotite oxidation kinetics. Am. Chem. Soc. Symp. Series 550, Amer. Chem. Soc., Washington, D.C. In: Alpers, C.N., Blowes, D.W. (Eds.), Environmental Geochemistry of Sulfide Oxidation, pp. 14e30.

Nordic Council of Ministers, 2014. Best Environmental Practices in the Mining Sector in the Barents Region. International Conference 23–25 April 2013. Conference Proceedings. Available: http://www.oecd-ilibrary.org/fr/environment/best-environmental-practices-in-the-mining-sector-in-the-barents-region_tn2014-501

Nordstrom, D.K., 1982. Aqueous pyrite oxidation and the consequent formation of secondary iron minerals. In: Acid sulfate weathering, L.R. Hossner (ed.) Soil Sci. Soc. Amer. Publ., 10, 37-56.

Parbhakar-Fox, A. and Dominy, S.C., 2017. Sampling and blending in geoenvironmental campaigns – current practice and future opportunities. Eighth World Conference on Sampling and Blending, Perth, Australia. May 9-11, p. 45-54. Available: https://goo.gl/2Vw8YA

Price, W.A., 2009. Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials. MEND Report 1.20.1. 579pp. Available: http://www.abandoned-mines.org/pdfs/MENDPredictionManual-Jan05.pdf

PolyMet Mining, 2017a. Permit to Mine Application, NorthMet Project. December.

PolyMet Mining, 2017b. Permit to Mine Application, NorthMet Project. Appendix 2. Mine Waste Characterization Documentation and Results.

PolyMet Mining, 2017c. Permit to Mine Application, NorthMet Project. Appendix 11. Management Plans Updated for Permit to Mine.

PolyMet Mining, 2015a. NorthMet Project. Waste Characterization Data Package, v. 12. Prepared by Barr Engineering Co. Feb. 13.

PolyMet Mining, 2015b. NorthMet Project. Water Modeling Data Package, Volume 1 – Mine Site. Version 14. February 27. Prepared by Barr Engineering Co.

Sherlock, EJ, Lawrence, RW, and Poulin, R. 1995. On the neutralization of acid rock drainage by carbonate and silicate minerals. Environmental Geology 25 #1, 43-54.

SRK Consulting, 2006a. RS33A – Reactive Residues Progress Report – NorthMet Project. May.

SRK Consulting, 2006b. NorthMet Project. Tailings and Hydromet Residue Testwork – Update on Sample Selection from 24 Hour Testwork. Memo from Stephen Day to Jennifer Engstrom, MDNR. January 6.

SRK Consulting, 2007a. RS53/RS42 – Waste Rock Characteristics/Waste Water Quality Modeling - Waste Rock and Lean Ore – NorthMet Project – DRAFT. February/Draft 01, March 9, 2007.

SRK Consulting, 2007b. RS54/RS46 – Waste Water Modeling – Tailings. NorthMet Project – DRAFT. Prepared for PolyMet Mining Inc. July 20.

Steffen, Robertson and Kirsten (SRK), 1989. Draft Acid Rock Drainage Technical Guide prepared for British Columbia Acid Mine Drainage Task Force (Steffen, Robertson and Kirsten: Vancouver)

SRK Consulting, 2011. Water Quality Modeling for Waste Rock and Pit Walls, NorthMet Project – DRAFT 4. From Stephen Day, SRK, to Jim Scott, PolyMet and Peter Hinck, Barr. March 15. (Attachment A of PolyMet Mining, 2015a).

SRK Consulting, 2011b. Results of an Experiment to Evaluate solubility Limits for Category 1 Waste Rock, NorthMet Project – DRAFT. From Stephen Day, SRK, to Jim Scott and Richard Patelke, PolyMet and Peter Hinck, Barr. February 16. (Attachment b of PolyMet Mining, 2015a).

United Nations Environment Programme and GRID-Arendal, 2017. Mine Tailings Storage: Safety Is No Accident. A UNEP Rapid Response Assessment. Roche, C., Thygesen, K., Baker, E. (Eds.). Available: https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/371/original/RRA_MineTailings_lores.pdf?1510660693

Michael A. Malusis, Ph.D., P.E. 15 Hawthorne Drive, Lewisburg, PA 17837
Consulting Geotechnical and Geoenvironmental Engineer Phone (570) 412-2069; Fax (570) 577-3415

February 21, 2018

Mr. David Patton
Staff Attorney
Minnesota Center for Environmental Advocacy (MCEA)
26 East Exchange Street, Suite 206
Saint Paul, MN 55101

Subject: Review Comments on the revised NorthMet Project Permit to Mine Application

Dear Mr. Patton:

In accordance with your request dated January 8, 2018, I have completed my review of the revised NorthMet Permit to Mine Application and related documents (including appendices and draft permit conditions), as well as ancillary documents (most notably email correspondence and EOR review summaries) provided to me by MCEA. Based on my review, I have several concerns related to the protectiveness of the systems proposed by PolyMet for containing the mine waste rock and tailings that are either not addressed or are only partially addressed by the permit conditions. My concerns are presented in the comments below, which I have separated into the categories of Wet Closure, Bentonite-Amended Dams and Beaches, Category 1 Cutoff Wall, Tailings Basin Cutoff Wall, and Category 2/3 and Category 4 Stockpile Liners.

My comments are focused on the geotechnical and geoenvironmental aspects of the containment systems proposed for this project and are based on my review and interpretation of information in the documents described above as well as the existing body of literature relevant to these issues (relevant sources are cited in my comments and included in a reference list at the end of this report). I did not perform any independent geotechnical, hydraulic/hydrologic, or contaminant transport calculations or modeling beyond those discussed specifically in the comments.

Wet Closure

(1) The proposed wet closure conflicts with Minnesota Rules Part 6132.2200 Subpart B(2), which states that storage of reactive mine waste, at closure, must "permanently prevent substantially all water from moving through or over the mine waste." The design percolation rate through the pond bottom based on the current plan is 6.5 inches per year, which is approximately one-fourth of the average annual precipitation rate in the vicinity of the site. In contrast to the proposed approach, dry closure generally achieves much lower percolation rates into the waste, typically less than 5 percent of the average annual precipitation rate and often on the order of a few millimeters per year or less (e.g., see Woyshner and Yanful 1995, O'Kane et al. 1998, Ayres et al. 2003, Keller et al. 2010). <u>Dry closure would be a much better approach for meeting the intent of Part 6132.2200 Subpart B(2), and DNR should consider making dry closure a permit condition rather than an option for PolyMet to explore at their discretion.</u>

(2) The alternatives currently under consideration for the pond bottom are untested and unproven, and could yield actual percolation rates well in excess of 6.5 inches per year. PolyMet has proposed three possible subaqueous placement methods (i.e., subaqueous broadcasting of bentonite granules or pellets, bentonite injection into the existing bottom, or placement of a geosynthetic clay liner over the existing bottom), none of which are supported by laboratory studies, field case studies of successful use on similar projects, or any other type of feasibility assessment. The DNR has already been informed by other experts that injection is may not be a reliable method for distributing bentonite uniformly (see emails from Dr. Craig Benson and Neil Schwanz to Kim Lapakko at DNR dated November 29, 2010 attached here as Appendix A and November 30, 2010 attached as Appendix B). Moreover, a similar Darcy's law calculation to that presented by PolyMet in the According to the Water Management Plan – Plant (Barr Engineering, Version 7, December 2017, Appendix 11.3) indicates that the GCL option is probably not viable for meeting the design percolation rate.

PolyMet claims that a hydraulic conductivity (*k*) of 2×10^{-8} cm/s or less is required for the pond bottom to function as intended, and notes that the *k* of a freshly manufactured GCL is approximately 5×10^{-9} cm/s. However, PolyMet's calculation assumes a pond bottom thickness of 0.2 ft, whereas the thickness of a GCL is approximately 10 times lower (i.e. ~10 mm or 0.03 ft). Given this thickness, the required GCL *k* is $\sim 3 \times 10^{-9}$ cm/s. Also, the testing conditions associated with the *k* values reported by GCL manufacturers typically involve application of at least 35 kPa of effective stress and permeation of the GCL specimen with potable (if not deionized) water. In contrast, the effective stress at the pond bottom will be almost nil, and the pond water will have a more aggressive chemical composition. Thus, the testing conditions used by GCL manufacturers are unconservative (i.e., yield lower *k*) relative to the conditions expected in the field. According to the Water Management Plan – Plant (Barr Engineering, Version 7, December 2017, Appendix 11.3), the pond water will contain appreciable concentrations several multivalent cation species, most notably Ba, Ca, Cu, Fe, Mg, Mn, Ni, and Zn. Several published studies have shown that bentonite hydrated in water having high ionic strength and containing multivalent cations may exhibit *k* on the order of 10^{-7} or even 10^{-6} cm/s under low stress, due to inadequate swell of the bentonite (e.g., see Kolstad et al. 2004, Jo et al. 2005, Shackelford et al. 2010). Based on these considerations, it may not be possible for a GCL or even a broadcasted/injected bentonite layer to exhibit a *k* low enough to meet the design percolation rate.

<u>Given the uncertainties with the proposed methods, I recommend that the special conditions 88 and 89 be limited to the field testing phase and that the DNR require PolyMet to demonstrate proof of concept based on completion of field-representative bench scale testing before approving the permit.</u>

(3) Even if a permanent pond can be maintained above the tailings, the success of wet closure in terms of minimizing oxidation of tailings hinges on the ability of the bentonite-amended layers in the dams and beaches to remain at or near saturation continuously for a long period of time. This is also an unproven and untested approach, and lessons learned from studies on the field performance of near-surface earthen barriers indicate that these layers may not perform as intended over the long term. This concern is similar to the concern raised by Mr. Don Sutton (Spectrum Engineering) to DNR staff in an email dated May 31, 2017 (attached

here as Appendix C) in which Mr. Sutton states “The methods and assumptions used to place the bentonite and to control the infiltration and tailings saturation are unsubstantiated, and wishful thinking. We do not believe it will function as intended, because of the unproven application methods.” My specific concerns regarding the bentonite-amended dams and beaches are itemized separately below.

Bentonite-amended Dams and Beaches

(4) Studies on field performance of earthen barrier layers in cover systems, including covers containing bentonite-rich layers, indicate that the proposed bentonite-amended tailings layers will be susceptible to degradation in performance over the long term due to wet-dry cycling combined with cation exchange (see Benson et al. 2007, Scalia and Benson 2011), as well as pedogenic effects such as root penetration, animal burrowing, and freeze-thaw (Benson et al. 2011). PolyMet provides no evidence that 3 % bentonite amendment will be an effective barrier against these effects. Regarding cation exchange, the same multivalent metal cations expected to be prevalent in the pond water (see comment 2) will likely be prevalent in the tailings as well. These cations will exchange with the Na on the bentonite, potentially causing inadequate bentonite swell during initial hydration or subsequent rehydration after drying *in situ*. If the swelling is not adequate to plug the voids in the mixture, then the bentonite-amended tailings layer will be a poor water/oxygen barrier.

A recent study by Benson et al. (2007) shows that burying a bentonite-rich barrier under a 30-inch surface layer is unlikely to protect against adverse effects to bentonite swell resulting from dehydration combined with cation exchange of divalent cations for the Na on the bentonite. Likewise, a 30-inch surface layer may not provide adequate protection the aforementioned pedogenic effects, which can create macropores (i.e., large scale features such as cracks and fissures) that alter the network of pores controlling retention and movement of water (and air) in barrier layers. These types of problems are well documented for earthen cover systems (Benson et al. 2011). The DNR was informed of these concerns by Dr. Benson in 2010 (see email from Benson to Kim Lapakko dated November 29. 2010 attached as Appendix A), who noted that “Most earthen layers used in covers tend to become damaged over relatively short time frames unless they are covered with a geomembrane or are very deep (meters).”

The possibility also exists that inclusion of the bentonite-amended tailings layer in the dams will exacerbate erosion of the overlying tailings on the dam faces, which would undermine dam stability. This concern has been raised on multiple occasions since 2010 by Don Sutton via email correspondence to DNR staff (e.g., see Appendix C and Appendix D). Mr. Sutton notes in these messages his concerns that “placing bentonite on the embankment and interior surfaces will increase the run-off and erosion rate” and “the bentonite seal is a hail Mary type of concept in my opinion. I believe it will exacerbate erosion and slope failure and will eventually fail.”

Because these issues may or may not manifest themselves within the time frame of the proposed pilot testing, <u>a robust long-term monitoring and maintenance plan should be required as a condition of the permit to ensure that the bentonite-amended layers continue to</u>

function as intended after the pilot testing is complete. The current plan for monitoring does not appear to include any long-term monitoring of the bentonite amended layers with regard to moisture retention, saturation, or hydraulic performance. In addition, the permit should include a plan for implementing corrective actions, in the event that these layers fail.

(5) Despite the fact that the primary objective of the bentonite-amended dams and beaches is to maintain a continuous zone of saturation, such that these layers serve effectively as air barriers to minimize tailings oxidation in perpetuity, the required degree of saturation has not been specified as a performance metric. The degree of saturation required to be maintained in the field should be defined, justified, and used as the basis for mix design (including determination of mixture proportions and compaction requirements) and for designing the pilot test and evaluating the resulting data. The only requirement currently specified for these layers is a maximum k of 10^{-6} cm/s, but no data or other evidence have been provided to show that achieving this k will translate to maintaining adequate saturation for the layers to be effective long-term air barriers.

(6) Related to the comment above, laboratory testing and analysis have been inadequate for demonstrating the feasibility of the proposed layers in terms of maintaining acceptable saturation and functioning effectively as long-term air barriers. For example, the specified 3 % granular bentonite amendment appears to be based solely on the results of a single laboratory k test, and the reported k ($\sim 1.5 \times 10^{-7}$ cm/s) is much lower than expected based on comparison with data available for sand-bentonite mixtures in the geotechnical engineering literature (e.g., see Gleason et al. 1997, Abichou et al. 2002). Multiple lab k tests should be performed to check reproducibility, to evaluate the required bentonite content based on the range of possible gradations for the coarse LTVSMC tailings (noting that these tailings have been shown to contain as little as 3 % native fines) and to evaluate the influence of compaction variables (energy, moisture content) on k.

Also, k is only one material property that impacts moisture migration in soil. Assessment of the potential extent of drying in these layers in the field also requires measurement of the moisture retention characteristics and unsaturated flow modeling based on the anticipated field geometry and meteorological conditions. Such testing and analysis should be conducted prior to field testing and, in my opinion, should already have been conducted as part of this permit application. While I fully support the use of pilot/field testing to establish means and methods and demonstrate field performance, PolyMet needs to establish appropriate performance criteria and design the layers accordingly, with appropriate bench-scale testing and modeling, before conducting field trials. The absence of bench-scale testing and modeling from the pilot testing template is a particular concern.

(7) I remain concerned that a 3 % granular bentonite amendment will be too low to create a uniform layer in the field that is free of zones containing no bentonite. I am not aware of any projects in which such a low bentonite content has been used in a compacted sand-bentonite barrier. Minimum bentonite contents for compacted sand-bentonite layers typically are at least 7 % (e.g., see Lundgren 1981, Garlanger et al. 1987, and O'Sadnick et al. 1995) due to the limitations of field mixing procedures. These percentages are consistent with the findings of a study by Kenney et al. (1992), who observed that bentonite contents

less than 7 % resulted in many void spaces within a compacted sand-bentonite mixture being devoid of bentonite.

(8) Veneer slope stability analyses conducted for the bentonite-amended dam faces are based entirely on shear strength parameters taken from the literature. This is not appropriate for unproven technology being proposed for a wet closure that already has inherently higher risks and uncertainties with respect to dam stability. Shear strength tests need to be conducted on representative mixtures of the bentonite-amended tailings the company intends to actually use. The shear strength parameters for the bentonite-amended tailings and the sensitivity of these parameters to bentonite content, tailings gradation, compaction energy and compaction moisture content should be evaluated, and the slope stability analysis should be updated accordingly.

(9) The pilot/field testing template does not describe any laboratory QC testing that will be performed to verify the efficacy of the field mixing or the adequacy of the proposed 3 % granular bentonite amendment for meeting the design objective. According to Specification 03100 in the Flotation Tailings Management Plan (Barr Engineering, Version 7, May 15, 2017, Appendix 11.5), laboratory test requirements should be part of the pilot testing plan. Finally, although the pilot/field testing template presents a list of considerations for field testing and describes various field testing and monitoring methods that "could" be used, the template provides only a conceptual level of detail for how the field tests may be carried out and does not specify the performance metrics that will be used to determine success or failure. Thus, the template, in its current form, falls short of being a work plan. The permit should be revised to include a requirement for PolyMet to prepare and obtain DNR approval of a work plan for the bentonite-amended dams and beaches, similar to the requirement for the pond bottom in Special Condition 88.

Category 1 Cutoff Wall

(10) PolyMet's claim that the Category 1 stockpile cutoff wall and collection system will capture 91-99 percent of the seepage is likely optimistic. Cutoff walls typically are constructed with a nominal thickness of 24-36 inches. However, PolyMet's seepage model assumes a cutoff wall thickness of 60 inches (67 to 150 % greater than typical cutoff walls). Also, there is no indication that the wall will be keyed into the underlying bedrock. Specifications generally call for a minimum depth of key into the lower confining unit to ensure an adequate seal that minimizes underseepage. Without a proper key, the assumption of perfect contact between the cutoff wall and the bedrock in the seepage model is probably a poor assumption that will overestimate the actual seepage capture. The permit should include a commitment to a minimum depth of key for the wall.

(11) Use of a cutoff wall with a maximum allowable *k* of 10^{-5} cm/s is not consistent with standard practice for vertical barriers used in long-term hydraulic control or geoenvironmental containment (i.e., pollution control) applications. The typical maximum *k* in these applications is 10^{-6} or 10^{-7} cm/s (e.g., Owaidat and Day 1998, McKnight and Owaidat 2001, Spaulding 2007, Ryan and Spaulding 2008), which is 10 to 100 times lower than proposed for this wall. This point is further underscored by considering that the

maximum k specified for the cutoff wall around the tailings basin is 10^{-6} cm/s, and that the technical memorandum prepared by Barr Engineering (Attachment D of the Rock and Overburden Management Plan, Barr Engineering, Version 10, December 2017, Appendix 11.1) provides no examples of vertical barriers used at other sites for long-term seepage or pollution control in which the maximum k was 10^{-5} cm/s. The permit should be revised to include a maximum k requirement of 10^{-6} cm/s for this wall.

(12) The cutoff wall will be ineffective as a long-term pollution control barrier unless a sufficient inward head difference is maintained in perpetuity to prevent outward advective transport and adequately reduce the outward diffusive flux of miscible contaminants in the groundwater. However, there does not appear to be a commitment to maintaining a particular minimum head difference or gradient at all locations along the wall. The magnitude of the inward head difference or gradient that needs to be maintained across the wall should be specified.

Tailings Basin Cutoff Wall

(13) Similar to comments 10 and 12 above, the required depth of key and the magnitude of the inward head difference or gradient that needs to be maintained across the wall should be specified in the permit.

Category 2/3 and Category 4 Stockpile Liners

(14) PolyMet notes that the composite liner systems proposed for these stockpiles are similar to those used for modern heap leach facilities. However, a maximum k of 10^{-6} cm/s is recommended for the compacted soil component of heap leach pad liners (e.g., see Lupo 2008). While this is the case for the Category 4 stockpile, a maximum hydraulic conductivity of 10^{-5} cm/s is prescribed for the Category 2/3 stockpile liner. A maximum k of 10^{-6} cm/s should be specified for both liners, consistent with the standard of practice for heap leach pads.

(15) There seems to be an inconsistency between the text (page 10) and Table 1 of the Construction CQA Plan (Attachment I of the Rock and Overburden Management Plan, Barr Engineering, Version 10, December 2017, Appendix 11.1). Quality control and quality assurance testing of hydraulic conductivity for the compacted soil component of these liners should be performed on undisturbed (Shelby tube) samples of placed soil, not remolded samples of soil collected from the stockpiles.

References

Abichou, T. et al. (2000). Foundry Green Sands as Hydraulic Barriers: Laboratory Study. *Journal of Geotechnical and Geoenvironmental Engineering*, 126(12), 1174-1183.

Ayres, B., Silveira, C., Ellice, E., Christensen, D., and O'Kane, M. (2003). Development of a cover system design for potentially acid-forming tailings and Peak Gold Mines. *Proceedings, 6th International Conference on Acid Rock Drainage (ICARD)*, 957-963.

Benson, C.H., Thorstad, P.A., Jo, H.-Y., and Rock, S.A. (2007). Hydraulic performance of geosynthetic clay liners in a landfill final cover. *Journal of Geotechnical and Geoenvironmental Engineering*, 133(7), 814-827.

Benson, C.H., Albright, W.H., Fratta, D.O., Tinjum, J.M., Kucukkirca, E., Lee, S.H., Scalia, J., Schlicht, P.D, and Wang, X. (2011). Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-Term Performance Assessment. NUREG/CR-7028 Volume 1, U.S. Nuclear Regulatory Commission, Nuclear Regulatory Research (http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr7028/).

Garlanger, J.E., Cheung, F.K., and Bishar, S.T. (1987). Quality control testing for a sand-bentonite liner. *Geotechnical Practice for Waste Disposal '87*, R.D. Woods, Ed., Geotechnical Special Publication 13, ASCE, New York, 488-499.

Gleason, M.H., Daniel, D.E., and Eykholt, G.R. (1997). Calcium and sodium bentonite for hydraulic containment applications. *Journal of Geotechnical and Geoenvironmental Engineering*, 123(5), 438-445.

Jo, H.Y., Benson, C.H., Shackelford, C.D., Lee, J-M, and Edil, T.B. (2005). Long-term hydraulic conductivity of a geosynthetic clay liner permeated with inorganic salt solutions. *Journal of Geotechnical and Geoenvironmental Engineering*, 131(4), 405-417.

Keller, J., Milczarek, M., Yao, T.M., and Buchanan, M. (2010). The effect of tailings characteristics on cover system success. *Tailings and Mine Waste 2010. CRC Press*, 121-130.

Kenney, T.C., van Veen, W.A., Swallow, M.A., and Sungaila, M.A. (1992). Hydraulic conductivity of compacted bentonite-sand mixtures. *Canadian Geotechnical Journal*, 29(3), 364-374.

Kolstad, D.C., Benson, C.H., and Edil, T.B. (2004). Hydraulic conductivity and swell of nonprehydrated geosynthetic clay liners permeated with multispecies inorganic solutions. *Journal of Geotechnical and Geoenvironmental Engineering*, 130(12), 1236-1249.

Lundgren, T.A. (1981). Some bentonite sealants in soil mixed blankets. *Proceedings, 10th International Conference on Soil Mechanics and Foundation Engineering*, Stockholm, 15-19 June, Balkema, Rotterdam, Vol. 2, 349-354.

Lupo, J.F. (2008). Heap leach pad liner design. https://www.geosynthetica.net/Uploads/Lupo.pdf

McKnight, J.T. and Owaidat, L.M. (2001). Quality control and performance of a cutoff wall for containment of a DNAPL plume. *Proceedings, 2001 International Containment and Remediation Technology Conference*, Orlando, FL, Florida State University, Tallahassee, FL, CD-ROM (5 p).

O'Sadnick, D.L., Simpson, B.E., and Kasel, G.K. (1995). Evaluation and performance of a sand/bentonite liner. *Geoenvironment 2000*, Y.B. Acar and D.E. Daniel, Eds., Geotechnical Special Publication 46, ASCE, New York, 688-701.

Owaidat, L.M. and Day, S. (1998). Installation of a composite slurry wall to contain mine tailings. *Tailings and Mine Waste '98*, Balkema, Rotterdam, 421-429.

Ryan, C.R. and Spaulding, C.A. (2008). Strength and permeability of a deep soil bentonite slurry wall. *Proc., Geo-Congress 2008*, New Orleans, LA, ASCE.

Scalia, J. and Benson, C.H. (2011). Hydraulic conductivity of geosynthetic clay liners exhumed from final landfill covers with composite barriers. *Journal of Geotechnical and Geoenvironmental Engineering*, 137(1), 1-13.

Shackelford, C.D., Sevick, G.W., and Eykholt, G.R. (2010). Hydraulic conductivity of geosynthetic clay liners to tailings impoundment solutions. *Geotextiles and Geomembranes*, 28, 149-162.

Spaulding, C.A. (2007). Soil bentonite cut-off walls for confinement of existing landfills: Tempe Tip – a case study. *Proceedings, XVIth Asian Conference*, New South Wales, Australia.

O'Kane, M., Wilson, G.W., and Barbour, S.L. (1998). Instrumentation and monitoring of an engineered soil cover system for mine waste rock. *Canadian Geotechnical Journal* 35(5) 4, 828-846.

Woyshner, M.R. and Yanful, E.K. (1995). Modelling and field measurements of water percolation through an experimental soil cover on mine tailings. *Canadian Geotechnical Journal*, 32, 601-609.

Thank you for the opportunity to offer my services to MCEA on this project. If you have any questions or concerns regarding my comments, please do not hesitate to contact me at 570-412-2069 or michael.malusis@bucknell.edu.

Sincerely,

Michael A. Malusis, Ph.D., P.E.
Consulting Engineer

Appendix A

Message

From: craig h. benson [chbenson@wisc.edu] [craig h. benson [chbenson@wisc.edu]]
To: lapakko; kim a
Subject: Re: Covers on tailings basins

Kim --

The laminate does increase the price, but not substantially. The GCLL with a textured geomembrane laminate is superior product to LDPE or a GCL alone. The combination of the laminate and the bentonite makes for a resilient barrier.

Craig

On Nov 29, 2010, at 11:36 AM, Lapakko, Kim A (DNR) wrote:

> Craig,
>
> Thanks for your response and there is no problem with its timing. I can see the advantage of the laminated GCL for solutions with high Ca or Mg. Ca might be less problematic in some mining applications because concentrations might be limited by CaSO4 solubility. Based on Figure 6 in the paper you attached, I might expect roughly an order of magnitude increase in hydraulic conductivity for many mining-related waters (although these compositions cover a wide range). Two questions that arise immediately.
>
> 1) Does the laminate substantially boost the cost of the GCL?
> 2) How much better than a LDPE is the GCLL?

The
>
> No matter what the case, the problem with modeling chemical release remains (What fraction of underlying solutes will be transported as a result of flow through the membrane?), and it seems that you might have a path forward on this. I'll suggest the mining company (PolyMet) contact you for further discussion.
>
> Your thoughts on the bentonite application appear to be consistent with ours. The draft proposal indicated that the "surficial" bentonite layer would be located at a depth of 1m, which seems too shallow based on your comment. We'll carry your thoughts forward in further discussions.
>
> It sounds like you're referring to Mesabi Nugget and, possibly, capping of historical waste rock piles. I've crossed paths with Golder on a couple other MN mining projects but not that one. Nonetheless, we might cross paths on whatever project it is.
>
> Thanks for taking time to provide your comments. Much appreciation. I look forward to seeing you in MN.
>
> Kim
>
>
>
>
> -----Original Message-----
> From: Craig H. Benson [mailto:chbenson@wisc.edu]
> Sent: Saturday, November 27, 2010 7:01 AM
> To: Lapakko, Kim A (DNR)
> Subject: Re: Covers on tailings basins
>
> HI Kim -
>
> Sorry for the slow reply. I wanted to think about your comments before I replied. Please see my notes below. Please let me know if you need more input or my help.
>
> We may have a chance to work together again. I am working with Golder on a project with Mesabi in Minnesota, and I am sure you are in engaged in it.
>
> I hope you have been doing well and had a Happy Thanksgiving.
>
> Keep in touch, Craig
> ---
> Craig H. Benson, PhD, PE, DGE
> Chair, Geological Engineering
> Wisconsin Distinguished Professor
> University of Wisconsin-Madison
> 2218 Engineering Hall
> 1415 Engineering Drive

> Madison, WI 53706 USA
> +1 (608) 262-7242 (O)
> chbenson@wisc.edu
> www.gle.wisc.edu
>
>
> On Nov 19, 2010, at 1:50 PM, Lapakko, Kim A (DNR) wrote:
>
>> Craig,
>>
>> Hi! As usual I'm looking for information regarding cover application to mine wastes. A GCL is being evaluated as a cover for a tailings basin, as is creating a reduced permeability bentonite-amended tailings layer. With regard to the former, the solute release from the facility is being modeled by 1) calculating the rate of oxygen diffusion through the cover (with consideration given to defects) and determining the rate of sulfide mineral oxidation using this, and 2) assuming any infiltrating water will transport solutes generated. Whereas this calculation appears to be a reasonable upper bound, do you have information regarding the extent to which solute transport might decrease due to the infiltration decrease resulting from the cover? That is, it seems unlikely that flow through defects would contact all of the underlying tailings and transport the associated solutes from the facility. It seems it might be possible to estimate the extent of contact by considering the flow paths through the cover defects, and that aspects of site geometry might be necessary to make these estimations. Are you aware of any information on this?
>
>
> I have not seen this done before, but it would make sense and could be evaluated using existing tools. This would apply to applications where the GCL is overlain by a geomembrane or to a laminted GCL (also known as a GCLL, or a GCL with a geomembrane bonded to one surface). If a GCL was used alone, however, than I would evaluate it as a distributed areal source of water rather than with localized defects.
>
> We have found that the laminated GCLs work very well in covers and are very durable. The newest CETCO products with a thicker textured laminate are excellent. We have had less successs with conventional GCLs (no laminate), which are affected by ion exchange and wet-dry cycling. The attached paper has a case history illustrating the performance of both types of GCLs in a cover near Cassville, WI. I am currently involved in a mining project in Idaho where a lamianted GCL is planned for closure of the waste rock piles. In that application we explicity accounted for defects in the laminate, but we still treated the source as areally distributed.
>
>>
>> Second, the bentonite amended layer is proposed for two different applications. First, layer is intended largely to increase moisture retention in the near-surface, subaerial tailings and thereby decrease downward oxygen diffusion through the tailings. Second, it would be used beneath the tailings pond to decrease downward flow and, consequently, maintain a water cover that would limit oxygen diffusion. The method suggested for the bentonite application is through use of an implement that is essentially a hollow tined rake. This approach has been apparently used for manure application in an agricultural setting. I'm not highly optimistic about its potential for incorporating bentonite into tailings. It's being suggested for applications to both dry tailings and tailings under water. I'm apprehensive about the ability of this technique to achieve a fairly continuous layer of reduced permeability.
>
> I am not sure how well the bentonite-amended tailings layer will work in the surface. Most earthen layers used in covers tend to become damaged over relatively short time frames unless they are covered with a geomembrane or are very deep (meters). The liner application should work very well, but chemical compatibilty should be checked with the worst-case tailings leachate. Bentonites used in hydraulic barriers generally are sodium bentonites, and are susceptible to cation exchange reactions with other metals in the leachate.
>
> The accepted method for construction high quality bentonite-amended barrier layers is to blend the soil and bentonite in pug mill or other device that ensures good mixing and uniformity. My intutiion is that the injection method, which I have seen in agricultural manure applicaitons, will not result in adequate uniformity. I recommend that other methods for applying the bentonite be explored.
>
>>
>> Hope things are well with you and that you are getting a reasonable balance between work and "the real world".
>>
>> Kim (651/259-5401)
>

Appendix B

Message

From: schwanz; neil t mvp [neil.t.schwanz@usace.army.mil] [schwanz; neil t mvp [neil.t.schwanz@usace.army.mil]]
To: lapakko; kim a
Subject: RE: Covers on tailings basins (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: FOUO

Hi Kim,

I think that's right. Barr had a layer of tailings above the bentonite amended soil in their schematics to keep this soil damp (prevent desiccation cracking) and avoid root penetration. In my item #5 below I indicate cover with a tailings layer. Bentonite contains sodium montmorillonite which is quite expansive and conversely, contractant upon drying leaving open cracks. Therefore the need to keep damp. To avoid root penetrations I would expect a thicker overlying tailings layer than just 1-ft.

Neil

-----Original Message-----
From: Lapakko, Kim A (DNR) [mailto:Kim.Lapakko@state.mn.us]
Sent: Tuesday, November 30, 2010 7:24 PM
To: Schwanz, Neil T MVP
Subject: RE: Covers on tailings basins (UNCLASSIFIED)

Neil,

Maybe I'm confused on this one. I had the sense that Benson was saying that the bentonite layer had to lie at depth, below a layer of tailings. This would protect the layer and, in the case of PolyMet, keep the layer wet to serve as an impediment to oxygen diffusion.

Further thoughts on this?

Kim

-----Original Message-----
From: Schwanz, Neil T MVP [mailto:Neil.T.Schwanz@usace.army.mil]
Sent: Tuesday, November 30, 2010 5:58 PM
To: Lapakko, Kim A (DNR)
Subject: RE: Covers on tailings basins (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: FOUO

Hi Kim,

I really haven't thought about an amended layer thickness except I didn't feel that 3 ft was unrealistic. Just off the top of my head, several meters seems pretty high. Whatever is done is going to require lab work and field demonstration. At this stage my gut feeling is that a 3 ft bentonite cap could be mixed in place in the following manner (other plans can be thought of as well):

1. Dewater the pond and let dry to a point that equipment can be supported and material pushed around.
2. Doze 2 ft of tailings to the side to dry and for future mixing with bentonite 3. Spread dry bentonite on the exposed surface (call it EL-2 ft) and thoroughly mix to a depth of 1 ft, this is not disking but instead roto-tilling, and compact.
4. Thoroughly mix more dry bentonite with tailings dozed to the side and re-work this as another soil layer placed in an 8-inch thickness and compact. Repeat this two more times to create an amended 3-ft cap.
5. Cover with a tailings layer as previously presented by Barr.

Neil

-----Original Message-----
From: Lapakko, Kim A (DNR) [mailto:Kim.Lapakko@state.mn.us]
Sent: Tuesday, November 30, 2010 4:16 PM
To: Schwanz, Neil T MVP
Subject: RE: Covers on tailings basins (UNCLASSIFIED)

Neil,

What do you think the appropriate depth for a bentonite amended tailings layer might be? Benson thought it should be at least "meters" deep.

Kim

-----Original Message-----
From: Schwanz, Neil T MVP [mailto:Neil.T.Schwanz@usace.army.mil]
Sent: Monday, November 29, 2010 2:16 PM
To: Lapakko, Kim A (DNR)
Cc: David Blaha; Ahlness, Jon K MVP
Subject: RE: Covers on tailings basins (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: FOUO

Hi Kim,

Thanks for copying me. Talking with Tom Radue it seems the goal would be to reduce the permeability by 2 orders of magnitude. I'm pretty much convinced you can't get that with the bentonite injection method being considered even with a multi-port injection system. I think you could get that with a pug mill as Craig discusses, which is probably the best way to mix material, but would likely involve drying and excavating tailings, mixing and then placing the mixed material in layers the dry. I think you could also get it by dewatering the site and mixing in dry bentonite in place with a roto-tiller attachment on a crawler or wheeled tractor (we have done that with lime). But that method would involve drying the surface enough to support putting equipment on it. The ability to achieve the desired permeability in the lab is better than that in the field and I believe there will need to be some type of lab work and then field mechanical action to mix the bentonite thoroughly (more than the hollow tine effort and more than just disking the surface).
Regards,
Neil

-----Original Message-----
From: Lapakko, Kim A (DNR) [mailto:Kim.Lapakko@state.mn.us]
Sent: Monday, November 29, 2010 11:36 AM
To: Craig H. Benson
Cc: Engstrom, Jennifer N (DNR); Kellogg, Chev (DNR); Schwanz, Neil T MVP
Subject: RE: Covers on tailings basins

Craig,

Thanks for your response and there is no problem with its timing. I can see the advantage of the laminated GCL for solutions with high Ca or Mg. Ca might be less problematic in some mining applications because concentrations might be limited by $CaSO_4$ solubility. Based on Figure 6 in the paper you attached, I might expect roughly an order of magnitude increase in hydraulic conductivity for many mining-related waters (although these compositions cover a wide range). Two questions that arise immediately.

1) Does the laminate substantially boost the cost of the GCL?
2) How much better than a LDPE is the GCLL?

No matter what the case, the problem with modeling chemical release remains (What fraction of underlying solutes will be transported as a result of flow through the membrane?), and it seems that you might have a path forward on this. I'll suggest the mining company (PolyMet) contact you for further discussion.

Your thoughts on the bentonite application appear to be consistent with ours. The draft proposal indicated that the "surficial" bentonite layer would be located at a depth of 1m, which seems too shallow based on your comment. We'll carry your thoughts forward in further discussions.

It sounds like you're referring to Mesabi Nugget and, possibly, capping of historical waste rock piles. I've crossed paths with Golder on a couple other MN mining projects but not that one. Nonetheless, we might cross paths on whatever project it is.

Thanks for taking time to provide your comments. Much appreciation. I look forward to seeing you in MN.

Kim

-----Original Message-----
From: Craig H. Benson [mailto:chbenson@wisc.edu]
Sent: Saturday, November 27, 2010 7:01 AM
To: Lapakko, Kim A (DNR)
Subject: Re: Covers on tailings basins

HI Kim -

Sorry for the slow reply. I wanted to think about your comments before I replied. Please see my notes below. Please let me know if you need more input or my help.

We may have a chance to work together again. I am working with Golder on a
project with Mesabi in Minnesota, and I am sure you are in engaged in it.

I hope you have been doing well and had a Happy Thanksgiving.

Keep in touch, Craig

Craig H. Benson, PhD, PE, DGE
Chair, Geological Engineering
Wisconsin Distinguished Professor
University of Wisconsin-Madison
2218 Engineering Hall
1415 Engineering Drive
Madison, WI 53706 USA
+1 (608) 262-7242 (O)
chbenson@wisc.edu
www.gle.wisc.edu

On Nov 19, 2010, at 1:50 PM, Lapakko, Kim A (DNR) wrote:

> Craig,
>
> Hi! As usual I'm looking for information regarding cover application
> to
mine wastes. A GCL is being evaluated as a cover for a tailings basin, as is
creating a reduced permeability bentonite-amended tailings layer. With regard
to the former, the solute release from the facility is being modeled by 1)
calculating the rate of oxygen diffusion through the cover (with consideration
given to defects) and determining the rate of sulfide mineral oxidation using
this, and 2) assuming any infiltrating water will transport solutes generated.
Whereas this calculation appears to be a reasonable upper bound, do you have
information regarding the extent to which solute transport might decrease due
to the infiltration decrease resulting from the cover?
That is, it seems unlikely that flow through defects would contact all of the
underlying tailings and transport the associated solutes from the facility.
It seems it might be possible to estimate the extent of contact by considering
the flow paths through the cover defects, and that aspects of site geometry
might be necessary to make these estimations. Are you aware of any
information on this?

I have not seen this done before, but it would make sense and could be
evaluated using existing tools. This would apply to applications where the
GCL is overlain by a geomembrane or to a laminted GCL (also known as a GCLL,
or a GCL with a geomembrane bonded to one surface). If a GCL was used alone,
however, than I would evaluate it as a distributed areal source of water
rather than with localized defects.

We have found that the laminated GCLs work very well in covers and are very
durable. The newest CETCO products with a thicker textured laminate are
excellent. We have had less successs with conventional GCLs (no laminate),
which are affected by ion exchange and wet-dry cycling. The attached paper
has a case history illustrating the performance of both types of GCLs in a
cover near Cassville, WI. I am currently involved in a mining project in
Idaho where a lamianted GCL is planned for closure of the waste rock piles.
In that application we explicity accounted for defects in the laminate, but we
still treated the source as areally distributed.

>
> Second, the bentonite amended layer is proposed for two different
applications. First, layer is intended largely to increase moisture retention
in the near-surface, subaerial tailings and thereby decrease downward oxygen
diffusion through the tailings. Second, it would be used beneath the tailings
pond to decrease downward flow and, consequently, maintain a water cover that
would limit oxygen diffusion. The method suggested for the bentonite
application is through use of an implement that is essentially a hollow tined
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I'm apprehensive about the ability of this technique to achieve a fairly
continuous layer of reduced permeability.

I am not sure how well the bentonite-amended tailings layer will work in the
surface. Most earthen layers used in covers tend to become damaged over
relatively short time frames unless they are covered with a geomembrane or are
very deep (meters). The liner application should work very well, but chemical
compatibilty should be checked with the worst-case tailings leachate.
Bentonites used in hydraulic barriers generally are sodium bentonites, and are
susceptible to cation exchange reactions with other metals in the leachate.

The accepted method for construction high quality bentonite-amended barrier layers is to blend the soil and bentonite in pug mill or other device that ensures good mixing and uniformity. My intutiion is that the injection method, which I have seen in agricultural manure applicaitons, will not result in adequate uniformity. I recommend that other methods for applying the bentonite be explored.

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> Hope things are well with you and that you are getting a reasonable
> balance
between work and "the real world".
>
> Kim (651/259-5401)

Classification: UNCLASSIFIED
Caveats: FOUO

Classification: UNCLASSIFIED
Caveats: FOUO

Classification: UNCLASSIFIED
Caveats: FOUO

Appendix C

FW: PolyMet Tailings Dam Comments Appendix 6

Dostert, Dana M (DNR)

To:	Boyle, Jason (DNR)
CC:	Kunz, Michael (DNR); Woldeab, Irina (DNR)
Attachments:	Flotation Tailings Basin_Permit Apps Dwg FTB-009 FTB-024 05_12_2017.pdf; image001.jpg;
Sent:	6/7/2017 8:20 AM

Dana Dostert PE, PG
Senior Engineer – Dam Safety
MN Department of Natural Resources
500 Lafayette Road, St. Paul, MN 55155-4032
(651)-259-5663

mailto:dana.dostert@state.mn.us

From: Tom Radue [mailto:TRadue@barr.com]
Sent: Tuesday, June 06, 2017 12:29 PM
To: Dostert, Dana M (DNR) <dana.dostert@state.mn.us>; 'donsutton@spectrum-eng.com' <donsutton@spectrum-eng.com>
Cc: Jennifer Saran (jsaran@polymetmining.com) <jsaran@polymetmining.com>
Subject: PolyMet Tailings Dam Comments Appendix 6

Dana – in follow-up to your E-mail and the associated E-mail string, please see responses below (in red font) and also see the attached PDF. The plans submitted 05-16-2017 are for permitting. A detailed plan set will be developed for each phase/segment of construction, after permits are issued and once the start of construction is imminent.

On behalf of PolyMet, we'd be happy to discuss further as needed. Note too that I've copied Don on this response. Please circulate to others as needed.

Thanks,

Tom

Tom Radue, PE

Vice President
Senior Geotechnical Engineer
Minneapolis, MN office: 952.832.2871
cell: 952.240.4051
tradue@barr.com
www.barr.com

From: Dostert, Dana M (DNR) [mailto:dana.dostert@state.mn.us]
Sent: Monday, June 05, 2017 11:56 AM
To: Tom Radue <TRadue@barr.com>
Cc: Dostert, Dana M (DNR) <dana.dostert@state.mn.us>; 'Cecilio Olivier' <colivier@eorinc.com>; 'Steve Gale' <smg@gale-tec.com>; Kunz, Michael (DNR) <michael.kunz@state.mn.us>; 'Nate Lichty' <nml@gale-tec.com>; 'Stu Grubb' <sgrubb@eorinc.com>; Woldeab, Irina (DNR) <irina.woldeab@state.mn.us>
Subject: FW: PolyMet Tailings Dam Comments Appendix 6

Tom,

Don Sutton has some questions about the under drain\foundation layer. Could you please respond to Don. I think you can give him a much better response than I can.

Thanks,

Dana D.

Dana Dostert PE, PG
Senior Engineer – Dam Safety
MN Department of Natural Resources
500 Lafayette Road, St. Paul, MN 55155-4032
(651)-259-5663

mailto:dana.dostert@state.mn.us

From: donsutton@spectrum-eng.com [mailto:donsutton@spectrum-eng.com]
Sent: Friday, June 02, 2017 10:25 AM
To: Dostert, Dana M (DNR) <dana.dostert@state.mn.us>; 'Cecilio Olivier' <colivier@eorinc.com>; 'Steve Gale' <smg@gale-tec.com>; Kunz, Michael (DNR) <michael.kunz@state.mn.us>; 'Nate Lichty' <nml@gale-tec.com>; 'Stu Grubb' <sgrubb@eorinc.com>
Cc: Boyle, Jason (DNR) <jason.boyle@state.mn.us>
Subject: RE: PolyMet Tailings Dam Comments Appendix 6

I don't think the drawings illustrate what Tom Radue intends, because as drawn, it appears that the surface water will run down the outside of the embankment, collect as a pond on the two benches with the underdrains, and leak into the underdrain. See the sticky-notes on the attached PDF. Which is exactly the opposite of the purpose of the underdrain, which is supposed to guide water away from the embankment rather than into the embankment. The term "underdrain" is possibly being given too much weight – what is needed is a zone of material having a specific material gradation, permeability, shear strength, and dimensions such that it performs as modeled for seepage and slope stability modeling. The material (anticipated to be LTVSMC coarse tailings or engineer approved substitute) is already at least partially in place; confirmation of this will be required during construction. It doesn't appear to me that the surface water fate is being recognized or managed. Am I missing something? For large disposal facilities in Minnesota having soil covered geomembrane closure systems (limiting infiltration; similar in action to the proposed bentonite-amended layer) common practice is to limit the uninterrupted (no benches and/or ditches) flow length on slopes to not greater than 200 feet. Barr's decades of experience with this approach has been good. Uninterrupted flow length for the proposed Flotation Tailings Basin is currently 135 feet. Though we can anticipate some need for maintenance of erosion areas on final slopes in early years of closure, the slopes at 4.5H:1V are relatively flat (erosion on the steeper slopes on the existing basin is not overly problematic but does require periodic maintenance; particularly in areas of sparse vegetation and/or channelized flow) and establishment of dense vegetation should provide adequate erosion control. If it is determined during design of each dam raise that additional erosion control would be beneficial and/or proven over time that dense vegetation cannot be established and maintenance needs become excessive and/or specific areas are continually prone to erosion, then additional erosion controls such as ditches, spillways, and subsurface drainage can be added to the closure system.

Donald G. Sutton P.E.
Spectrum Engineering & Environmental
1413 4th Ave. North
Billings, MT 59101
Direct: 406-534-4660
Mobile: 406-670-7270

From: Dostert, Dana M (DNR) [mailto:dana.dostert@state.mn.us]
Sent: Thursday, June 1, 2017 7:17 AM
To: donsutton@spectrum-eng.com; 'Cecilio Olivier' <colivier@eorinc.com>; 'Steve Gale' <smg@gale-tec.com>; Kunz, Michael (DNR) <michael.kunz@state.mn.us>; 'Nate Lichty' <nml@gale-tec.com>; 'Stu Grubb' <sgrubb@eorinc.com>
Cc: Boyle, Jason (DNR) <jason.boyle@state.mn.us>
Subject: RE: PolyMet Tailings Dam Comments Appendix 6

Hi Everybody,

Just as an update, I talked to Tom Radue earlier this week about the under drain. In the most recent plans revised about two weeks ago, they have renamed the two underdrain layers as foundation layers. Their primary purpose will be to provide foundation support for the perimeter dam and they will be constructed of gravel and coarse tailings. They were also meant to collect seepage waters and draw them back into the stack. The drainage area for these seepage collection sites is quite small, being the outside face of the dam, so there is unlikely to be a large volume of precipitation entering the stack. There groundwater model has not shown any issues with rising groundwater levels at this time.

Barr comment (06-05-2017) - see Barr responses to Don Sutton E-mail above for clarity. We believe the comment below is DNR internal – updated plans were delivered by PolyMet to DNR 05-16-2017.

We have not yet received the redesigned plans. More discussion will be needed.

Thanks,,

Dana D.

Dana Dostert PE, PG
Senior Engineer – Dam Safety
MN Department of Natural Resources
500 Lafayette Road, St. Paul, MN 55155-4032
(651)-259-5663

mailto:dana.dostert@state.mn.us

From: donsutton@spectrum-eng.com [mailto:donsutton@spectrum-eng.com]
Sent: Wednesday, May 31, 2017 5:18 PM
To: 'Cecilio Olivier' <colivier@eorinc.com>; 'Steve Gale' <smg@gale-tec.com>; Kunz, Michael (DNR) <michael.kunz@state.mn.us>; 'Nate Lichty' <nml@gale-tec.com>; 'Stu Grubb' <sgrubb@eorinc.com>
Cc: Boyle, Jason (DNR) <jason.boyle@state.mn.us>; Dostert, Dana M (DNR) <dana.dostert@state.mn.us>
Subject: PolyMet Tailings Dam Comments Appendix 6

Steve Gale, Nat Lichty and I discussed the FTB drawings in Appendix 6 today.

1. As shown on the drawings, (FTB-009) none of us completely understand the function of the 4-foot thick coarse LTV tailings underdrain beneath lifts 1 and 5 along the north face of the embankment. It appears that the underdrain will collect and direct surface run-off into the embankment, potentially saturating the embankment, and reducing the stability. This item requires further explanation and review. (see first image below) We don't think that the purpose of the underdrain is to collect surface water, but that's what is illustrated.

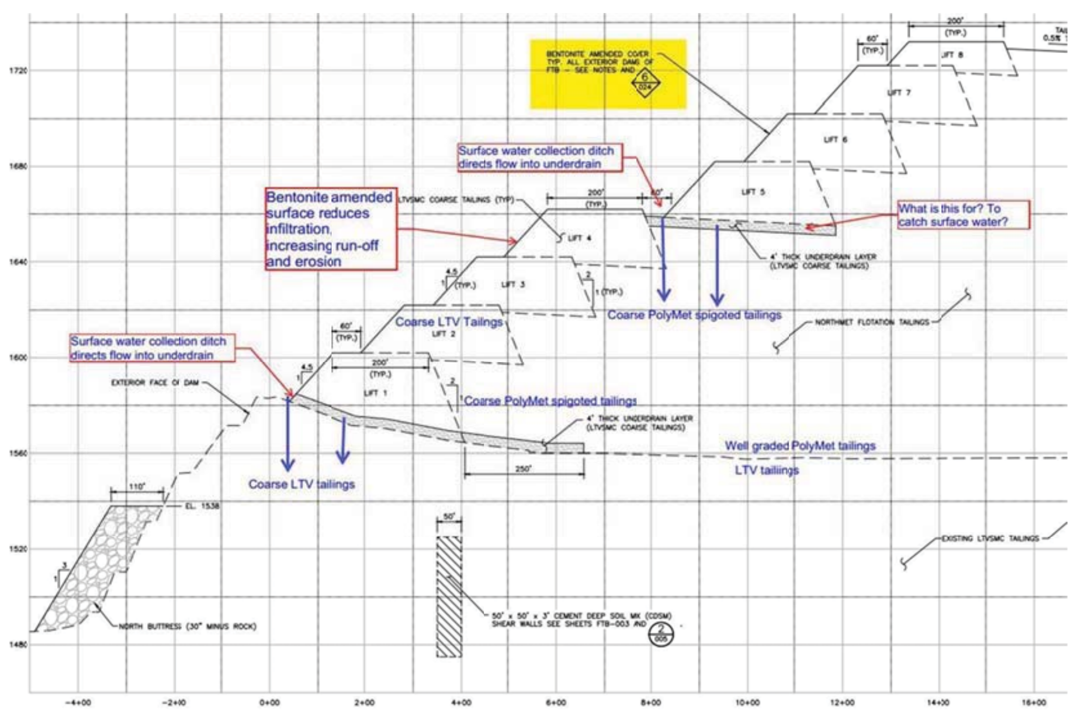
2. I wasn't tasked to look at the dam stability, so don't know if the stability analysis assumed the embankment was saturated or dry. The analysis needs to be done considering rainy wet conditions where the surface run-off is being forced into the embankments. This will shift the phreatic surface closer to the embankment, especially below lift 5. Below, I describe some other scenarios where erosion can alter the phreatic surface assumptions and potentially cause embankment failure. The analysis also needs to be made when the pond is overflowing the spillway and the embankment is saturated. This is the worst case, unless an earth quake occurs at the same time.

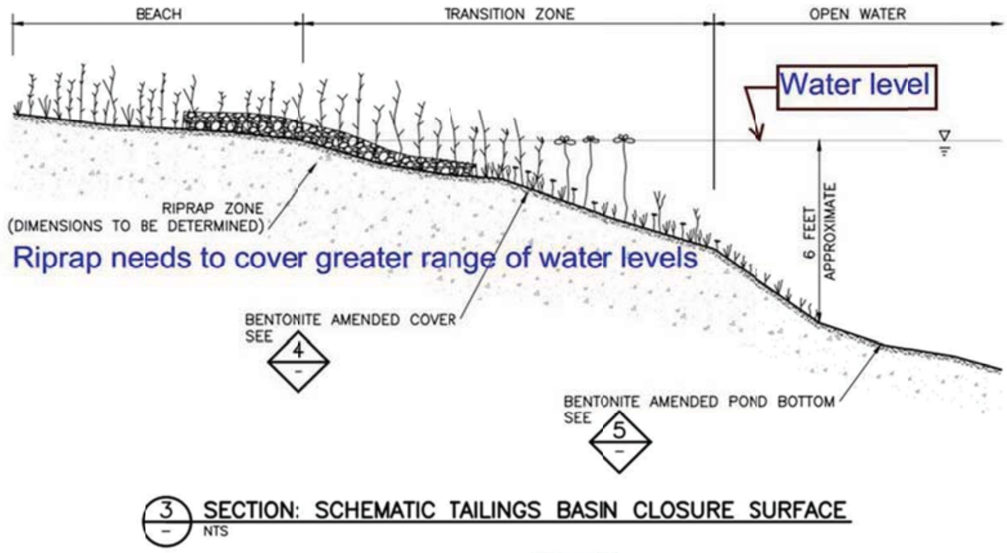
3. The stair step FTB embankment sealed with bentonite is geomorphologically unstable and will erode, potentially cutting back into the pooled water, releasing the water and saturated tailings. Initially, surface water will collect in the horizontal ditch/ponds along the toes of lifts 1 and 5, and infiltrate into the embankment via the underdrain and the coarse LTV tailings beneath lift 1. Later, after the bentonite soil erodes from the slopes, the ditches will fill, plugging the underdrain, forcing the water to overflow the bench and cause head cutting in the non-cohesive tailings. If the FTB is to remain as a permanent structure without perpetual maintenance, then I recommend that the embankments be designed using established geomorphologic land

reclamation principals. Otherwise there is a high probability that the embankments will eventually fail due to erosion, and catastrophically release the saturated tailings.

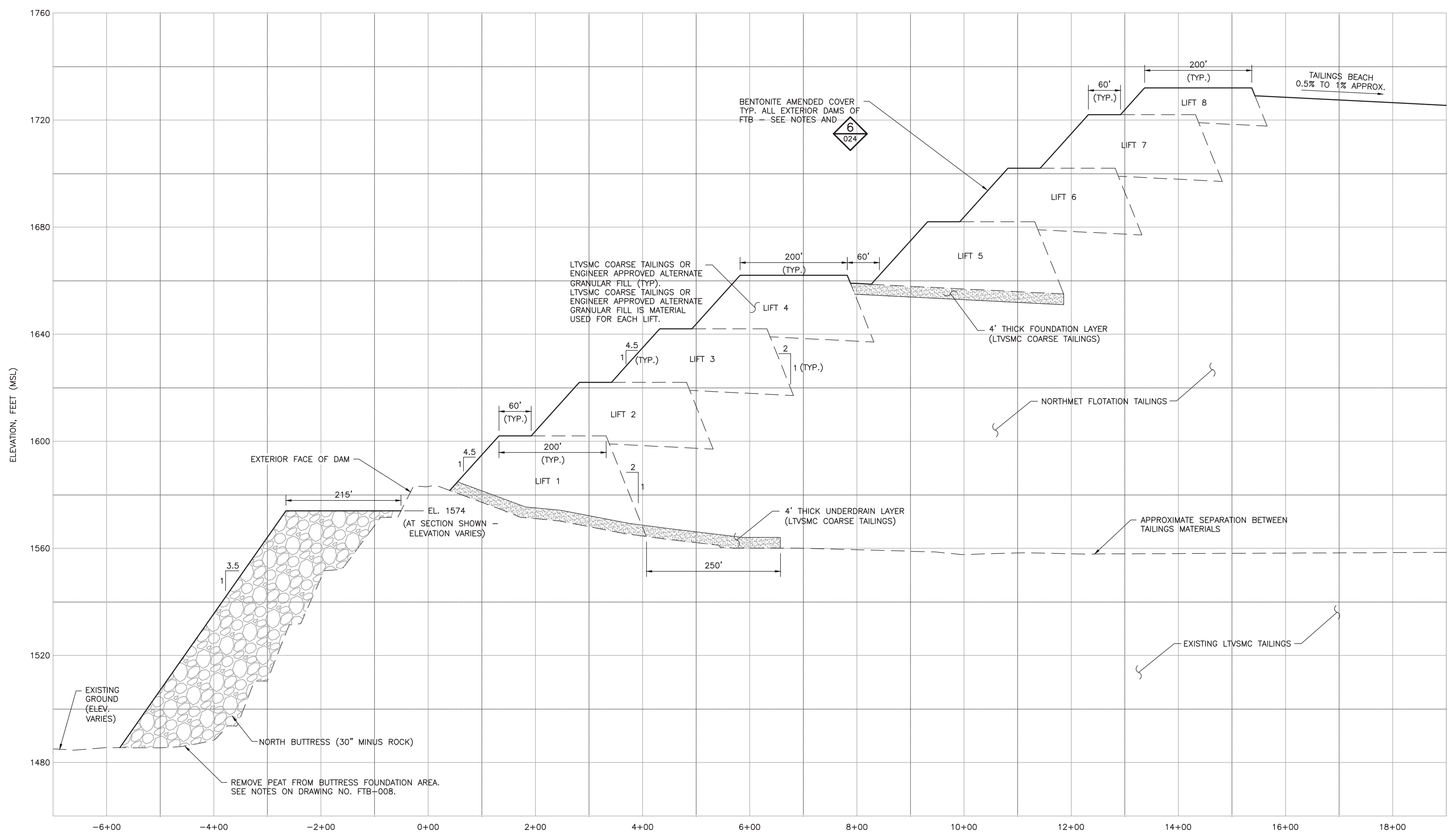
4. As illustrated in Drawing FTB-024, the portion of beach protected by riprap appears to be too narrow, but the width is subject to change. The total extent of the riprap needs to be designed as part of the closure. The size and thickness of riprap need to be justified based on wave action and ice. If the water level fluctuates, wave action could erode above or below the riprap, thus setting up a head cutting scenario from the inside towards the embankment. This could lead to piping and embankment failure. (see second image below). The 625 foot beach slopes 1%, then transitions to a 3% slope to the pond bottom. If the water level drops below the elevation predicted, then the 1% to 3% transition nick point could initiate a head cut that will run back to the embankment. This could trigger piping by allowing water a clear path into the coarse embankment fill when the water level rises. This may not be an issue if the site is perpetually managed and repaired, but will be an issue if the site is abandoned. The water level will not remain constant unless it is managed. If it is not managed, then depending on the bentonite efficacity, the pond could either periodically dry up or over fill. Climate change makes precipitation predictions 100 or 200 years from now impossible, so the design needs to assume the worst case. The range of water level possibilities needs to be addressed in the closure design. If the water level drops lower than designed due to higher infiltration rates or lower precipitation, then the geochemistry assumptions will change as the tailings dry out and oxidize.

The design of the FTB in this permit application will require perpetual maintenance to ensure it will not fail and release the tailings. Placing bentonite on the embankment and interior surfaces will increase the run-off and the erosion rate. The stair-step design is geomorphologically unstable. The methods and assumptions used to place the bentonite to control the infiltration and tailings saturation are unsubstantiated, and wishful thinking. We do not believe it will function as intended, because of the unproven application methods.





Donald G. Sutton P.E.
Spectrum Engineering & Environmental
1413 4th Ave. North
Billings, MT 59101
Direct: 406-534-4660
Mobile: 406-670-7270



1 – ELEVATION: NORTH DAM TYPICAL CROSS SECTION

0 100 200
HORZ. SCALE IN FEET

NOTES:

1. DAMS AND BUTTRESS DIMENSIONS MAY CHANGE WITH EVALUATION OF FUTURE DAM STABILITY PERFORMANCE DATA.

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
3	04/12/13	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 3 – ATTACHMENT A
4	11/25/14	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 4 – ATTACHMENT A
5	03/03/15	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 5 – ATTACHMENT A
6	05/20/15	ISSUED FOR INCLUSION IN PERMIT APPLICATIONS
7	05/12/17	PERMIT APPLICATION UPDATES

ISSUE STATUS		
ISSUED	VERSION	DATE
FOR PERMITTING	7	5/12/17
FOR CONSTRUCTION	–	–
NOT APPROVED FOR CONSTRUCTION		

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
NORTH DAM
TYPICAL CROSS SECTION

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

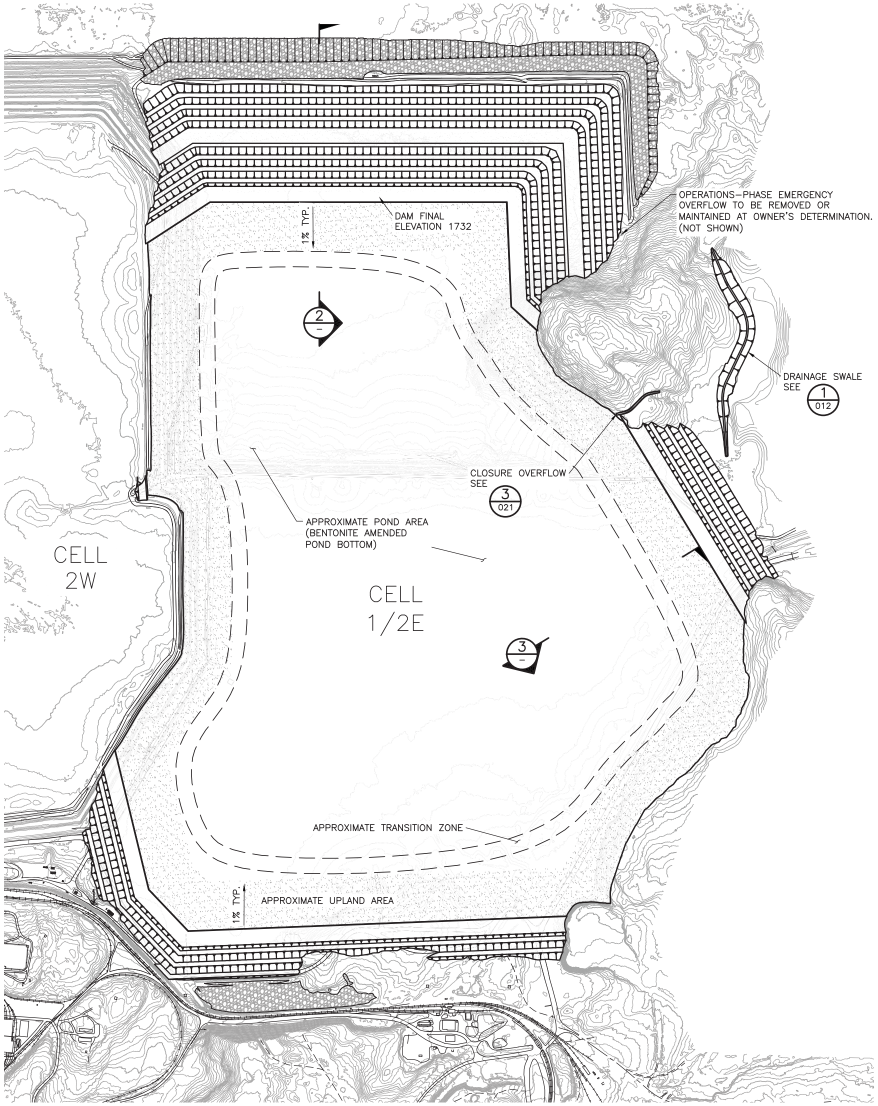
BARR

BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. FTB-009
REV A

INCHES 1 2

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-009.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:06 AM



1 PLAN: PROPOSED CLOSURE PLAN

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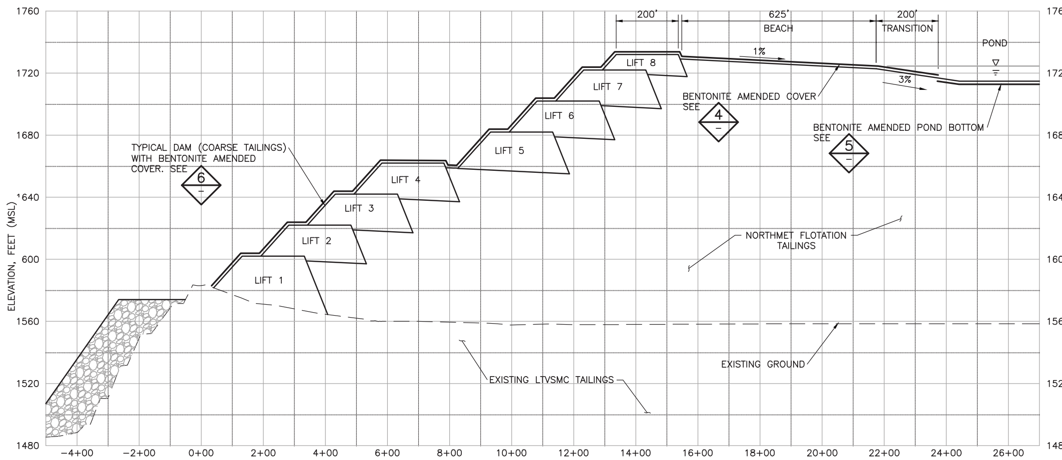

2 SECTION: CELL 2E TAILINGS BASIN CLOSURE TYPICAL SECTION

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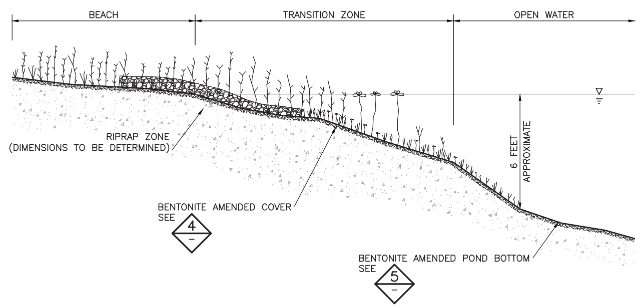
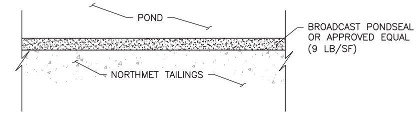
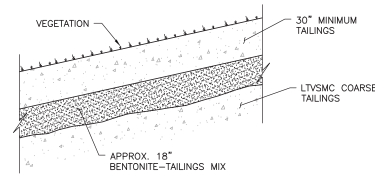


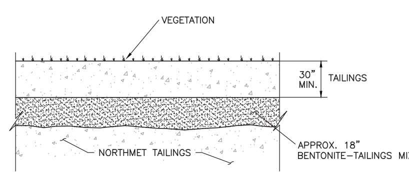
3 SECTION: SCHEMATIC TAILINGS BASIN CLOSURE SURFACE NTS



5 DETAIL: BENTONITE AMENDED POND BOTTOM NTS



6 DETAIL: DAM SLOPE BENTONITE AMENDED COVER NTS



4 DETAIL: BENTONITE AMENDED BEACH COVER NTS

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
3	04/12/13	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 3 – ATTACHMENT A
4	11/25/14	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 4 – ATTACHMENT A
5	03/03/15	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 5 – ATTACHMENT A
6	05/20/15	ISSUED FOR INCLUSION IN PERMIT APPLICATIONS
7	05/12/17	PERMIT APPLICATION UPDATES

ISSUED	VERSION	DATE
FOR PERMITTING	7	5/12/17
FOR CONSTRUCTION	–	–

NOT APPROVED FOR CONSTRUCTION

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN CLOSURE PLAN

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. FTB-024

REV A

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-024.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:56 AM

INCHES 1 2

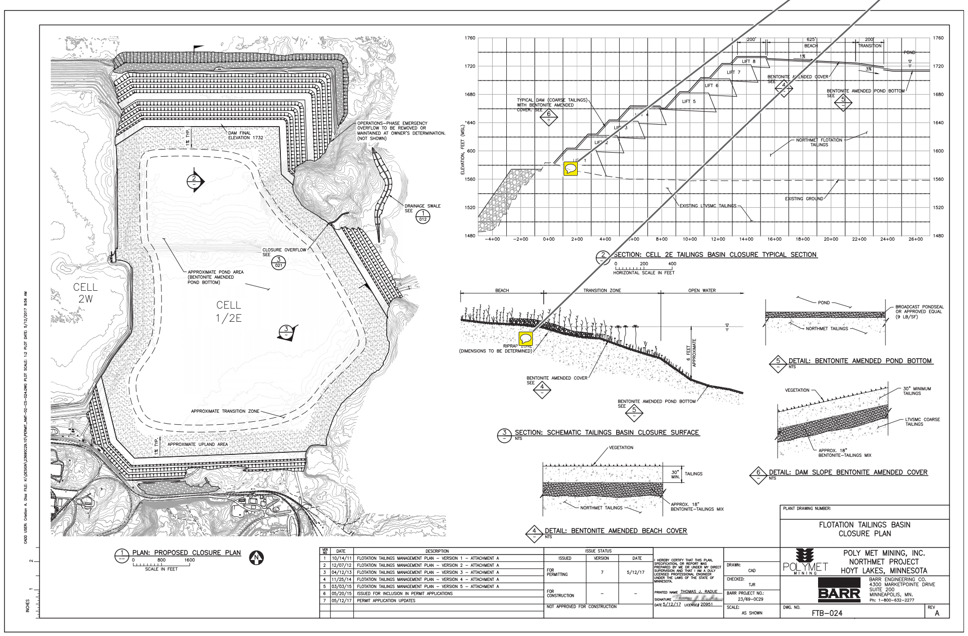
Page: 2

Author: tjr Subject: Sticky Note Date: 6/6/2017 8:33:42 AM -05'00'

Northern exposure of underdrain layer to be covered with bentonite-amended tailings.

Author: tjr Subject: Sticky Note Date: 6/6/2017 8:19:09 AM -05'00'

This detail is not to scale; the dimensions of the riprap zone will require final determination and confirmation at the time of basin closure and will depend on factors such as beach slope at time of closure, projected water level bounce from combined pond area/beach area existent at time of closure, and based on pond fetch at time of closure.



Appendix D

SPECTRUM ENGINEERING

To:	Jennifer Engstrom, MDNR
From:	Donald Sutton
Date:	February 24, 2012
Subject:	HydroMet and Stockpiles - review of Barr responses to comments

PolyMet Geotechnical Modeling Work Plan comments

Flotation Tailings Basin Geotechnical Model for SDEIS, FEIS and Permitting:

1. Item 3a. The bentonite seal is a hail Mary type of concept in my opinion. I believe it will exacerbate erosion and slope failure and will eventually fail, so I recommend that the stability analysis should assume the bentonite doesn't prevent seepage so far as stability is concerned.
    a. What is the stability of the side slopes if a layer of tailings is placed above the bentonite and it becomes saturated? Will the bentonite slope fail?
    b. What if the bentonite slope is saturated and there is an earthquake or a thunderstorm?
2. I am concerned about long term climate change and how it will affect the water balance in the tailings facility because this can affect the water level, the water head, the saturation, and most importantly, erosion.

    Erosion can cause the shape of the embankments to change over time, it can cause erosion and gullying that can create a pathway for water to escape from the pond. This bothers me, because the proposed design is temporary and will fail unless it is perpetually maintained. I am surprised that the Minnesota statutes allow a temporary impoundment structure to be permitted permanently. This wouldn't be allowed in other jurisdictions. I realize that this will be addressed during the permitting and financial assurance review. Estimating the liabilities will be contentious.

Stockpile Geotechnical Models for SDEIS, FEIS and Permitting:

1. Is there a schedule for collecting the foundation data? How does it relate to the EIS if the data isn't obtained in time?
    a. As a practical matter, I think the stockpile geotechnical designs pose no geotechnical EIS related concerns provided they honor the statutes. My concerns are related to water management, erosion control and geochemical issues.
    b. There is a potential minor leak risk with the liners, but this is minimal and has been addressed. I would like to see the sub-base designed so that any leakage can be collected or directed to the pit pumping system. At some point, someone needs to check this, but it isn't a geotechnical item.

1413 4th Avenue North • Billings, Montana 59101 • 406/534-4660 • Fax 406/259-1456 • sutton@spectrum-eng.com

Issues surrounding the PolyMet Discharge Permit

Glenn C. Miller, Ph.D.
Consulting Environmental Chemist
Reno, NV

February 24, 2018

The draft NPDES/SDS permit for PolyMet's NorthMet Mine Project is unprecedented in its long-term requirements for effective agency oversight and financial requirements for long-term protection of Minnesota citizens from large financial liability. This is a new type of NPDES/SDS permit. The draft permit requires PolyMet to store the contaminant load from the hard-rock mine mostly on site since the mine contaminants (particularly sulfate) cannot be legally discharged into surface water. The high rainfall in the area, as well as the requirement of a very long-term membrane process for cleaning up the discharge (while storing the load on site), presents an increasing risk of catastrophic release of contaminants when the regulatory or engineering plans fail. It appears that there is effectively no closure of the mine, since treatment of the discharged water is an *in perpetuity* requirement. And, because treatment must occur *in perpetuity*, the responsibility of maintaining protection of the environment will eventually rest squarely on regulatory agencies and Minnesota citizens. I offer the following comments:

A. The time frame for discharge of sulfate-containing water from the NorthMet Mine meeting the 10 mg/L discharge is effectively forever (>several centuries) for the following reasons:

1. <u>Inaccuracy of Predictions</u>. Predictions of pit lake water quality have been conducted by the mining industry, using hired consulting companies, for over 20 years, largely in Nevada for gold mines. While some improvements have occurred, the predictions of water quality that evolves as water refills a pit have effectively always been incorrect and mostly underestimate the amount of sulfate delivered to the pits. Although the rock surrounding the NorthMet pits is known to be tight, the wall rock, as well as the dewatered cone of depression, does contain sulfides which suggests that sulfate will be released as the pit lake fills.

2. <u>Predictions Underestimate Sulfate</u>. Most predictions about pit lake water quality underestimate the amount of sulfate for a couple reasons. First, many underestimate the contribution that originates when oxygen reacts with sulfidic rock. This occurs during the dewatering of the pit when air

replaces water in the groundwater system and a cone of depression is created. As the pit is flooded at the end of mining, the oxidized surfaces release the oxidation products (primarily sulfate) into the pit lake, and, as water ultimately flows out of the pit lake, it will need to be treated.

A second source of sulfate is from refilling the East Pit. Oxidation products from that rock will be released, and ultimately provide an additional loading to the groundwater system, as well as the pit lake, assuming that the refilled pit will have some ultimate discharge to surface water. This additional load of sulfate will slowly mix with the pit water flow, and contribute a long-term source of sulfate that will need to be removed by the membrane system in the water treatment plant.

3. <u>Drainage from Waste Rock Dumps Is Unlikely to Stop</u>. It is unlikely that the drainage from the waste-rock dumps will stop because sulfides are present in the rock and, while they may or may not generate acid, oxidation of sulfides will continue until they are consumed. Sulfides are not stable in an oxygen-containing atmosphere and sulfates will be produced at rate that will depend on the depth in the rock, the oxygen availability and the type of sulfide that is available. Because if this, waste-rock dumps will contribute additional sulfate that will need to be treated by the membrane system in the water treatment plant.

Overall, the multiple sources of sulfate will contribute this contaminant in such a manner that it is highly unlikely that sulfate concentrations will consistently dip below 10 mg/L, and allow PolyMet to cease water treatment.

B. There are no known passive treatment systems that will effectively remove sulfate consistently to 10 mg/L, except for a continuously-operating membrane system.

PolyMet previously proposed examining sulfate-reducing bioreactors (SRB) to remove sulfate after closure, although that proposal appears to have been withdrawn. The purpose of this alternative treatment system was to potentially transition to a more passive-treatment system that would not require the energy and treatment processes that the membrane systems require.

While sulfate-reducing bioreactors have a place in mine water treatment, an SRB system simply will meet water quality standards; there are no examples that exist where a treatment system of this type has consistently been effective for removing sulfate to 10 mg/L. In fact, none of the systems I have observed can consistently reduce sulfate below 30 mg/L. And, a system at the NorthMet site will be especially ineffective since: (1) the extreme-cold conditions at the site will hinder treatment during cold months; (2) high flows during the spring and high rainfall events will increase the difficulty of treating water; (3) while sulfate-reducing systems will initially remove sulfate with reasonable efficiency, the readily available reducing sources in the substrate are consumed over the first several months, the activity decreases over time, and the ability to remove sulfate decreases; and (4) the product of sulfate reduction is reduced sulfur products which, if not precipitated as metal sulfides or sulfur, will simply be re-oxidized when the water is discharged into an aerobic water system. The result of the characteristics at the NorthMet site is increased sulfate in the receiving water.

Additionally, any passive, sulfate-reducing system will require removal and disposal of the organic substrate periodically, since any sulfate that is precipitated in some form (e.g. sulfur) will be susceptible to re-oxidation in the years following sulfate removal (even if it ultimately does initially remove sulfate). As the organic substrate is consumed, systems are plugged with metal sulfides and microbial mass. And oxygen from the water to be treated will change the oxidation-reduction potential and allow re-oxidation of reduced and precipitated sulfur species.

Overall, in the absence of any effective passive treatment system, it is highly likely that a membrane water treatment system will be required to meet the 10 mg/L standard. While new technology can never be completely discounted, the thermodynamics of removal of sulfate suggests that it will always be an expensive process and will require regulatory management by the existing agency for a longer period of time than the U.S. has existed. Can we expect that regulatory programs will exist centuries forward, or is this mine and waste reservoirs a source of contamination which will continue to present an environmental risk for future generations? That is the gamble PolyMet asks Minnesota to take on with the NorthMet Mine.

C. The tailings facility has similar issues; pumping the collected water and treating it relies on an effective financial system and engineering design that will be required *in perpetuity*.

The tailings basin will soon become a highly contaminated repository that contributes a substantial contamination load to receiving waters if the pump and treatment system fails. If, as proposed, the tailings basin seepage treatment train and the sludge from the high-density sludge precipitation process are deposited in the flotation tailings basin and/or the hydrometallurgical residue facility, these two areas will represent long-term source of high concentrations of sulfate. The gypsum sludge in the tailings and waste basins will release sulfate at the gypsum solubility limit, on the order of 1000-1400 mg/L depending on temperature and calcium concentrations. While these facilities are proposed to have a catchment system and will rely on pumping and treatment, it will be an additional *in perpetuity* required process. The amount of water to be treated will depend on the stability of the cap that is projected to be added when the tailing facility is closed. We have no experience or data on how long a clay or high-density polyethylene (HDPE) cap will last; failure of the cap will ultimately occur.

HDPE liners are reputedly designed to last 30 to 300 years depending on the specific conditions of a site. When the liner fails and the pump and treatment facility is gone, the release of contaminants from the tailings facility will occur in an unpredictable manner. But this will occur over a long time, since the tailings facility will contain gypsum (calcium sulfate) sludge from the water treatment facility, as well as oxidation products from the tailings. The extent of discharge is unpredictable, but the cost of controlling that contaminant source is likely to be high. Ultimately, the state agency should assume control of the integrity of the cap, as well as the pump and treatment system, and have sufficient funding to hire a third-party contractor to manage the site. To my knowledge, no U.S. mining company has been around for more than 150 years and the threats posed by this tailings facility will exist for a time well beyond then.

D. While the NorthMet Mine Project has undergone substantial environmental review, the very nature of a large, open-pit, metallic mining in a sensitive environmental region in a wet climate presents long-term problems that are not well understood.

A large open-pit mine in wet climates poses many problems that are not fully understood, including management of the large volumes of contaminated mine water that are produced during the spring thaw and management of the large flows that occur during major precipitation events. Mining in arid regions, alternatively, while having negative impacts in a localized area, often do not present regional environmental problems since the amount of water evaporating can be 5 to 10 times more than the amount of water falling as precipitation. This is clearly not the case at the NorthMet Mine. Requirements for treating discharged water is a much greater concern in the wet, cold northeastern Minnesota climate and water treatment requirements are much greater.

The proposed NorthMet Mine is a large, open-pit mine and, except for much more benign iron mines, no regulatory agency in the U.S. has permitted a hard-rock mine with a 10 mg/L sulfate discharge standard. Modeling results are notoriously inaccurate, and there remains a distinct possibility that the contaminant load will be much larger than projected by the geochemical and geological predictions. With this permit, the regulators in Minnesota are assuming that treatment systems will operate in a time-frame of centuries and a regulatory presence will be required in a similar time frame. As others review the proposed mine and long-term impacts, there is apparently a substantial reliance on engineering designs and geochemical predictions that have not been adequately tested. The agencies need to assume that they will take over the long-term liabilities of the mine site, and need to know that they will have sufficient funds to treat the long-term consequences.

Issues surrounding the PolyMet Discharge Permit

Appendix A

March 11, 2014

Lisa Fay
EIS Project Manager
MDNR Division of Ecological and Water Resources
Environmental Review Unit
500 Lafayette Road, Box 25
St. Paul, MN 55155-4025

Dear Ms. Fay,

I have been asked to comment on various aspects of the Polymet Mine proposal. I have reviewed numerous mining proposals over the past 30 years, primarily in the western United States, but also participated in review of the Eagle Mine in the Upper Peninsula of Michigan.

The proposed Polymet mine is a large open pit proposal that contains varying amounts of sulfides in the rock that will be removed. The proposal has the potential to affect surface and groundwater quality far into the future, and will, for the foreseeable future require water treatment to meet discharge standards. Unlike proposals in the arid regions of the western United States, where evaporative processes will largely keep water quality impacts localized to the area around the mine, this mine is being proposed in a well-watered region of the U.S. and will be a potential source of sulfate and metals release to surface waters that will potentially affect the environment distant from the mine. As such, while certain comparisons to mines in arid regions are appropriate, the proposed open pit Polymet mine creates additional potential problems that will exist for many generations to come.
I offer the following comments.

1. **General Comments:** The proposal for the Polymet mine has received extensive study to identify the potential environmental threats, and that degree of investigation is laudable. However, once this vast amount of information is reviewed, the threats to water quality become increasingly apparent. While the sulfide content is not high in much of the waste rock, the buffering capacity is also very low and the release of metals and sulfuric acid will be substantial, as recognized in the SDEIS. Most of the mitigation measures rely on very large water collection and treatment processes that are unparalleled in modern mines. While the treatment technology (e.g. reverse osmosis treatment) has been shown to be effective in much smaller treatment facilities, it has not, to my knowledge, been utilized on such a grand scale and certainly not for centuries, as is projected in the SDEIS.

The largest threat to surface and groundwater quality is from the fugitive and uncontrolled releases, particularly to groundwater. Having observed large pit lake formation in Nevada over the past 20 years, the sulfate and metals loadings to the East Pit (refilled) and the West Pit Lake are, I believe, substantially underestimated in the proposed Polymet plan. Particularly for the East Pit, the plan to rinse and withdraw the expected highly contaminated water from the pore spaces in the waste rock is untested, and very likely to fail due to the extreme difficulty of efficiently rinsing rock that has been added to the pit. Both from the refilled East Pit and the West Pit Lake, sulfate and metals loading is very likely to exceed the groundwater standards of the State of Minnesota. This plume of contaminated water will migrate long distances and potentially be a source of contamination to groundwater and surface water for centuries. Also, as discussed by others (see the Maest comments), the water from the East Pit will almost certainly contain large amounts of nitrate and ammonia from the blasting activities from residues of ANFO(ammonium nitrate-fuel oil). Removal of these substances is largely untested.

Once the pits are created, and water quality predictions turn out to be wrong, the problems are magnified, due to the massive size of the excavations. The MDNR will then be faced with the dilemma of what to do, since the rock pieces cannot be put back together, and the source of the contaminants might be impossible to control.

2. **Pit Lake water quality:** Geochemical modeling is indeed important for a better understanding of the potential contaminant concentrations that will need to be managed as pit lakes begin to fill. Modeling of pit lakes has been required for nearly 20 years for precious metals mines in Nevada, many of which have relatively low sulfide concentrations in the rock surrounding the pits, and/or high neutralization potential due to the carbonate hosted rock in many of the ore bodies.

   However, the further those models are removed from actual data in humidity cell tests, and from a correct conceptual model, the more uncertain they become for estimating concentrations that will ultimately result in a pit lake or in the water draining into a pit lake. The water quality in the ultimate West Pit Lake is estimated to contain 800 mg/L sulfate (range of 500-1200 mg/L). The basis for this estimate is on rinsing of wall rock that has been exposed to air. The actual concentration is likely to be considerably higher, and is likely to approach gypsum (calcium sulfate) saturation (probably supersaturation), similar to what is found in almost all pit lakes in Nevada. Concentrations of sulfate can vary from 500 mg/L to over 3000 mg/L, depending on conditions at the specific site (see attached Nevada Division of Environmental Protection file in Appendix 1 that provides limited data on some of the Nevada pit lakes).

   Modeling of pit lake water quality has typically assumed that sulfate will come from wall rock oxidation very near the surface of the pit lake, as is apparently the case for the West and East pits. This so-called "rind" model neglects what actually happens when a cone of depression is created as water is pumped (or flows into the pit) to lower the groundwater table to the bottom of the pit. The water is replaced by air that is brought into the cone of depression created by removal of water; the result is oxidation of sulfides that are present in the large volume of rock distant from the actual pit faces. Concentrations of sulfate present in the water draining into the pit are effectively impossible to predict, since there have been no estimates made of sulfides in the rock surrounding the pit that will exist in the dewatered cone of depression. However, the sulfate concentrations that have been found in Nevada pit lakes have been uniformly higher than what was predicted by the pit lake models, prior to the pit lake formation. (see, for example the Lone Tree Pit Lake model initially produced in 2004, and the sulfate concentrations that were actually observed- Nevada Division of Environmental Protection, 2014). In this case, even in 2010, when an estimate of approximately 11,000-15,000 tons of lime would be required (Geomega 2010 Lone Tree pit lake modelling and Management Plan Update, obtained from the Nevada Division of Environmental Protection), in 2013, over 60,000 tons of lime have been added to neutralize the pit lake since that 2010 prediction. Even within three years, the modelling effort was off by a factor of 6-7, and was low. While each system is different, the likelihood of > 2000 mg/L sulfate in the refilled void volume of the East Pit and the West Pit lake is high.

A second aspect of this type of oxidation is that sulfate concentrations will be elevated far into the future, since rinsing of those surfaces will continue until the entire cone of depression is rinsed, and would include any gypsum that may have precipitated in the aerated pores where sulfides had been oxidized, and the solid gypsum redissolved. Thus, the concentration of sulfate in the pit lakes remains highly uncertain, although they are likely to be much higher than the concentrations predicted. No discussion of this source of sulfate and contaminants was presented. In fact, the estimates of sulfate in the West Pit Lake are very similar to what was projected in pit lakes in Nevada, but most (effectively all) of these predictions have been wrong, and all have been wrong when the pits intercepted sulfide bodies, similar to the Polymet deposit. The SDEIS for the Polymet mine, and accompanying documents have uncertainty estimates for sulfate release, and they utilize the 90-95% confidence estimates for sulfate release. This same type of Monte Carlo simulations have been completed for many mines in Nevada, but are still wrong by sometimes over an order of magnitude, primarily a result of utilizing an incorrect basic conceptual model. I believe that this is the case for the East and West pits of the Polymet mine.

If water is being treated with a concentration of 2000 mg/L, and needs to be treated to a discharge limit of 10 mg/L, the increased sulfate loading will extend the time for treatment many years past the time for refilling of the pit lake (estimated at approximately year 40 (p. 3-72 of the SDEIS)) and could be considerably longer. Additionally, the groundwater discharge is likely to have much higher concentrations than the groundwater limit of 250 mg/L for over 100 years. This will potentially create a contaminated zone of groundwater that will be extensive.

Removal and treatment of water at a rate of 300 gal/min thus is unlikely to result in sufficient dilution of the contaminants (particularly sulfate) for a much longer period than predicted. Instead of 200 years to dilute the pit lake to approximately 35 mg/L (Fig. 6-61 in the Water Modeling Data Package – Mine Site), the time frame could be much longer, and prolong treatment for additional centuries. This water quality prediction must necessarily be based on an accurate physical model for the formation of the pit and the cone of depression in the groundwater system. I believe that the physical model proposed for the Polymet West Pit Lake to be fundamentally incorrect, and certainly not consistent with pit lakes formed in gold bearing deposits in Nevada.

Recommendation: Monitoring of the groundwater downgradient from the East and West pit lakes is not given much focus, and should be part of the EIS. The water treatment plan has the term "adaptive management" in several sections, and the data on which to base adaptive management decisions should involve groundwater monitoring at various distances down gradient from the East and West pits. For example groundwater monitoring wells should be established 5, 20 and 100 meters from the expected groundwater flow path. This would allow the MDNR to know when groundwater quality was being degraded earlier than if the wells were located distant from the pit lake.

3. **Water Treatment:** The treatment of water from the various units has received substantial focus in the available documents. While these documents have shown that water treatment to meet discharge standards is possible, the complexity of the system, as well as the long-term cost of treatment is high, and the MDNR should be very careful that these systems are thoroughly analyzed and regulated. This technology is going to be very expensive, and has not been demonstrated to be successful on this scale or time frame.

   The long term treatment of water from the West Pit and the Category 1 Stockpile is discussed in terms of 200-500 years, and in fact, is likely to be required *in perpetuity.* The Minnesota regulatory agencies need to realize that this length of treatment is almost unheard of for mining projects, although other mine waters in other states (e.g. Nevada, Arizona, Utah) will probably also require treatment of discharge water forever. But, Minnesota is different than these arid lands states in that the rain and snow fall will preclude any walk-away solution. The Category 1 Stockpile will almost certainly generate and release sulfates or sulfuric acid and contaminating metals far into the future, well beyond the time frames where institutional and regulatory control has existed in the past. Some people have made a somewhat cynical comment that only the Catholic Church has been in existence for the time frame that discharge will occur from the Polymet closed mine, and that bonding into the future should be within the purview of an institution that has existed for this time frame.

The Category 1 Stockpile is a particular concern, since it will drain contaminated water until the sulfides have all been oxidized and the residue rinsed. This time frame is in the thousands of years, and will require active management of the discharges. Whether a mine of this type should even be permitted remains an open question, since the impacts and management requirements will exist for thousands of years. The plastic geomembrane cover on the Category 1 stockpile is made of carbon polymers, and those liners will oxidize, crack and degrade over time. If society is lucky, those cracks and polymer oxidation will not occur for a century or two, but when the geomembrane ultimately breaks down, as it surely will, the drainage from that waste rock dump will increase both in volume and contaminant load. Those future generations will then need to decide how to handle the waste, and may or may not have the resources to manage the waste. Moving a volume of rock of that type will be very expensive and require large amounts of energy then, just as it would now.

Recommendation: The SDEIS should thoroughly evaluate the alternative of putting all of the Category 1 Waste material into the East Pit, or potentially, the West pit, or a combination of the various pits. Leaving the reactive rock on the surface provides an *in perpetuity* water treatment requirement, and a very likely long term management problem when the plastic liners degrade. Although Category 1 rock contains the lowest sulfide concentrations, this is a variable estimate, and few will argue (at least successfully) that there is no acid generating rock in this future waste rock dump. The arguments that it will increase water treatment needs if deposited in the East Pit (section 3.2.3 in the SDEIS) and the remaining rock in the West Pit have some level of validity; however, once the Category 1 waste material is submerged, oxidation processes will largely stop, and the water treatment required for the East Pit will be temporarily increased, but over the long term (centuries) the water treatment requirements will be much less, and limit the threat that reactive rock drainage will have on surface and groundwater. As is the case with pit lakes in other states, it is highly unlikely that the pit will ever be remined, at least within the next decades to centuries. Once the pit lakes fill, the large volume of pit lake water will need to be entirely pumped and treated to meet the 10 mg/L sulfate requirement, and the cost and time required for pumping and treating the entire pit lake prior to remining effectively eliminates this as a possibility. Similar arguments for remining have been made as a reason for not refilling pits in Nevada, but the same argument holds here. Treating a huge volume of water to discharge standards using membrane processes is more expensive than moving the previously mined rock out of a pit by conventional methods. In fact, remining of a rock-filled pit is probably more likely than pumping and treating a pit lake full of water.

Overall, the long term stability of the waste rock deposited in the pits and covered with water is a much lower long-term risk that leaving it on the surface with a plastic sheet over it.

Bonding and long-term water treatment estimates are major environmental issues. No estimates of bonding for reclamation and long-term water treatment and management were provided, and this is a major deficit of the analysis presented in the DSEIS. From experience with mining projects in the Western U.S. over the past 30 years, the largest environmental problems are revealed during closure, which is the same time that the mining companies have no operating money, since the project is in closure and funds are not being generated. Thus, those discussions on the long-term closure costs should have been part of the environmental analysis. These should include the costs for long-term treatment, the cost of repairing the covering on the Category 1 Stockpile (if not put back in the pits), and the replacement/upgrading of the various water treatment facilities every 50-75 years. The discount rate(s) to be used for the estimate of treatment funds should also be included, since the ultimate water treatment and management of the facility will directly depend on the funds that are generated and available in the centuries ahead, assuming that a functioning society still exists.

Specific issues on the treatment processes

1. The NorthMet Project Adaptive Water Management Plan. The Adaptive Water Management Plan v.5 discusses "non-mechanical" water treatment options broadly in section 6.0 (p. 94). This section implies that a biological treatment alternative actually exists and could treat water being discharged from the various contaminated sources from the closed Polymet mine, as the concentrations presumably decrease as the decades and centuries pass. Biological treatment processes can be successful for reducing the contaminant load from acidic drainage (EPA 2004). My laboratory at the University of Nevada has developed a semipassive sulfate reducing system at the Leviathan Mine in Alpine County, California, and it has been operating for over 10 years. It works well, and reduces sulfate to below 1000 mg/L, but it does not totally remove sulfate. I am unaware that any passive biological system can reliably allow a walk away solution from any site, for two reasons. First, biological treatment is highly variable, depending on a variety of conditions, including temperature, flow, contaminant load, and treatment objectives. Second, while sulfate concentrations can be reduced, I am not aware of any single passive (no pumping or added reagents) system that is sustainable over the long term. These systems may start out working well, but the treatment efficacy drops off after weeks to months of operating. The available organic reducing sources are simply consumed, and those systems plug rapidly with metal sulfides and microbial mass. The plugging is observed in effectively every completely passive biological system of which I am aware. None of these systems that I have observed can reduce sulfate to under 30 mg/L. At the least, there are no completely passive biological systems that have been shown to operate continuously. This section (6.0) borders on being disingenuous in that there is an implication that water can be treated in a walk away design. But in fact, active (and expensive) water quality treatment will be required for centuries, if the present water quality standards are going to be met. Regulators 200-500 years from now will almost certainly be managing/regulating this mine discharge.

2. There is something of a disconnect as to how the mine site WWTF is going to be operated. In some sections, there is the implication that this facility is going to be operated only as a chemical precipitation process during the first 20 years, followed by installation of membrane processes beyond that period. Much of the water is expected to be used as process water, which is reasonable.

   However, some of the treated water will be used to flood the pits to reduce further sulfide oxidation. This treated water will come from a variety of sources, including the east pit water that has rinsed off acids and metals from the oxidized rock. Thus, it is likely that the sulfate loadings will generally be above 2000 mg/L and potentially much higher. The treatment proposed is a chemical precipitation process which utilizes hydrated lime/ferric chloride for partial metals removal, followed by addition of more lime to increase the concentration of calcium to precipitate sulfate as gypsum. Carbon dioxide is then added to precipitate excess calcium as calcite, which can be filtered and removed. This is all reasonable, except perhaps for the suggestion that the pH can be reduced to less than 8.0 by carbon dioxide, when the maximum reduction under atmospheric conditions is 8.3.

   The overall goal of this process is to reduce sulfate concentrations to less than 250 mg/L, which can then be discharged back into the East Pit. However, I was unable to locate any data that indicated that sulfate could be reduced from 2000-3000 mg/L to 250 mg/L using this approach. I seriously doubt that sulfate can be reduced by this amount, and in the absence of any scalable data for a continuous process, the MDNR should assume that it cannot. Ultrafiltration (section 3.1.2) is unable to provide much assistance, since it is primarily for the removal of fine particulate. Nanofiltration can remove very small calcium sulfate particles, although this is not proposed to be used until general RO treatment systems become operation during reclamation.

   So how is the water in the East Pit going to be treated during mining of the West Pit, and how much will be treated during the latter half of mining the West Pit? In the SDEIS (page 3-64), treated process water from the WWTF will be used to flood the pit and the waste rock to limit further oxidation of sulfidic material.

   > "While being backfilled with waste rock, the pits would be flooded with water to minimize the amount of pit wall and backfilled waste rock exposed to the atmosphere, thus limiting the oxidation of the sulfide minerals and reducing the amount of metals leaching to the pit water" SDEIS page 3-64

   The contaminant load in the water in the East Pit will be very high, and a portion of this water is likely to penetrate the pit wall surface and be delivered to groundwater, despite the fact that the hydrologic gradient will be towards the pit, rather than away from it.

3. Essentially no mention is made (at least that I could find) of where the thousands of tons of precipitated sludge will be deposited, other than it will be moved offsite. This is a serious deficiency of the SDEIS, since the precipitated sludge is a major component of the water treatment process, and this sludge contains contaminants that are water soluble and will readily leach in the Minnesota climate. At a minimum, the following questions should be answered?
    a. What is the expected contaminant load in the waste? While this will vary, depending on the type of sludge that is generated, some general description should be required for each type of waste transported off site.
    b. What is the legal characterization of the waste- will it be accepted by municipal waste repositories?
    c. How much will be generated each year, and what is the total amount expected over the long-term?
    d. How will it be transported?
    e. What specific sites will accept the waste? What is their capacity and what are the design characteristics of those facilities? Are there agreements in place at sites that will accept the sludge waste?

4. Chloride was mentioned in some of the documents as remaining in some of the water. While not particularly toxic, it will increase the total dissolved solids concentration, and with sulfate (and the associated cation) combined together will present a total dissolved solids concentration that is potentially greater than 300 mg/L. How is chloride being used (calcium chloride or hydrochloric acid) and can it be eliminated?

5. Rinsing the East Pit refilled pit is going to be a major problem. To my knowledge, a refilled pit has never been completely rinsed, and will threaten groundwater from the initial period when waste rock is submerged in the East Pit, but even more so when the groundwater table rebounds and the hydrologic gradient towards groundwater is re-established. If water is removed from the base of the refilled pit, treated and released back into the refilled pit, this will indeed reduce concentrations. However, the expectation that the sulfate concentrations will be reduced to less than 250 mg/L is overly optimistic. Rinsing surfaces in a refilled pit to meet a water quality standard has not even been attempted to my knowledge, and is quite frankly, an absurdly optimistic proposal. A refilled pit is not uniform and homogeneous and any attempt at rinsing the rock in the pit will be complicated by preferential pathways for water migration, and regions of the rock matric that will have only very slow mixing processes. To suggest that groundwater will be protected by this process is untested, and very likely to fail.

   At the least, a thorough monitoring plan should be developed that requires collection of water samples at various distances from the refilled pit and at regular time intervals. If the rinsing is unsuccessful, as I expect, and contaminants exceed maximum allowed concentrations, how will the MDNR respond to this groundwater degradation?

6. While the water collected during the period when the pit is deepened and water pumped to maintain a dry pit, the reference to how the water will be collected is unclear. Pits in Nevada, a much drier place, require extensive wells around the pits, in order to keep water out of the pit. As far as I can tell, there are no proposed dewatering wells, and simply a collection of water in a sump that will be pumped out and used for mining and milling operations. Based on a maximum of approximately 2000 acre-feet per year, this equates to a pumping rate of approximately 1200 gallons/minute to keep the pit dry, which compares to up to 60,000 gallons/minute of some of the Nevada mines, which admittedly are larger and deeper, but also exist in a much drier climate. If the pit dewatering calculations are incorrect, the volume of water needed to be removed could substantially exceed the capacity of the needs for mining and milling, and would need to be discharged. Sulfate, ammonia and nitrate (as well as other contaminants) could be in higher concentrations than the discharge limits and exceed the capacity of the treatment system to handle the contaminated water. While this possibility is admittedly speculative, the volumes of water that will be pumped appear low, and if the dewatering rate is 2-3 times higher, the water treatment, as proposed, will not be sufficient to manage this water, as well as the volumes indicated in the SDEIS.

I appreciate the opportunity to respond to this SDEIS.

Sincerely,

Glenn C. Miller, Ph.D.
Consulting Environmental Chemist.

Attached is appendix 1: Obtained from the Nevada Division of Environmental Protection, 2013

NEVADA - PAST, PRESENT, AND FUTURE PIT LAKES

MINE SITE	EASTING	NORTHING	Water Quality (Good, Poor)	pH, Constituents of Concern & Amounts (mg/L), Date of Last Sample*	Elevation
Adelaide Crown Mine	455360	4518409			
Argenta Mine- F Pit	523620	4499390	Poor		
Atlanta Standard			Dry		
Bald Mountain Mine- 1/5 Pit lake	621525	4424452			
Bald Mountain Mine - RBM Pit lake			Dry		
Barth Pit Lake	561770	4492380	G		
Bateman	520666	4480885			
Big Mike	452550	4488210			
Big Springs- 303	585470	4601830			
Big Springs- SWX	585360	4601620			
Borealis			Dry (Dries up in Summer)		
Boss Mine	443410	4214750			
Buckhorn- Bar	543390	4448890	Poor (Dries up in Summer)	pH 4.5, TDS 2240, SO4 1460, Al 10.6, Fe 4.71, Mn 9.6 (2nd qtr 2008)	
Buckhorn- Ghost	543450	4448500	Poor (Dries up in Summer)	pH 2.9, TDS 2750, SO4 1820, Al 36.3, Fe 62.7, Mn 13.2 (2nd qtr 2008)	
Buena Vista- East	402145	4433090			
Buena Vista- West	397420	4436210			
Buena Vista- North	398530	4438315			
Buena Vista- South	400180	4425400			
Casino/Winrock	632490	4422870			
Clipper Pit	514120	4455410		Barite Pit	
Contention Pit- Newmont	496870	4495690	Back-filled	NA	
Cortez Gold Mine- Cresent pit			Dry		
Esmeralda--Humboldt Pit	335320	4240020	Good	pH 8.2, TDS 1100, SO4 660, Mn 0.09 (6/11/08)	4.9 feet from top of spillway (6/11/08)
Florida Canyon- Stage 4 Pit	394800	4492140	Backfilled	NA	
Fortitude/Reona (Phoenix)- Fortitude Pit Lake	488770	4488660	P	pH 7.5, SO4 1990, TDS 2900, Cd 0.058, Mn 12 (2nd Qtr 08)	
Genesis			Dry		
Getchell- Center Pit			Dry		
Getchell- North Pit			Dry		
Getchell- South Pit			Dry		
Getchell- Summer Camp Pit	478990	4558850			
Getchell- Main Pit			Dry		
Gold Quarry			Dry		
Golden Eagle- Lady Bryan Pit	277265	4355775	Meets Standards		
Greystone			Dry		
Hog Ranch			Dry		
Hollister - West Pit	536400	4550850	P		
Jerritt Canyon - Queenstake - Dash Pit Lake	589440	4579650	Backfilled		
Ketchup Flat	416800	4288525	Quality unknow		
Lone Tree	482280	4519650			
Manhatten - RMGC West Pit Lake	492680	4265570			
McCoy/Cove	482820	4465340	G	Sulfate & TDS elevated	
Mule Canyon- Ashcraft Pit	526350	4494260			
Mule Canyon- Main Pit	526520	4493600			
Mule Canyon- North Pit	526110	4494420			
Mule Canyon- Northwest Pit	526090	4494000			
Mule Canyon- West Pit	526150	4493520			
Mule Canyon - South Pit	526460	4492800			
Northumberland- Co				Oct 08	

Joint Petition Ex. 6

Technical Memorandum

Review of PolyMet Project NPDES/SDS Permit Application

Prepared for Minnesota Center for Environmental Advocacy

Prepared by Tom Myers, Ph.D., Hydrologic Consultant, Reno NV

February 19, 2018

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Executive Summary

The NPDES/SDS permit application for the PolyMet Project is insufficient to protect surface and groundwater in the area around the project. This review considers the assumptions relied upon by PolyMet to complete their application.

This review also used a groundwater flow model to assess various problems with the permit. The groundwater model, originally developed in 2014 to assess impacts of the project as outlined in the environmental impact statement, was updated to improve mass balance and transport calculations near the sources, so the predictions herein should be considered more accurate and precise than those made previously.

The report outlines and details the following results:

- The nondegradation analysis relies on the assumption that the engineered seepage capture system, covers, and mine site will be 100% effective. Based on my analysis, the assumptions underlying the seepage capture system are questionable. Applying more realistic assumptions, this analysis assumes there will be some leaks from the system. Any leaks will result in a contaminant plume that would be very difficult to remediate. And any leaks will result in groundwater and surface water contamination.
- Dewatering rates will vary substantially, and will likely exceed the treatment facilities capacity to treat water. Increases in dewatering due to fracture flow will likely require dewatering techniques such as dedicated dewatering wells that will cause the mine to violate the zero-discharge standard.
- Dewatering creates a groundwater divide under the mine site, creating pathways for contaminants to go both north and south, to the headwaters of or to downstream reaches of the Partridge River.
- Backfilling the East Pit with highly reactive waste creates a high concentration water in the pit that will increase the concentrations in dewatering flow that is not considered in the application.
- Backfilling the East Pit with highly reactive waste and then filling it with water creates a situation where pit water will likely flow into surrounding groundwater, at least temporarily, and contaminate it.
- Rapid fill of the West Pit will cause pit water to flow into surrounding groundwater, thereby degrading the groundwater. The application does not consider this groundwater degradation.
- Leaks emanating from different portions of the plant or mine site will follow different pathways to the rivers. Plume maps produced in Appendix A show that contamination

from leaks will follow a specific pathway with dispersion causing contamination to expand horizontally and vertically.

- Waste water seeping from both the tailings impoundment and waste sites on the Mine Site will reach surface water, as shown by transport analysis. Contaminant plumes released from both mine site and plant site sources will reach long stretches of surface water. This includes waste from the tailings impoundment reaching the Embarrass River and from mine site sources reaching the Partridge River both to the north and south.
- Variable slopes in the cumulative load curve for the Embarrass River, both with and without the cutoff wall, show areas of differing load reaching the river. This shows the need for at least four surface water monitoring points along the river, at about mile point 6, 8, 10, and 13.
- Pathways from both sites show the need for substantially more surface water monitoring. Contaminants could reach the river along substantial reaches, and it is necessary to monitor at many locations to identify the source.
- Proposed groundwater monitoring is insufficient. Contaminant plumes would move between widely-spaced monitoring wells. This observation holds for monitoring between the mine site and Partridge River and between the tailings impoundment and the Embarrass River.
- Groundwater monitoring wells should be placed where contaminant plumes are most likely to pass. This requires an understanding of flow in the area, which requires a conceptual flow and transport model (CFTM), prepared a scale appropriate to the site. This would include identifying all potential sources and sinks, such as facilities on the mine site that could release contaminants. Sinks that could be damaged are downgradient wells, springs, or streams. Once identified, it is necessary to determine the potential flow path from the source to the sink.

The NPDES/SDS permit for the PolyMet mine proposal should not be awarded because the application is based on overly optimistic design assumptions, modeling that does not consider flow path details near either the mine site or tailings impoundment, inaccurate analysis of pathways for contaminants to reach the rivers, and grossly insufficient proposed monitoring.

Introduction

PolyMet applied for a NPDES/SDS (National Pollutant Discharge Elimination System/State Disposal System) for its proposed Northmet mine. The NPDES/SDS permit is for discharge to surface water and groundwater protection in the area. PolyMet applied for a NPDES permit only at the plant site at the water treatment plant which will discharge water into three small streams near the tailings impoundment. Other conditions in the permit are intended to protect groundwater under state standards.

The NPDES/SDS permit application includes seven volumes, including an introductory volume describing the general permit requirements and issues, one volume for the mine site and five volumes for plant site. The focus of this review is PolyMet's NPDES/SDS permit application as it applies to the mine site (Volume II), the tailings facility (tailings basin and beneficiation plant) (Volume V), the hydrometallurgical residue facility (Volume VI), and aspects of the waste water treatment system (WWTS) (Volume III). The review is primarily of the revised application issued in October 2017. References to the application are to Volume number.

Volume I introduced the project and provided the most detail regarding the proposed monitoring. This review memorandum focuses on contamination from the mine site and tailings impoundment. It does not focus on stormwater management, the transportation system, or the details of the wastewater treatment. The memorandum identifies pathways through which discharges to groundwater may reach surface, thereby being a surface water discharge. It does this by considering the conceptual and numerical flow models of Myers (2014) to analyze pathways for contaminant transport to surface water. It also assesses the monitoring plans set forth in the application.

Description of the Application

NPDES/SDS refers to separate state-administered programs regarding how the project discharges water. NPDES in this application is for a traditional point-source discharge to waters of the state and SDS for the protection or remediation of groundwater, a state program described under Minn. R. 7060.0100-.0900. The project requested an NPDES permit only for the WWTS, specifically described in Volume III, which discharges as point source into three streams.

PolyMet's application primarily pertains to the first 5 years of the mine's operation, although it sometimes describes the plan for 11 years (*see, e.g.*, Vol. I, p. 27) and through closure in some places. The application identifies eleven types of water:

- <u>Mine water</u>: water collected by the mine water management systems, which includes runoff and groundwater from the mine site. Ostensibly, this is only water that has contacted mine sources, such as pit wall, waste rock, or ore, and has been collected from the pit sumps or various collection systems on the mine site.
- <u>Treated mine water</u>: water routed from the mine site to the plant site, after collection and treatment at the mine site water treatment facility.
- <u>Process water</u>: water used in beneficiation or hydrometallurgical process.

- Sewage: water from sanitary facilities.
- Tailings basin water: water in the tailings basin pond or the pores of the tailings, which includes process water, treated mine water route to the tailings basin, tailings basin seepage, treated sewage, and precipitation on the tailings.
- Tailings basin seepage: tailings basin water that infiltrates through the tailings basin.
- Hydrometallurgical residue facility (HRF) water: water collected and stored within the HRF.
- Plant reservoir water: water stored in the plant reservoir, including makeup water from Colby Lake and precipitation on the plant reservoir.
- Industrial stormwater
- Construction stormwater
- Non-contact stormwater

Volume II describes water management at the mine site, which PolyMet claims just collects mine water from a variety of sources, treats it, and pumps it to the plant site (into the tailings impoundment). The application completes a groundwater nondegradation analysis to show how the facilities with various liners, ponds, stockpiles, and pit will not degrade groundwater quality. This will be considered in detail below because there are many possible ways the project will degrade groundwater and it is possible the project will create an effective discharge to surface water.

Volume III considers the water treatment system, including the facilities at the mine site which would treat mine water prior to pumping it to the plant site and the water treatment plant at the plant site. Some water would be discharged from the plant site treatment facility to surface water in three separate drainages as hydrologic mitigation to make up for water lost to the seepage containment system at the tailings impoundment. The focus of this review is on whether the plant can accommodate the expected water flow rates, not on treatment processes.

Volume V describes water management at the tailings impoundment and beneficiation plant. PolyMet describes the water management as collection and management of process water, tailings basin water, and tailings basin seepage (Vol. V, p. 11). The tailings impoundment would be constructed on top of an existing ferrous metal tailings impoundment that has substantial leakage, with at least six seeps around its base, and significant downgradient groundwater contamination. Current seepage collection points would be replaced with a seepage containment system. There are many ways in which operations at this facility could fail and become major sources of contamination and are considered below.

The structure of this review is as follows. First, I consider the mine site NPDES/SDS issues. Second, I consider the Plant Site NPDES/SDS issues. Third, I consider pathways for flow to the rivers and the adequacy of the monitoring plans for each using an updated version of the Myers (2014) groundwater model.

Mine Site NPDES/SDS Analysis

There are three primary problems concerning permitting at the mine site. These are:

1. Groundwater and surface water degradation is highly likely because the assumption that the seepage capture system, covers, and mine site will be 100% effective is improbable and fractures in the bedrock will lead to surface water contamination;
2. The monitoring plan is unlikely to detect contaminants once a leak at the mine site occurs;
3. The size of the WWTS is inadequate for the volume of dewatering water in the system.

This section, supported by the modeling in Appendix A, describes each of these inadequacies.

Groundwater and Surface Water Degradation

The first issue with the draft NPDES/SDS permit is that it is based on PolyMet's promise that it designed the "Project to comply with the State's groundwater nondegradation policy" (Vol. II, p. 45). For this claim to be accepted, it is necessary for numerous engineered barriers to be 100% effective, and for the analyst to ignore several pathways for mercury to escape the overburden laydown area. This section explains the high likelihood that barriers will not function perfectly and both groundwater and surface water degradation will occur as a result.

Sources of Groundwater and Surface Water Degradation

I simulate paths and potential plumes from facilities on the mine site and the plant site in Appendix A. The simulations include seepage distributed around each facility and from leaks that could occur within each facility. The simulations include plumes that are compared to monitoring well locations to assess whether the proposed monitor well network is sufficient. Modeling also demonstrates that the monitoring is insufficient to detect the leaks with certainty.

The mine site would not intentionally discharge directly to surface water, but waste rock stockpiles, mine ponds, and open pits are potential sources of contamination to groundwater, as the following subsections describe. There are also sources throughout the mine site. Runoff from stockpiles could contaminate shallow groundwater. Mine ponds are potential sources of contaminants to groundwater if they are not lined or if the liners leak. Each time they fill, groundwater seepage will cause a plume to enter groundwater. This includes stormwater ponds if runoff from dumps will enter stormwater ditches and flow to a pond.

There are many examples of how the mine site could be a source of groundwater and surface water degradation. For example, if water reaches the ditch on the north side of the Category 2/3 dump, it will reach the stormwater pond from which it could seep into groundwater. The pond on the NE corner of the Category 1 dump collects runoff from all along the NE and NW side of the dump, essentially half of the dump. Vol II Sheet SW-008 shows no liner on Pond A and sheet SW-017 shows no liner for the North Perimeter Stormwater Ditch. There is also no liner for the ditch on the north side of the Category 2/3 stockpile. The ditches would carry mine-impacted water and the pond would contain mine-impacted water at least until the dump is reclaimed. The ditch essentially overlies the cutoff ditch, so that seepage would be into the one-inch rock filling the cutoff trench. GCS-010 shows the cutoff trench and stormwater ditch do not coincide. On the north side, the stormwater ditch, unlined, lies outside of the perimeter of the dump and cutoff trench. On the south, there is no stormwater ditch and the cutoff is between the dump and the pit lake. The combination of unlined ditches, cutoffs, and ponds could lead to a significant contaminant source not prevented by the NPDES/SDS permit.

Waste Stockpiles

One major source of leaks into surface water is the waste stockpiles. Contrary to other permeations of the project, the Category 1 stockpile will not have an underdrain liner, but it does have a cutoff wall. For the first 11 years, the Category 1 stockpile will have no cover, so infiltration will occur as it would for bare soil and rock. If the cutoff is not 100% effective, contaminants will reach the upper part of the Partridge River and will begin to flow south toward the lower reaches of the Partridge River. The more reactive Category 2/3 and Category 4 waste rock would be stockpiled over a liner and cutoff trench, but only temporarily. Again, any leaks would have a short path to the river.

Overburden Storage and Laydown Area

The overburden storage and laydown area (OSLA) is another area where leaks into ground and surface waters could occur. The OSLA will not have a liner (Vol. II, p. 48), even though it could be a source of mercury pollution. The base would have low permeability and drainage, water not entering the soil would be collected in an unlined mine water pond. The OSLA would have no liner in spite of the fact that peat can release mercury when it decomposes (Vol. II, p. 49). PolyMet would rely on two physical processes to prevent mercury from reaching waters, volatilization and attenuation with organic and soil matter (Id.). PolyMet ignores the ways that each of these factors could fail to prevent mercury from reaching ground or surface waters.

Mercury does volatilize, a process which could lower the concentration within the OSLA. However, gaseous mercury may not travel far before it settles from the atmosphere. This is the process by which power plant and gold mine refinery mercury emissions pollute soils and waters downwind from the source. Mercury volatilized from the OSLA could settle on soils downwind, which could leach to shallow groundwater or transport during runoff events to the rivers. PolyMet has not analyzed the potential for this and the draft NPDES/SDS permit fails to address this important issue.

Mercury also does attenuate in organic and soil matter by adhering to small particles, primarily clay and silt. Erosion of the organic or soil matter could wash the particles with mercury directly into surface water, where it could dissolve into the water column increasing mercury concentration or settle into the sediments. PolyMet has not analyzed the potential for this and the draft NPDES/SDS permit fails to address the issue.

Mine Pits

The mine pits could also be a source of contaminants to surrounding groundwater, even though dewatering could generally maintain a gradient toward the pits (Vol. II, p. 50). PolyMet would complete mining the East Pit in 11 years, after which it would be backfilled with Category 2, 3, and 4 waste rock (Vol. II, p. 51). Because the waste is reactive, PolyMet would pump water into the backfilled pit to maintain a water level above the top of the backfilled waste. As PolyMet attempts to fully saturate the backfilled waste, water levels could be higher than the surrounding groundwater for substantial periods. If this occurs, water (and contaminants) will flow into the groundwater. Fracture zones that intersect the pit could allow contaminants to escape the hydraulic control of the pit. PolyMet has not considered this source of groundwater contamination nor provided monitoring to document whether it occurs.

Similar considerations apply to the West Pit, which would be pumped full within six months of closure. The lake water levels would at that point be higher than the surrounding groundwater and, therefore, could flow into the groundwater. Once the West Pit Lake level reaches a certain level, it becomes a source of flow into the groundwater. For natural refill, the West Pit would leak a range of 400 to 450 m^3/d to the south, with about half going to bedrock, and up to 150 m^3/d to the west, mostly to bedrock (Myers 2014, p. 3-27). PolyMet fails to consider this pathway. Modeling performed in Appendix A highlights the importance of this pathway.

PolyMet has not considered these pathways. Although closure is beyond the period of this permit, now is the time to consider it because the mine operating plan could be changed if the West Pit was found to be a significant contaminant source.

Travel Times

PolyMet does simulate minor leakage rates from the mine site sources, and shows their estimated arrival time for the plume reaching the Partridge River (Vol. II, Table 4-1). The times for seepage through waste range from 30 to 90 years, and for seepage through the East/Central Pit to reach the river within 100 years, simulations presented in Appendix A shows the plumes reaching the river far sooner. The Myers MT3DMS model is far more physically realistic and accurate than the Goldsim One-D simulation (Myers 2015).

Monitoring

PolyMet relies on monitoring to determine whether leaks have occurred. As discussed below in the following section and as simulated in Appendix A, the monitoring is insufficient. But even if monitoring does detect a plume moving to the river or otherwise degrading the groundwater, there is little PolyMet would be able to do to prevent the plume from reaching the river. Once the monitoring wells, especially those midway between the mine site and the Partridge River, detect contaminants, the plume would consist of a huge mass. There are no plans to remediate the groundwater, so the degradation would be ongoing. It would be almost impossible to fully remediate the groundwater and prevent a discharge to surface water. And PolyMet failed to present any plan that would attempt to prevent this discharge.

Monitoring

Conceptual flow model for monitor well placement

There is no simple, uniform boilerplate format or guideline for developing a groundwater monitoring plan. However, groundwater monitoring wells should be placed where contaminant plumes are most likely to pass, in order to be effective. Small scale monitoring plans usually are site specific with a focused intent. To detect groundwater contamination from a large mine site, it is necessary to identify all potential sources and sinks. Sources would be the facilities on the mine site that could release contaminants. Sinks that could be damaged are downgradient wells, springs, or streams. Once identified, it is necessary to determine the potential flow path from the source to the sink. This requires an understanding of flow in the area, which requires a conceptual flow and transport model, prepared to a scale appropriate to the site. Regional models are insufficient.

Four steps emerge as being necessary for the establishment of an adequate monitoring plan.

1. Identify the groundwater dependent ecosystems and wells that should be protected. Determine what is necessary to protect them.
2. Develop a localized conceptual flow model (CFM) that describes the hydrologic system that supports each groundwater dependent ecosystem and water right. This would be

more detailed than a CFM used for a large region because broad-scale flows do not describe small features well. For example, some springs may be perched and therefore affected only by nearby local contaminations but larger sinks such as the Partridge and Embarrass Rivers could be supported by groundwater flow from much further away.

3. Implement the more refined CFM to estimate the detailed pathway between the potential sources and sinks. Because the sources could be a large area, such as the entire area beneath the Category 1 waste rock stockpile, the pathways could be defined as an envelope of paths. This may require numerical modeling or data collection to estimate the paths.
4. Determine the type and location of monitoring that would allow the prediction of changes. For water quality, this means determining the depths to screen the well. Understanding uncertainty should inform these decisions, with more monitoring required where pathways are difficult to estimate.

PolyMet's application does not describe how the location of monitor wells was determined. The introduction states the proposed monitoring strategy would be described (Vol. I, p. 30), but at no point in that volume, or other volumes, is a strategy actually described. Substantial changes to the flow paths caused by the project, such as mine dewatering at the mine site, must be considered. Where groundwater discharges to large sinks, such as the Partridge River, the pathway analysis must consider the depth of the flow path. In other words, how much groundwater discharging to the river comes from the bedrock, at what depth, and from which surficial aquifer? The travel time and attenuation properties could differ substantially among formations.

Detailed modeling of the mine site and the plant site presented in Appendix A show that contaminant plumes would miss much of the proposed monitoring. As noted, there was no CFM developed for the site. There was obviously no consideration given to dispersion of the contaminants or the advective path other than that the general direction was north or south. Contaminant plumes could easily pass between the point of compliance wells.

There are wells closely spaced around the tailings impoundment and the Category 1 stockpile designed to determine if the containment systems are leaking. They are close to the facilities and would provide a quick warning of a leak, but only if they lie on a pathway. The monitor wells or piezometers would only detect a leak directly upgradient, and any leaks from upstream would hit the well only if directly on the flow path. There would not be sufficient dispersion of most plumes to allow detection. Piezometers and monitoring wells may not be the best indicator monitoring available for sites near the containment walls.

PolyMet should develop a detailed conceptual model of flow and transport for all potential leaks from its proposed facilities. It must consider advective flow paths, reasonable dispersion that controls the shape of a plume, and travel times. It should ignore attenuation unless there is overwhelming evidence supporting it. PolyMet should use this model to locate its proposed monitoring wells, rather than relying on its relatively random placement that forms its application.

Mine Site

PolyMet's monitoring plan is also unlikely to detect contamination into ground and surface waters if and when leaks occur. PolyMet proposes 75 monitoring wells at the mine site (Vol. 1, p. 34), but that is insufficient. PolyMet's proposal includes monitoring to demonstrate compliance, indicator monitoring to allow for early detection of impacts, performance monitoring to examine the performance of engineering features, and background monitoring to track upgradient conditions (Vol. 1, p. 30-31). The proposal requires 15 compliance monitoring wells, with 9 existing in the surficial aquifer and 6 new wells proposed for bedrock (Vol. 1, p. 32). The proposal provides that there would be 28 indicator monitoring wells at the mine site, with 3 existing and 12 proposed in the surficial aquifer and 3 existing and 10 proposed in bedrock (Id.). There would be 32 performance monitoring wells with 1 existing and 6 new paired wells and 7 new paired piezometers along the Category 1 stockpile seepage containment system (Id.). PolyMet does not identify any background wells. Many surficial and bedrock wells are paired which should show connections between aquifers. As the modeling in Appendix A demonstrates, the proposed monitoring plans are insufficient because the wells are spaced too far apart to provide confidence that contaminant plumes would not pass through the monitoring well network (Appendix A, p. 9-24).

Compliance wells north of the Category 1 stockpile are spaced about one mile apart just north of the Category 1 stockpile. Compliance wells between the mine and the river southeast of the site are spaced by approximately 2/3 mile and are about 1/2 mile from the mine boundary and 1/4 mile from the river (Vol. 1, Large Fig. 6). Performance wells along the Category 1 stockpile seepage capture system would be spaced by around 1/3 mile, or 3 times as dense as the compliance wells. Because they are so close to the seepage containment system, they would likely detect contaminants only if the leak or bypass of the containment system is just upgradient of the well because dispersion would not be sufficient to reach the wells. The spacing could also allow contaminant plumes to pass through the perimeter monitoring well transect without being detected. Similar spacing issues apply for wells throughout the mine site, as demonstrated in Appendix A.

Volume II, section 3.1.2 describes the monitoring wells proposed to be installed at the site. PolyMet provides no information on why it chose the proposed locations. There is no conceptual flow and transport model that suggests those wells being on a pathway downgradient from a source. The proposed monitoring plan (Vol. II, § 3.2) does not include any monitoring wells beyond those currently installed; this may be seen by comparing Volume II Large Figure 3 (existing) with Large Figures 4, 5, and 6.

Surface water monitoring (Vol. II, § 3.1.1; Vol. I, § 3.3) is insufficient to demonstrate that the project is not contaminating surface waters. The mine site drains to the Partridge River and, although the PolyMet contends the mine site will have no surface water discharges, there are various potential groundwater pathways for contamination to reach surface water.

The headwaters of the Partridge River, including Yelp Creek, borders the north side of the mine site, especially the Category 1 stockpile, but there is no monitoring for about 2 ½ miles of river to station PM2/SW002 which is about ½ mile north of the site. Contaminants detected there could be from the Category 1 stockpile, the East Pit, Central Pit, or the Northshore Mine which is not part of this project. The next station PM3/SW003 is about 2 miles further downstream but near the east end of the Mine Site. Station PM4/SW004 is several miles further downstream and about 1 mile south of the mine site; station SW004a monitors the river a little further downstream below a tributary. Seepage from the Category 1 stockpile could reach Yelp Creek to the north and the Partridge River below SW004 to the south and from the Category 2/3 stockpile could reach the Partridge River near SW003 within 11 years (Myers 2014). The East Pit may prevent groundwater from flowing north, but runoff from the Category 4 stockpile, if not captured, could reach the river to the north through shallow groundwater and surface pathways. The groundwater section should also include an analysis of surface water discharge to show where the contaminants would discharge to surface waters.

Plant Site

There are 28 performance monitoring wells, or 14 pairs, to be used around the base of the tailings impoundment installed in the surficial aquifer. These wells are designed to show the effect of the cutoff trench capturing seepage. They will show a decrease in concentration due to seepage capture, but they will not show leaks with certainty because they are spaced too far apart.

Monitoring wells located midway between the impoundment and the river show contaminants reaching the wells, but do not begin responding for 20 or more years. This shows they would not be good indicators of a leak. Simulated plumes from leaks placed within the simulated tailings basin could miss the monitoring wells (Appendix A, p. 32-60). This is because the width of the plumes is less than the spacing of the monitoring well. The plume from the leaks barely approaches monitoring wells GW015 and GW109 (Appendix A, p. 54- 55). Proposed monitoring wells on the edge of area between the tailings and the Embarrass River are too far west and east to monitor most plumes emanating from either the entire tailings impoundment or from specific leaks within the impoundment. There should be more compliance wells along the center of the simulated plumes to increase the chances of detecting plumes, as shown in Appendix A (p. 32-60).

Dewatering (Sizing of the Wastewater Treatment Facility)

A final major issue with the mine site is that the size of the WWTS is inadequate for the volume of dewatering water in the system. Dewatering water is a primary source of water for production and the treatment facilities and pipeline must be able to accommodate the flow. Dewatering includes the pumpage of groundwater that seeped into the pits and runoff that has accumulated in the pits. Rainfall into the pit either runs off the pit walls to accumulate in the bottom of the pit or enters the formations surrounding the pit and flows through shallow groundwater or as interflow to the bottom of the pit. Precipitation within the pit does not recharge groundwater and therefore no longer supports the water table or maintains wetlands near the mine site.

Because PolyMet would treat the water, dewatering rates are very important to consider in the NPDES/SDS permit. The Water Management Plan (PolyMet 2017) describes PolyMet's predicted mine dewatering as follows. The East Pit would have the highest inflows due to it intersecting the Virginia Formation. PolyMet predicts the following: total inflow to the East Pit in year 1 would average 205 gpm and range as high as 252 gpm (the 90th percentile prediction using the GoldSim model), and during year 11 and 20 would average and range to 378 and 863 gpm and to 448 and 1096 gpm, respectively (PolyMet 2017, Table 2-2). Dewatering rates at the West and Central Pits would be lower because, according to PolyMet, the bedrock conductivity is much smaller. Regardless of PolyMet's expected bedrock conductivity, the dewatering inflow rates are highly uncertain. PolyMet's estimates are based on limited understanding of the hydrogeology of the bedrock at the site, especially the hydrologic properties of the bedrock which control the inflow rates to the pit.

In a study to design pit dewatering mitigation, Foth (2017) details many ways in which the dewatering estimates could be too low, including unplanned-for fractures.

Conductivity Assumptions

Myers (2014) predicted that overall dewatering rates would be significantly higher than PolyMet. Myers-estimated total dewatering is close to that of the FEIS model for the first few years but then exceeds the FEIS model by about 80% by year 12. After year 12, the Myers model predicts the total dewatering rates to remain high until about year 16, after which it begins a decrease. In contrast, the FEIS model predicts that dewatering rates would drop beginning in year 11. Figures 1 and 2 show predicted dewatering rates based on Myers (2014) modeling. Myers' (2014) dewatering rates are higher because much more groundwater needs to be dewatered in light of calibrated bedrock conductivity being higher than that used by PolyMet and the recharge rate is twice that used by PolyMet.

Dewatering rates could be several times higher (or lower) than predicted, especially during short-term periods, as a result of fractures draining into the pit or due to other sources.

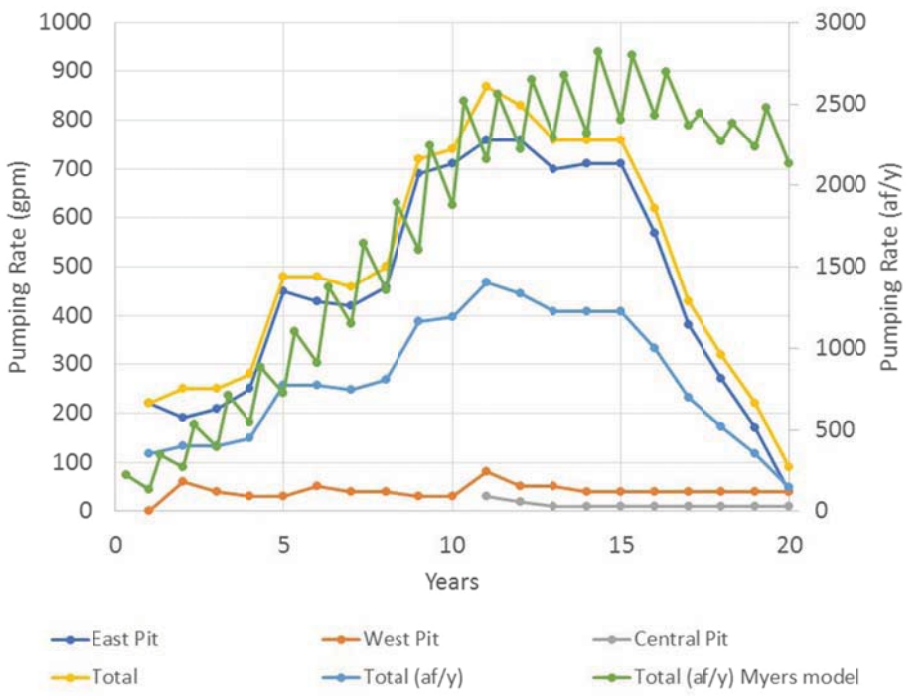

Figure 1: Groundwater dewatering rate by mine pit, based on FEIS Table 5.2.2-19 and Myers (2014).

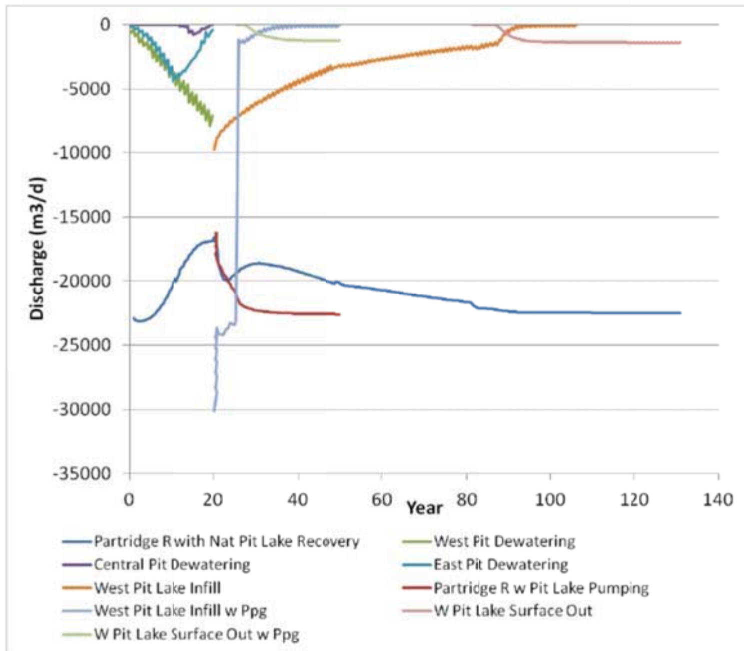

Figure 12: West Pit and Pit Lake Fluxes, Partridge River discharges for dewatering and pit backfill as described (Polymet 2013c) and natural pit lake inflow. The river flow is an average of the flow at the end of the recharge and no recharge periods.

*Figure 2: Snapshot of Figure 12 from Myers (2014) showing modeled fluxes through the simulation period. (Cubic meters per day * 0.18345 equals gpm)*

PolyMet would dewater the pits by pumping from sumps in the bottom of the pits (PolyMet 2017, p. 9). It would accommodate short-term flow exceedances by allowing water to pond in the bottom of the pit and temporarily not mining near the bottom until it can be pumped dry. The quality of the water ponded at the bottom of the pit would depend on the percentage of groundwater inflow that enters through various formations. PolyMet does not estimate the relative proportions of water entering through different layers or elevations in the pit, which could result in different water quality due to flow through different formations. PolyMet's treatment plans can accommodate short-term event-driven high flows by temporarily storing it (PolyMet 2017, p. 11), but not long-term changes. Rates that consistently exceed the forecasted rates could prove a problem for the treatment plans and cause PolyMet to change its dewatering plans. If significantly higher groundwater inflow rates manifest, PolyMet may need to install groundwater wells to capture the inflow before it reaches the pit. Groundwater wells could have the advantage of capturing water before it is contaminated by seepage through the pit walls.

Appendix A uses the updated Myers (2014) model to provide a more realistic estimate of the potential range of inflows to the pits (and to the mine site). Estimates would be based on realistic variability in transmissivity of flow to the pits (Appendix A, p. 24-29).

High Water Table

An additional source of water that PolyMet may need to manage is groundwater dewatered to lower the water table beneath the bottom of the sumps and ponds (PolyMet 2017, p. 18). PolyMet suggests several methods for lowering the water table to avoid pore pressures on the liner, but has not settled on a final design (Id.). There has not been sufficient groundwater analysis completed to know precisely the depth to groundwater near the ponds and sumps, so there has been no estimate of the additional required pumping, including flow rate and whether it would be seasonal or year-round.

The rate of dewatering to lower the water table beneath the stockpiles could vary seasonally, with substantial amounts of water needed to be dewatered during wet years. This water would be added to the inflow to the WWTS. If the rates are high enough, the design flow rate to the WWTS could be exceeded. PolyMet presented no analysis of the extra water; therefore, the permit should not be issued without additional analysis and assurance that extra flow would not exceed the WWTS capacity.

Plant Site NPDES/SDS Review

Like the mine site, there are also three problems concerning permitting the plant site. These are:

1. Groundwater and surface water degradation is highly likely because the assumption that containment system at the tailings impoundment will be 100% effective is improbable;
2. There is an underestimation of the amount of high concentration flow at the plant site; and
3. The project would likely violate the zero-discharge requirement in 40 C.F.R. § 440.104(b)(1).

This section, supported by the modeling in Appendix A, describes each of these inadequacies.

Plant Site/Tailings Basin Groundwater Protection

Like the mine site, it is also improbable that the plant site's containment system will be 100% effective. Groundwater downgradient from the tailings impoundment has been degraded by long-term seepage from the existing ferrous tailings. PolyMet indicates the state's policy is therefore one of "abating (existing) pollution" and "rehabilitating degraded waters" (Vol. V, p. 38). Groundwater downgradient has elevated concentrations of total dissolved solids, sulfate, chloride, fluoride, and molybdenum, among others (Id.), and manganese and aluminum at the tailings basin (Vol. V, p. 37). PolyMet suggests they will rehabilitate the groundwater by capturing the seepage beneath the tailings impoundment. Initially, their seepage capture system would replace existing pumpback systems that are capturing the existing seeps. PolyMet intends the system to capture most seepage from the existing tails and from the proposed future flotation tails to recycle for beneficiation use; this would intercept the contaminant source and allow the groundwater to remediate.

The FEIS presented results of a MODFLOW cross-sectional analysis of PolyMet's seepage containment system. Myers (2014, p. 38-41, appended in Appendix B) found the analysis was essentially hardwired to have a much higher efficiency than would be realistic, for the following reasons:

- A river boundary downgradient of the cutoff wall artificially keeps the water table at the ground surface which decreases the flow through the wall.
- The seepage inflow was assumed to be vertically and horizontally uniform which would maximize the amount captured by the drains.
- The vertical conductivity of the bedrock is unrealistically high which allows seepage to flow vertically upward more easily with the gradient toward the drain. This led to unrealistic modeled flow paths.
- The model did not consider the potential for the drain to clog.

Based on Myers (2014) PolyMet's seepage containment system at the tailings impoundment should not be assumed to be 100% effective.

Water Treatment Issues

PolyMet's NPDES/SDS application has also underestimated the amount of high concentration flow that would be delivered from the mine site. Two of the three pipelines delivering water from the mine site to the plant site for treatment would be a high concentration and low concentration line, with the former being drainage from the Category 2/3, Category 4, and ore surge pile (OSP) and the latter being from the Category 1 stockpile and other supposed low concentration sources. Mine dewatering water would report to the low concentration basin. However, once backfill of the East Pit begins, water pumped from that pit would have a high concentration, but the draft NPDES/SDS application fails to account for the change in concentration.[1] The NPDES/SDS application Volume I, Large Figure 4 shows that 820 gpm from the East Pit would report to the Low Concentration EQ Basin. However, the East Pit would be in the process of being backfilled with Category 4 waste; this water would be very high

[1] FEIS p. 3-64, 65 describes the plan for backfilling the East Pit after year 11.

concentration. The other two sources shown on the same figure total only 130 gpm, so adding the flow from the East Pit could substantially tax the ability of the high concentration treatment scheme, a chemical precipitation train (Vol. 1, p. 94). If it is added to the Low Concentration treatment scheme, a membrane separation technique (Id.), it could upset the process so that expected quality is much poorer.

Zero Discharge

Finally, the project would likely violate the "zero discharge" requirement. A "zero-discharge" requirement applies to the process facilities, including tailings impoundment. The zero-discharge standard is described as follows:

> 40 C.F.R. § 440.104(b)(1): Except as provided in paragraph (b) of this section, there shall be no discharge of process wastewater to navigable waters from mills that use the froth-flotation process alone, or in conjunction with other processes, for the beneficiation of copper, lead, zinc, gold, silver, or molybdenum ores or any combination of these ores. The Agency recognizes that the elimination of the discharge of pollutants to navigable waters may result in an increase in discharges of some pollutants to other media. The Agency has considered these impacts and has addressed them in the preamble published on December 3, 1982.

PolyMet argues that net precipitation from the tailings impoundment and water mixed from other sources may be discharged as part of the zero-discharge standard (Vol. III, p. 91). Other sources include mine drainage which will be treated at and pumped from the mine site. In Appendix D of Volume III, Barr presents an assessment of the legal requirements of "zero discharge," noting that no discharge is allowed from process facilities that use the froth-flotation method because recycling of the water is simple. The volume of net precipitation (precipitation – evaporation) on the tailings may be discharged. Mine drainage may also be discharged at the plant site, according to PolyMet, because it is part of a combined waste system with the net precipitation. Mine dewatering water could be considered mine drainage, so as not to be included in the zero-discharge requirement, because it would be pumped from a sump in the pits; it would be considered mine-impacted because it would have entered through and flowed along the mine pit walls according to PolyMet. The limits on discharge from the WWTS to surface water will include the amount of mine drainage coming from the mine site. Effectively, if the mine pumps new water for use in processing, discharge would be subject to the zero-discharge requirement because experience had shown the EPA that recycling could allow them to avoid discharge. Because the fresh process water is from mine dewatering, zero discharge does not apply. To the extent mine dewatering water substitutes for pumping new water, the zero-discharge requirement does not apply.

PolyMet would effectively meet the zero discharge by planning to collect and recycle all tailings water that seeps beneath the facility (Vol. III, § 5.2) even if the collected seepage would be treated and later discharged to surface streams. Seepage that escapes the tailings seepage collection system would violate the zero-discharge standard because it will not be a combined waste stream and will reach the Embarrass River or tributaries.

PolyMet will violate the zero-discharge standard in two ways.

- First, tailings seepage not captured by the collection system will violate the standard, regardless of the effect on groundwater quality. If PolyMet's assumption regarding seepage collection does not manifest, PolyMet will violate its permit.
- Second, mine dewatering water would violate the standard if dedicated dewatering wells become necessary. As discussed in the NPDES modeling section, there is a substantial chance that the dewatering requirements will exceed the predicted rates. If dewatering needs exceed the predicted rates, and PolyMet requires dedicated dewatering wells, PolyMet will violate the permit.

Conclusion

The NPDES/SDS permit for the PolyMet mine proposal should not be awarded because the application is based on overly optimistic design assumptions, modeling that does not consider flow path details near either the mine site or tailings impoundment, inaccurate analysis of pathways for contaminants to reach the rivers, and grossly insufficient proposed monitoring. The NPDES/SDS permit application for the PolyMet Project will not protect surface and groundwater in the area around the project for many reasons.

The nondegradation analysis assumes that the engineered seepage capture system, covers, and mine site will be 100% effective. The assumptions underlying the seepage capture system are questionable. Applying more realistic assumptions, there will definitely be leaks that would be very difficult to remediate, and result in groundwater and surface water contamination.

Dewatering rates will vary substantially and likely exceed the treatment facilities capacity to treat water. Increases in dewatering due to fracture flow will likely require dewatering techniques such as dedicated dewatering wells that will cause the mine to violate the zero-discharge standard.

Leaks emanating from different portions of the plant or mine site will follow different pathways to reach the rivers. Dewatering creates a groundwater divide under the mine site, creating pathways for contaminants to go both north and south, to the headwaters of or to downstream reaches of the Partridge River. Waste water seeping from both the tailings impoundment and waste sites on the Mine Site will reach surface water, as shown by transport analysis. Contaminant plumes released from both mine site and plant site sources will reach long stretches of surface water. This includes waste from the tailings impoundment reaching the Embarrass River and from mine site waste sources reaching the Partridge River both to the north and south.

The application fails to consider the high concentrations that will occur in the dewatering water from the East Pit, after it is backfilled with highly reactive waste. Also, the backfill would create a situation where pit water will flow into surrounding groundwater, at least temporarily, and contaminate it. Rapid fill of the West Pit will cause pit water to flow into surrounding groundwater, thereby degrading the groundwater. The application does not consider groundwater degradation due to groundwater flowing from either the West or East Pit into surrounding groundwater.

Surface water monitoring is grossly insufficient to determine the location of seepage that will eventually contaminate the river. Pathways from both sites show the need for substantially more surface water monitoring. Contaminants could reach the river along substantial reaches, and it is necessary to monitor at many locations to identify the source. Variable slopes in the cumulative load curve for the Embarrass River, both for with and without the cutoff wall, show areas of differing load reaching the river. This shows the need for at least four surface water monitoring points along the river, at about mile point 6, 8, 10, and 13.

Proposed groundwater monitoring is insufficient. Contaminant plumes would move between widely-spaced monitoring wells. This observation holds for monitoring between the mine site and Partridge River and between the tailings impoundment and the Embarrass River. Groundwater monitoring wells should be placed where contaminant plumes are most likely to pass. This requires an understanding of flow in the area, which requires a conceptual flow and transport model (CFTM), prepared a scale appropriate to the site. This would include identifying all potential sources and sinks, such as facilities on the mine site that could release contaminants. Sinks that could be damaged are downgradient wells, springs, or streams. Once identified, it is necessary to determine the potential flow path from the source to the sink.

For these reasons, the NPDES/SDS permit for the PolyMet Northmet mine proposal should not be awarded.

Appendix A: Numerical Modeling of Groundwater Pathways, Loads, and Monitoring

This appendix presents analysis completed with the Myers (2014) groundwater model, modified as described herein, for the mine site. Although the Myers (2014) model simulates the region, modifications for the mine site and plant site were made separately because they are separate source areas.

The objective for revised simulations for both areas is to consider flow paths from separate discrete sources rather than simply from seepage dispersed across the bottom of the facilities and to consider the adequacy of the groundwater monitoring. There are three goals to additional simulation of contaminants from the mine site, including seepage from the waste rock and OSP facilities and the backfilled and flooded pits.

- First, consider the time for contaminants to reach the river from the various sources.
- Second, consider whether the monitoring plan would detect contaminants moving offsite.
- Third, consider the sensitivity of parameters controlling the mine dewatering rates; mine dewatering water reports to the treatment facilities and significant changes due to a lack of understanding of the hydrogeology could require much larger dewatering facilities.

Proposed Mine Site Operations

This report used the description of the mine site operations as described in the FEIS, and verified the NPDES/SDS application used the same mine site operations. The Category 4 stockpile would produce seepage from years 1 to 11, after which the waste would be moved into the East Pit so that the Central Pit could be mined. Disposal of waste rock into the East Pit and subsequent flooding is simulated using injection wells for three years, with significantly decreasing concentration with time. The Category 1 stockpile would commence construction in the first year and be constructed by year 13, with reclamation commencing in year 14 and finishing in year 20 (FEIS, p. 3-65, 3-66). The facility would remain in perpetuity. There would be a groundwater containment system constructed around the facility to capture seepage.

The Category 2/3 stockpile would be constructed beginning in year 1 and continue until year 11. Category 2/3 stockpile would begin to be moved to a pit lake beginning at year 11, but the rock would not be fully moved until year 20 (FEIS, p. 3-44, 3-65). Some waste rock would remain in place until year 20, so the area would remain a contaminant source until the waste is fully removed and the area reclaimed. Leak modeling could conservatively assume the leak continues through year 20 or end at year 11, to simulate a range in times.

The OSP area would be used through the 20-year mine plan. Ore would be stacked as high as 40 feet to wait for transport to the process facilities. There would be a liner beneath the OSP. Constant addition of ore and removal of ore would cause significant wear to the liner, and leaks would be expected.

Waste Rock Stockpile Simulation

Mine development creates waste rock stockpiles and the OSP which have seepage rates and contaminant loads that differ from the natural recharge rates. Myers (2014) used four recharge zones, Zones 21-24, that were added to the model (Figure 3 and Table 1). Zone 21 is the permanent Category 1 stockpile. Zones 22 and 23 are the temporary Category 2/3 and Category 4 stockpiles, respectively. Zone 24 is the OSP.

PolyMet variously proposes to cover, line, provide underdrains, and construct seepage barriers for their waste rock facilities, as described above, so the modeling for pathways reflects those plans. For the Category 2/3 stockpile, the rock and overburden management plan (PolyMet 2012) suggests the seepage rate through the liner under the temporary stockpiles will be 0.6 and 0.16 gal/acre/day (1.84x 10^{-6} and 4.91x10^{-7} ft/d or 5.61 x 10^{-7} and 1.50 x 10^{-7} m/d) for the Category 2/3 and Category 4 stockpiles, respectively. These rates would apply from year 1 to year 11 after which the waste would be moved into the East Pit.

Infiltration to the Category 1 stockpile without a cover is 13.6 in/y and with the proposed cover is 0.14 in/y (0.000947 m/d and 9.74 x 10^{-6} m/d, respectively). The cover will be constructed starting in year 14. The Category 1 stockpile is proposed to have a groundwater containment and collection system that would allegedly capture 93-99% of the drainage over the life of the mine and closure (PolyMet 2013, 2012). Therefore, during the third mine period, simulation would have the seepage rate decrease from 0.0000947 m/d to 1/10 of that value in annual time steps.

Seepage concentrations from the stockpiles depends on oxidation based on the category as noted above. PolyMet (2013, Attach. H) shows concentration values for the sources that are mostly constant except for a few constituents with concentrations that drop off toward the end of a 200-year period. Concentration increases early due to oxidation occurring since the waste rock was emplaced. Concentrations in Figure 4 represent the median values from a series of tests and the peak is achieved at 20 years for Category 1 waste rock, 16 years for Category 2/3 waste rock, and 11 years for Category 4 waste rock. The concentration becomes steady for the

Category 1 waste rock after closure. Seepage rates for the OSP equal those of the Category 2/3 stockpile. The sulfate concentration increases to 8 million ug/l by year 11, after which it decreases to 6 million ug/l at year 18 and zero at year 20 (Figure 4).

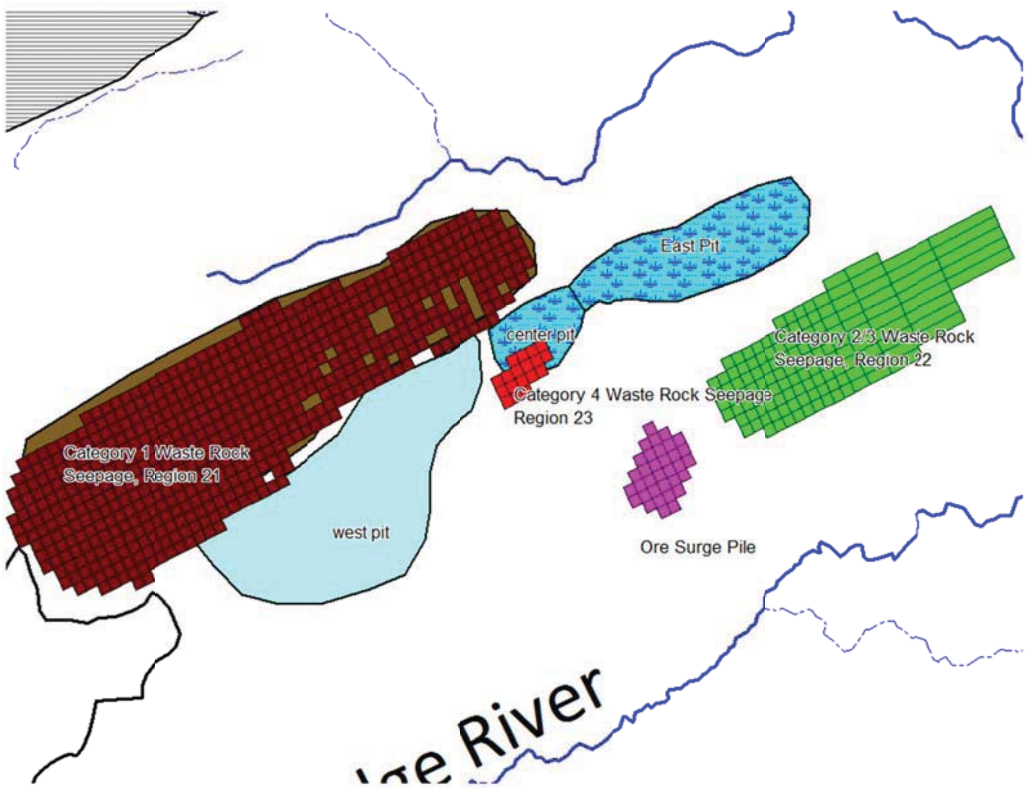

Figure 3: Waste rock seepage areas, near the mine site. See Table 3 and the text for a description of the seepage, rates, and concentrations.

Table 1: Recharge rates for the transient production model. See Figure 3 and Table 3 in Myers (2014), p. 3-12, for the location of the recharge areas.

Recharge zone	Rate (m/d)	Source	Years
1	0.000946*	Embarrass River watershed	All
5		West pit lake rain on surface	After 20
6	0.001144	Tailings seepage	All
10	0.000239*	Partridge River watershed, organic soils	All
11	0.000687*	Partridge River watershed	All
12	0.000449*	Lower Partridge River watershed	All
21	0.000947, 9.74×10^{-6}	Category 1 stockpile	All
22	5.61×10^{-5}, 5.61×10^{-7}	Category 2/3 stockpile	1-11
23	1.49×10^{-5}, 1.497×10^{-7}	Category 4 stockpile	1-11
24	5.61×10^{-7}	Ore surge pile	All
	* - seasonal. All recharge during four-month period.		

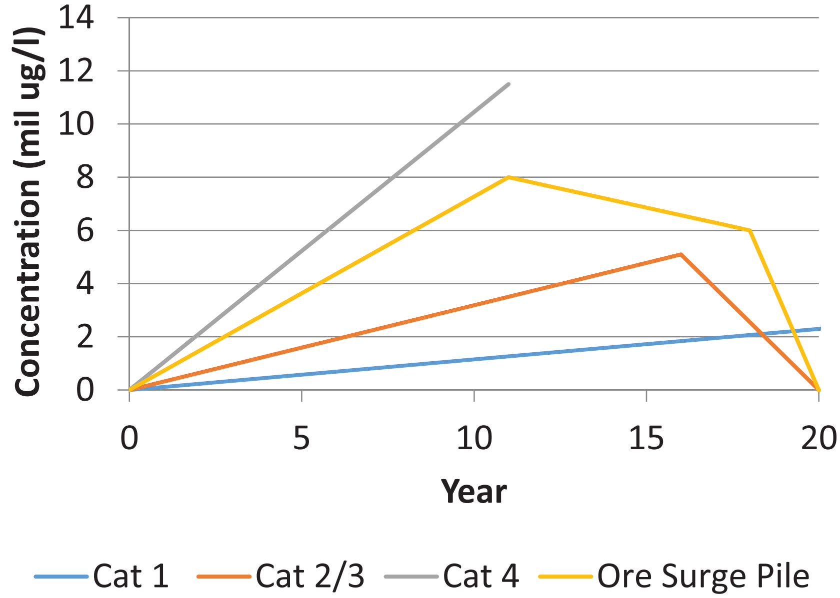

Figure 4: Simulated SO4 concentration for seepage from the various waste rock stockpiles and the OSP (PolyMet 2013). Concentration for Category 1 waste equals 2.6 mil ug/l in perpetuity.

After mining the East Pit ceases in year 11, it is backfilled with waste rock from the Category 2/3 and Category 4 waste rock stockpiles. The moist rock will have undergone oxidation while on the stockpile and while in the pit until the groundwater level covers the rock and reduces oxidation. The transport model used (Myers 2014) MT3DMS does not model oxidation or the development of these products, so a load was specified as input to the model to represent the backfill. Dewatering has continued through year 11, so SO4 loading due to pit backfill occurs from year 12 through year 20 according to the mass indicated by PolyMet (2013, Figure 6-39). These loads exceed the load for the pit walls by three orders of magnitude, therefore pit walls as a source were ignored. This model simulates loading to the East Pit as 100 m^3/d well injection spread over three injection wells into layer 3 with concentration varying as described here - for years 12 through 20, the injected SO4 concentration equals 88, 30, 5.5, 0, 16, 22, 22, 22, and 11 mil ug/l, respectively. The injection rate was low, compared to other flux values, to not upset the water balance.

Model Improvements

The numerical model, originally developed and presented in Myers (2014), has been improved in two ways. First, the updated model improved the discretization near the mine site and plant site by halving the size of the model cells over a significant area. This resulted in four cells where the original model had one cell (Figures 5 and 6 for the mine site and Figures 7 and 8 for the plant site). The second improvement was that layer 2 was split into two layers of equal thickness. Originally, layer 2 was an upper bedrock layer, where conductivity values are closer to those of the surficial aquifer. In the updated model, layers 2 and 3 have the same conductivity, and other parameters, so layers 2 and 3 are the same as layer 2 in the original model. These changes improve the water balance and contaminant transport computation. Steady state calibration statistics changed only slightly, so I performed no additional calibration (Table 2).

Table 2: Model calibration statistics for the original model (Myers 2014), the original model with just model cell discretization, and the updated model including five layers.

		Mine site		Tailings
	original	4 layers	5 layers	5layers
Residual mean	0.19	0.01	0.42	0.61
Residual std dev	2.45	2.71	2.74	2.46
Abs Res Mean	2.01	2.19	2.26	2.04
Res Sum Squares	374	455	477	399
RMS error	2.46	2.71	2.77	2.54
Min Res	-5.04	-6.27	-5.33	-4.32
Max Res	5.16	7.26	7.26	7.26
Range	53.97	53.97	53.97	53.97
Scaled Res Std Dev	0.045	0.05	0.051	0.046
Scaled Abs mean	0.037	0.041	0.042	0.038
Scaled RMS	0.046	0.05	0.051	0.047

The changes were made within the GWVistas graphical unit interface (GUI) framework, which automatically adjusts the conductance for boundaries such as DRAINs. Resulting boundary cells have the conductance as determined by GWVistas, so the overall boundaries are the same as Myers (2014) even if the features are two or more cells in width (Figure 6).

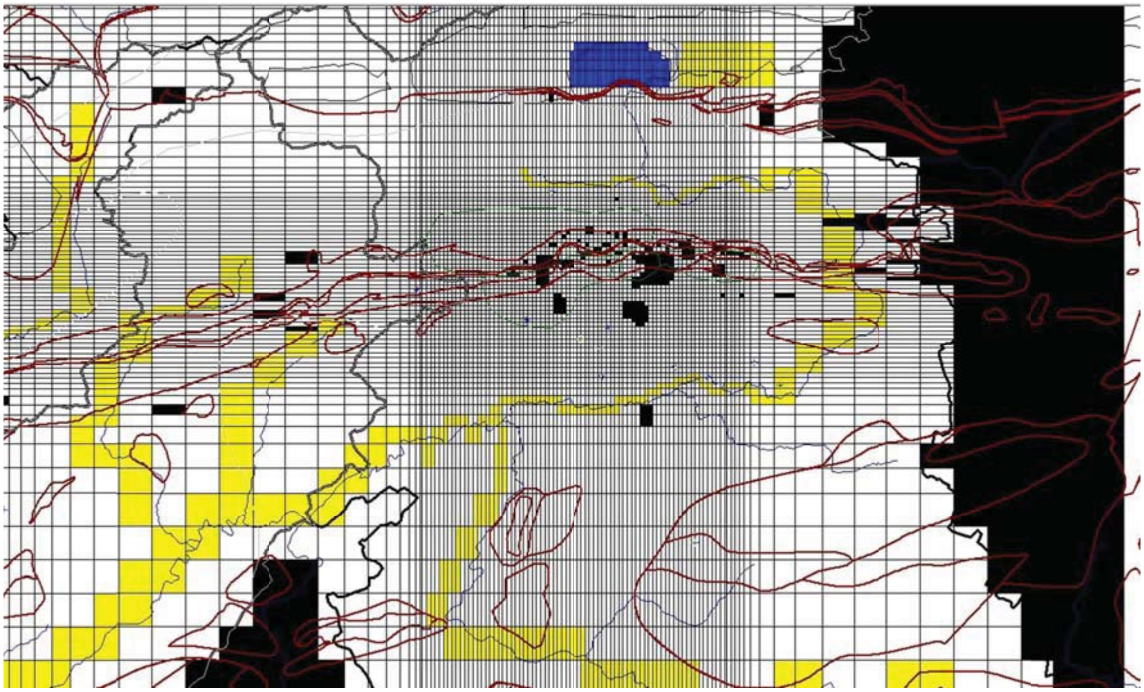

Figure 5: Grid of mine site portion of the original model (Myers 2014). 125 rows and 154 columns. Taken from the steady state model files.

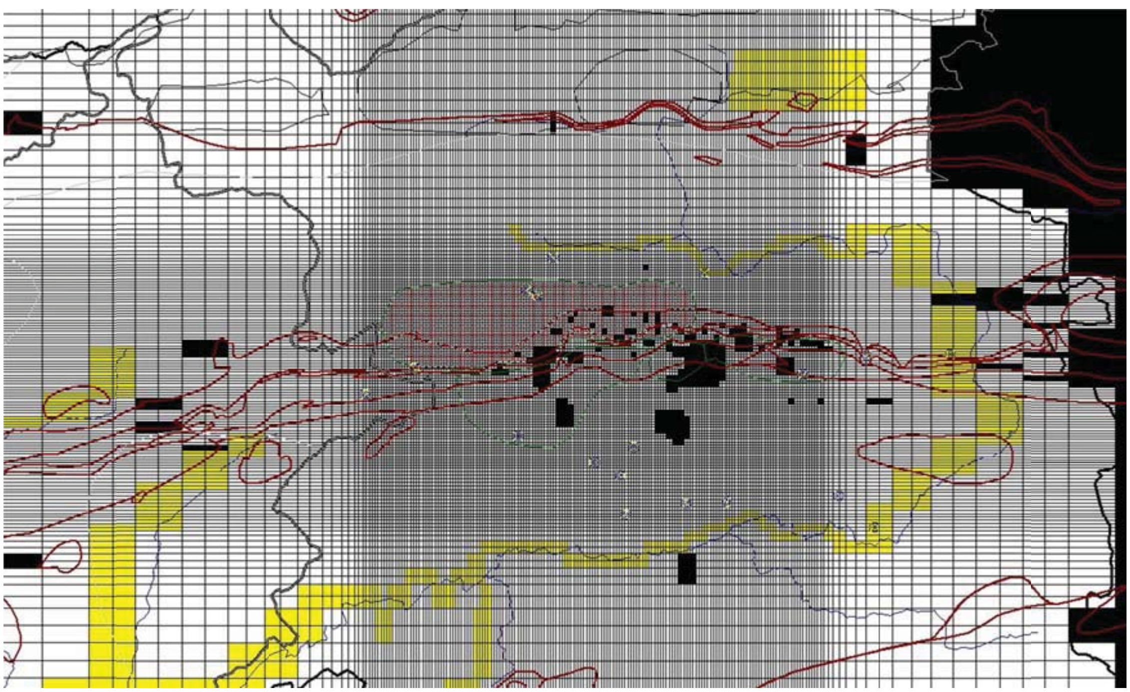

Figure 6: Revised grid for the mine site portion of the model, showing increased detail around the mine site. 192 rows and 250 columns. Taken from the transient model, first period.

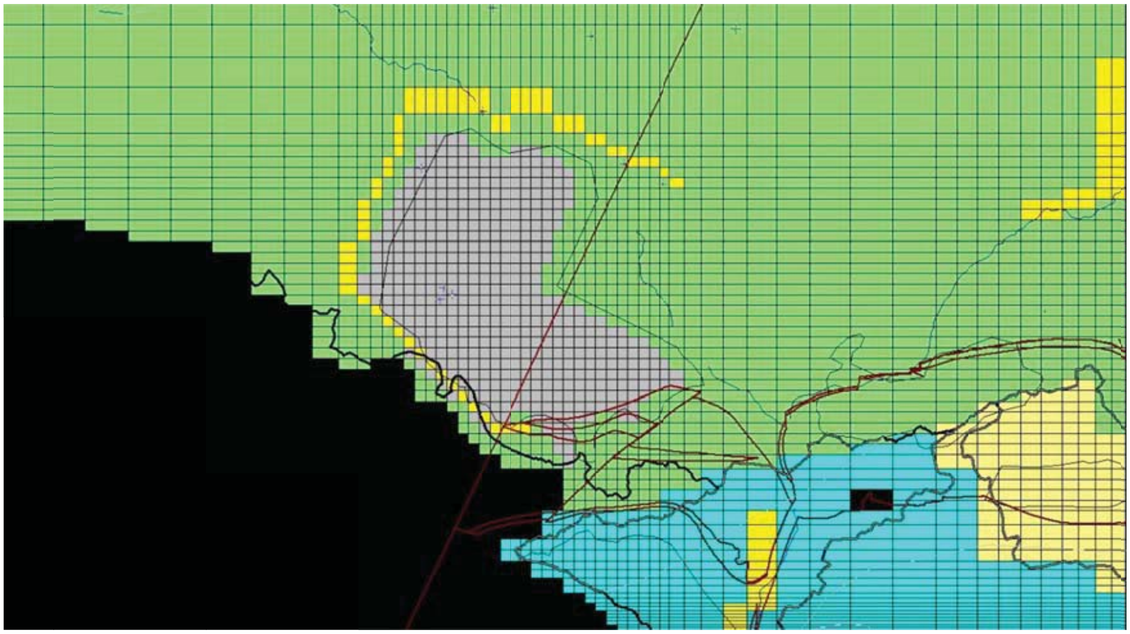

Figure 7: Grid of plant site portion of the original model (Myers 2014). 125 rows and 154 columns. Taken from the steady state model files. Grey is recharge for the tails and yellow is DRAIN simulating seep around tails.

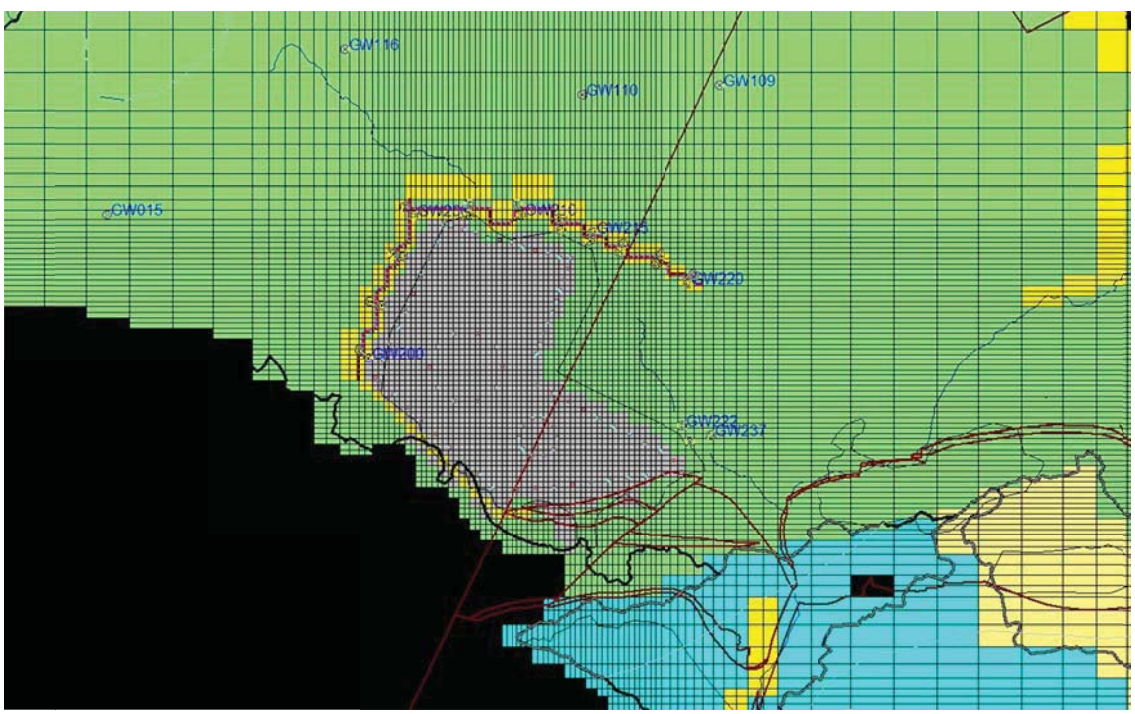

Figure 8: Revised grid for the mine site portion of the model, showing increased detail around the mine site. 163 rows and 192 columns. Taken from the transient model, first period. Grey is recharge for the tails and yellow is DRAIN simulating seep around tails.

Results of Simulation

As with the FEIS model, groundwater flow and contaminant transport simulations for the three mining periods: years 1 to 11, years 12 to 14, and years 15 to 20 (Myers 2014). These simulations are specifically for seepage distributed evenly around the base of the sources.

Groundwater flow paths control contaminant advection on the site, with dispersivity controlling the lateral and vertical spread of the contaminant plumes. After 11 years, the groundwater levels show that the flow direction is generally toward the West Pit and East Pit (Figure 9) because the facilities are being dewatered, which creates a drawdown toward the pits (Figure 10). Exceptions include the east half of the Category 2/3 stockpile which lies over a groundwater divide so that some water will flow south. The OSP also lies near the divide and some groundwater would flow south. Finally, contours west of the West Pit and south of the Category 1 stockpile are complicated and indicate the flow could occur south of the West Pit.

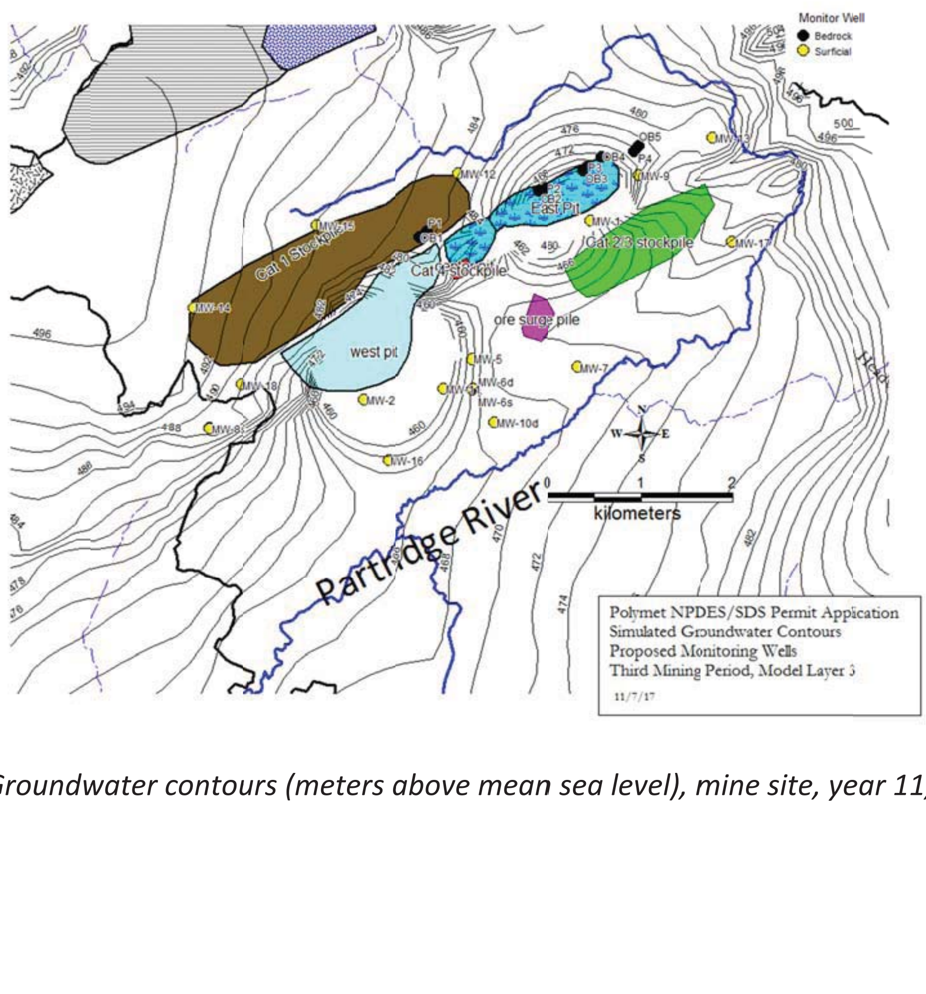

Figure 9: Groundwater contours (meters above mean sea level), mine site, year 11, layer 3.

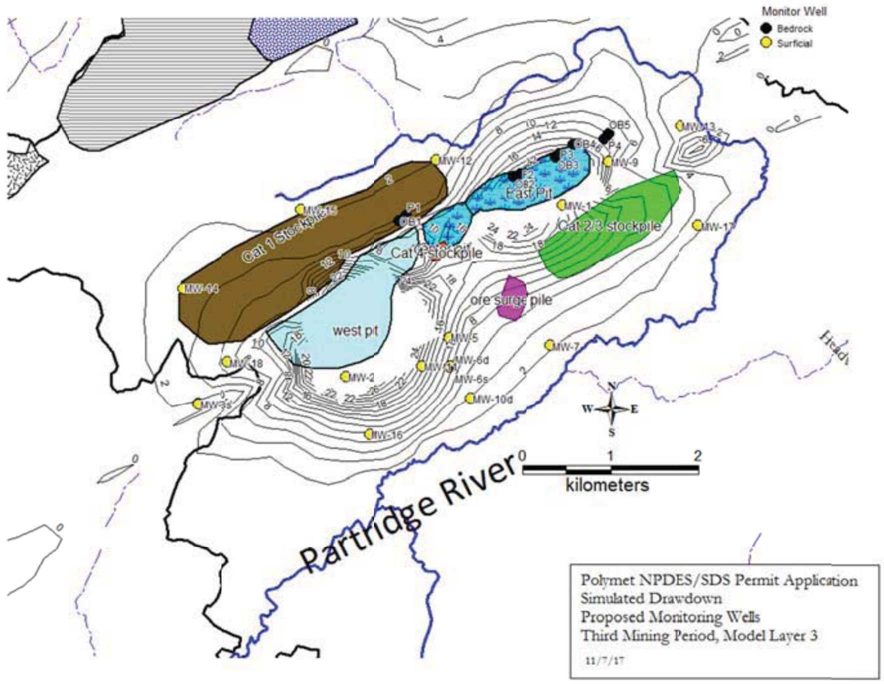

Figure 10: Drawdown contours (meters), PolyMet mine site, year 11, layer 3.

Figures 11 through 13 show the SO4 concentration contours for years 11, 14, and 20, and the proposed monitoring network for layer 3, the upper portion of the bedrock aquifer. Layer 1, the surficial aquifer, and layer 2, the highest part of the bedrock, have substantial dry areas that make the contours more difficult to interpret. However, they generally parallel the contours in layer 3. Figure 14 shows that the contours in layer 4 generally parallel those in layer 3.

The plumes reach a maximum extent in year 14 for three reasons. The recharge rate in the Category 1 stockpile begins reducing in year 14. Second, the Category 4 stockpile is removed after year 11 so the source is gone. Third, the drawdown caused by dewatering the three pits draws groundwater (and contaminants) toward the pit lakes.

Contours shown on the figures away from the facilities peak at between 1000 and 10,000 ug/l. These predictions are based on PolyMet-estimated rates and concentration. If leaks occur in addition to the predicted rate or the overall seepage rates exceed the assumed rates, the concentrations will be much higher. The plumes demonstrate the overall pathway contaminants would follow through the aquifer.

Simulated plumes down to 1 ug/l would mostly miss the proposed monitoring wells south of the mine site (Figures 11-14). The plumes miss monitoring wells MW-5, MW-6s and d, MW-10s and d, and MW-11. At 14 years, the shape of the plume in layer 4 (Figure 14), deeper bedrock, paralleled that in layer 3 (Figure 12). Simulated seepage from these facilities was distributed across the facilities, so the plume footprint should be representative of the extent of the footprint even for a more substantial leak.

Contaminant plumes emanating from various facilities reach the Partridge River within 11 years (Figure 11). This occurs because the OSP and Category 2/3 stockpile are wholly or partly south of the groundwater divide and because seepage from the Category 1 stockpile flows west of the drawdown caused by the West Pit, as noted above (Figure 9).

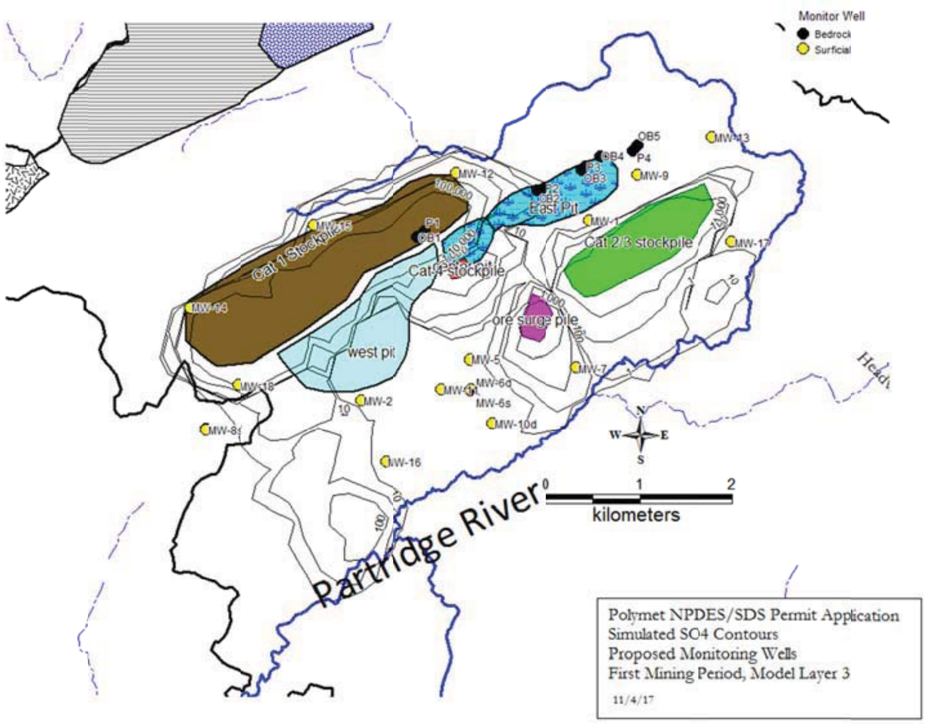

Figure 11: Sulfate concentration at PolyMet mine site, year 11 after start of mining, layer 3.

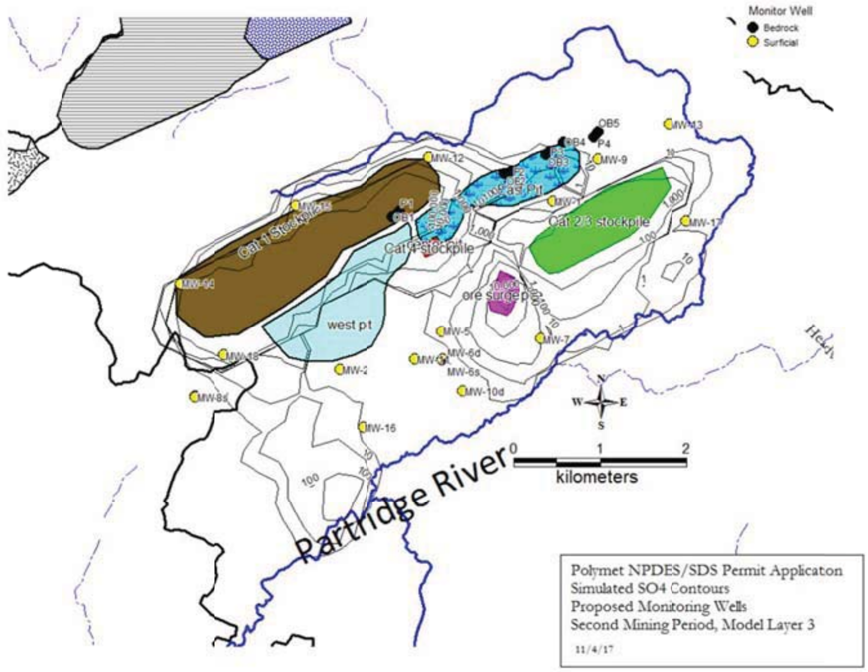

Figure 12: Sulfate concentration at PolyMet mine site, year 14 after start of mining, layer 3.

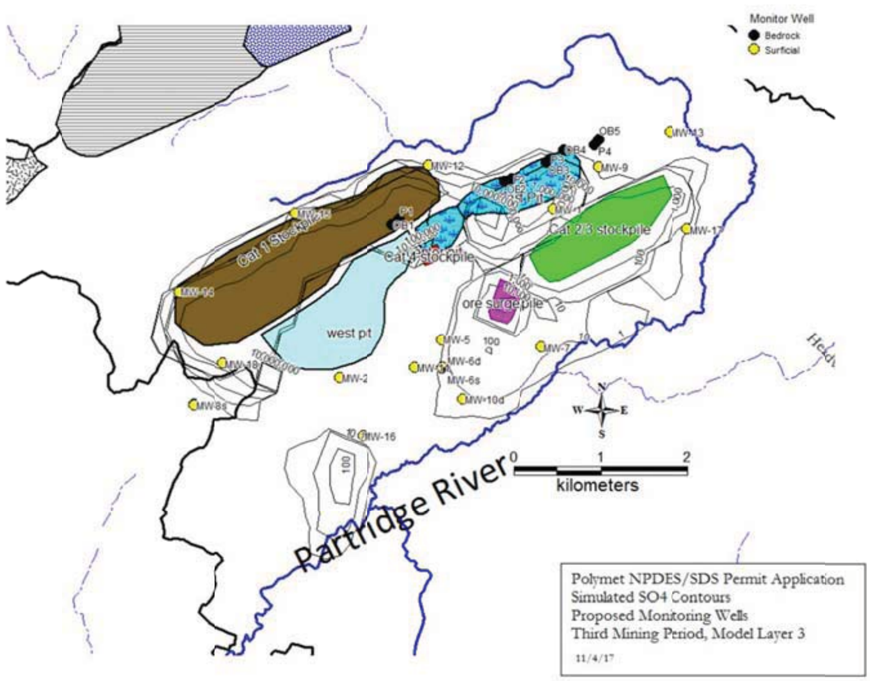

Figure 13: Sulfate concentration at PolyMet mine site, year 20 after start of mining, layer 3.

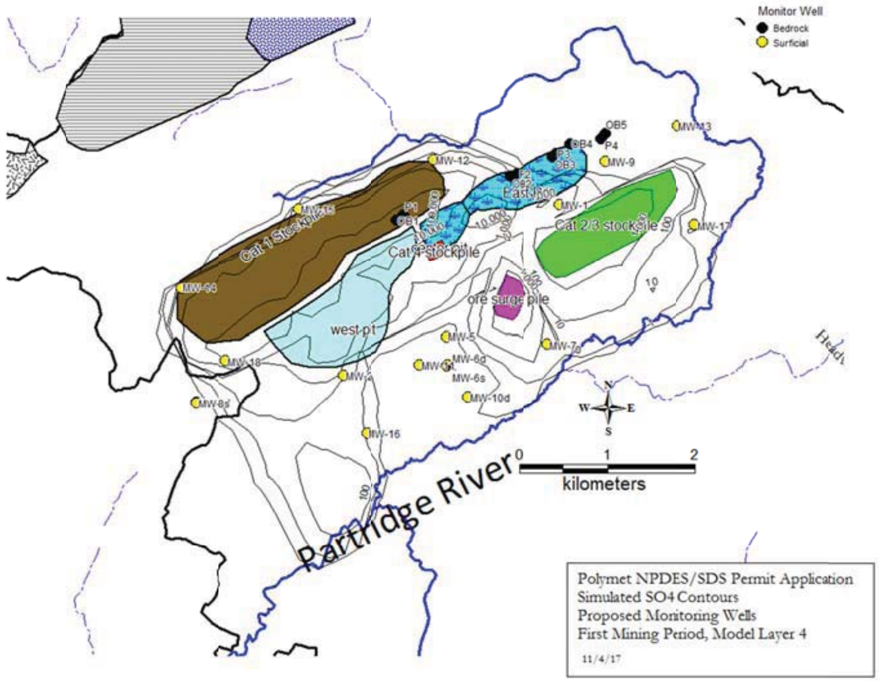

Figure 14: Sulfate concentration at PolyMet mine site, year 14 after start of mining, layer 4.

Simulated sulfate concentrations at various monitor wells peak within the first 20 years, with some peaking within the first 11 years (Figures 15 through 20, the contour plot maps, Figures 9 through 14, show the location of the monitor wells). Monitor well MW-14 demonstrates how the general groundwater flow direction prevents significant transport north of the Category 1 stockpile. MW-14 lies in the middle of the closely-spaced contours. Concentration peaks at 1000 ug/l (Figure 15), but if the well was a couple hundred meters closer to the stockpile, it would have been much higher. Well MW-05-09 is also on the north edge of the Category 1 stockpile and concentration peaks more than 400 times higher than at MW-14 (Figure 16). Monitor well MW-12 (Figure 17), on the northeast corner of the Category 1 stockpile, peaks at levels in between those of MW-14 and MW-05-09. It also peaks at about 8 years, presumably reflecting the influence of dewatering drawing groundwater back toward the West Pit. Deeper well OB-1 peaked later than the other wells and maintained a high concentration for a longer period (Figure 18). This reflects the longer transport time to reach the deep aquifer level. It also indicates that contaminants reaching the deeper layer could provide a contaminant source to downgradient sinks after the shallower wells have shown that contamination has begun to dissipate.

Monitor well MW-7 lies just east of the Category 2/3 stockpile (Figure 9). If transport went southeast from that stockpile, the monitoring well would detect it, but instead it peaks at or near 200 ug/l (Figure 19). The plume lies southwest of this monitor well. Monitor well MW-05-

02 lies toward the south portion of the site, and its concentration peaks at about 15 years (Figure 20),but varies by layer.

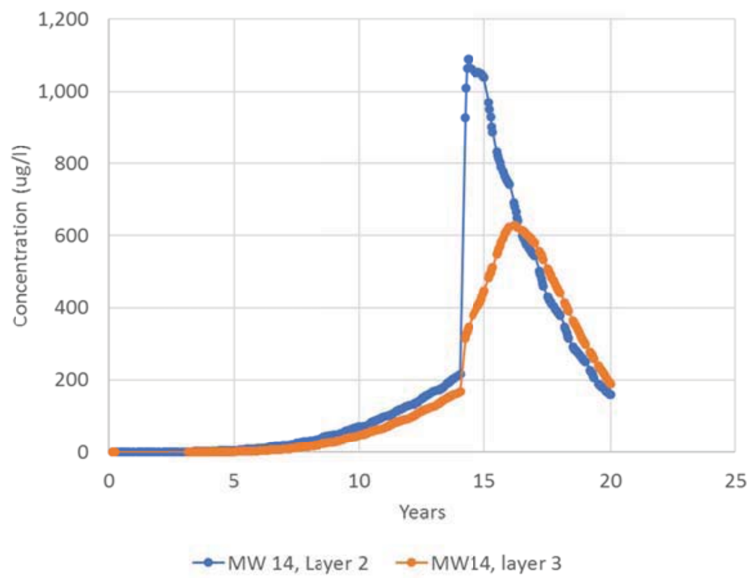

Figure 15: Sulfate concentration graph at well MW-14.

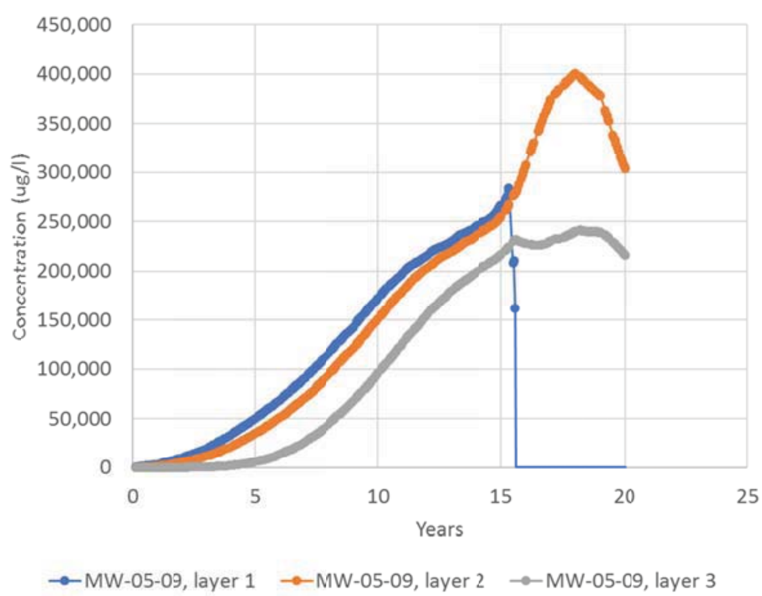

Figure 16: Sulfate concentration graph at well MW-05-09.

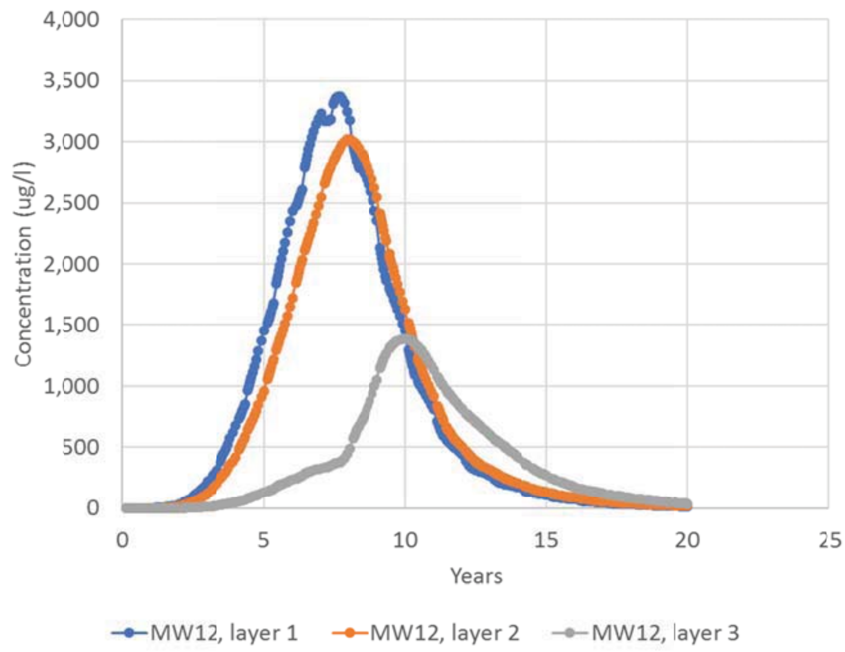

Figure 17: Sulfate concentration graph at well MW-12.

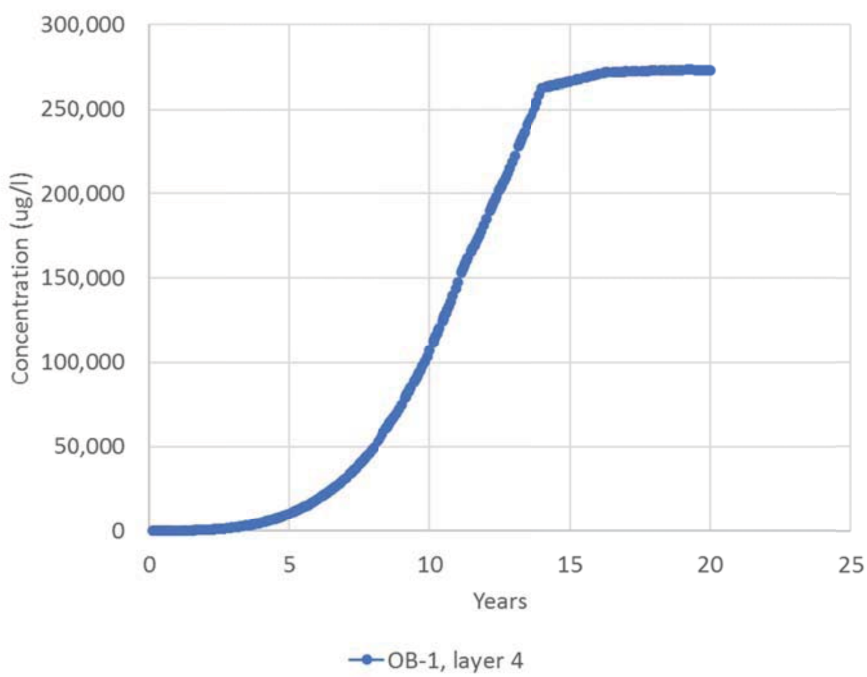

Figure 18: Sulfate concentration graph at well OB-1.

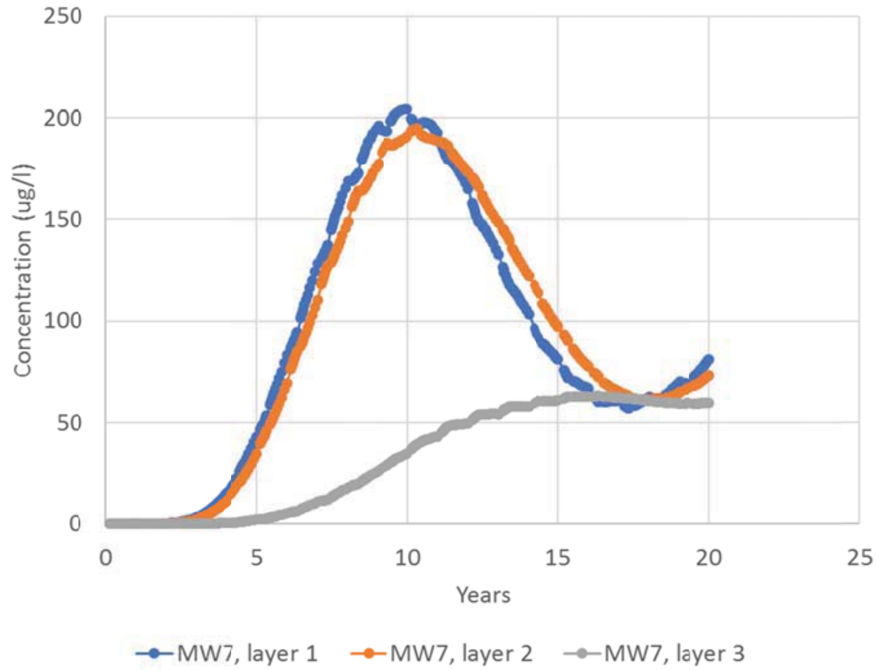

Figure 19: Sulfate concentration graph at well MW-7.

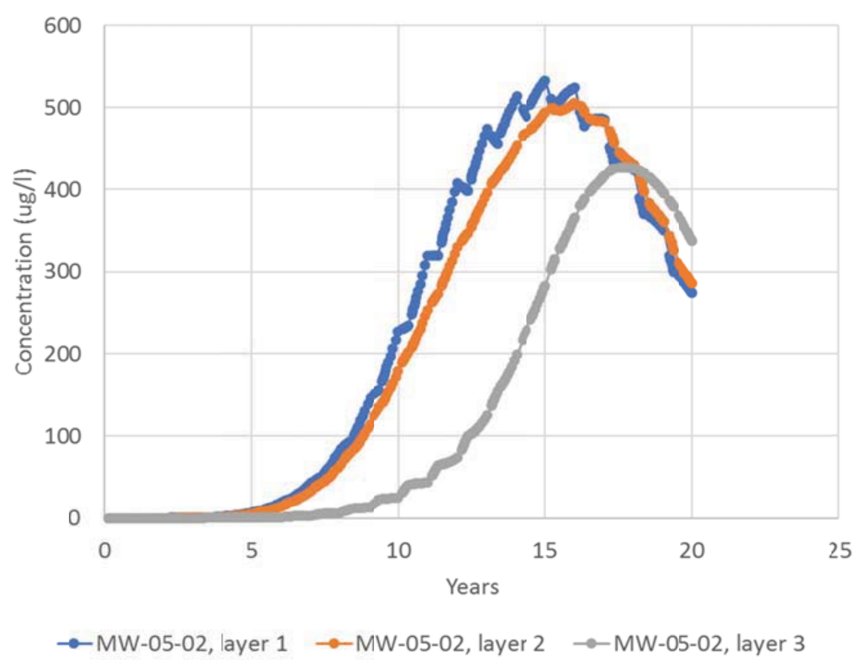

Figure 20: Sulfate concentration graph at well MW-05-02.

Individual Mine Features

The effect of each mine site feature, the three waste rock stockpiles and the OSP, were considered separately by simulating each feature individually for the first mine development period (year 1 to year 11). This scenario was completed by setting concentration for the three not being simulated equal to zero and allowing seepage rates through each facility as simulated for the whole mine site analysis. The assumption is that each feature would be in place and the purpose of the analysis was to determine the individual contribution to the contaminant plume that had been estimated in Figure 11. These scenarios provide a test of the proposed monitoring network, by testing whether contamination released from a specific facility would be detected. The magnitude of the contours is not important because the simulations here do not consider the background concentration, with initial conditions simulated as being zero, and because these simulations assume seepage distributed evenly beneath the facility, not as a large leak at an individual location.

Releases from the Category 1 stockpile transport less than a 1/4 mile to the north because that is effectively upgradient into groundwater flow toward the West Pit (Figure 21). Releases from the west end of the West Pit flows toward the Partridge River south of the mine site (Figure 21). The transport passes west of the groundwater divide that occurs in the groundwater table due to dewatering the West Pit (Figure 21); dewatering the West Pit does not capture the seepage from the Category 1 stockpile. Monitor well MW-18 would detect the concentration increases near the Category 1 stockpile, but there are no wells south of the stockpile that would detect concentration increases before they reach the Partridge River (Figure 21).

Releases from the Category 2/3 stockpile flow south toward the Partridge River, which is a primary discharge point for contaminants from that stockpile (Figure 22). A groundwater divide directly beneath the Category 2/3 stockpile (Figure 9) allows transport to the south. The plume flows undetected between the proposed monitor wells, MW-7 and MW-17. The SO4 graph for MW-7 (Figure 19) showed a modest increase, but that could be linked to the Category 4 stockpile and the OSP.

Seepage from the Category 4 stockpile, which has the highest concentrations (Table 1), is drawn to the dewatered pits until year 11 when it would be backfilled into the East Pit. The plume extends about a mile south of the Category 4 stockpile, but is obviously drawn toward the West Pit (Figure 23). Residual SO4 would draw to the pit, although some would flow toward the Partridge River.

The OSP lies south of the groundwater divide, so the plume extends south to a discharge point at the Partridge River (Figure 24). The edge of the plume intersects well MW-7, but the midline of the plume lies between that well and a line of monitoring wells to the west that are outside of the plume area.

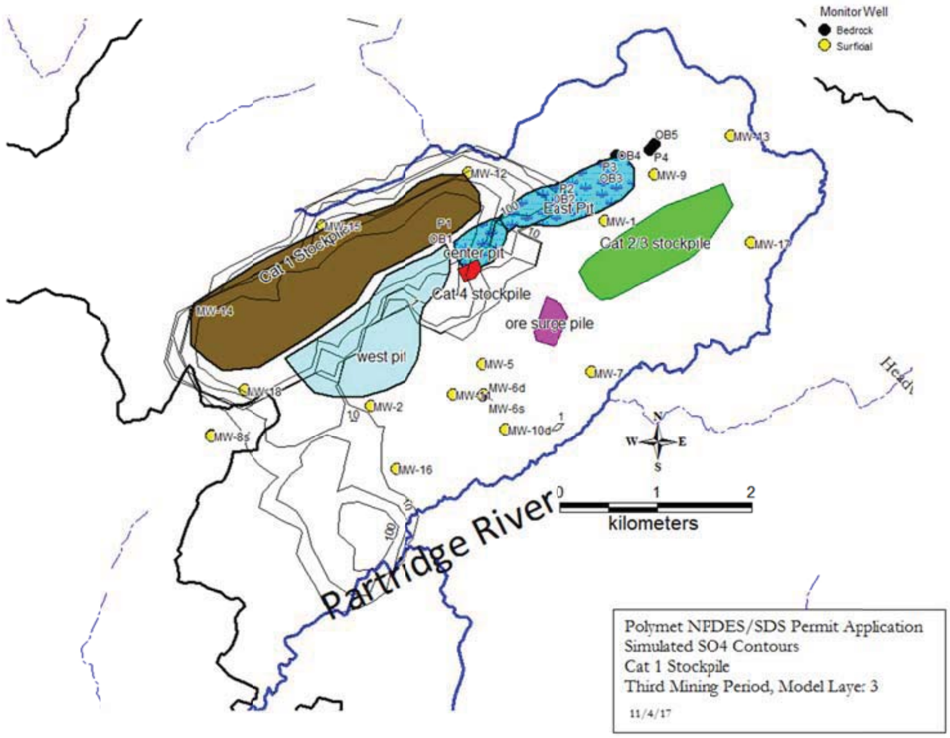

Figure 21: Sulfate contours, Category 1 stockpile only, year 11, layer 3.

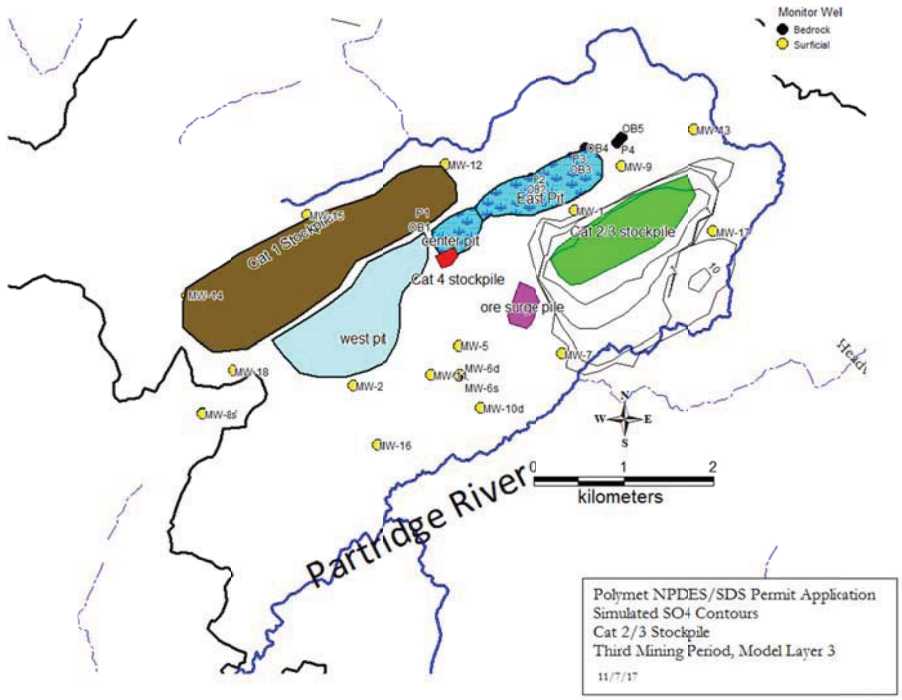

Figure 22: Sulfate contours, Category 2/3 stockpile only, year 11, layer 3.

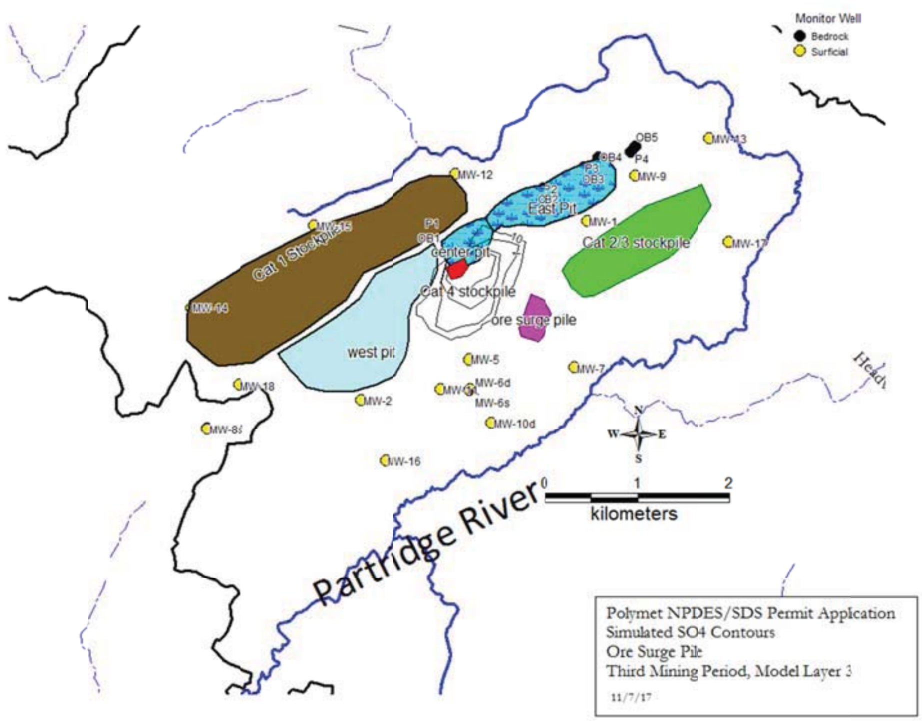

Figure 23: Sulfate contours, Category 4 stockpile only, year 11, layer 3.

Figure 24: Sulfate contours, OSP, year 11, layer 3.

The following simulations consider the facilities separately, with the addition of a substantial leak to the seepage, except for the Category 4 stockpile. Two potential leaks in the Category 1 stockpile, one in the far west and one in the far east portion, and leaks in the center of the OSP and Category 2/3 stockpile were considered separately. Each leak was at the concentration as simulated for the entire facility, but with a rate equal to the rate of the entire facility. The simulation for seepage from an entire facility and from a specific leak was that each facility leaked at twice the predicted rate with half of the seepage discharging through one model cell.

Adding a leak to the west end of the Category 1 stockpile essentially added sulfate load to the seepage on the west end of the stockpile that transports around the west end of the West Pit. Although the plume shape did not expand substantially, the concentration increased from 100 to 10,000 ug/l (Figures 21 and 25). Concentrations at monitor well MW-16 may have increased slightly, but it lies far outside the centroid of the plume and would not provide an indication of the true magnitude of the contamination emanating from the west end of the Category 1 stockpile.

Adding a leak to the east end of the Category 1 stockpile does not expand the plume substantially but increases by an order of magnitude the concentration contours (Figure 26). There is little change in the west from the scenario without a leak. There is little overlap between the plumes emanating from the leaks. A leak on the east end of the Category 1 stockpile would increase the load reaching the far upstream end of the Partridge River, or Yelp Creek, because the transport from the east of the Category 1 stockpile is north and east. Some would be captured by dewatering the East Pit. Monitoring well MW-12 should detect the increased concentration, but monitor wells P2 and OB2 are too far south and close to the East Pit to provide any information about the plume moving northeast. There is no monitoring that would detect the movement of contaminants northeast from the Category 1 stockpile toward the Partridge River.

The plume from the Category 2/3 stockpile with a leak near its centroid expanded about half a kilometer further south of the river than did the plume for the Category 2/3 stockpile without a leak (Figure 27). The magnitude increased about ten times, with a closed contour representing a peak in the middle of the plume (Figure 27). As for the plume without a leak (Figure 20), the monitor wells would not detect these changes.

Adding a leak to the OSP caused little change in the plume extent (Figure 28 and 21), but the magnitude increased about ten times. Monitor well MW-7 would detect an increase, but the threshold for detection would have to be low. MW-5 might detect a slight increase because of a small expansion to the southwest, but likely not raise an alarm. The monitor well layout is far from the center of the plume.

Summarizing, leaks that occur under the mine site facilities have little effect on the size of contaminant plumes emanating from the facilities because dispersivity coefficients control the spread of the plume. The plumes simulated for PolyMet predicted seepage rates would fit between the monitor wells in some areas, and essentially discharge to downgradient sinks undetected, or with minor increases at some wells. The exception would be monitor wells that lie within the footprint of the facilities which would record high concentrations if the predicted seepage manifests. The leaks as simulated would increase the load by up to 200 times, considering concentration increases of 100 times and a doubling of the seepage rate. Most of the plumes miss the monitor well layout. The monitoring well network should be established based on an accurate conceptual flow model for the transport from the specific facilities (see the section in the primary text).

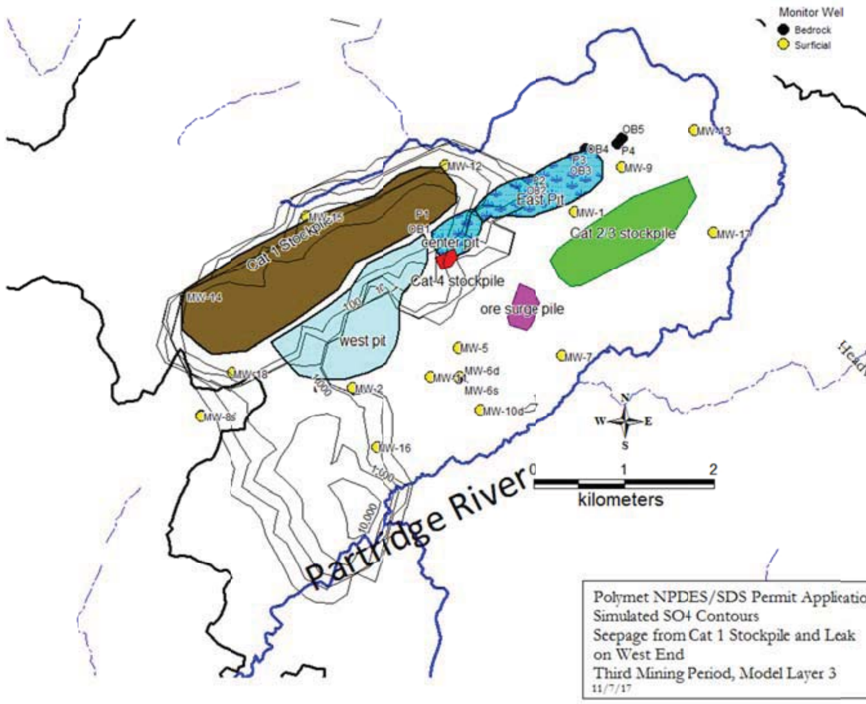

Figure 25: Sulfate contours, Category 1 stockpile with leak on the west side of the pile, 11 years, layer 3.

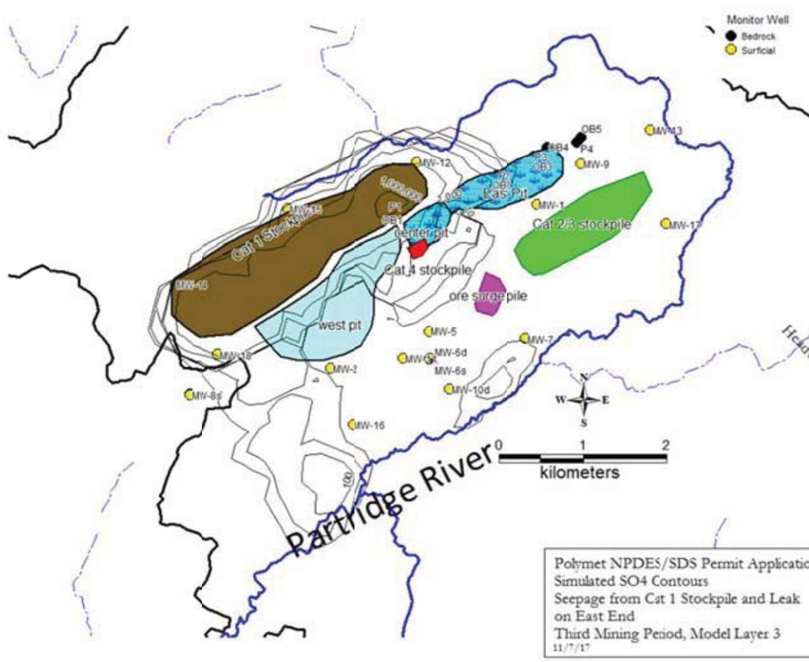

Figure 26: Sulfate contours, Category 1 stockpile with leak on the east side of the pile, 11 years, layer 3.

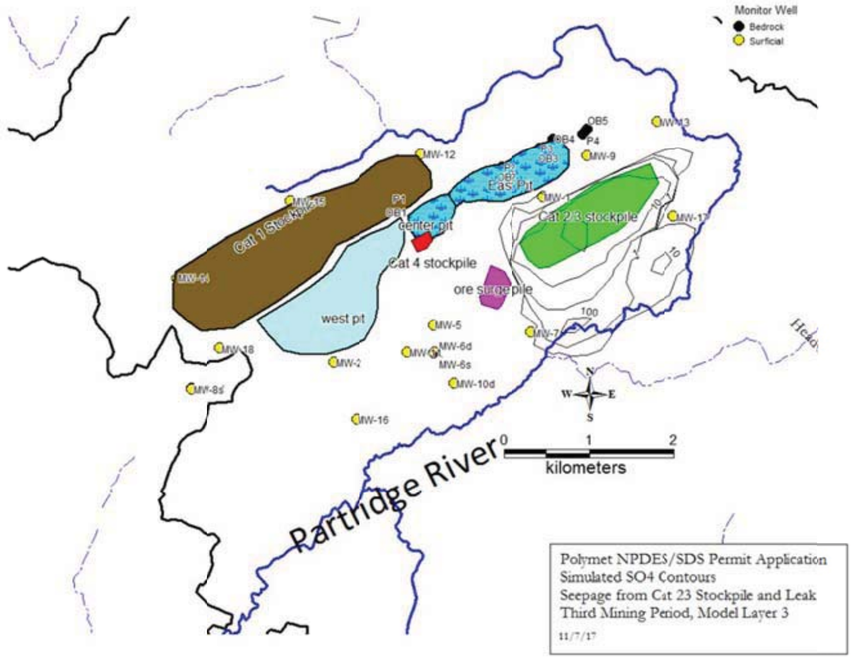

Figure 27: Sulfate contours, Category 2/3 stockpile with leak in the middle, 11 years, layer 3.

Figure 28: Sulfate contours, OSP with leak in the middle, 11 years, layer 3.

Sensitivity Analysis of Dewatering Discharge

The discharge permit, and the entire mine plan, depends on treating mine water prior to reuse or discharge. Dewatering water would be mine water that requires treatment because it would be pumped from sumps in the bottom of the pit. The treatment plans have used rates that were determined in PolyMet (2015), as described in the primary text of this report. If the actual rates differ or vary substantially, the ability to treat the water may be compromised. If the aquifer parameters differ from calibrated values, the amount of dewatering could differ substantially from the predicted rates. This section evaluates how dewatering rates could vary with variable parameters and how seasonal variation in recharge affects the dewatering rates.

I used the Myers (2014) model modified as described above to assess the sensitivity of dewatering rates to increased hydraulic conductivity (K). I increased the horizontal and vertical K for each parameter zone intersecting the pits by two times and ten times, separately for each zone. By doing it separately, the effect of variation in just one zone is being considered rather than a more cumulative consideration of changing all zones. I determined the mass balance for the section of the model including each pit to determine flux to the DRAIN cells used for dewatering using the mass balance feature in GWVistas. To complete this analysis, I digitized an area around the pits and GWVistas summed the water balance for all model layers so that the DRAIN flux equaled total dewatering. I completed the water balance for each of the 22 stress periods used to simulate the 11 years of mining. Recharge occurred for 122 days and no recharge occurred for 243 days. Comparison of hydrographs of predicted dewatering for the first 11 years of mining shows the effect of differing K values. Additionally, I plotted drawdown after 11 years for each K value. The Central Pit requires no dewatering during the first 11 years of mining, so, the analyses were for the West and East Pit.

The parameter zones that intersect the West and East Pit are Zones 19 through 23. As described in Myers (2014, Table 1, p. 1-6), Zones 20 through 23 are the Partridge formation and Zone 19 is Pokegama Quartzite. Also considered here is Zone 24 just north of the East Pit, which is the higher conductivity to the Virginia formation.

Table 3 compares the dewatering rates after 11 years for the original model runs (using calibrated parameters as used for mine site transport simulations above) and sensitivity model runs during which six different parameters zones were increased by ten times. Increasing this parameter, Zone 20 had the largest effect by far on dewatering rates, which reflects the Zone 20 intersecting the south half of the West and East Pit. Increasing parameter Zone 23 had the second largest effect, almost exclusively due to its large effect on dewatering the East Pit. Zone 23 underlies and intersects a larger portion of the East Pit, which may be why dewatering the East Pit was not sensitive to changing most zones (other than Zones 19 and 23). Parameter

Zone 19 had the third largest effect, reflecting that its east-west trend intersects the middle of the pits. However, its effect is smaller because Zone 19 represents a much smaller section of the aquifer and affects flow over a much smaller area. The increase due to changing other parameters zones was less than 10%.

Dewatering the West Pit increased most for increasing K for parameter Zone 20, while for the East Pit there was almost no change (Figure 29). Increasing parameter Zone 19 increased dewatering rates for each pit by almost equal amounts (Figure 30), which reflects that the pits excavated into and essentially split the Zone 19 formation. Because the conductivity values differ by direction (Table 3), dewatering would have increased drawdown along the formation substantially and drawn groundwater into either East or West Pit as it was being dewatered dewatered.

The hydrographs (Figures 28 and 30) show seasonal changes in dewatering rates that indicate seasonally changing recharge rates cause substantial seasonal variation around an average. Dewatering rates would also increase substantially during a wet year. In fact, wet years would likely have a threshold effect, meaning that the increase in recharge beyond the average rate would occur because precipitation increments above average are likely to exceed the average evapotranspiration and soil water holding capacity so that more will seep past the soil layer. Wet years would lead to substantial increases in dewatering and, therefore, treatment rates.

Changing K values affect drawdown less than dewatering rates. After 11 years, drawdown spread slightly further for increasing K19 than drawdown for the calibrated model (Figure 31). Increases in the extent of drawdown reflect the lower gradient needed with higher conductivity controlling the flow rates. Increasing K24 had little effect on drawdown contours (Figure 32) because dewatering increased only slightly (Table 3), except that the 5-m contour spread far to the west from the pit through that parameter zone. Changing K caused the model to draw groundwater from different formations even if the overall rate does not change substantially. Spreading drawdown further from the mine site could increase the drawdown effects on wetlands further from the mine than expected.

In summary, if the actual conductivity exceeds that used to estimate dewatering rates, dewatering will be much higher than predicted, and drawdown would expand further into nearby wetland areas. If conductivity is underestimated by an order of magnitude for just one formation intersecting the pits, the dewatering rate could be almost doubled. Seasonal changes during average recharge years indicate that wet years that could increase recharge substantially, without regard to the accuracy of K values, and could also cause much higher dewatering rates. If either factor manifests, the rate of water requiring treatment would be much higher than predicted for the draft NPDES/SDS permit.

Table 3: Dewatering rates (gallons per minute) for the West Pit, East Pit, and Total, after 11 years of mining, for the calibrated model and for six conductivity parameter zones with K (meters/day) increased by ten times, as shown in the table.

	West Pit	East Pit	Total	Kx	Ky	Kv
Original	637.1	615.7	1252.8			
K19	756.0	846.8	1602.8	0.05	0.002	0.05
K20	1768.8	613.6	2382.5	0.36	0.36	0.0774
K21	643.9	684.1	1328.0	0.0265	0.0265	0.318
K22	640.6	671.1	1311.7	0.0043	0.0043	0.043
K23	654.5	1019.6	1674.2	0.08	0.0043	0.128
K24	639.5	705.0	1344.5	1	1	1

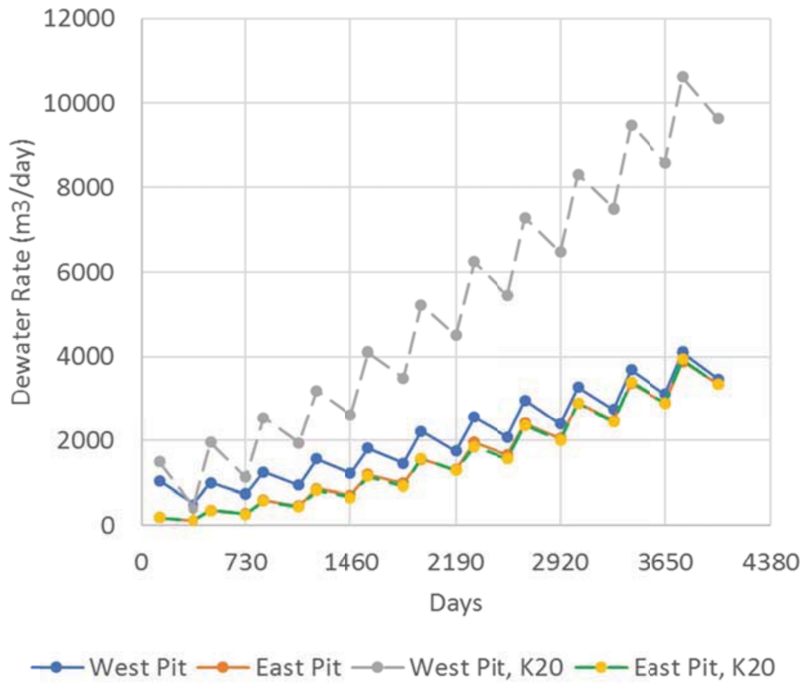

Figure 29: Hydrograph of dewatering rates for the West and East Pit as calibrated and with hydraulic conductivity values for parameter Zone 20 increased by 10 times.

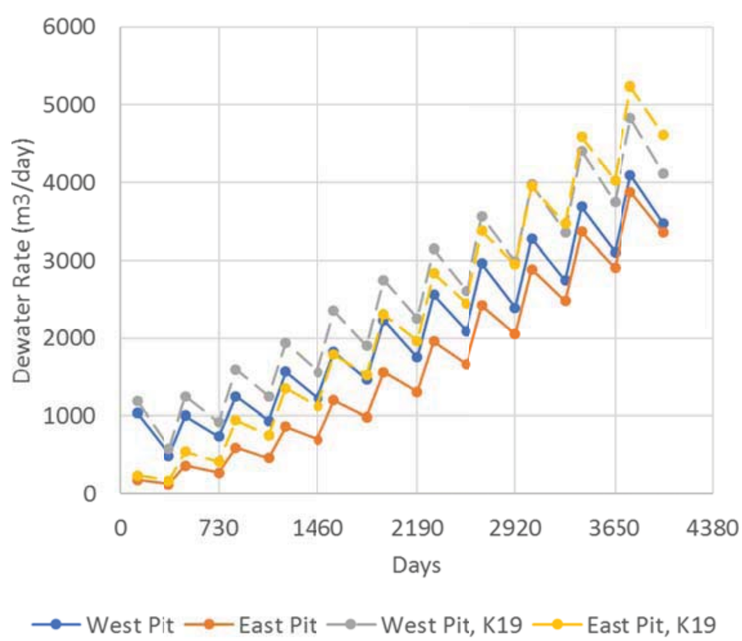

Figure 30: Hydrograph of dewatering rates for the West and East Pit as calibrated and with hydraulic conductivity values for parameter Zone 19 increased by 10 times.

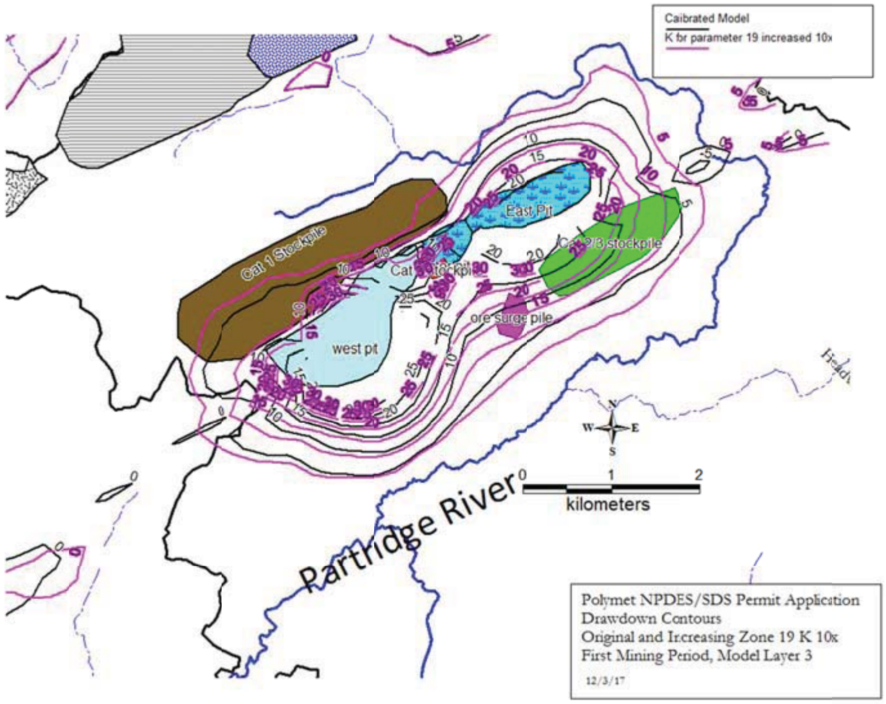

Figure 31: Drawdown contours for the calibrated model and for increasing K for Zone 19 by 10 times.

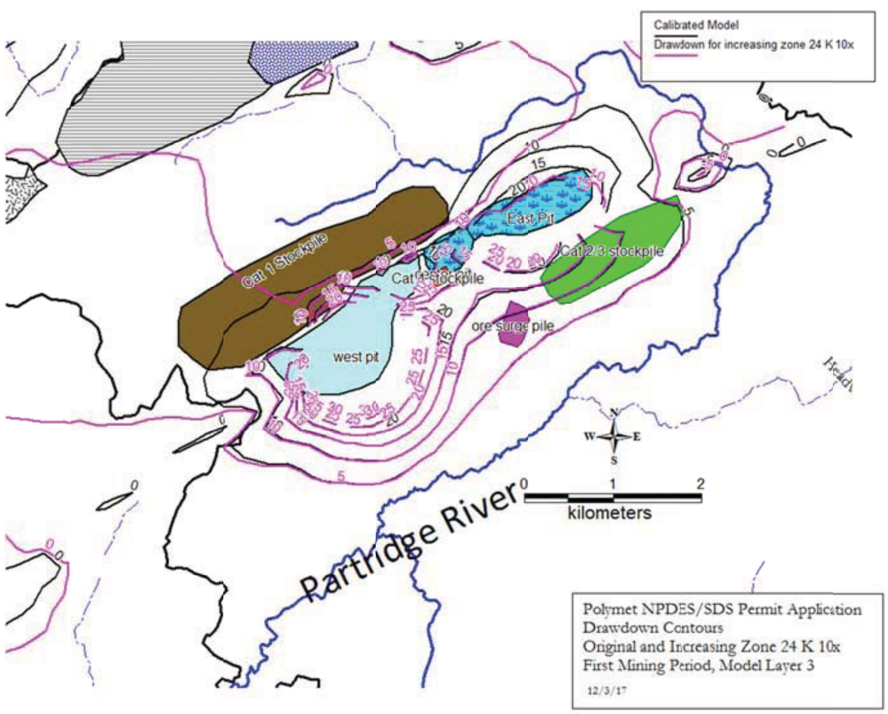

Figure 32: Drawdown contours for the calibrated model and for increasing K for Zone 24 by 10 times.

Load and Discharge to the Partridge River

Groundwater seepage in the Mine Site area discharges to the Partridge River, simulated as DRAIN reach 15 through its upstream reach near the mine site. Reach 15 extends from the headwaters to the confluence with the South Partridge River, or about 9.96 miles. The confluence is near surface water management station SW004a (Figure 33). Both simulated groundwater discharge and load rates are highly variable along the reach (Figure 34).

Almost half of the simulated load, seepage from the Category 1 stockpile, reached the river at the upstream end (Figure 34). For about three miles, no groundwater discharges to river (the horizontal flow reach in Figure 34). Groundwater discharge occurs from upstream of mile 4 to about mile 6.5, but the load curve remains flat indicating groundwater flow with no contaminant, as would be expected east of the mine site. The discharge increases substantially after mile 6 through about mile 10, a reach through which the load also doubles, but from the load that entered at the very upstream end (Figure 34).

Groundwater concentration reaching the river can be estimated by dividing the load reaching a reach by the flow rate reaching a reach, as shown in Figure 34. Up to mile 0.77, the load entering the river at the upstream end would have a concentration of about 60 mg/l. Failure to capture seepage discharging from the west part of the Category 1 stockpile during mine operations could have a substantial deleterious effect on the Partridge River. The concentration reaching the reach between mile 6.5 and 0.96 is about 8 mg/l. The river reaches flowing from east to southwest of the mine site receive contaminated groundwater along the entire reach. Because of the short horizontal section between about mile 8.2 and 9.6, the actual concentration is higher in the other portions of the reach. Thus, there is significant variability in the groundwater fluxes and loads reaching the river, probably based on the contaminant source (the mine feature with seepage into groundwater) and the actual pathways.

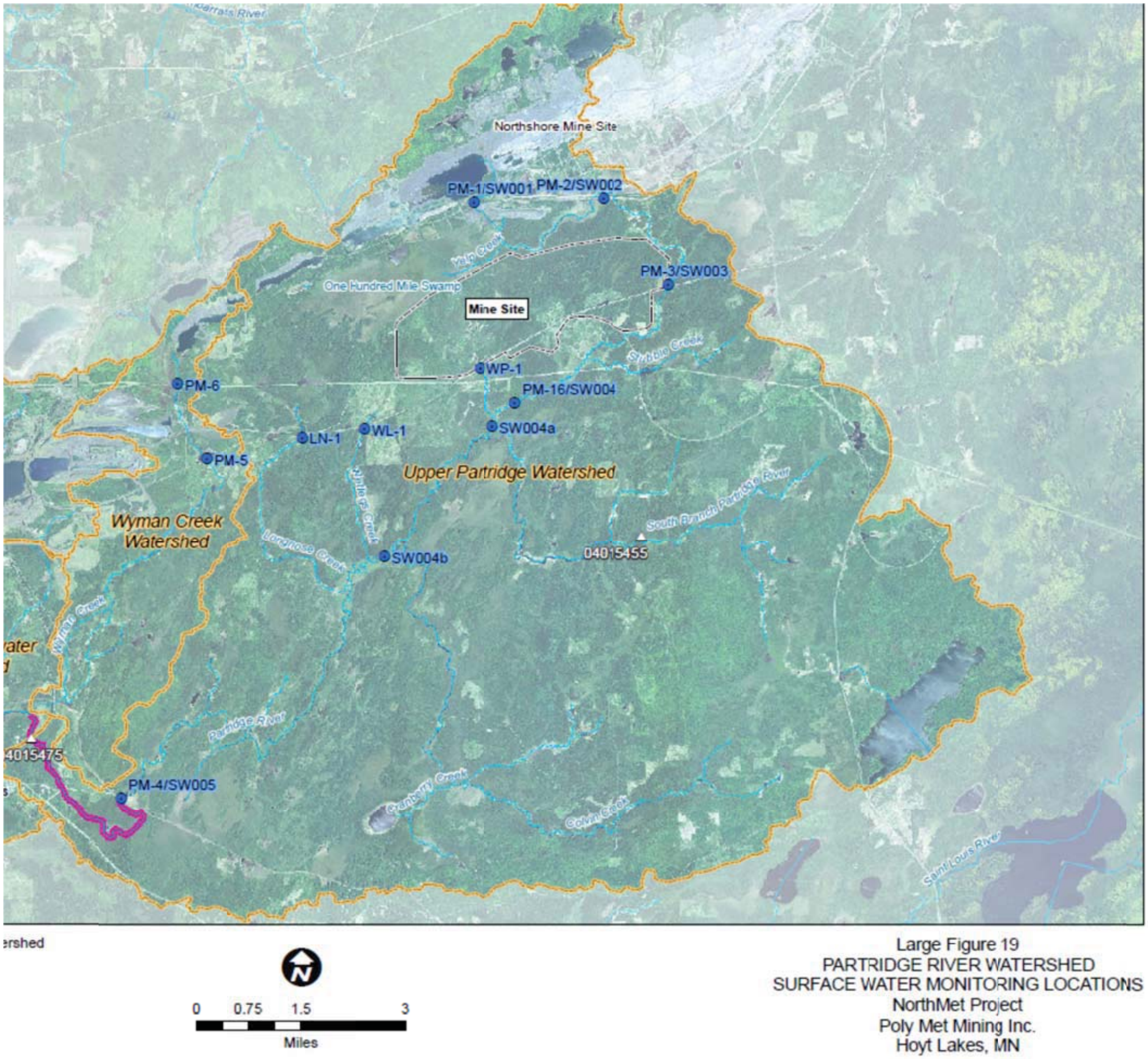

Figure 33: Snapshot of a portion of Large Figure 19, PolyMet (2015), showing the rivers near the Mine Site.

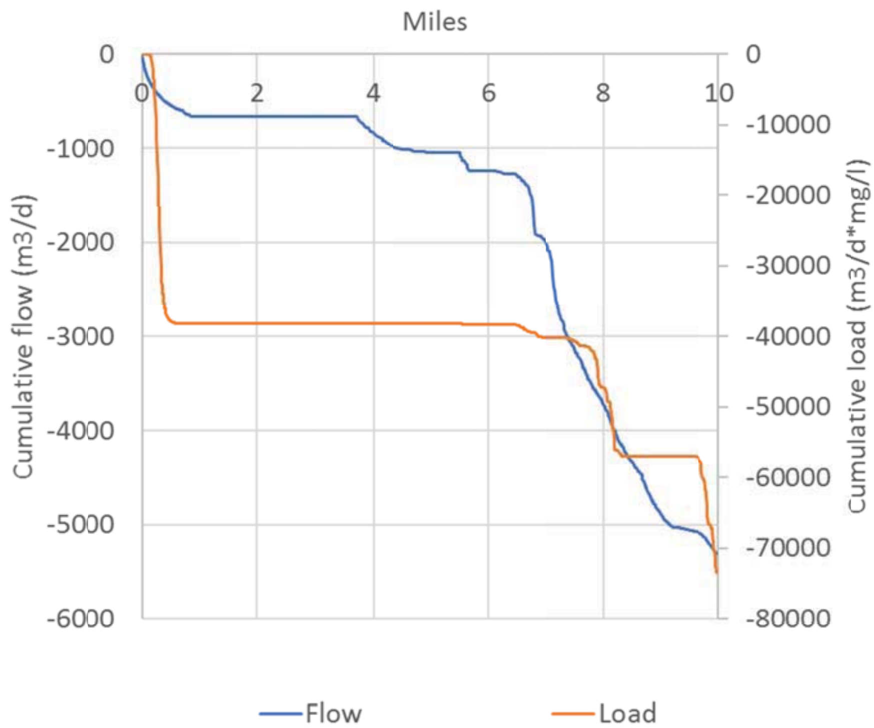

Figure 34: Cumulative flow and load on reach 15, the Upper Partridge, by mile from up- to downstream.

Plant Site Operations

This section considers the NPDES/SDS application for discharges from the plant site. The NPDES application (Volume V) references Northmet Project Water Management Plan – v6, dated 2017, but the MPCA reference for it is version 5, dated 2016 (https://www.pca.state.mn.us/sites/default/files/wq-wwprm1-50a_0.pdf, accessed 12/19/17).

Discharges from the Plant Site reach surface water through groundwater pathways. The PolyMet tailings impoundment would be constructed on top of an existing tailings impoundment, with the plan including the addition of bentonite to the ponds on top of the impoundment to reduce the seepage and the addition of a cutoff wall around much of the tailings impoundment to capture the continuing seepage. This section reports on modeling of seepage from the tailings impoundment to assess pathways and monitoring well plans.

Three scenarios are considered. First is a baseline with seepage distributed through the impoundment without a cutoff wall. The second scenario included a cutoff wall and DRAIN boundary to simulate the PolyMet proposed wall. The simulation, as described below, does not capture 100% of the seepage as estimated by PolyMet. See the detailed review of the cutoff wall in Appendix B. The assumption holds only if the surface of the bedrock is impervious so that no seepage can enter it and flow beneath the cutoff walls. The modeling used herein and described below captures much of the seepage but realistically simulates some going beneath the cutoff wall and continuing downstream. The goal is to consider how that seepage develops downgradient, when the cutoff wall does not perform as modeled by PolyMet.

Third, with the impoundment seeping at its average rate, specific leaks were added to four locations in the impoundment, with the leak equaling ten percent of the total rate. The intent is to estimate how fast a plume would develop and whether the monitoring as designed would show it.

There are 28 performance monitoring wells to be used around the base of the tailings impoundment (Figure 35). They are paired wells, with both installed in the surficial aquifer, installed up- and down-gradient of the new cutoff wall.

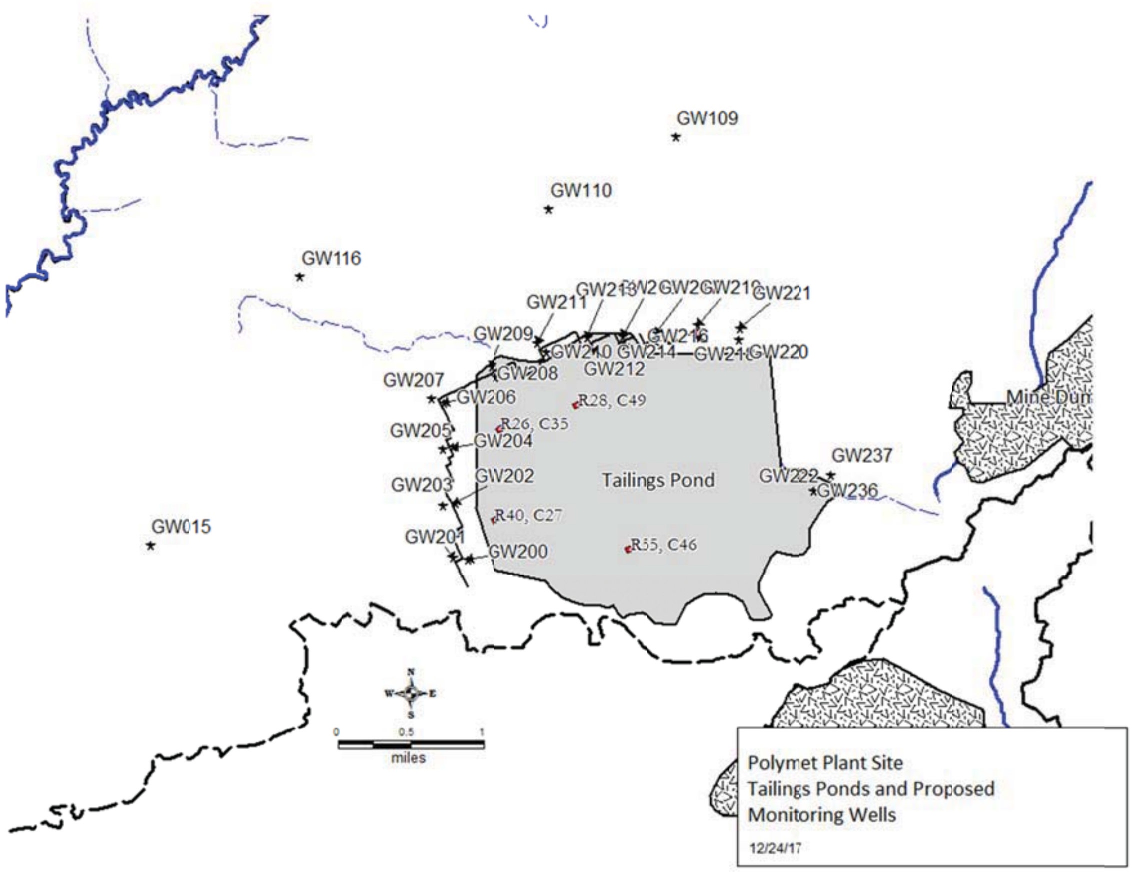

Figure 35: Existing PolyMet plant site, showing tailings pond and waste rock dumps, and proposed monitoring wells and cutoff wall/drain as simulated in the groundwater model. The

*map also shows the location of four simulated leaks, labeled as R**, C**, where R** and C** are row and column numbers.*

Groundwater Modeling of the Plant Site

Discretization of the model around the impoundment was improved, as described above (Figures 7 and 8), to improve the water balance and transport calculations near the impoundment. The top of layer 1 is the top of the existing tailings impoundment. The cutoff wall was simulated using the horizontal flow barrier (HFB) package to prevent horizontal flow and a DRAIN boundary to remove captured seepage (Figure 8). The seepage DRAIN simulated in Myers (2014) is seepage around the base of the current tailings impoundment, and changes in flux from this boundary would demonstrate changes due to the new cutoff DRAIN. The newly established cutoff drain elevation is 8 m below the bottom of layer 1 in both layer 1 and 2. The DRAIN used an effective K of 10 m/d and the HFB used an effective horizontal K of 10^{-4} m/d. Sensitivity analyses of these boundaries showed that decreasing K for the HFB made the drain more effective at increasing the capture of seepage. Increasing K in the DRAIN to 100 m/d increased captured flux by just a few percent, but decreasing K in the HFB from 10^{-3} to 10^{-4} m/d increased seepage capture by 30%. This demonstrates the importance of a tight cutoff wall as part of the seepage capture system. If K varies substantially, these calculations demonstrate that the drain will not successfully capture all of the water.

Transient simulation of the mining and reclamation periods was completed in eight steps. The first was a 20-year period simulating the mining period. It was 7300 days using 40 time steps and a time step multiplier of 1.05. The following six periods were 5 years, or 1830 days, with 20 times steps and a time step multiplier of 1.20. The eighth period was 200 years, or 70,000 days, with 200 time steps and a time step multiplier of 1.05. The simulation did not account for seasonal variation in seepage rate because there was little difference in the results, unlike at the mine site.

Tailings seepage reductions lowered the groundwater level sufficiently that, even without the simulated cutoff wall and drain, DRAIN reach 2 representing the seeps at the base of the impoundment reduces to zero. The DRAIN flux rate at the end of mining was 3260 m^3/d for simple distributed tails seepage, and reflects the drawdown caused by reducing seepage through the tailings impoundment.

For modeling, each of the pairs is simulated as up- and down-gradient of the simulated wall, with each well close to the middle of each cell. Digitization was based on locations shown in Volume I, Large Figure 7. The simulated wells will be completed in layers 1 through 3, meaning they will monitor upper two layers of the bedrock in addition to the surficial layer.

Mass Balance for the Tailings Impoundment

Changes in groundwater flow from the tailings impoundment area with and without the cutoff wall was estimated for the area near the tails (Figure 36), and computed using the mass balance feature in GWVistas. Slight variations in some fluxes which should be the same occurred because the polygon was digitized separately into each model file. Tables 4 and 5 present fluxes for the polygon in layers 1, 2, and 3 and for the total model thickness. The Xmin, Xmax, Ymin, and Ymax fluxes are fluxes through the left, right, lower, and upper directions of the polygon (Figure 36). Bottom and top are fluxes through the bottom or top of the polygon by layer, with inflow being into the layer meaning downward through the top or upward through the bottom. Storage inflow is water leaving storage and entering the model and storage outflow is water that is stored.

Flux through the top of the polygon is decreased to about half by adding a cutoff wall, although the reported flux is for all five model layers (Figures 37 and 38). This reflects the cutoff wall deflecting flow mostly into the drain. Flux to the natural seeps that surround the tailings impoundment decreased by more than two-thirds initially. By the end of the simulation, flux to the seeps decreased to zero for both scenarios due to the decreased seepage rates. Both reductions are due primarily to discharge to the cutoff wall DRAIN (Figure 38).

There is a substantial flux both up and down through the bottom of layers 1 and 2 (Tables 4 and 5). However, the next flux outward through the bottom of layer 2 is greatest with the cutoff wall (Figures 37 and 38), although there are substantial fluxes in each direction (Tables 4 and 5). The increased downward flow is due to the cutoff wall causing a higher groundwater level within layer 2. The gradient for flow through the cutoff wall increases, so there is more downward gradient to force flow deeper. This would primarily occur in the center of the tailings impoundment. A paradoxical effect of the cutoff wall is to increase flow deeper into the bedrock.

Much more recharge occurs in layer 2 within for the with cutoff wall scenario because the DRAIN in layer 2 (the cutoff) lowers the water table causing parts of layer 1 to be unsaturated. Dry cells are inactive. Because recharge is added to the highest active layer, it occurs in layer 2, and some in layer 3.

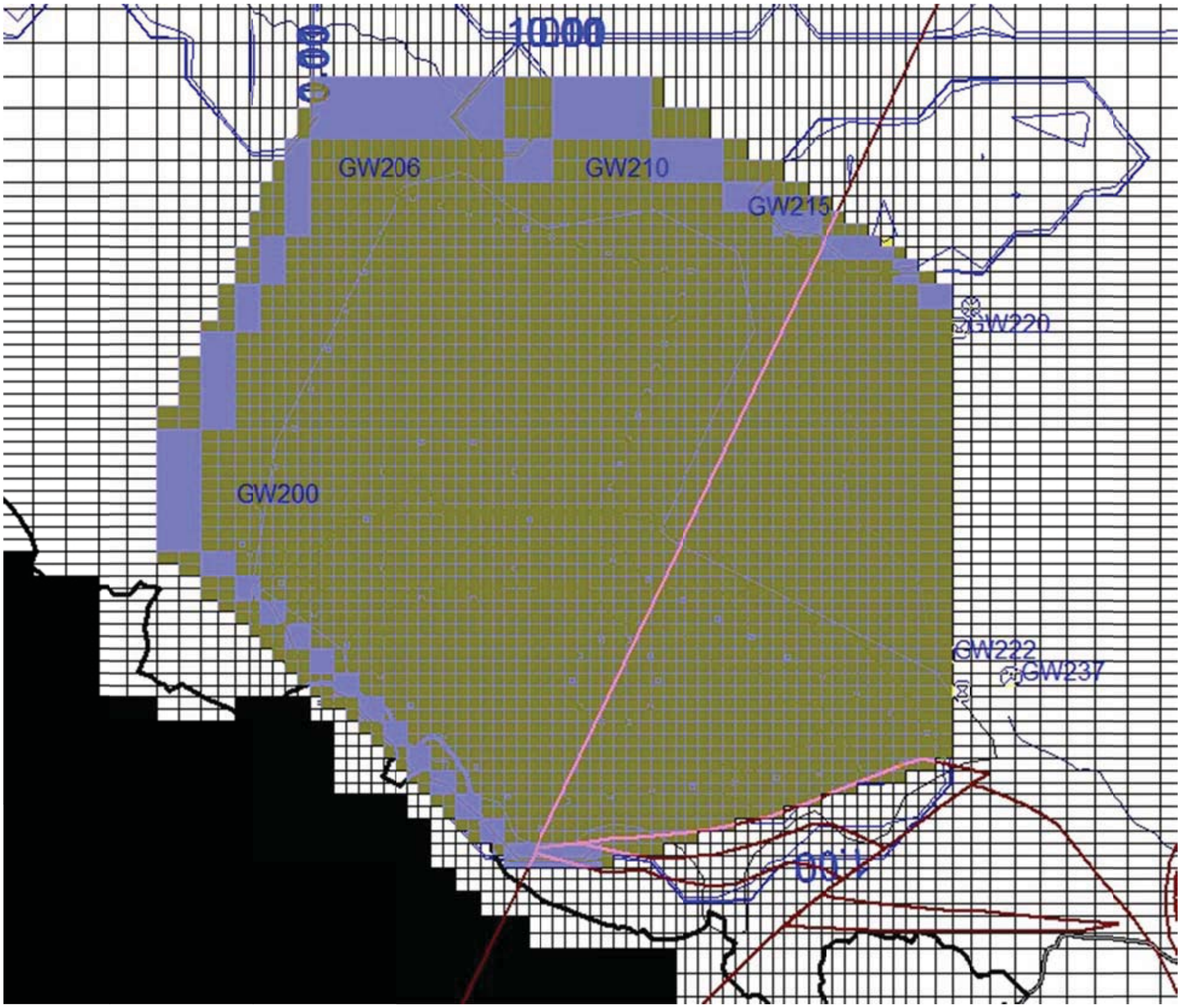

Figure 36: Polygon used for mass balance calculations at the tailings impoundment. The area includes the existing seep. The cutoff wall and drain are inside of this polygon. The polygon connects the outer edge of the DRAIN for the existing seep, and the corner in the east, bottom right, is at Row 65, column 78.

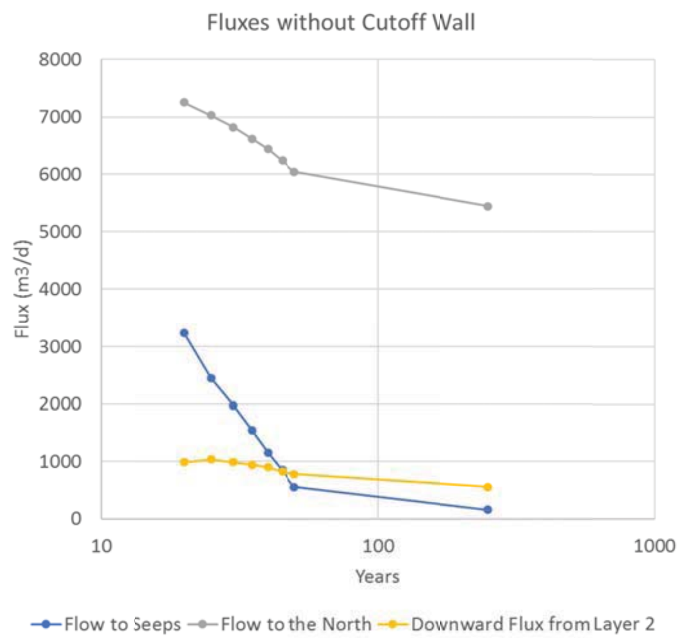

Figure 37: Representative fluxes for mass balance for area in Figure 36, without the simulated cutoff wall. Flow to north is vertical upward on Figure 36. Downward flux is the net, outflow – inflow, for the bottom of layer 2.

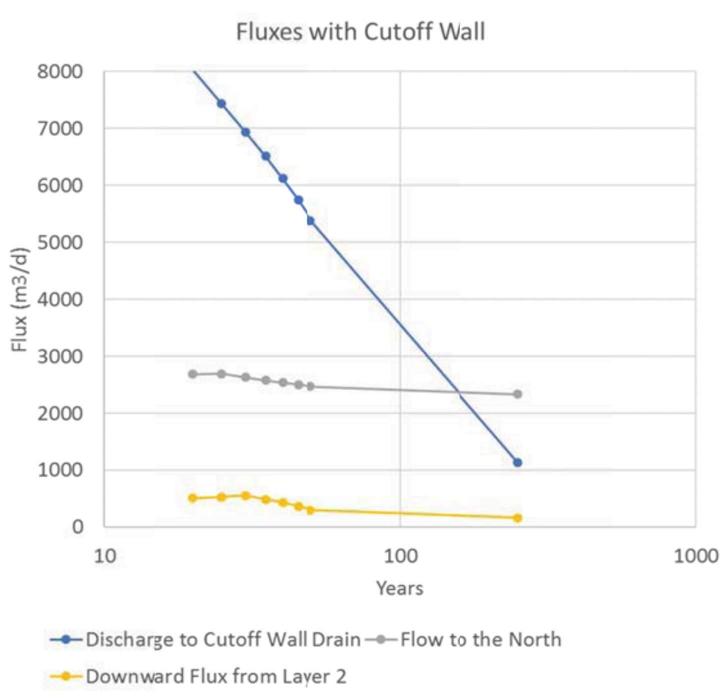

Figure 38: Representative fluxes for mass balance for area in Figure 36, with the simulated cutoff wall. Flow to north is vertical upward on Figure 36. Downward flux is the net, outflow – inflow, for the bottom of layer 2.

Table 4: Water balance fluxes for layer 1, 2, and 3, and the total thickness for the polygon shown in Figure 36, without the cutoff wall.

		Layer 1	8	Layer 2		Layer 3		Total	
Cum Time		Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
20	Bottom	7606	10555	1520	2503	617	1120		
25	Bottom	6732	9739	1367	2403	572	1069		
30	Bottom	6087	8970	1283	2269	542	1010		
35	Bottom	5523	8287	1216	2159	522	958		
40	Bottom	5088	10589	1178	2078	508	918		
45	Bottom	4623	8046	1144	1966	497	874		
50	Bottom	4286	6591	1121	1899	491	832		
250	Bottom	3346	5076	999	1552	449	686		
Period	Drain		3240						3240
2	Drain		2451						2451
3	Drain		1973						1973
4	Drain		1543						1543
5	Drain		1148						1148
6	Drain		848						848
7	Drain		549						549
8	Drain		157						157
1	Recharge	9562		646		21		10230	
2	Recharge	8952		686		22		9661	
3	Recharge	8340		725		28		9092	
4	Recharge	7719		784		27		8531	
5	Recharge	7110		821		31		7963	
6	Recharge	6486		871		37		7394	

7	Recharge	5874		911		41		6826	
8	Recharge	5005		1194		58		6257	
1	Storage	1018	3	180		191		1408	3
2	Storage	764	8	125		129		1031	8
3	Storage	652	7	102		103	0	868	7
4	Storage	572	6	81	0	81	0	742	6
5	Storage	525	2	73	0	69	0	674	2
6	Storage	540	1	70	0	69		686	1
7	Storage	561		69	0	64		700	1
8	Storage	0	1	0	0	0	0	0	1
1	Top			10555	7606	2502	1520		
2	Top			9739	6732	2403	1367		
3	Top			8971	6087	2269	1283		
4	Top			8286	5526	2159	1216		
5	Top			10589	5087	2078	1178		
6	Top			8046	4623	1967	1144		
7	Top			6591	4287	1899	1121		
8	Top			5075	3346	1552	999		
1	Xmax	199	184	37	421	24	229	270	1008
2	Xmax	147	159	28	421	16	224	197	975
3	Xmax	120	166	24	398	12	213	160	941
4	Xmax	108	166	22	383	9	201	142	904
5	Xmax	97	165	21	364	6	189	126	862
6	Xmax	88	157	19	345	5	176	115	811
7	Xmax	83	145	20	329	4	163	108	760

8	Xmax	56	108	24	269	3	103	85	555
1	Xmin	129	409	23	571		362	152	1665
2	Xmin	130	410	13	551		351	143	1622
3	Xmin	116	386	11	535	0	339	127	1556
4	Xmin	114	384	6	522		328	121	1520
5	Xmin	107	370	5	512		320	112	1481
6	Xmin	108	364	2	519		312	110	1465
7	Xmin	102	341	2	505		304	104	1415
8	Xmin	84	284	1	484	0	269	85	1271
1	Ymax		4387		2085		465		7260
2	Ymax		4217		2050		455		7036
3	Ymax		4057		2015		446		6824
4	Ymax		3905		1983		437		6625
5	Ymax		3763		1957		430		6444
6	Ymax		3595		1934		422		6240
7	Ymax		3451		1897		414		6044
8	Ymax		2987		1799		390		5441
1	Ymin	294	3	206	10	343	2	1130	15
2	Ymin	282	6	191	7	328	4	1079	17
3	Ymin	256	4	185	4	336		1063	8
4	Ymin	255	2	177	3	342		1067	5
5	Ymin	248	1	173	4	345		1066	5
6	Ymin	240	1	162	1	352		1061	2
7	Ymin	171		166		374		1032	
8	Ymin	126	0	153	0	384	30	1000	0

Table 5: Water balance fluxes for layer 1, 2, and 3, and the total thickness for the polygon shown in Figure 36, without the cutoff wall.

		Layer 1	8	Layer 2		Layer 3		Total	
Period		Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
1	Bottom	1074	9071	2050	2557	827	1144		
2	Bottom	1092	7821	1950	2478	795	1109		
3	Bottom	939	8416	1851	2404	765	1056		
4	Bottom	817	6630	1787	2272	743	1015		
5	Bottom	717	6795	1734	2165	726	973		
6	Bottom	674	5633	1688	2056	711	930		
7	Bottom	609	5569	1647	1945	697	887		
8	Bottom	475	3747	1432	1595	612	712		
1	Drain		973		8026				8999
2	Drain		773		7433				8206
3	Drain		575		6940				7514
4	Drain		389		6513				6902
5	Drain		293		6119				6411
6	Drain		120		5746				5866
7	Drain		50		5382				5432
8	Drain				4511				4511
1	Recharge	7930		2230		22		10181	

2	Recharge	7397		2259		27		9682	
3	Recharge	6819		2257		38		9114	
4	Recharge	6275		2232		46		8553	
5	Recharge	5703		2234		48		7984	
6	Recharge	5179		2183		55		7416	
7	Recharge	4649		2134		64		6848	
8	Recharge	3788		2416		76		6279	
1	Storage	827	39	148	5	159		1149	44
2	Storage	682		116		120		930	0
3	Storage	559		86		86		739	1
4	Storage	469	2	69		68		612	2
5	Storage	473	1	65		66		610	2
6	Storage	465	1	58		58		586	1
7	Storage	505		59	1	60		630	1
8	Storage	0	0.6	0		0		0	1
1	Top			9071	1075	2557	2050		
2	Top			7822	1092	2478	1950		
3	Top			8416	939	2404	1851		
4	Top			6630	817	2272	1787		
5	Top			6795	717	2165	1734		
6	Top			5633	674	2057	1688		

7	Top			5569	609	1945	1647		
8	Top			3748	475	1595	1432		
1	Xmax	367	76	152	266	25	165	555	635
2	Xmax	371	81	107	236	17	165	503	609
3	Xmax	334	75	107	224	13	146	459	561
4	Xmax	309	69	100	199	10	136	422	513
5	Xmax	293	62	97	187	8	126	401	474
6	Xmax	280	55	96	178	6	115	385	438
7	Xmax	273	48	97	171	6	105	377	405
8	Xmax	239	21	89	131	6	52	339	243
1	Xmin	18	155	62	144		303	80	907
2	Xmin	3	134	65	141		287	68	852
3	Xmin	3	128	54	136		281	57	825
4	Xmin	2	122	55	126		275	57	796
5	Xmin	2	116	54	125		266	57	771
6	Xmin		114	55	123		261	55	757
7	Xmin		108	55	126		256	55	741
8	Xmin		78	56	113	0	215	57	622
1	Ymax		799		1264		349		2683
2	Ymax		997		1121		323		2690
3	Ymax		945		1121		321		2633

4	Ymax		906		1115		317		2579
5	Ymax		878		1107		313		2538
6	Ymax		857		1100		309		2501
7	Ymax		838		1091		305		2466
8	Ymax		760		1065		293		2336
1	Ymin	309	1	221	6	425	3	1315	11
2	Ymin	273	6	186	6	396	1	1190	13
3	Ymin	264	8	182	3	396	1	1179	11
4	Ymin	252	6	172	2	393		1159	8
5	Ymin	245	6	165	2	399		1155	8
6	Ymin	182		168		417		1125	
7	Ymin	175		169		428		1138	
8	Ymin	112	8	144	3	414	25	1038	80

Comparison of Concentration Changes through the Cutoff Wall

The NPDES/SDS permit application (Vol. I and V) prescribes paired performance monitoring wells up- and down-gradient of the tailings impoundment. These were simulated within the model to compare the effect of the cutoff wall. Figure 35 shows these wells and Figure 36 shows some of these wells on a model figure of the tailings impoundment.

The concentration decreased substantially as it passed through the cutoff wall. This would be due to a much-decreased load mixing with the background groundwater downgradient from the cutoff wall. From GW202 to GW203, concentration decreased by half prior to 50 years (Figures 39 and 40). After 50 years, concentration increased more steeply but the decrease remained almost half for another 25 years. In the long-term, the downgradient concentration at GW203 remained less than the upgradient concentration up to about 150 years, after which the cutoff loses its effectiveness.

Between upgradient GW208 and downgradient GW209, the reduction was almost two-thirds (Figures 41 and 42). After about 200 years, however, the downgradient concentration increased to equal the upgradient concentration. Between GW216 and GW217, the concentration also decreased by more than half, although the upgradient concentration was much lower initially (Figures 43 and 44). The walls effectiveness was gone by about 100 years.

For all performance monitoring wells, the concentration was higher in layer 2 than in layer 3 up to more than 100 years, after which the concentration values converged. This was due to dispersion into layer 3 lagging. Layer 1 was dry except for initially at GW217 (Figure 44). While layer 1 is saturated under most of the tailings impoundment, it is not near the edge. More of it is unsaturated with the cutoff because the DRAIN in layer 2 lowers the water table to capture flow.

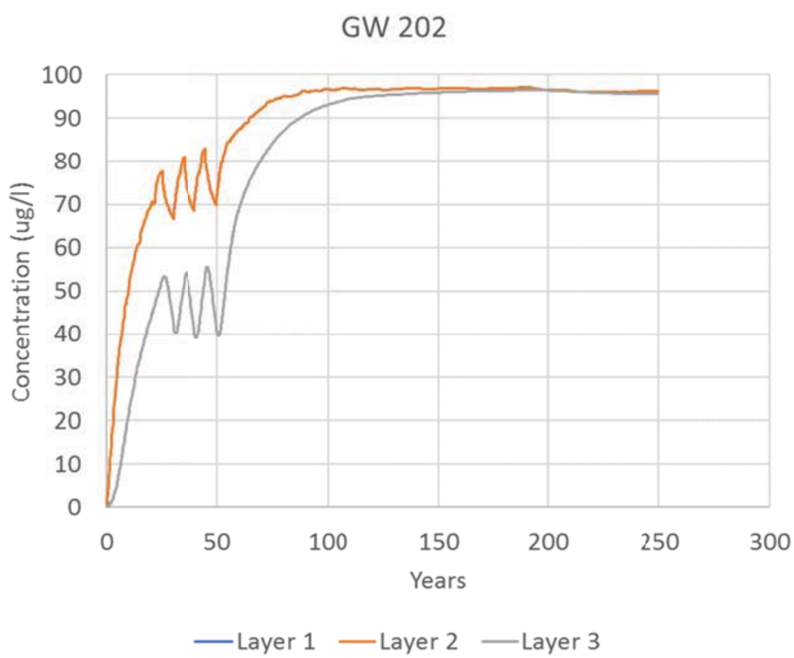

Figure 39: Graph of concentration for monitoring well GW 202, layers 1, 2 and 3.

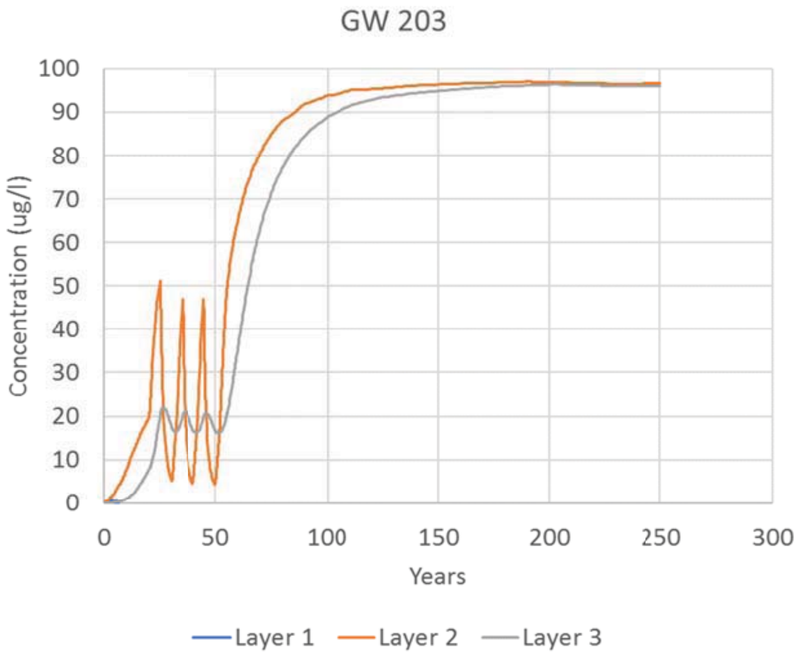

Figure 40: Graph of concentration for monitoring well GW 203, layers 1, 2 and 3.

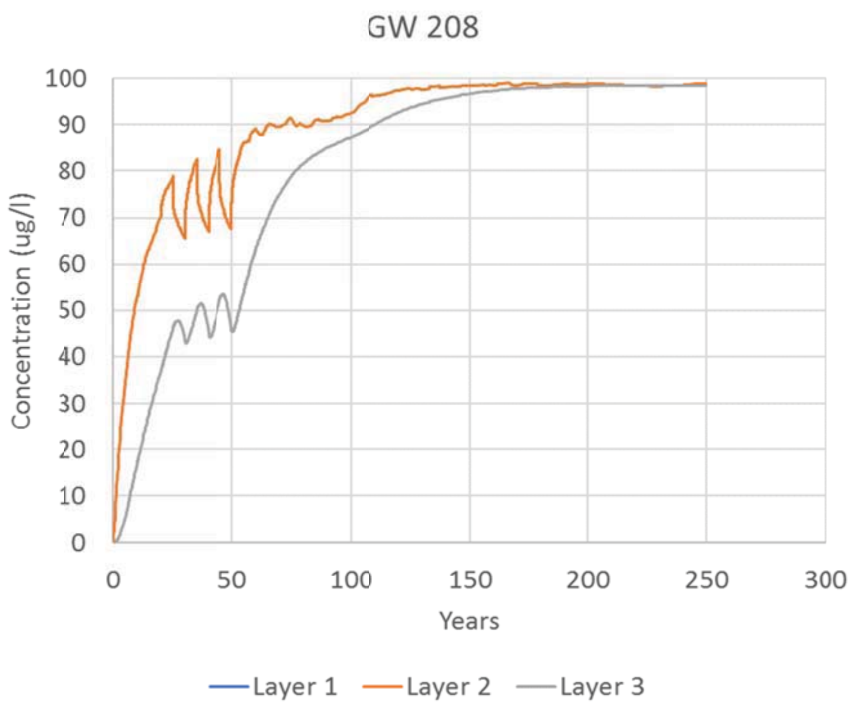

Figure 41: Graph of concentration for monitoring well GW 208, layers 1, 2 and 3.

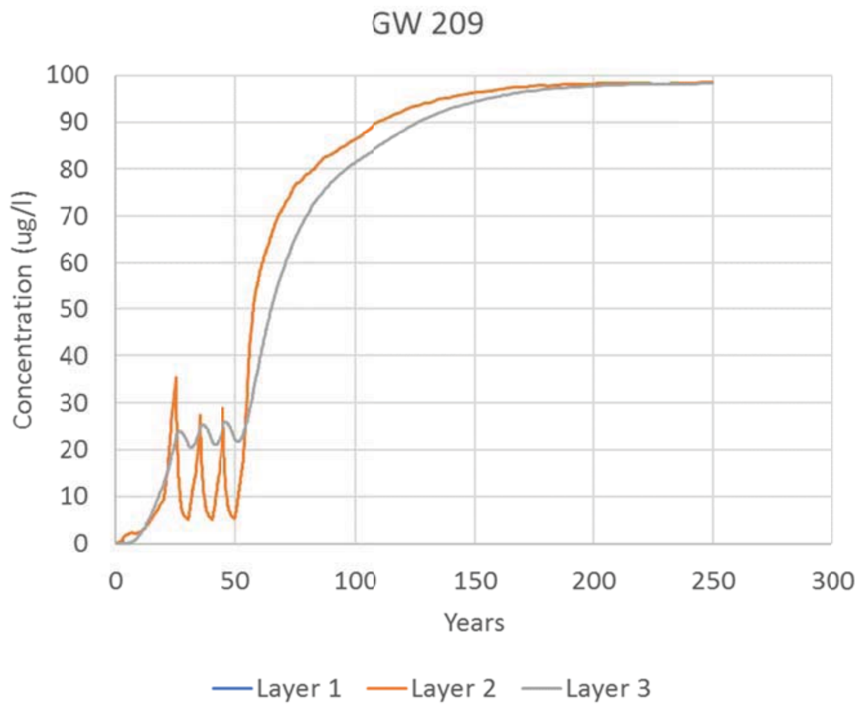

Figure 42: Graph of concentration for monitoring well GW 209, layers 1, 2 and 3.

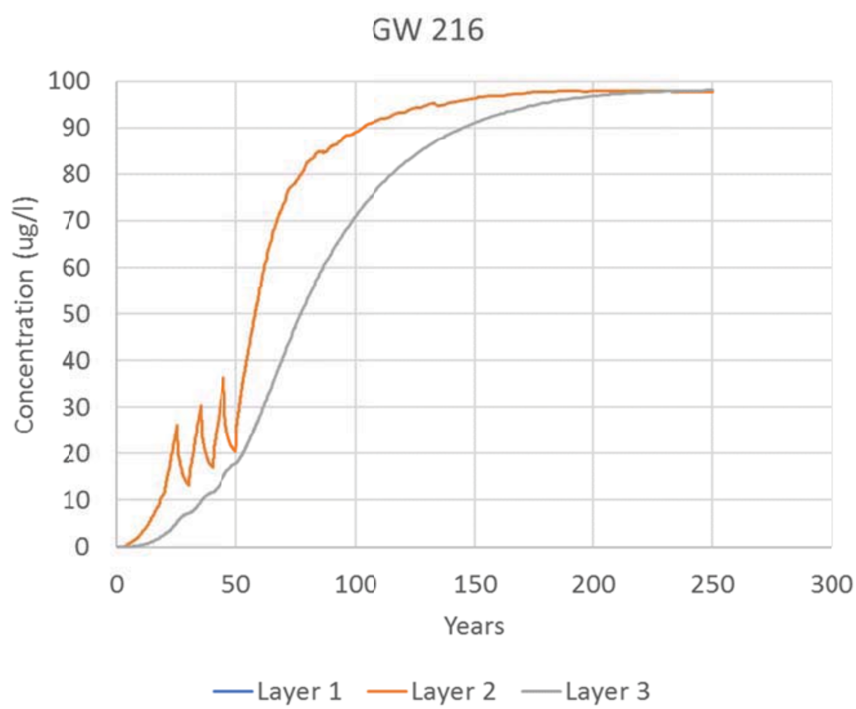

Figure 43: Graph of concentration for monitoring well GW 216, layers 1, 2 and 3.

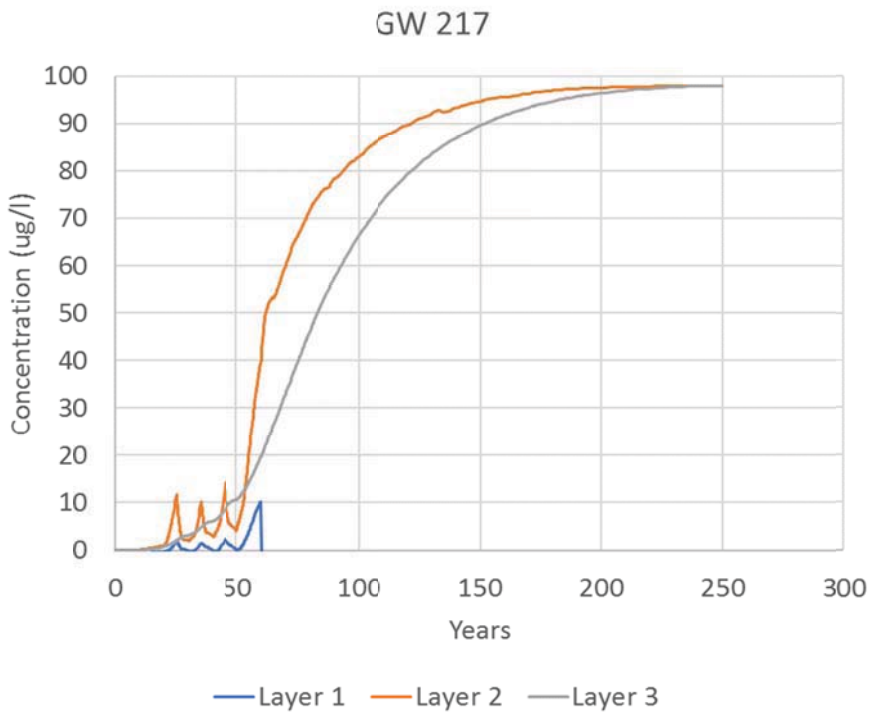

Figure 44: Graph of concentration for monitoring well GW 217, layers 1, 2 and 3.

Growth of Plume with and without Cutoff Wall

The cutoff wall has a significant effect on the expansion of a contaminant plume away from the tailings impoundment. Without the wall, after 20 years, the 10 mg/l contours have spread to the Embarrass River, but only to the edge of the impoundment for the scenario with the cutoff wall (Figures 45 and 46). After 250 years, with no cutoff wall, the 10 mg/l contour has completely opened and the 50 mg/l contour extends about halfway to the river (Figure 47). Groundwater reaching the Embarrass River over a long stretch has a concentration between 10 and 50 mg/l (Figure 48). With the wall, the 10 mg/l contour remains closed about two-thirds the distance to the Embarrass River, and the 50 mg/l contour remains near the impoundment cutoff wall (Figure 48). The horizontal extent of smaller contours is much less with the wall. The simulated cutoff wall has decreased the groundwater flux, thereby capturing contaminants, which delays the spread of and lower concentration of the contaminants. However, the simulation shows that contaminants will seep into weathered bedrock and move away from the mine site, contrary to claims by PolyMet (*see* Vol. V).

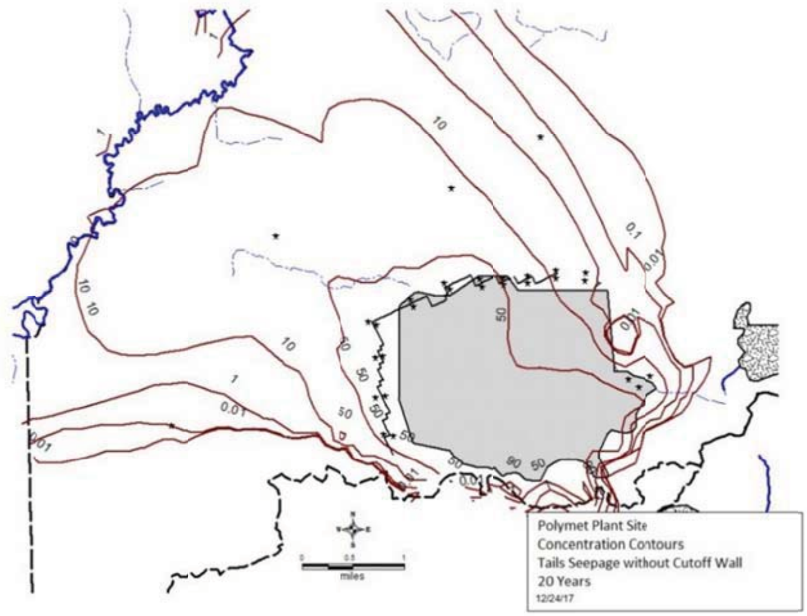

Figure 45: Concentration contours at the Plant Site, 20 years after start of mining, no cutoff wall. Layer 2.

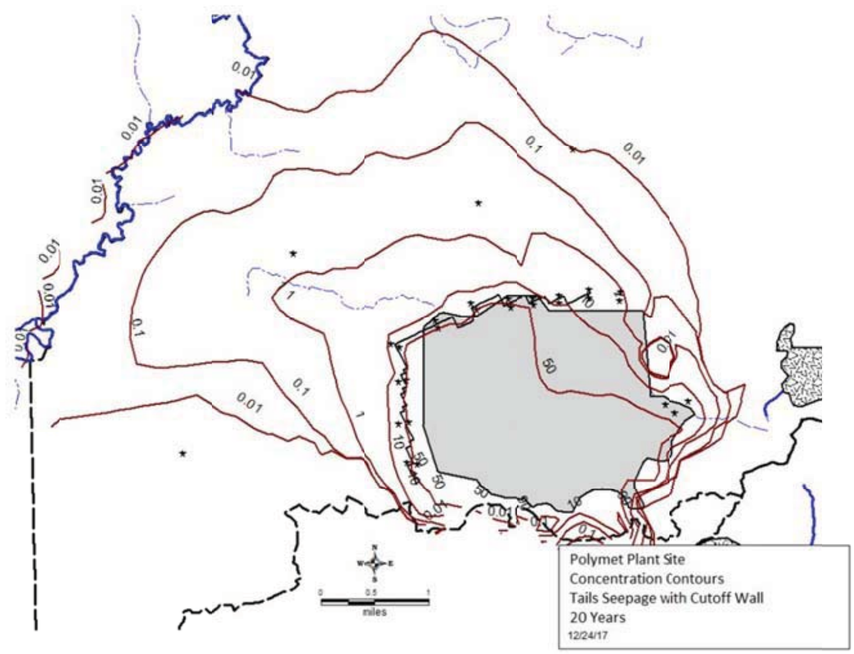

Figure 46: Concentration contours at the Plant Site, 20 years after start of mining, with cutoff wall and drain. Layer 2.

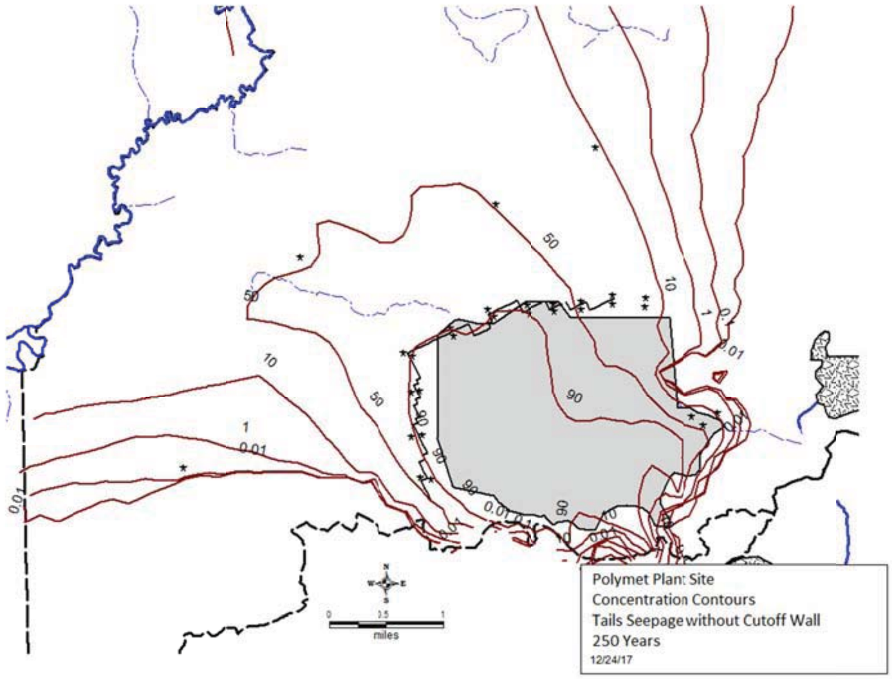

Figure 47: Concentration contours at the Plant Site, 250 years after start of mining, no cutoff wall. Layer 2.

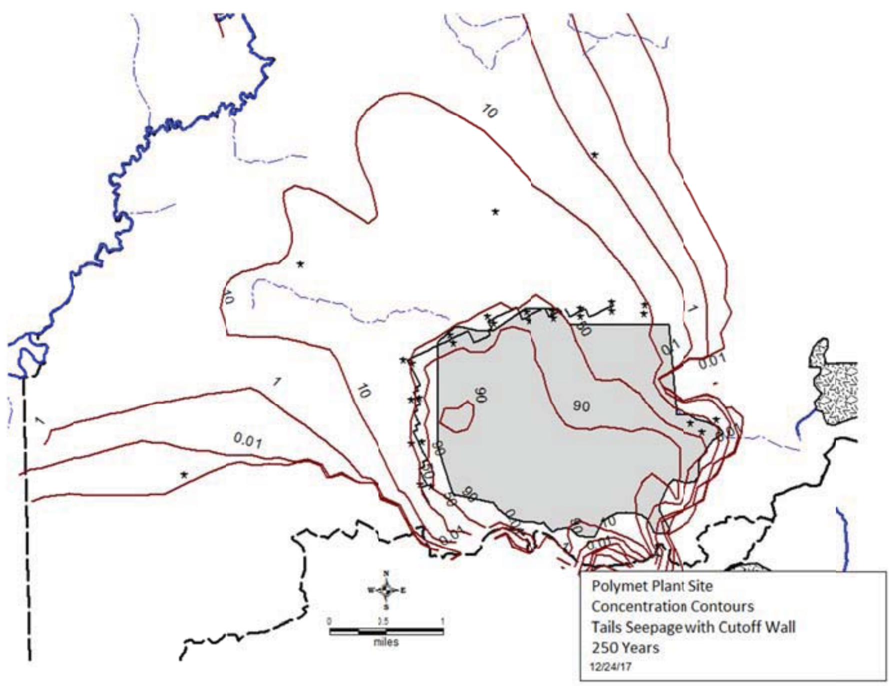

Figure 48: Concentration contours at the Plant Site, 250 years after start of mining, with cutoff wall and drain. Layer 2.

Monitoring wells midway between the impoundment and the river show a delay in contaminants reaching the wells (Figures 49 through 51). The monitoring wells do not begin responding for 20 or more years, and at least two of them began to decrease before reaching 250 years. This would be due to the lower seepage rate causing a smaller load that becomes diluted by fresh recharge. Monitoring wells, for the without cutoff wall scenario, show that concentration begins to increase within a few years (well concentration graphs not shown), so that the wells show significant concentrations years before contamination reaches the wells with the cutoff wall. Discharge to the Embarrass River (DRAIN reach 10) also reflects the differences in flow. The with-wall scenario decreases baseflow discharge by about 10%; initially the load is almost zero, but the load without a wall increases quickly. In the long-term, there is more groundwater flow and lower loads reaching the river because there is more water for dilution and the lower load concentration tailings seepage is also reaching the river.

In summary, the cutoff wall as simulated captures substantial load and slows the passage of contaminants. The response at the monitoring wells with the wall lags several decades behind the response without a wall. For some wells, the peak has not been reached after 250 years. This demonstrates that monitoring must continue for hundreds of years after closure, even if the wells show little contamination at closure.

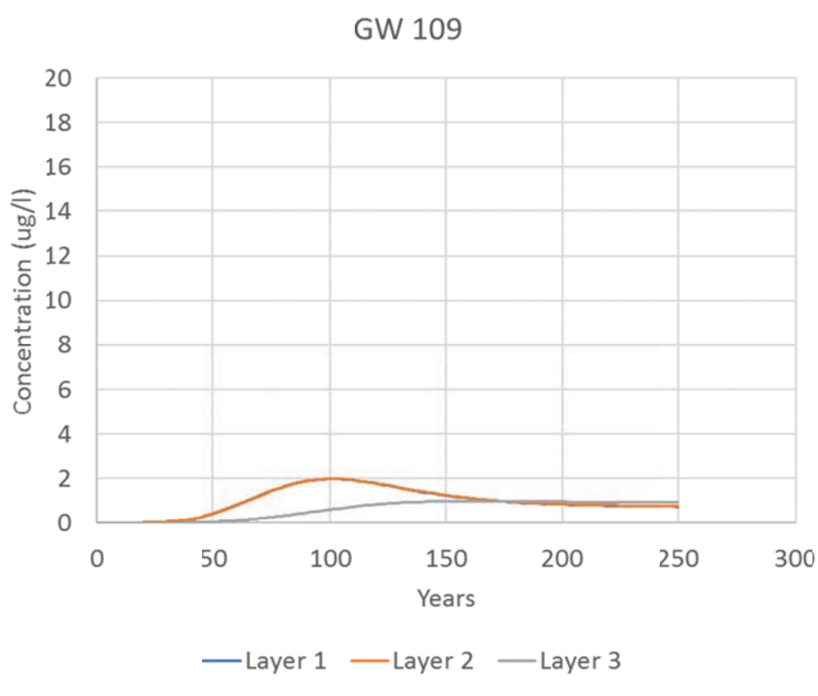

Figure 49: Graph of concentration for monitoring well GW 109, layers 1, 2 and 3, with cutoff wall.

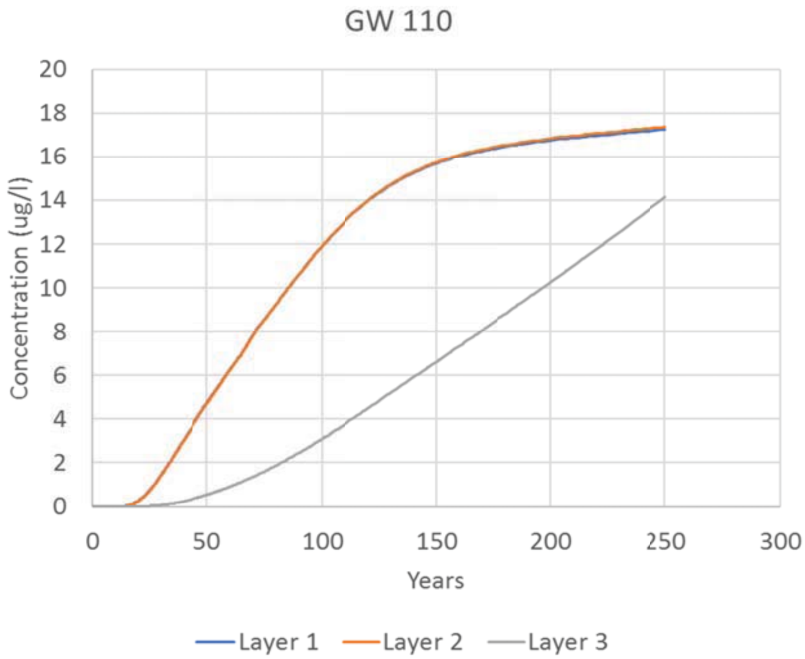

Figure 50: Graph of concentration for monitoring well GW 110, layers 1, 2 and 3, with cutoff wall.

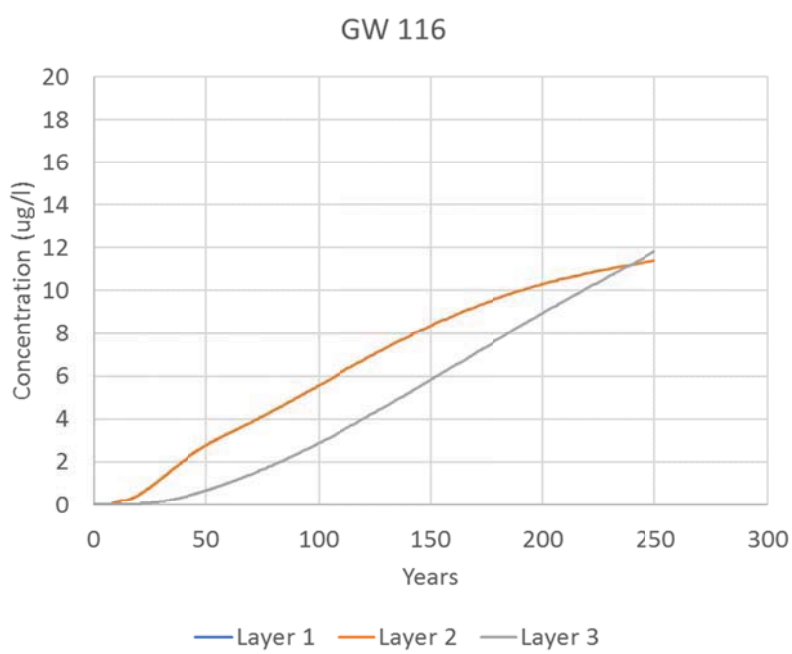

Figure 51: Graph of concentration for monitoring well GW 116, layers 1, 2 and 3, with cutoff wall.

Growth of Plume with Leaks

The with-wall scenario was also considered with four leaks occurring at different locations in the tailings impoundment. They were considered to leak at 10% of the rate for the entire impoundment while the entire impoundment continued to leak with concentration equal to zero. All contaminants in the simulation would be the result of the leak, and therefore the contours show the growth of a plume simply from one location. The magnitude of the contours is important only from a relative perspective and should be considered with respect to a contaminant reaching a given point, such as a monitoring well or the river.

Leaks at row 28, column 49, cause a plume to elongate in a northwesterly direction (Figure 52 and 51). Comparison with the plumes generated for the entire area (Figure 46) shows a direction generally more north for the leak than for the overall impoundment. Similar observations apply to leaks at row 26, column 35 (Figures 54 and 55). The plume at row 40, column 27, initially grows mostly northward, to a point near the northwest corner of the impoundment where it turns northwest (Figures 56 and 57). The leak at row 55, column 46, is closer to the middle of the impoundment, and the plume from it grows wider and resembles the plume emanating from the distributed seepage (Figures 58 and 59).

The performance monitoring wells around the perimeter of the tailings impoundment would detect the individual leaks. Because the plumes expand past the perimeter much sooner than 20 years, these wells could be sufficient monitoring for leaks. Based on the expansion of the plume, the initial detection would occur early and concentrations would increase several orders of magnitude over the simulation period. If the threshold is low enough, the performance monitoring wells could detect the leaks.

It is a different situation for the compliance wells between the impoundment and the Embarrass River. Although the plume for the leak at row 28, column 49, encompasses two monitoring wells, the center of the plume would have concentrations almost two orders of magnitude higher than at the wells after 250 years (Figure 52). At 20 years, the change at any compliance well is more than four orders of magnitude less than near the impoundment. This is due to the slow expansion of the plume, but is also due to the middle of the plume being far from the monitoring well.

The center of the plume emanating from the leak discharging from row 26, column 35, goes over a monitoring well. The plume from the leak at row 40, column 27, also goes directly over a monitoring well, but due to its northward followed by northwestward growth, compliance well GW116 would eventually detect the plume but only with a long lag time from the mining period. Two monitoring wells, would detect the plume from the leak at row 55, column 46. None of the plumes approach well GW015.

All leaks follow a general northwest pathway toward the Embarrass River. The pathway is especially obvious for the leak at row 26, column 35 (Figure 53). The plume from the leaks barely approaches monitoring wells GW015 and GW109. These monitoring wells are on the edge even of the plumes emanating from the entire tailings impoundment. The plume shapes indicate there is strong advection pulling contaminants from the impoundment in a northwesterly direction. There should be more compliance wells along the center of the plumes to increase the chances of detecting plumes.

The simulations herein are based on the standard simplifications of the hydrogeology into heterogeneous, anisotropic cells. These cells do not replicate flow through significant fracture preferential flow zones. The results herein do not obviate the concern over potential pathways not simulated herein (or by PolyMet). PolyMet should use geophysical methods to identify pathways that should be monitored.

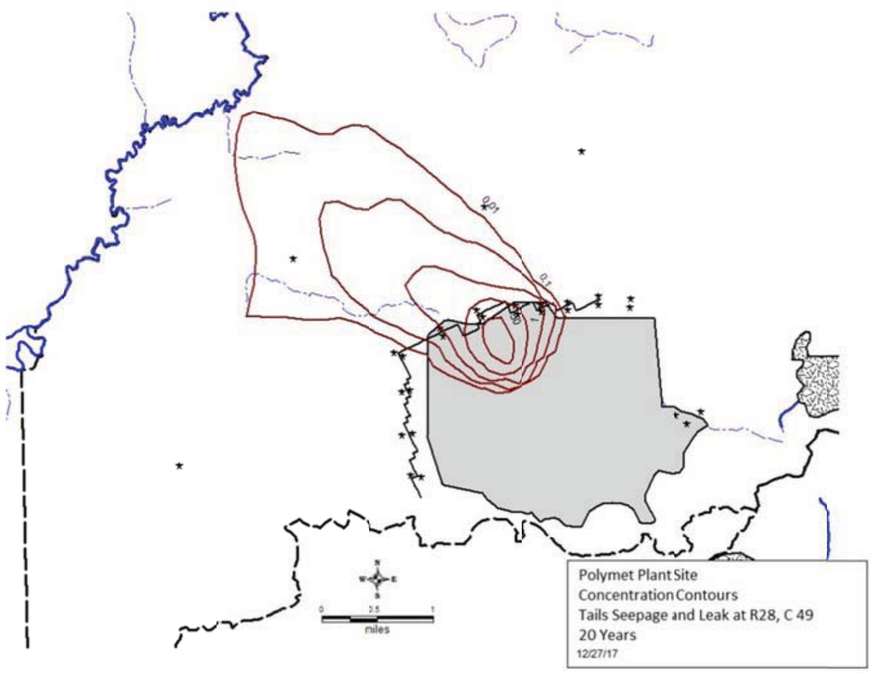

Figure 52: Concentration contours at the Plant Site, 20 years after start of mining, with cutoff wall and drain, and with leak at Row 28, Column 49. Layer 2.

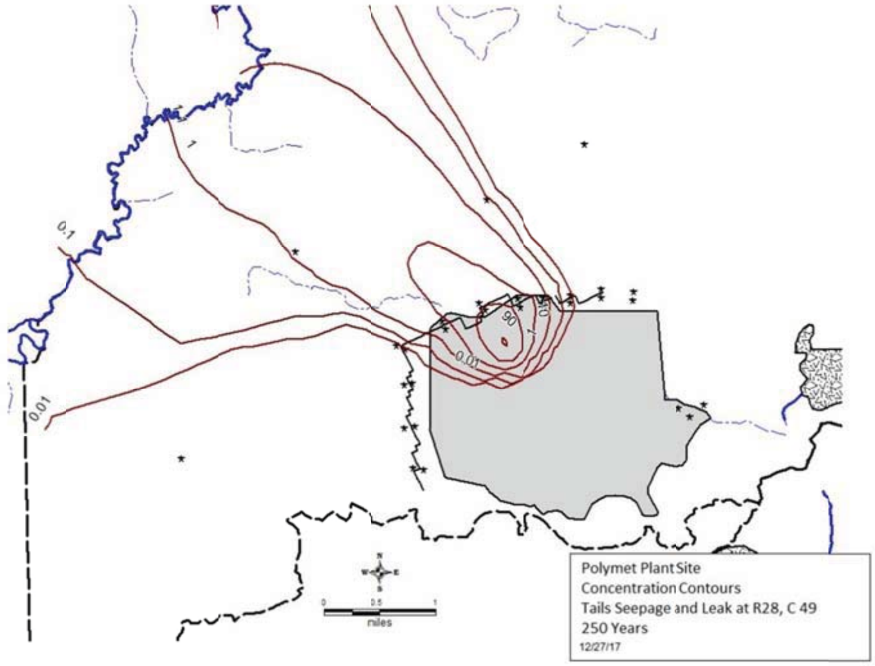

Figure 53: Concentration contours at the Plant Site, 250 years after start of mining, with cutoff wall and drain, and with leak at Row 28, Column 49. Layer 2.

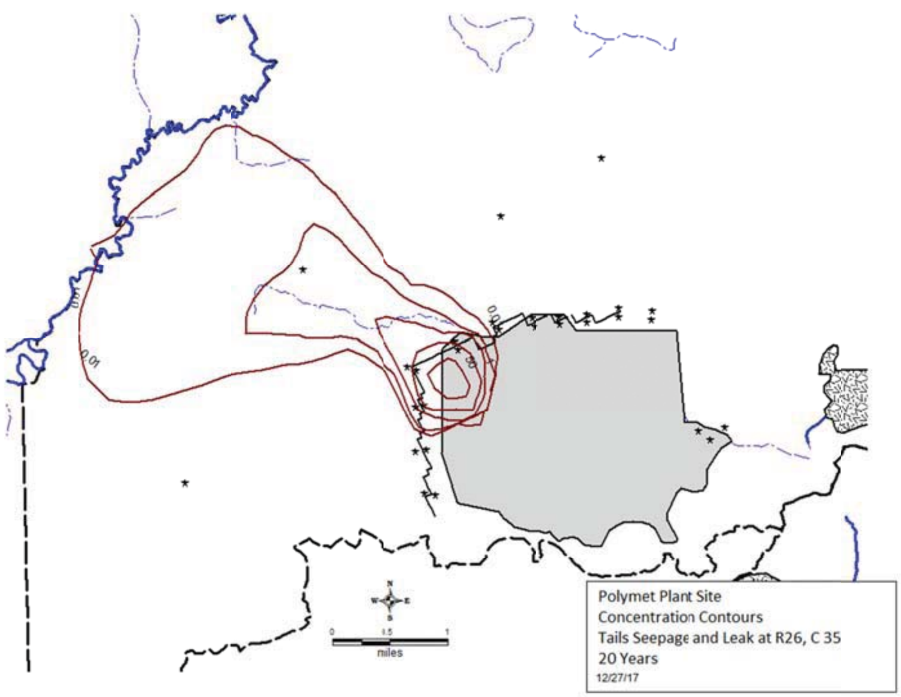

Figure 54: Concentration contours at the Plant Site, 20 years after start of mining, with cutoff wall and drain, and with leak at Row 26, Column 35. Layer 2.

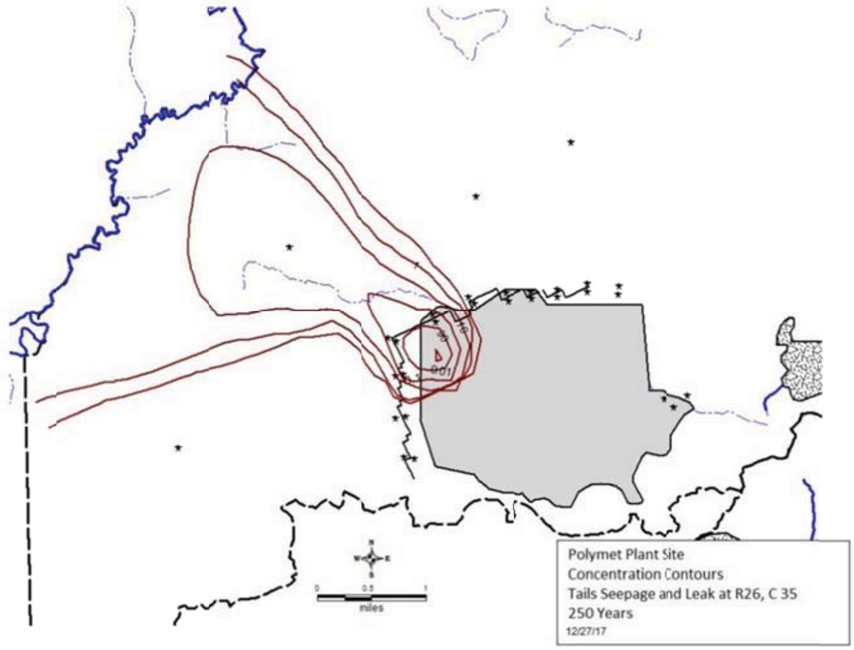

Figure 55: Concentration contours at the Plant Site, 250 years after start of mining, with cutoff wall and drain, and with leak at Row 26, Column 35. Layer 2.

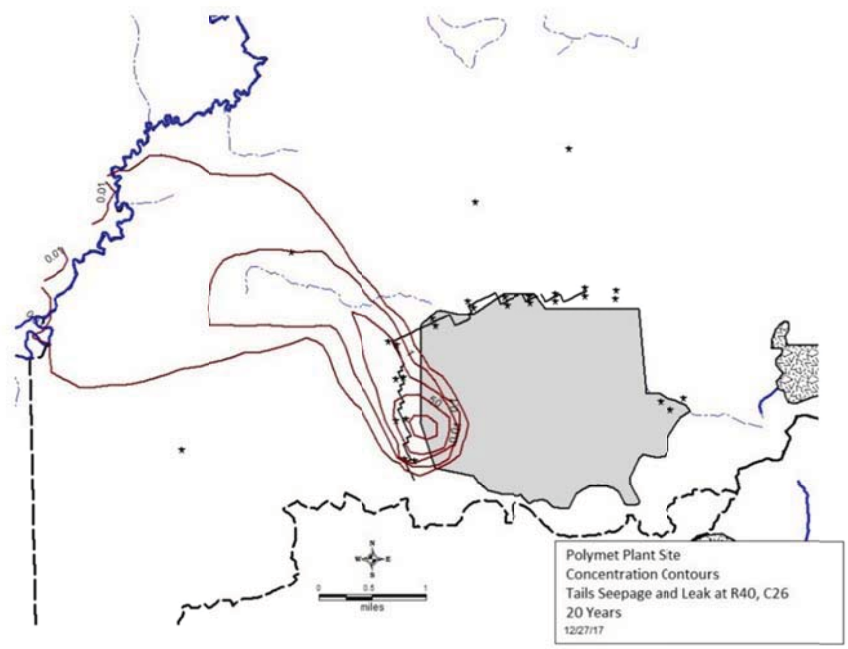

Figure 56: Concentration contours at the Plant Site, 20 years after start of mining, with cutoff wall and drain, and with leak at Row 40, Column 27. Layer 2.

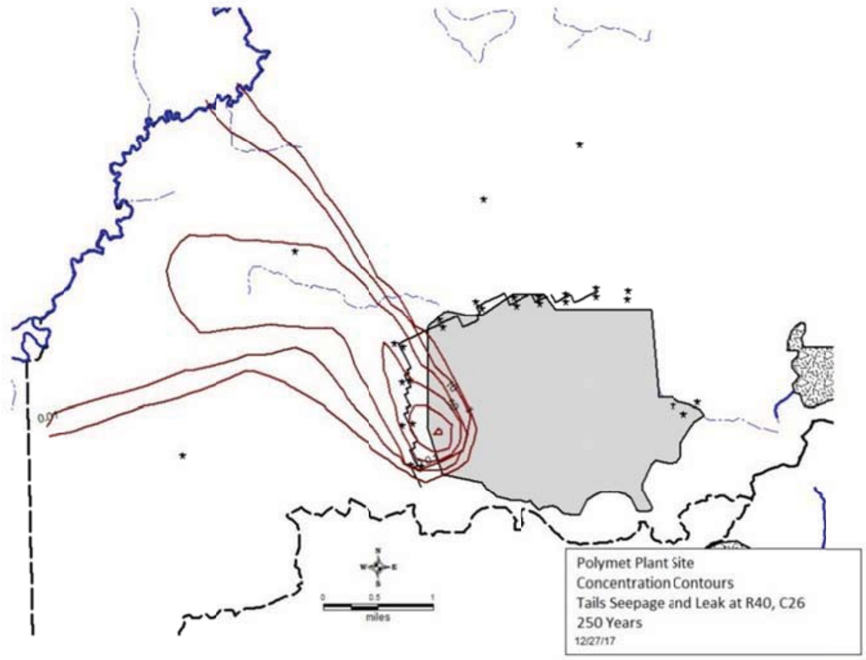

Figure 57: Concentration contours at the Plant Site, 250 years after start of mining, with cutoff wall and drain, and with leak at Row 40, Column 26. Layer 2.

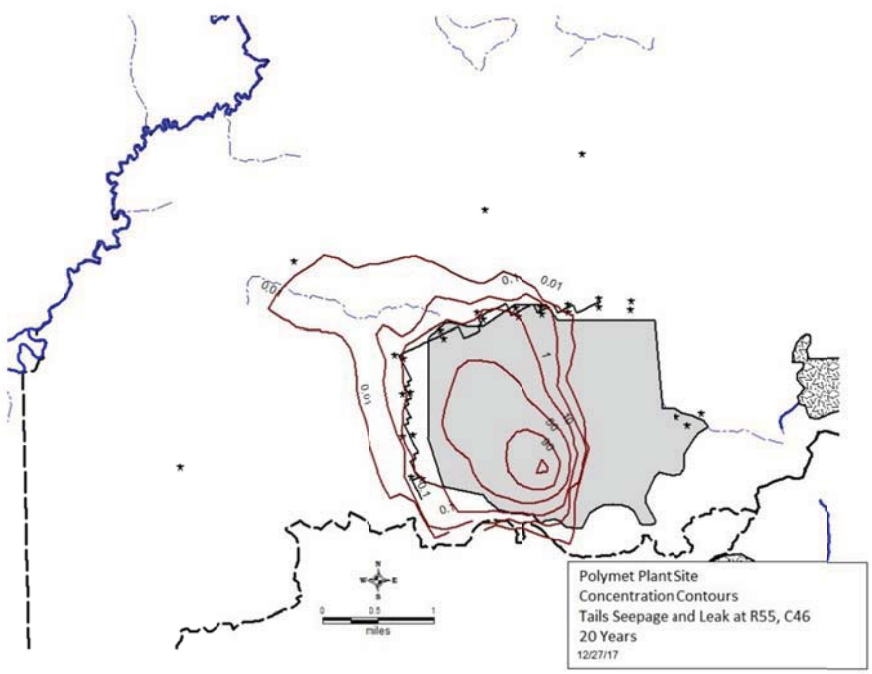

Figure 58: Concentration contours at the Plant Site, 20 years after start of mining, with cutoff wall and drain, and with leak at Row 55, Column 46. Layer 2.

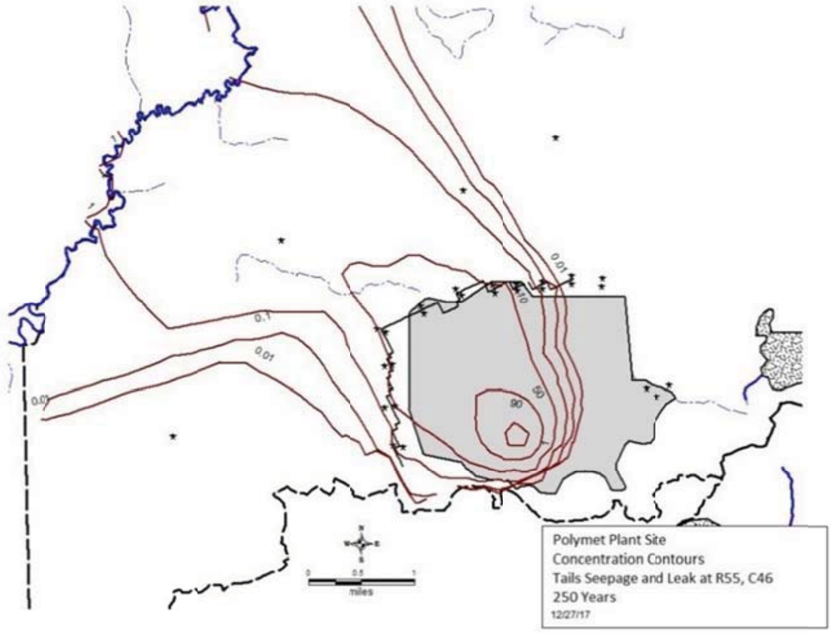

Figure 59: Concentration contours at the Plant Site, 250 years after start of mining, with cutoff wall and drain, and with leak at Row 55, Column 46. Layer 2.

Load and Discharge to the Embarrass River

Groundwater seepage in the Plant Site area discharges to the Embarrass River, simulated as DRAIN reach 10. Reach 10 extends from the headwaters to the confluence with Bear Creek, or about 13.7 miles. There are no mainstream monitoring sites for several miles upstream from this confluence. Both simulated groundwater discharge and load rates are highly variable along the reach (Figure 60), with a substantial difference between the with and without cutoff wall scenarios.

The cutoff wall made a significant difference in the load being delivered to the river, reducing from about 370,000 m^3/d*mg/l to 60,000 m^3/d*mg/l (Figure 60). About 8% of the reduction was due to a decrease in flow, which primarily is the flow captured by the cutoff wall. Because that flow contained a high concentration of contaminant, the remaining groundwater reaching the river had a low concentration.

Based on the load and flow rate reaching the river after about mile 6 where the inflow was affected by plant site load, the average concentrations with and without the cutoff wall was about 5 and 29 mg/l. The variable slopes in the cumulative load curve, both for with and without the cutoff wall, shows the need for at least four surface water monitoring points along the river, at around mile point 6, 8, 10, and 13.

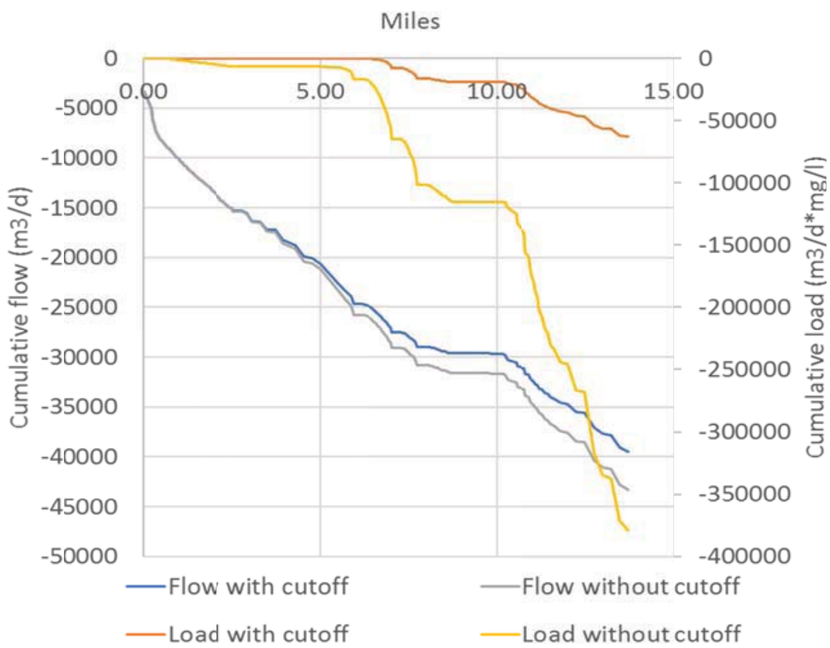

Figure 60: Cumulative flow and load on reach 10, the Embarrass River, by mile from up to downstream

References

Foth Infrastructure and Environment (2017) NorthMet Pit: Conceptual Plan for Bedrock Groundwater Flow Mitigation. De Pere, WI.

Myers T (2015) Technical Memorandum: Review of the Final Environmental Impact Statement, NorthMet Mining Project and Land Exchange. December 19, 2015, Reno NV

Myers T (2014) Groundwater Flow and Transport Modeling, Northmet Mine and Plant Site, Prepared for the Minnesota Center for Environmental Advocacy. March 10, 2014, Reno NV.

PolyMet Mining (2017) NorthMet Project Water Management Plan – Mine, Version 7-certified. December 2017

PolyMet Mining Inc. (2016) NorthMet Project, Water Management Plan – Plant, Version 5. Barr Engineering.

PolyMet Mining Inc. (2015) NorthMet Project Water Modeling Data Package Volume 1 – Mine Site (v14) February 2015

PolyMet Mine Inc. (2013) NorthMet Project, Water Modeling Data Package, Volume 1 – Mine Site, Version 11, March, 2013.

PolyMet Mining (2012) Northmet Project, Rock and Overburden Management Plan, Version 5. December 28, 2012.

Appendix B Review of Tailings Seepage Collection System, excerpted from Myers (2015)

Tailings Seepage Containment System: The FEIS presents a new report, Barr (2015b), to justify the estimate of seepage capture, or “to support the simplifying assumption that 90% of groundwater will be captured” (Barr 2015b, p 2). That is an interesting purpose for a study – to justify a previous assumption. Barr (2015b) describes a cross-sectional model that simulates the capture by the trench and cutoff walls, completed with MODFLOW. The next paragraphs summarize several errors with the modeling that suggest that the model results are not reliable or accurate.

The model is a cross-section, one foot wide, from near the edge of the tailings impoundment to the Embarrass River. The size of the model cells near the edge of the tailings impoundment is two feet. The model cell size expands systematically to 150 feet in the rows between the cutoff wall and the river. Vertical layers are also 2 feet thick. Figure 5 shows part of one of the cross-sections showing the area downgradient from the tails near the cutoff branch. The surficial aquifer (upper layer in green) is 10 model layers, or 20-feet, thick. Three scenarios were used to simulate bedrock, with fractured bedrock either 25, 50, or 100 feet thick. The bottom is a no flow boundary so that no flow leaves the bottom of the model. The discretization and model layer thicknesses are reasonable and should provide an accurate computation of the flow paths through the cross section.

Boundaries are a specified flux on the upgradient end at the edge of the tailings. The model uses a well boundary to inject seepage uniformly into each model layer. The rate for each cross-section is determined as total seepage from the tailings spread uniformly along the perimeter of the impoundment. The top of the model has average steady recharge as a specified flux recharge boundary. The top of the model also simulates a wetland, using a DRAIN boundary upgradient of the cutoff wall (to the left of the cutoff wall in Figure 5) or as a river boundary downgradient of the cutoff wall. A drain boundary is a head-dependent flux boundary that only allows water to leave the model domain and a river boundary is the same type except that water also enter the model domain if the head in the model falls below the head specified in the boundary. Only discharge from the model into the upper boundary on the surface upgradient of the cutoff wall can occur but flow can enter or leave the domain downgradient of the wall. A river boundary downgradient of the wall is not appropriate for this model because the river boundary will allow water to discharge into the model and artificially maintain the model head at a higher level. This will effectively be a hydraulic barrier preventing flow from continuing from above to downgradient of the containment wall. The report does not specify actual flux from this boundary (or to the Embarrass River), so it is difficult to be certain of its effect. This would depend on the relative difference between boundary conductance and the K in the surficial aquifer because it is possible for the head to fall below the river boundary such that the river would provide flux to the model based on a unit gradient. These boundaries may impose inaccurate controls on the flow through the section.

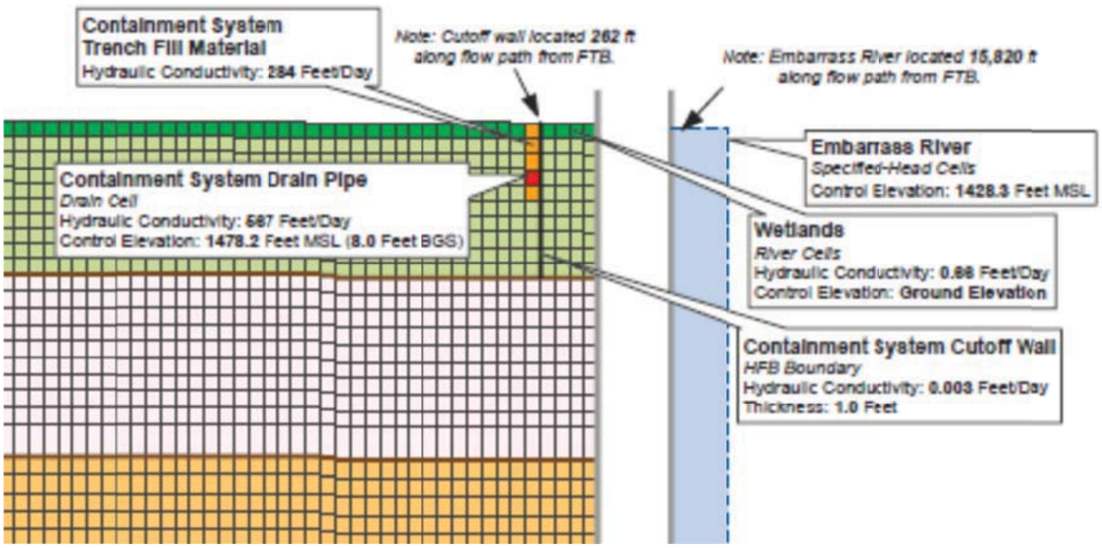

*Figure **5**: Snapshot of small portion of Large Figure 1 in Barr (2015b) showing the MODFLOW cross-section for the North Flow Path from the Plant Site.*

At the upgradient end of the cross section (at the edge of the tailings basin on the left of the section shown in Figure 5), specified seepage depends on the modeled seepage from the tailings impoundment as described above. This conceptualization forces the estimated seepage to reach the base of the tailings impoundment uniformly through a vertical section, weighted based on the relative K values. The same flow enters every possible one-foot thick cross-section spread uniformly along the vertical section. Thus, the discharge to a cross-section assumes the same amount of seepage occurs under every foot of the perimeter of the tails and that the vertical distribution of flow depends on the transmissivity of each layer.

The problem with this specified flow is that actual flux from the bottom of the tailings impoundment into the ground is not uniformly spread but rather would have substantial preferential flow pathways due to variable K in the surficial aquifer. Data presented for the plant site MODFLOW model (Barr 2015b) reviewed above shows a large horizontal variation in conductivity. The high K zones would have preferential flow, possibly many times higher than simulated here due to the large order of magnitude difference in K.

Stratification in the surficial aquifer leading to lower vertical K would cause the flow to be distributed nonuniformly vertically along the section. Seepage from the tails would flow vertically downward into the surficial aquifer where it would divert laterally and flow with the general gradient in the surficial aquifer. It would contact the underlying bedrock over all of its footprint and some would flow into the bedrock through which it would also flow downgradient to the edge of the tails. The plant site model did not even simulate bedrock, rather treating it as a no flow boundary. Because of the layering in both the surficial and bedrock aquifer, the horizontal flow would not be distributed uniformly along the vertical section. The large variability in bedrock K, from near zero to more than 3 ft/d, discussed above would lead to significant seepage in some bedrock sections and none in others.

Thus, the specified flux boundary with constant flow for each layer of the surficial and bedrock aquifer is not realistic. Because some 1-foot wide cross sections would have much more flow and it would not be uniformly distributed vertically through either bedrock or unconsolidated deposits, the model overestimates the efficiency of the drain and likely underestimates the amount of flow under the cutoff wall.

Modeled horizontal K equaled 13 ft/d with a vertical anisotropy of just 2.5 in the surficial aquifer. The bedrock layer, representing the fracture zone, had horizontal K equal to 0.14 ft/d and conditions were assumed isotropic (Barr 2015b), which means there would be no more resistance to vertical flow than to horizontal flow. Compared to the PolyMet plant site MODFLOW model which assumed bedrock beneath the unconsolidated deposits to be a no flow boundary, this is a very high vertical K. The report does not justify assuming the fractures are as extensive in the vertical as in the horizontal direction, which is necessary for horizontal K to equal vertical K. Fracturing due to weathering would have occurred along the bedding plane, which in these formations is closer to horizontal, thus horizontal K should be ten or one hundred times the vertical K.

Specified horizontal K values for both surficial and bedrock aquifers are reasonable but the vertical K is not. In this cross-section model, the low vertical anisotropy very much allows vertical flow, through both aquifer layers. The model parameters for bedrock provide almost no resistance to vertical flow which allows the seepage entering the bedrock portion of the section to flow vertically into the upper part of the surficial aquifer.

The conceptualization of the containment system is reasonable, with a horizontal flow barrier and high K cells representing a DRAIN and then a drain cell at the bottom of the drain on the upgradient side of the HFB (Figure 6). Barr (2015b) should provide references for K values in the drain because they are much higher than the surrounding formation. The design is similar to a French drain with gravel and cobbles in the trench adjacent to the wall. The bottom would have perforated irrigation pipe which Barr modeled as a DRAIN in the bottom cell. Barr set the conductance extremely high. This DRAIN would effectively control the head in the entire cross section because of the high conductance and the fact that the DRAIN elevation would be half the surficial aquifer thickness below the ground surface. The model does not consider varying conductance to reflect changes that could occur if the drain becomes clogged.

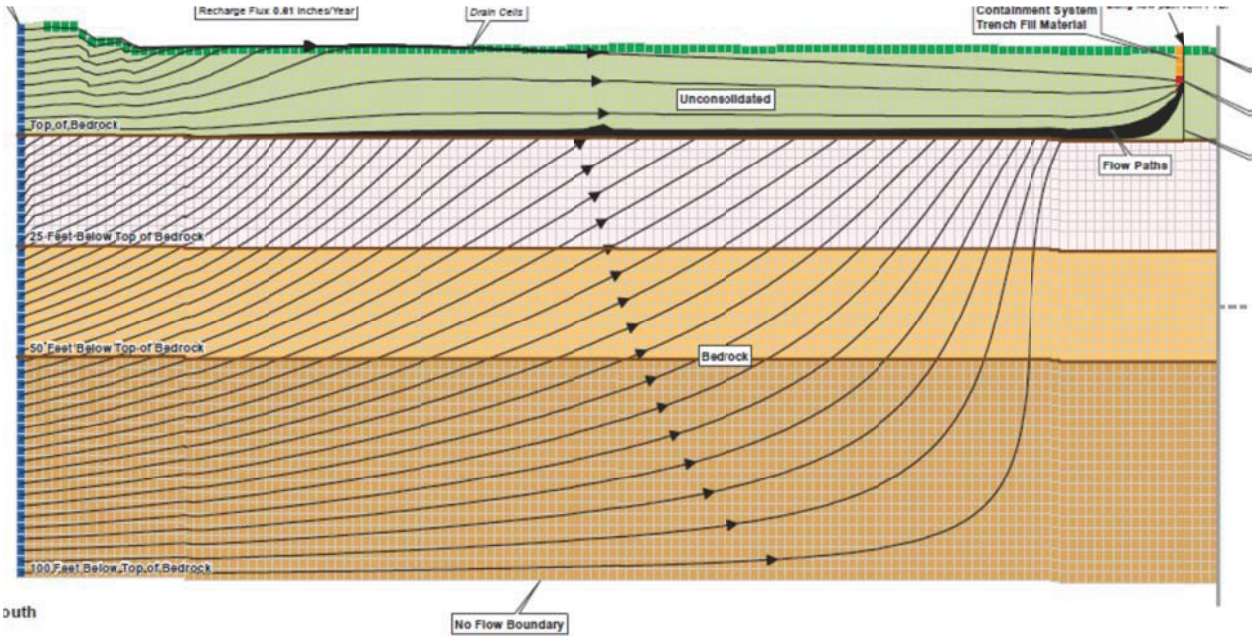

Figure 661: Snapshot of part of Large Figure 4 in Barr (2015b) showing flow paths for the cross section simulation for the North Flow Path.

Thus, at the upstream edge of the section, the well injection establishes an even flux profile in the two aquifer formations and it could be assumed the head distribution is hydrostatic. The report does not show the head at the upstream end of the section, so this is an assumption. In reality, the seepage emerging from under the tails would likely be close to hydrostatic. The DRAIN would be a local low head sink for flow. Depending on the K of the formations, the DRAIN could effectively draw most of the flow otherwise passing the wall through the section profile to the DRAIN. The high simulated vertical conductivity eases the flow to the drain. Barr should also consider a sensitivity analysis which assesses what would occur if the DRAIN conductance became significantly less; this would be a test of potential clogging of the drain.

The method of simulating flow in steady state with particle tracking was acceptable for this purpose. Essentially, the method shows the ultimate sink for flow discharging into each model layer at the edge of the tailings impoundment. However, they should also introduce particles into the river boundary below the cutoff trench.

For all but one of the simulations, none of the particle paths continued past the DRAIN, as shown in Figure 6 for the North Flow Path simulating the flux during operations. A few paths discharge into the DRAIN representing the wetlands but most discharge into the DRAIN. These results are highly unrealistic. Flow paths curve upward from 100 feet below the surficial aquifer in just a few hundred horizontal feet only because of the high relative vertical K as discussed previously. Additionally, the RIVER boundary downstream of the wall may also create a hydraulic barrier which helps divert the flux from upstream into the DRAIN; it could do this just as downstream injection wells may act as a flow barrier[2]. These factors lead to a much higher capture efficiency than is realistic.

Additionally, spreading recharge uniformly through the year, as occurs with a steady state model, would artificially increase the efficiency. Considering that factors affecting flow near the cutoff trench occurs on a much shorter time frame, recharge should be considered with more temporal variability. Seepage from the tails may not vary due to precipitation events, but recharge near the cutoff may dilute it or add to the flow rate. The flows could vary so that the capture efficiency is more variable than specified in the FEIS and at times the load passing the cutoff wall could be much higher than disclosed.

The FEIS's statement that "[m]odel results indicate that all seepage from the Tailings Basin would be captured along the north and northwest flowpaths under all assumptions of the bedrock fracture zone thickness" is true only because the model was set up in a highly biased fashion. The model was set up to confirm: "These results indicate that the Plan site Goldsim model assumption (that groundwater seepage equal to 10 percent of the aquifer's transmissive capacity bypasses the Tailings Basin containment system) is conservative" (Id.). The model was hardwired to show what the modelers were told by PolyMet to make it show. The evidence for this is that the model parameters do not resemble the parameters used for other modeling and the boundaries were set to create hydraulic barriers and sinks that will not be present in the field.

Recommendation: The cross section model is biased toward a high estimate of capture efficiency of seepage from the tails. The model should be reconceptualized with realistic vertical K in the formations and seepage from the tails that accounts for heterogeneity. The wetlands downstream from the wall should be simulated with a DRAIN boundary that does not provide a potentially unlimited source of water to the cross-section below the wall. The effect of the DRAIN conductance simulated the drain in the cutoff trench should be tested with sensitivity analysis. A proper analysis would give a range of capture efficiency that would allow the FEIS to better assess the potential flows from the tails. Failing to do that, the FEIS fails to adequately disclose the potential impacts of seepage from the tails.

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[2] The model report shows flow paths only commencing at the upstream end of the section. Initiating flow paths in the river boundaries would allow the reviewer to assess the role played by that boundary in preventing flow from passing the French drain.

The FEIS claims that Goldsim modeled the containment system conservatively by allowing "10 percent of the surficial groundwater" (FEIS, p 5-76) to bypass the system and enter pathways toward the Embarrass River. Considering the bias inherent in the modeling, this could be grossly too low.

In the Matter of the Petition by the Minnesota Center for Environmental Advocacy to Request a Contested Case Hearing for the Permit to Mine Application of Poly Met Mining, Inc.	**DECLARATION OF LORI ANDRESEN**

I, Lori Andresen, declare the following on the basis of personal knowledge to which I am competent to testify:

1. I am a member of the Minnesota Center for Environmental Advocacy (MCEA) and support its objectives in this case. I joined MCEA out of concern for the potential impacts of mining by PolyMet at the proposed NorthMet mine. I have been a member of MCEA for about twelve years. I am also a member of the Center for Biological Diversity.

2. I have long enjoyed Minnesota's environment and I believe PolyMet's NorthMet mine would directly affect my enjoyment of natural resources. I have visited and enjoyed the land that PolyMet would get in the U.S. Forest Service land exchange, as well as surrounding lands. If approved, the PolyMet sulfide mine will lead to downstream water quality degradation and other impacts, my use and enjoyment of downstream waters and related resources would be negatively impacted if the mine is approved.

3. I live in Duluth, Minnesota. My parents were both born and raised in Duluth. I was born and raised in Duluth, and have lived here most of my life, most recently for nearly the past two decades. My family owns property in northern Minnesota near the town of Isabella, near the headwaters of the Boundary Waters Canoe Area Wilderness, where we have canoed and fished for many years. During the spring and summer we fish, hike, or canoe a few times a month in the Superior National Forest, including the Boundary Waters Canoe Area Wilderness, and during the winter we regularly spend time outdoors hiking with our dogs.

4. I seek out and regularly consume local products made in Duluth and the surrounding region, including food and beverages that are produced using Lake Superior water.

5. Since I was a child, I have gone fishing in, and eaten the fish from many of the rivers and lakes in the St. Louis River watershed. This includes fish from the St. Louis and Cloquet Rivers, Island Lake, Side (Bowman) Lake, Morgan Lake, Whiteface Reservoir, Smith Lake, and Little Pequaywan. My family has long eaten wild rice from the local waters, including the St. Louis and Cloquet Rivers.

6. I have an arts background, and continue to express creativity through photography. I rarely canoe, boat, hike, or walk without one of my digital cameras, and take pictures constantly while enjoying the outdoors. My favorite subjects include nature and wild animals. I especially like to photograph local wildlife like moose, lynx, gray jays, loons, eagles, blue herons, etc. I have taken countless photos of the St. Louis River, including one that is featured on the American Rivers website.[1] These photos include wild rice from the Partridge, Embarrass, and St. Louis Rivers and other ecosystems that would be damaged or destroyed by sulfate and heavy metal pollution from upriver copper – nickel sulfide mining.

7. I own a canoe and use it to explore across the Superior National Forest. Closer to home, I have canoed the Embarrass and Partridge Rivers, two tributaries of the St. Louis River. I canoe quite often, and plan to frequently canoe in these rivers again, including this summer and fall.

8. Public lands and access to public waterways are important to me. I have also gone wild ricing on the Embarrass, St. Louis, and Partridge Rivers, and plan to do so again. In the past few years, I have also canoed on these rivers to take pictures.

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[1] https://www.americanrivers.org/2015/11/value-of-st-louis-river/

9. I have regularly boated on Lake Superior, including motor boating and sailing in the estuary of St. Louis Bay. I plan to do so again this coming summer and in future years. I have boated and sailed my whole life. We recently bought a small sailboat, as well as a small fishing boat.

10. I have visited the proposed site of the NorthMet project, including in 2005 when I toured the processing plant and did some hiking and berry picking at the potential mine site.

11. I frequently use public lands managed by the Forest Service and the State of Minnesota for recreation and harvesting various foods, and plan to continue doing so, including this spring, summer, fall, and winter. I go hiking on public lands throughout the region, and take photos of the natural beauty around me. I pick berries, herbs, mushrooms, pine cones, rose hips, and other dried plants when I can, and plan to do so this spring and summer.

12. I enjoy wildlife, and appreciate all the opportunities for animal watching that northeastern Minnesota affords me. My family has raised huskies for many years, and I often have one with me. I have regularly taken one of our dogs to the St. Louis River Bay and estuary, and occasionally they will go in the water, even though huskies are relatively water-averse. When I walk our dogs, I often see animals in the area. I especially appreciate spotting moose and birds in the area, on hikes or while driving. Continuing to see these animals in this area in the future is very important to me, both for my recreational interest and photography.

13. I have fished since I was a little girl, including river fishing. I have fished and canoed on the St. Louis, Partridge, Cloquet and Embarrass Rivers and consumed fish from most of these waters. On a trip in June of 2009 with other volunteers and friends, a companion on the trip caught a fish from the Embarrass River that was deformed. We assumed the deformity was due to already-existing taconite pollution. Taconite tailings already negatively impact the waters

in this area. I am very concerned about this existing impact on my fishing experiences and the probable worsening situation that would occur with more upriver mining, especially the mining of sulfide ores.

14. I have taken numerous trips to the Lake Superior watershed headwaters area. I enjoy and appreciate this special area of the Superior National Forest, it is quite 'wild' and provides important habitat for wildlife. I also enjoy visiting this area because I understand its importance to the Lake Superior watershed, and wish to do what I can to help protect it.

15. In 2017, I, along with two others, took trips to the headwaters area. We fished some in the nearby lakes and streams, including the St. Louis and Partridge Rivers. The hike was enjoyable due to the remoteness and solitude of the area, as well as all of the signs of moose and wolf that we saw.

16. I returned with my same companions, to the same land exchange headwaters area in November of 2017. I look forward to returning to this specific area of the Superior National Forest in the future.

17. I have flown over the proposed land exchange area numerous times, taking pictures of the former LTV plant and proposed land exchange area. While flying in a small plane, I have taken numerous pictures of the St. Louis River watershed.

18. Another specific location in the Superior National Forest that I enjoy visiting is Skibo Vista. Skibo Vista is the highest spot in this general area, allowing great views. The last time I visited Skibo Vista was in the spring of 2017. It was a clear day and we could see the site of the land exchange and proposed mine. Skibo Vista is currently closed and under construction, I will be returning to Skibo Vista once it reopens in the summer of 2018. If the federal lands that

are to be exchanged with PolyMet are logged, degraded, developed, or a mine is built on the site, my use and enjoyment of this viewpoint will be impaired.

19. I am concerned about the NorthMet open-pit mine proposal. The mining site includes or would affect precious lands that I have visited and plan to visit in the future: public forest lands, wetlands and waters. I am concerned about the impacts on wetlands at the site, especially water quality degradation and loss of moose, lynx, wolf, and other wildlife habitat. I am especially concerned at the potential catastrophic outcomes of mines, like the catastrophes in Libby, Montana, and Mount Polley, British Columbia. I fear a similar catastrophe at the NorthMet site would affect water and soil all the way downstream to Lake Superior and Duluth.

20. The NorthMet mine could negatively affect my ability to see moose and other wildlife on hikes, canoe and boat trips in the area because the mine will disrupt wetlands, and moose habitat. It would also disrupt Canada lynx and wolf habitat, and other wildlife I plan to photograph in the future. The state's moose population is already in significant decline, and lynx and wolves are already designated as threatened with extinction by the United States Fish and Wildlife Service.

21. I am concerned that this proposed mine would likely degrade water quality, affecting the recreational value of the St. Louis, Embarrass, and Partridge Rivers and surrounding area. This would impact my and my family's ability to canoe, boat, photograph, see animals, fish, and go wild ricing on the rivers and lakes, as well as the quality of our local drinking water. I am also concerned that polluted water from the NorthMet project could harm our dogs and taint the local (including Duluth) food and water supply. It could also affect air quality, leading to the deposition of heavy metals in local plant life, and preventing me from berry and plant picking.

22. I and my family own multiple properties in northern Minnesota, including in Duluth and on the northshore, and in the heart of the Superior National Forest near Isabella. Since PolyMet has been going through the approval process, lands located near PolyMet and nonferrous exploration areas have gone unsold – people are having a difficult time selling their property in these sulfide mining target areas. The real estate market in northeastern Minnesota has been destabilized by the potential for non-ferrous mining projects to move forward. According to PolyMet, their processing plant has 2/3 excess capacity with the possibility of future mine expansions and partnerships. I and my family have become increasingly concerned that if PolyMet is approved, large areas of northeastern Minnesota may be adversely impacted, including our land. Lands near PolyMet and the nearby sulfide deposits would be devalued, as no one wants to live near a copper sulfide mine.

20. If the state and federal agencies approve PolyMet's NorthMet proposed mine project, the waters and natural resources I and my family depend upon will be placed at greater risk of dangerous pollution.

21. I declare under penalty of perjury that the foregoing is true and correct.

Lori Andresen

Executed on: 2/10/2018
Date

Lori Andresen

In the Matter of the Petition by the Minnesota Center for Environmental Advocacy to Request a Contested Case Hearing for the Permit to Mine Application of Poly Met Mining, Inc.	**DECLARATION OF SCOTT MEAD**

I, Scott Mead, declare the following on the basis of personal knowledge to which I am competent to testify:

1. I am a member of the Minnesota Center for Environmental Advocacy (MCEA) and support its objectives in this case. I am grateful for MCEA's work to protect Minnesota's land, water, air, and other natural resources. In my membership and leadership roles with other conservation organizations, I became aware of, and gained appreciation for, MCEA's unique legal expertise, which sets them apart from many other conservation organizations.

2. Aside from three years of service with the United States Navy, I have lived in Minnesota my entire life. I was born and raised in Windom, Minnesota. At the age of eighteen, I joined the Navy. When I returned from service, I attended school in the Twin Cities and later began work there as a programmer. In 1969, I was transferred to Rochester, Minnesota and purchased a farm in nearby Millville, Minnesota, where I lived for 34 years. In 2003, I retired and moved from Millville to Pequaywan Lake, located north of Duluth, in Northeast Minnesota.

3. I learned to hunt, fish, and camp as a child and have hunted, fished, and camped ever since. I plan to continue hunting, fishing, and camping as long as I can. No matter where in Minnesota I lived, at all ages, I traveled around the state to access different areas and different types of lands for pristine hunting and fishing spots.

4. I live directly on Lake Pequaywan, which is upriver from the Little Cloquet River and the Cloquet River, in the Cloquet River Watershed. This watershed is surrounded to the west and

south by the St. Louis River Watershed, and the Cloquet River is the main tributary of the St. Louis River. I moved here in 2003 and, apart from my travels, have lived here since.

5. I am a longstanding and active member of conservation and environmental protection organizations in Minnesota. I am an active member and board member of the Izaak Walton League, W.J. McCabe Chapter, in Duluth, where I have been a member for ten years and a board member for seven years. I am an active member of Ducks Unlimited Minnesota and have been a member for over thirty years, first in Southeast Minnesota and now in Northeast Minnesota. For seventeen years I was on a local committee or a board member with Ducks Unlimited Minnesota. My wife and I have been active in our local Pequaywan Lakes Association since moving in 2003. We have scheduled programs on issues pertaining to the healthy conditions of our lake and nearby watersheds. We work to involve and inform other lake residents. My wife has served as the Association's chairman for eight years. I am also a township supervisor for Pequaywan.

6. I am currently retired. I worked on a farm during High School, where I began to develop an understanding and respect for good stewardship of the land and water. After service in the Navy, I returned to school to study electronics and become an electrician. I soon became a programmer, and I programmed professionally until my retirement.

7. Soon after I transferred to Rochester in 1969, I purchased a 120-acre farm in Millville. I raised horses, cattle, and hogs on that land, and rented out much of the basic cropland to other local farmers. I grew my own hay and allowed much of the livestock to pasture.

8. Conservation and stewardship were top priorities in my approach to farming. On April 22, 1970, I planted 2500 trees on my land because I wanted to encourage my land to become a wildlife sanctuary. I later learned that this date also marked the first Earth Day.

9. By the time I left the farm in 2003 to move to Lake Pequaywan, I had successfully realized my goal of creating a wildlife sanctuary. The land had 6500 trees and over one-third of the entire land was in the US Department of Agriculture-Farm Service Agency's Conservation Reserve Program (CRP). As a part of that CRP land, I would plant at least an acre of grain and forage sorghum, along with sunflowers, and an acre of corn to encourage wildlife to use the land.

10. I am an avid fisherman. I fish both recreationally—catch and release—and for food —preparing, cooking, and serving fish for my family. I take care to practice conservation in my fishing. I regularly fish in Lake Pequaywan, which primarily hosts walleyes and crappies. I leave the large and small walleyes to maintain breeding stock, but I cook and eat what is appropriate. I winter fish on Loaine Lake, a trout lake, which is four miles by snowmobile from my home. I travel to many nearby lakes within the St. Louis River watershed to fish for food and recreation, including Comstock Lake. I still fish all over Minnesota, and just last month returned from a catch and release trout-fishing trip to Southeast Minnesota. However, I primarily fish the waters near my home.

11. I have hunted ducks, pheasant, deer, and grouse across Northern Minnesota for most of my life. I am able to hunt in part because good conservation practices encourage wildlife populations. This is something I learned and practiced when running a farm for much of my life. I plan to turkey hunt on my upcoming hunting and fishing trips, and when I return to Pequaywan, so long as I am able, and so long as the public lands remain secluded and ripe for hunting, I will continue to hunt in the Cloquet River and St. Louis River Watersheds. Much of the best hunting is on public lands, where I often hunt.

12. I love to bird watch and to feed birds. I protect the loons that come to Lake Pequaywan in the summer. When I am out hunting or fishing, I enjoy more than just the activity, I enjoy going

out into nature, seeing the natural environment and healthy ecosystems in my area and across northern Minnesota. I know that the ducks and other waterfowl that I hunt, feed, and protect need wetlands and other clean water bodies in order to survive and thrive.

13. All three of my sons attended college in nearby Duluth and have resided there much of their lives. They and my nine grandchildren often visit and, with their dogs, regularly swim in Lake Pequaywan. It is good, clear water, with just a brown tinge due to drainage from the surrounding forest areas. My family and I often also travel locally to public lands for purposes of camping, hunting, fishing, hiking, and swimming.

14. I participate in the Minnesota Pollution Control Agency (MPCA) Citizen Lake Monitoring Program. As a part of this program, I test the water-quality on Lake Pequaywan. Beginning in early summer, I record water clarity and describe the water in the lake every three weeks. At the end of the year, I submit data to MPCA.

15. Recently, the Minnesota Department of Natural Resources (DNR) studied Lake Pequaywan for invasive species. The researcher issued a lake report, which noted that the lake is pristine with no invasive species.

16. My home uses a 220-foot well for its water. I, along with my family and grandchildren, use the groundwater from my well for drinking, washing, and bathing. When I moved to my home, I had the well water tested. I tested the water again for bacteria and chemicals in 2012. I wanted to get a baseline reading while the well was untainted so that if there is groundwater pollution from any industrial presence, I will know.

17. As a former farmer in Southeast Minnesota, I am very aware of the risk of groundwater contamination and very concerned with how easily pollution or water depletion in one area can affect distant users in connected aquifers. When groundwater users or polluters affect deep

groundwater, whether on lands that neighbor my own or on lands many miles away, those impacts can affect my groundwater. It is hard to identify what polluted water will do when it is underground, and if nearby mining projects affect my groundwater, I will be forced to dig a deeper well, find another water source, or, if possible, treat my water to usable standards. All of these options will come at significant financial cost to me.

18. My son is a park naturalist. I often visit him at his residence near Finland, Minnesota, which is surrounded by the Superior National Forest. While there, we hunt deer, fish trout, camp, and hike. I enjoy the feeling of seclusion and being distant from civilization, as well as the great hunting and fishing available on the Superior National Forest public lands.

19. When recreating with my family on public lands, my wife loves to photograph. She has documented many of our family trips with photos of our family and the lands on which we love to camp and recreate. My wife is a painter and she has painted landscapes of many of the areas we have visited. Much of her art is inspired by the pristine nature and wildlife we seek out from public lands. These photographs and paintings inspire us in our home and connect us to the land and waters we have sought to live near and protect.

20. I am concerned about copper-nickel mining in this watershed and area. Many mines claim to cause no pollution, but mines I have seen in Wisconsin appear to be leaching into the surrounding environment. A new copper-nickel mine with holding ponds will flood into the watershed and lakes and streams, and the ponds will also leach and get into the groundwater.

21. I am aware of the NorthMet mine proposal and am concerned about the impacts it would have on the rivers, lakes, and groundwater near to and supporting my family's home. I am also concerned for the impacts to the lands and waters to which I travel. Access to and enjoyment of these public lands was a large reason why my family and I decided to move from our farm in

Millville up north to Pequaywan. Much of my life is built around the seclusion and pristine nature of Northeast Minnesota's public lands and the wildlife that also resides here—wildlife that will also be negatively impacted by this operation. The unique untouched nature of many of these public lands encourages some of the world's best hunting, fishing, and camping, which I am fortunate to enjoy during my retirement, and which I do not want negatively affected.

22. I am concerned that the NorthMet mine will require maintenance of the site for the foreseeable future, at least 500 years or more, in order to prevent the pollution on the site from contaminating the surrounding environment and watershed.

23. I am concerned about the sulfuric acid effect of pollution leaving the mine site. I believe the pollution would be more extensive and damaging than the company realizes, and they will not have put up enough money for the maintenance required to keep pollution from getting off the mine site. Once pollution gets into the groundwater, it will go wherever it wants and will impact distant lands, waters, and wells.

24. I go shopping and go to church in Duluth. I spend time in Duluth, and my favorite restaurants include the Duluth Grill, where I typically eat with my family after church. This restaurant, like some others in Duluth, uses primarily locally sourced foods and beverages, and of course, uses the local water. The Duluth retailers and restaurants need the healthy environment in this area for their locally sourced foods and beverages and need to be able to provide safe drinking water to me and other customers.

25. I purchase and eat wild rice. I prefer to purchase and eat wild rice that has been harvested by local Indian tribes who have been harvesting wild rice in these areas for many, many years. I am concerned about the likely impacts to wild rice that will occur as a result of the NorthMet

project, and I fear that the tribes who harvest this rice, and who I wish to continue to support with my purchasing habits, will be negatively impacted.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: February 23, 2018 /s/ Scott Mead______________________

Date Scott Mead

In the Matter of the Petition by the Minnesota Center for Environmental Advocacy to Request a Contested Case Hearing for the Permit to Mine Application of Poly Met Mining, Inc.	**DECLARATION OF RICHARD STAFFON**

I, Richard Staffon, declare the following on the basis of personal knowledge to which I am competent to testify:

1. I am a ten-year member of the Minnesota Center for Environmental Advocacy (MCEA) and I donate to the organization, and participate in its activities. For example, in August 2015, I helped with an MCEA event in Duluth by describing MCEA's work and how it affects the Boundary Waters Canoe Area Wilderness and Lake Superior watersheds. I appreciate MCEA's work to protect Minnesota's natural resources, especially its legal expertise—a unique skill in conservation organizations. I believe MCEA is careful and moderate but very skilled in the issues it selects to pursue.

2. Apart from three years in Colorado for graduate school, I have lived in Minnesota since I was seven years old. Growing up here, I fished, hunted and camped, and I still fish, hunt and camp on a regular basis. I plan to keep doing so. My wife and I love to travel, but Minnesota always looks really good to come home to.

3. I own property in Cloquet, a city which straddles the St. Louis River, and with many properties, like mine, located not far from the river. I moved to this property in 1980, and have lived there since then.

4. I am concerned that my property will be affected by the proposed Poly Met (NorthMet) mining project if it is allowed to go forward without proper controls because part of the value of that property is its proximity to the St. Louis River, which is downstream from the

project. I am also concerned that my property will be affected by the NorthMet mining project because part of its value is its proximity to areas where fish and wildlife abound, and these resources may be affected by pollutants released by the project unless it is appropriately controlled.

5. I am very familiar with the land and wildlife in the vicinity of the proposed project and areas that could be affected by downstream impacts from that project, if it is not properly permitted. Before my retirement, I worked as a wildlife manager for the Minnesota Department of Natural Resources (DNR) for thirty-six years. I worked primarily in Carlton, Pine, and St. Louis Counties, and the St. Louis River goes through the center of my former work area. While I worked for the DNR, I worked regularly on wildlife issues in and around the St. Louis River. I worked on a project that resulted in the DNR's acquisition from Minnesota Power of 22,000 acres of land located along the river and I helped in drafting a management plan for those lands. I managed two state wildlife management areas located on man-made islands in the St. Louis River estuary, performed a wetlands inventory for the St. Louis River estuary, and I worked on habitat restoration, and on wild rice issues. For many years, I coordinated and conducted the survey and banding of Canada geese in the St. Louis River estuary as that population established and rapidly expanded following the cleanup of the river. I also worked on plans for restoration of Superfund sites in the watershed. Working for the DNR, I invested a great deal of time and energy in the St. Louis River watershed. I remain concerned about and committed to its protection.

6. One if my particular interests is in maintaining the health of wild rice. In my position at the DNR, I did aerial surveys of wild rice in the region. We also hand seeded wild rice by canoe in several wetlands and lakes to reestablish stands of wild rice. Water control

structures were installed and maintained on several water bodies to enhance and maintain stands of wild rice. My interest with wild rice has continued, as I am a hand-harvester of wild rice in public waterways in the region. As a result of my professional and personal experiences, I am interested in preserving the wild rice resource for my use and that of others. I am concerned by all potential pollution impacts to wild rice that will reduce its presence in the future and impact public access to healthy wild rice waters.

7. I had contact with the W.J. McCabe chapter of the Izaak Walton League of America (Ikes) during my time at the DNR, and the Ikes assisted and participated in many wildlife management plans for the St. Louis watershed. The Ikes are a national grassroots conservation organization founded in the 1920s by fishermen concerned about the Upper Mississippi River, and local chapters focus on soil, air, water, and youth education projects that promote or protect wilderness and other public lands.

8. I joined the W.J. McCabe chapter in 1998. Many of our members are hunters and fishermen. The chapter is focused on maintaining public access to public lands to engage in outdoor activities such as camping, fishing, and hunting. I believe that average Americans' access to public lands is a necessary prerequisite to experiencing these activities. These lands are to be held in trust for the public and managed sustainably by our natural resource agencies.

9. Since retiring from the DNR in 2012, I became president of the W.J. McCabe chapter, which is based in Duluth. The W.J. McCabe Ikes chapter takes a special interest in the St. Louis River and estuary at the headwaters of Lake Superior. As part of my work with the DNR and the Ikes, I helped to acquire the Minnesota Power lands on the St. Louis River. I was motivated to complete this project because it involved protecting a large swath of land in the

watershed so that those who use these resources, including myself and my family, would benefit from the restored area.

10. I have put significant amounts of my own time and resources into cleaning up the waters that have the potential to be polluted by the PolyMet project, if permitted. For example, I worked with the Ikes in a recent stakeholder group with the city of Duluth on plans for the Western Waterfront Trail to help rehabilitate and extend the trail, to control exotic species, and to improve public access to the river. Controlling exotic species is made harder when an ecosystem is polluted, harming native species. Pollution could also reduce the recreation value of the river. The Western Waterfront Trail is a trail that runs along the lower St. Louis River, in western Duluth. We have been working on this project for over three years, and in June of 2015, we supported the project by hosting a public forum to get citizen input on their desires for the trail. We held this public forum to also educate local residents and identify resources for the city. About one-hundred twenty-five people attended to hear the speakers, as well as a regional planner from another area.

11. I have been a fisherman for about sixty years, almost my whole life. Although I primarily fish in lakes, I have sometimes fished on the St. Louis River, and plan to do so in the future. I consume the fish that I catch from the St. Louis River and inland lakes, and so I am especially concerned with keeping the river clean so that I can continue to catch and eat fish from the St. Louis River. I am concerned that pollutants from the NorthMet project will make their way into the fish in the St. Louis River, especially the likelihood that it could increase the level of mercury contamination of fish in the river.

12. I canoe regularly, and, because I live so close, I canoe in the St. Louis River. I have been canoeing in the Duluth and Cloquet area and in the St. Louis River since I moved here

in 1980. I will usually canoe in the St. Louis a couple times each year. I plan to continue to do so as long as I live in the area. I am concerned that pollutants from the NorthMet project will affect the quality of the waters that I canoe.

13. When I worked for the DNR, one of the tasks I performed for the St. Louis River wildlife was to set up wood duck boxes on the river. Although retired now, I volunteer regularly with the DNR and continue to monitor these boxes, including checking up on them as recently as the winter of 2016, and I intend to continue with this volunteer work in the future. Because of these interests, I am very interested in helping to ensure that the St. Louis stays uncontaminated by pollution from mining operations.

14. I am aware of the proposed NorthMet project, and am concerned by its potential impacts on the St. Louis River watershed. The state and citizens have spent millions of dollars to restore the lower St. Louis River and this mine could put the river right back into trouble. I have personally expended significant resources in projects to clean up this area and maintain it for wildlife and the public. Through my work with government agencies and non-governmental organizations, like the Ikes, I have devoted a great deal of time and energy to protecting and restoring this watershed and this pollution could gut these efforts. I am not opposed to mining on principle, but I believe it to be a risky endeavor in a water-rich environment like Northern Minnesota, and PolyMet's proposed mining plan is not responsible because it is likely to degrade water quality. Copper-nickel mining involves highly risky practices and the existing and former taconite mines in the area already cause water quality problems.

15. I am concerned that water at the proposed mine site would flow downstream, carrying heavy metals and sulfates that will negatively impact plant and animal life in downstream waters, as well as water quality. I am also concerned that the increase in sulfates

will result in greater mercury contamination of fish in the river, which is already a serious problem.

16. I remember what the water was like in the St. Louis fifty years ago when I attended high school and college in Duluth: mothers warned their children not to swim in it, and industries along the river treated the water like a waste-dumping site. Duluth as a city kept Lake Superior and the St. Louis estuary at its back, and was focused away from the waters. The river is much cleaner following years of restoration work. Today, Duluth's attractions include the waterfront; the city faces the water now. I would not like to see it slide back into its former stance. I have devoted considerable time, resources, and effort to conserve this area and this proposed mine threatens all of that.

17. I am concerned that a decline in water quality would make canoeing in our own "backyard" impossible, and that would change how I can make use of the area. Polluted water would harm wildlife and likely would make it less safe and enjoyable for me to hunt ~~deer~~ waterfowl who use the river. Fishing in the river would also be a much riskier endeavor, and I would likely avoid it altogether.

18. I believe that a contested case hearing is the best way of determining whether this project will in fact pose the threat to wild rice, fish, and other wildlife in the St. Louis River watershed that I love.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: *2/27/2018* *Richard C. Staffon*

Date Richard Staffon

DNR Review of PolyMet's Dam Safety Permit Application: FTB
Reviewers: Jason Boyle and Dana Dostert

Comment #	Page	Section or Table Number	Comment/Concern	Date Discussed	PolyMet Response
1		General Comment	There are 9 separate references, not including the 2 references attached to the application. Please inform us of pertinent updates to other documents as the permitting process proceeds. The following comments are related mostly to the July 2016 Application document, not any of the 11 references.		
2		General Comment	The application, drawings, specifications, and all references need to be updated to reflect the current design showing the increased buttress, footprint, and deletion of the CDSM wall.		
3	6	Table 3-2	I assume bentonite means sodium bentonite, but that should be clarified somewhere as there are several types with differing properties.		
4	7	3.5	We agree dam breach is unlikely during the 20 years of plant operation but think there is a much higher possibility of dam failure during the indefinite post closure phase. This should be addressed in the documents.		
5	7	3.7	Please present more information on the purity and material parameters of the bentonite.		
6		FTB-003	Area 1 between Cell 2W and 2E is a major borrow area for coarse tailings and will be flooded by Polymet tails once operation begins. Will remaining materials below the excavated level, assumed to be coarse tailings, be a drain or leak for Polymet slurry into the underlying ground or possible exiting at the north toe between cells 2W and 2E?		
7		FTB-003	What will be the sequencing order for the borrow areas?		
8		FTB-009	If the intention of the bentonite on the perimeter lifts is to reduce the infiltration of rainwater, atmospheric humidity and oxygen into the Polymet tails, does not the underdrain become a source for those waters, humidity and oxygen?		
9		FTB-009	If water levels get too high in the basin, will those underdrain layers become artesian and a source for acid mine drainage?		
10		FTB-012	Why is there no underdrain layer needed for the east dam?		
11		FTB-015	Very uncomfortable with a 15% grade in the overflow channel. I assume the whole channel is concrete, other than the energy dissipater. What can be done to reduce these velocities?		

12		FTB-015	1). Will this create a hydraulic jump at the flat sections?		
13		FTB-015	2). How long will concrete last in this environment?		
14		Comment on Pond Closure and Management Plan	More development and discussion is needed related to the closure pond, spillway and overflow channel. Need to know what water levels in the pond need to be maintained: When to add water when water surface elevations are too low; frequency of overflows; seepage and loss due to infiltration; monitoring; etc. Hydraulic and hydrologic modeling, hydraulic jumps at 0% grade, etc.		
15		FTB-017	I have seen a lot of energy dissipators fail over the years and am uncomfortable that this one will last the design life. What is the expected design life of both the channel and the energy dissipator?		
16		FTB-019	Note that the divider dike between Cells 1E and 2E (borrow area 2) and the west side of 2E (borrow area 1) may exist with a different elevation and geometry at this time point in basin development. Should have a note stating does not reflect actual geometry if this is the case.		
17		FTB-024	It appears from the drawing that a high water event at closure could result in water exceeding the area of the bentonite bottom resulting in water flowing into the Polymet tailings.		
18		FTB-024	Is 3% bentonite enough? Seems 5 to 10% is the more common recommendation.		
19		Comment on Bentonite	Recent literature shows that sodium bentonite can alter to calcium bentonite by cation exchange when there is free chlorine in water. The process takes many years and results in a conversion to calcium bentonite, which has a bigger molecule, expands less and has a much lower permeability. Sodium bentonite can also degrade in environments with free iron. How can we be assured about the long-term performance of the bentonite?		
20		FTBCA-003	Note there is also a possibility of seepage at the location of the stream augmentation pumps. This does not appear to be addressed.		
21		FTBCA	Two general concerns: 1) any imperfection in the grout wall could allow significant waters into the seepage collection system, leading to costly treatment, and 2) uncomfortable how high the groundwater is at some locations, suggesting that a few wells and manholes may be artisan, or very close to artesian.		

22		General Comment	Will need to add discussion and methodology about management and monitoring of grout wall in Monitoring Plan and application (or reference it to HRF Application)		
23	01400-2	Item E.	Will need more information on the bentonite, including type, purity, %, etc.		

FW: PolyMet Tailings Dam Comments Appendix 6

Dostert, Dana M (DNR)

To: Boyle, Jason (DNR)
CC: Kunz, Michael (DNR); Woldeab, Irina (DNR)
Attachments: Flotation Tailings Basin_Permit Apps Dwg FTB-009 FTB-024 05_12_2017.pdf; image001.jpg;
Sent: 6/7/2017 8:20 AM

Dana Dostert PE, PG
Senior Engineer – Dam Safety
MN Department of Natural Resources
500 Lafayette Road, St. Paul, MN 55155-4032
(651)-259-5663

mailto:dana.dostert@state.mn.us

From: Tom Radue [mailto:TRadue@barr.com]
Sent: Tuesday, June 06, 2017 12:29 PM
To: Dostert, Dana M (DNR) <dana.dostert@state.mn.us>; 'donsutton@spectrum-eng.com' <donsutton@spectrum-eng.com>
Cc: Jennifer Saran (jsaran@polymetmining.com) <jsaran@polymetmining.com>
Subject: PolyMet Tailings Dam Comments Appendix 6

Dana – in follow-up to your E-mail and the associated E-mail string, please see responses below (in red font) and also see the attached PDF. The plans submitted 05-16-2017 are for permitting. A detailed plan set will be developed for each phase/segment of construction, after permits are issued and once the start of construction is imminent.

On behalf of PolyMet, we'd be happy to discuss further as needed. Note too that I've copied Don on this response. Please circulate to others as needed.

Thanks,

Tom

Tom Radue, PE

Vice President
Senior Geotechnical Engineer
Minneapolis, MN office: 952.832.2871
cell: 952.240.4051
tradue@barr.com
www.barr.com

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From: Dostert, Dana M (DNR) [mailto:dana.dostert@state.mn.us]
Sent: Monday, June 05, 2017 11:56 AM
To: Tom Radue <TRadue@barr.com>
Cc: Dostert, Dana M (DNR) <dana.dostert@state.mn.us>; 'Cecilio Olivier' <colivier@eorinc.com>; 'Steve Gale' <smg@gale-tec.com>; Kunz, Michael (DNR) <michael.kunz@state.mn.us>; 'Nate Lichty' <nml@gale-tec.com>; 'Stu Grubb' <sgrubb@eorinc.com>; Woldeab, Irina (DNR) <irina.woldeab@state.mn.us>
Subject: FW: PolyMet Tailings Dam Comments Appendix 6

Tom,

Don Sutton has some questions about the under drain\foundation layer. Could you please respond to Don. I think you can give him a much better response than I can.

Thanks,

Dana D.

Dana Dostert PE, PG
Senior Engineer – Dam Safety
MN Department of Natural Resources
500 Lafayette Road, St. Paul, MN 55155-4032
(651)-259-5663

mailto:dana.dostert@state.mn.us

From: donsutton@spectrum-eng.com [mailto:donsutton@spectrum-eng.com]
Sent: Friday, June 02, 2017 10:25 AM
To: Dostert, Dana M (DNR) <dana.dostert@state.mn.us>; 'Cecilio Olivier' <colivier@eorinc.com>; 'Steve Gale' <smg@gale-tec.com>; Kunz, Michael (DNR) <michael.kunz@state.mn.us>; 'Nate Lichty' <nml@gale-tec.com>; 'Stu Grubb' <sgrubb@eorinc.com>
Cc: Boyle, Jason (DNR) <jason.boyle@state.mn.us>
Subject: RE: PolyMet Tailings Dam Comments Appendix 6

I don't think the drawings illustrate what Tom Radue intends, because as drawn, it appears that the surface water will run down the outside of the embankment, collect as a pond on the two benches with the underdrains, and leak into the underdrain. See the sticky-notes on the attached PDF. Which is exactly the opposite of the purpose of the underdrain, which is supposed to guide water away from the embankment rather than into the embankment. The term "underdrain" is possibly being given too much weight – what is needed is a zone of material having a specific material gradation, permeability, shear strength, and dimensions such that it performs as modeled for seepage and slope stability modeling. The material (anticipated to be LTVSMC coarse tailings or engineer approved substitute) is already at least partially in place; confirmation of this will be required during construction. It doesn't appear to me that the surface water fate is being recognized or managed. Am I missing something? For large disposal facilities in Minnesota having soil covered geomembrane closure systems (limiting infiltration; similar in action to the proposed bentonite-amended layer) common practice is to limit the uninterrupted (no benches and/or ditches) flow length on slopes to not greater than 200 feet. Barr's decades of experience with this approach has been good. Uninterrupted flow length for the proposed Flotation Tailings Basin is currently 135 feet. Though we can anticipate some need for maintenance of erosion areas on final slopes in early years of closure, the slopes at 4.5H:1V are relatively flat (erosion on the steeper slopes on the existing basin is not overly problematic but does require periodic maintenance; particularly in areas of sparse vegetation and/or channelized flow) and establishment of dense vegetation should provide adequate erosion control. If it is determined during design of each dam raise that additional erosion control would be beneficial and/or proven over time that dense vegetation cannot be established and maintenance needs become excessive and/or specific areas are continually prone to erosion, then additional erosion controls such as ditches, spillways, and subsurface drainage can be added to the closure system.

Donald G. Sutton P.E.
Spectrum Engineering & Environmental
1413 4th Ave. North
Billings, MT 59101
Direct: 406-534-4660
Mobile: 406-670-7270

From: Dostert, Dana M (DNR) [mailto:dana.dostert@state.mn.us]
Sent: Thursday, June 1, 2017 7:17 AM
To: donsutton@spectrum-eng.com; 'Cecilio Olivier' <colivier@eorinc.com>; 'Steve Gale' <smg@gale-tec.com>; Kunz, Michael (DNR) <michael.kunz@state.mn.us>; 'Nate Lichty' <nml@gale-tec.com>; 'Stu Grubb' <sgrubb@eorinc.com>
Cc: Boyle, Jason (DNR) <jason.boyle@state.mn.us>
Subject: RE: PolyMet Tailings Dam Comments Appendix 6

Hi Everybody,

Just as an update, I talked to Tom Radue earlier this week about the under drain. In the most recent plans revised about two weeks ago, they have renamed the two underdrain layers as foundation layers. Their primary purpose will be to provide foundation support for the perimeter dam and they will be constructed of gravel and coarse tailings. They were also meant to collect seepage waters and draw them back into the stack. The drainage area for these seepage collection sites is quite small, being the outside face of the dam, so there is unlikely to be a large volume of precipitation entering the stack. There groundwater model has not shown any issues with rising groundwater levels at this time.

Barr comment (06-05-2017) - see Barr responses to Don Sutton E-mail above for clarity. We believe the comment below is DNR internal – updated plans were delivered by PolyMet to DNR 05-16-2017.

We have not yet received the redesigned plans. More discussion will be needed.

Thanks,,

Dana D.

Dana Dostert PE, PG
Senior Engineer – Dam Safety
MN Department of Natural Resources
500 Lafayette Road, St. Paul, MN 55155-4032
(651)-259-5663

mailto:dana.dostert@state.mn.us

From: donsutton@spectrum-eng.com [mailto:donsutton@spectrum-eng.com]
Sent: Wednesday, May 31, 2017 5:18 PM
To: 'Cecilio Olivier' <colivier@eorinc.com>; 'Steve Gale' <smg@gale-tec.com>; Kunz, Michael (DNR) <michael.kunz@state.mn.us>; 'Nate Lichty' <nml@gale-tec.com>; 'Stu Grubb' <sgrubb@eorinc.com>
Cc: Boyle, Jason (DNR) <jason.boyle@state.mn.us>; Dostert, Dana M (DNR) <dana.dostert@state.mn.us>
Subject: PolyMet Tailings Dam Comments Appendix 6

Steve Gale, Nat Lichty and I discussed the FTB drawings in Appendix 6 today.

1. As shown on the drawings, (FTB-009) none of us completely understand the function of the 4-foot thick coarse LTV tailings underdrain beneath lifts 1 and 5 along the north face of the embankment. It appears that the underdrain will collect and direct surface run-off into the embankment, potentially saturating the embankment, and reducing the stability. This item requires further explanation and review. (see first image below) We don't think that the purpose of the underdrain is to collect surface water, but that's what is illustrated.

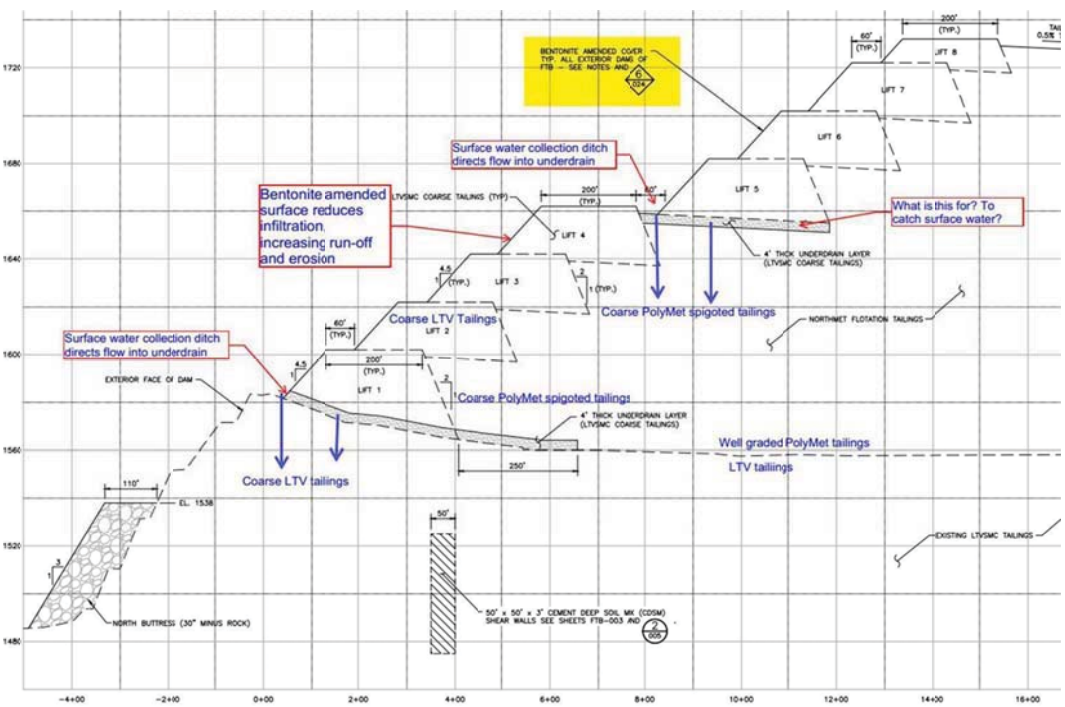
2. I wasn't tasked to look at the dam stability, so don't know if the stability analysis assumed the embankment was saturated or dry. The analysis needs to be done considering rainy wet conditions where the surface run-off is being forced into the embankments. This will shift the phreatic surface closer to the embankment, especially below lift 5. Below, I describe some other scenarios where erosion can alter the phreatic surface assumptions and potentially cause embankment failure. The analysis also needs to be made when the pond is overflowing the spillway and the embankment is saturated. This is the worst case, unless an earth quake occurs at the same time.

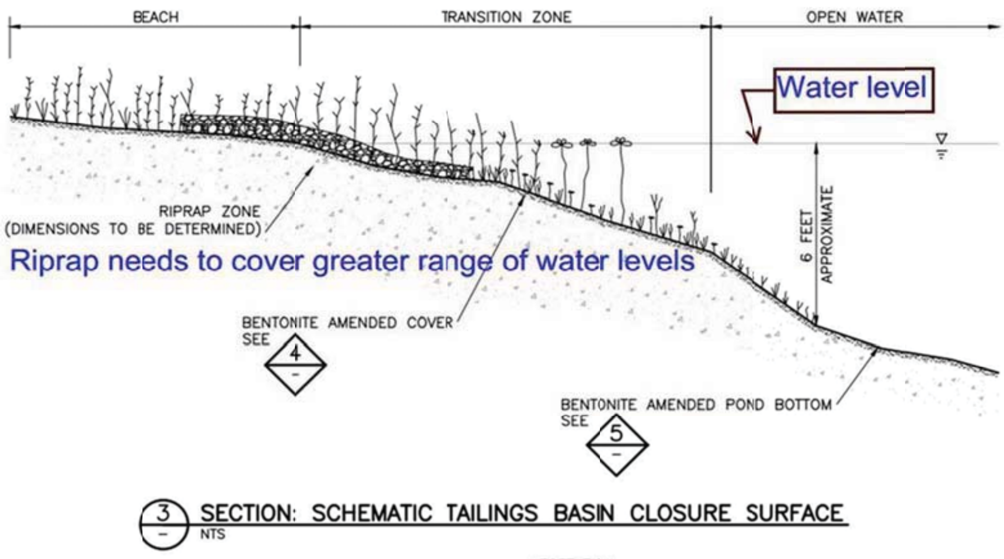
3. The stair step FTB embankment sealed with bentonite is geomorphologically unstable and will erode, potentially cutting back into the pooled water, releasing the water and saturated tailings. Initially, surface water will collect in the horizontal ditch/ponds along the toes of lifts 1 and 5, and infiltrate into the embankment via the underdrain and the coarse LTV tailings beneath lift 1. Later, after the bentonite soil erodes from the slopes, the ditches will fill, plugging the underdrain, forcing the water to overflow the bench and cause head cutting in the non-cohesive tailings. If the FTB is to remain as a permanent structure without perpetual maintenance, then I recommend that the embankments be designed using established geomorphologic land

reclamation principals. Otherwise there is a high probability that the embankments will eventually fail due to erosion, and catastrophically release the saturated tailings.

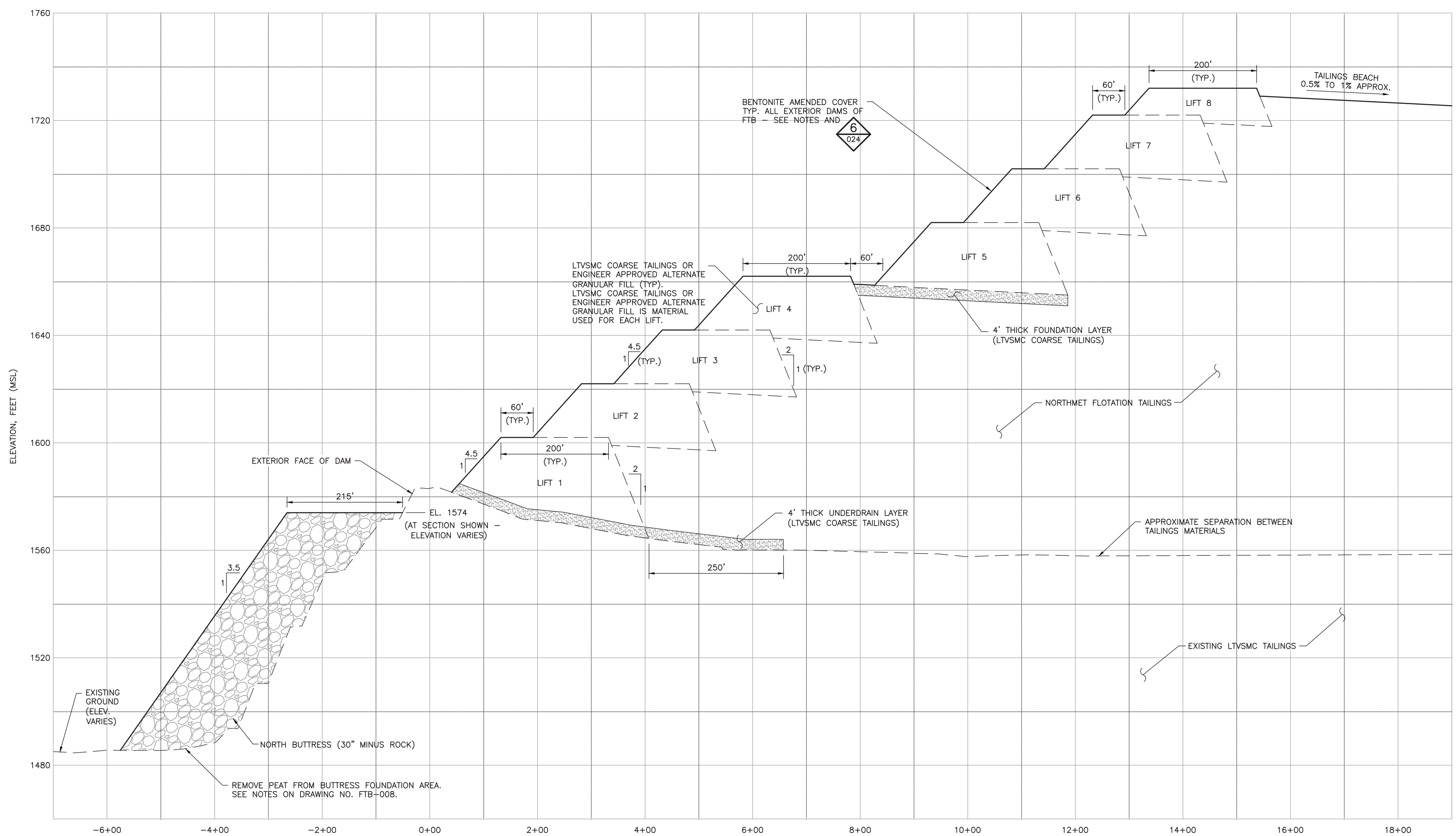
4. As illustrated in Drawing FTB-024, the portion of beach protected by riprap appears to be too narrow, but the width is subject to change. The total extent of the riprap needs to be designed as part of the closure. The size and thickness of riprap need to be justified based on wave action and ice. If the water level fluctuates, wave action could erode above or below the riprap, thus setting up a head cutting scenario from the inside towards the embankment. This could lead to piping and embankment failure. (see second image below). The 625 foot beach slopes 1%, then transitions to a 3% slope to the pond bottom. If the water level drops below the elevation predicted, then the 1% to 3% transition nick point could initiate a head cut that will run back to the embankment. This could trigger piping by allowing water a clear path into the coarse embankment fill when the water level rises. This may not be an issue if the site is perpetually managed and repaired, but will be an issue if the site is abandoned. The water level will not remain constant unless it is managed. If it is not managed, then depending on the bentonite efficacity, the pond could either periodically dry up or over fill. Climate change makes precipitation predictions 100 or 200 years from now impossible, so the design needs to assume the worst case. The range of water level possibilities needs to be addressed in the closure design. If the water level drops lower than designed due to higher infiltration rates or lower precipitation, then the geochemistry assumptions will change as the tailings dry out and oxidize.

The design of the FTB in this permit application will require perpetual maintenance to ensure it will not fail and release the tailings. Placing bentonite on the embankment and interior surfaces will increase the run-off and the erosion rate. The stair-step design is geomorphologically unstable. The methods and assumptions used to place the bentonite to control the infiltration and tailings saturation are unsubstantiated, and wishful thinking. We do not believe it will function as intended, because of the unproven application methods.





Donald G. Sutton P.E.
Spectrum Engineering & Environmental
1413 4th Ave. North
Billings, MT 59101
Direct: 406-534-4660
Mobile: 406-670-7270



1 ELEVATION: NORTH DAM TYPICAL CROSS SECTION

0 100 200
HORZ. SCALE IN FEET

NOTES:

1. DAMS AND BUTTRESS DIMENSIONS MAY CHANGE WITH EVALUATION OF FUTURE DAM STABILITY PERFORMANCE DATA.

VER NO	DATE	DESCRIPTION
1	10/14/11	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 1 – ATTACHMENT A
2	12/07/12	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 2 – ATTACHMENT A
3	04/12/13	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 3 – ATTACHMENT A
4	11/25/14	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 4 – ATTACHMENT A
5	03/03/15	FLOTATION TAILINGS MANAGEMENT PLAN – VERSION 5 – ATTACHMENT A
6	05/20/15	ISSUED FOR INCLUSION IN PERMIT APPLICATIONS
7	05/12/17	PERMIT APPLICATION UPDATES

ISSUE STATUS		
ISSUED	VERSION	DATE
FOR PERMITTING	7	5/12/17
FOR CONSTRUCTION	–	–

NOT APPROVED FOR CONSTRUCTION

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

PRINTED NAME THOMAS J. RADUE
SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN
NORTH DAM
TYPICAL CROSS SECTION

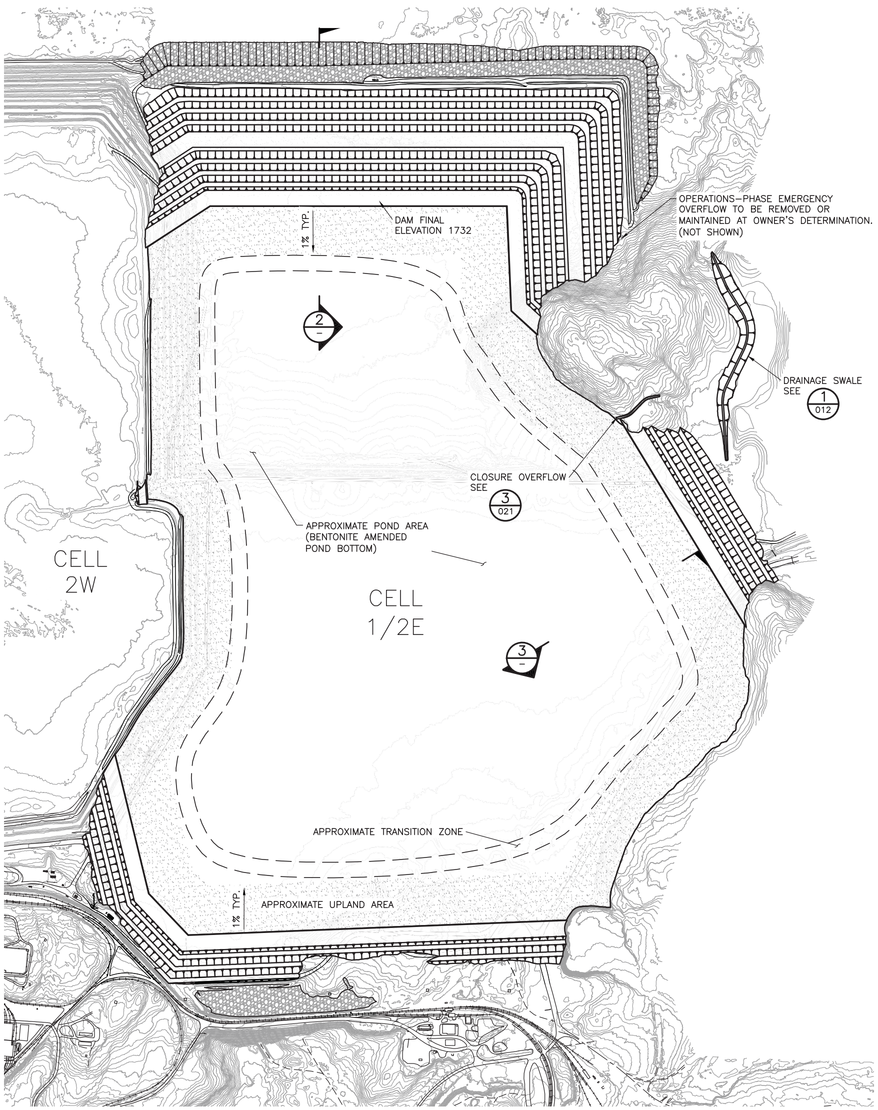
POLYMET MINING
POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR
BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. FTB-009
REV A

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-009.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:06 AM

INCHES 1 2



1 PLAN: PROPOSED CLOSURE PLAN
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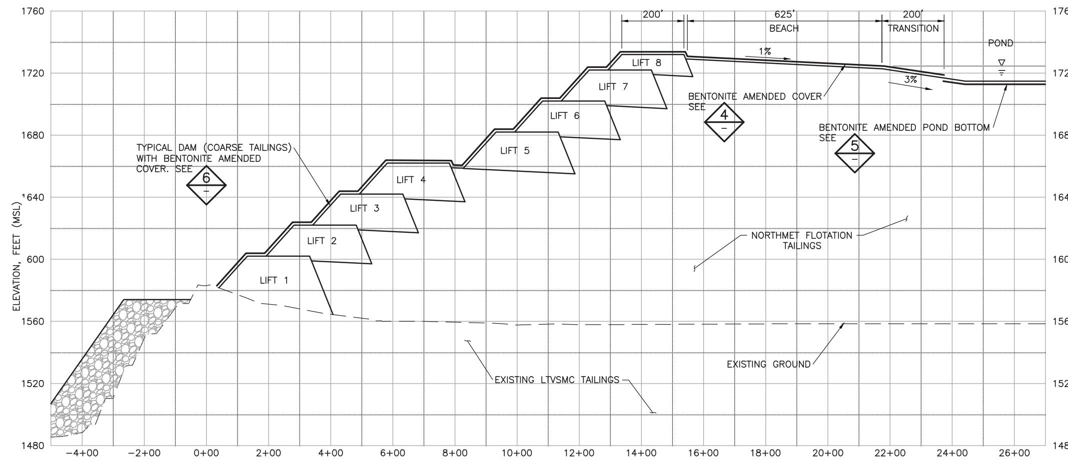

2 SECTION: CELL 2E TAILINGS BASIN CLOSURE TYPICAL SECTION
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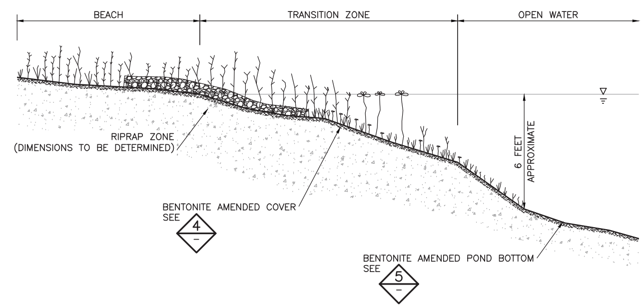
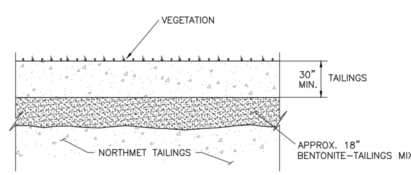


3 SECTION: SCHEMATIC TAILINGS BASIN CLOSURE SURFACE
NTS



4 DETAIL: BENTONITE AMENDED BEACH COVER
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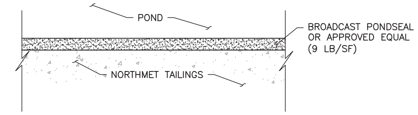
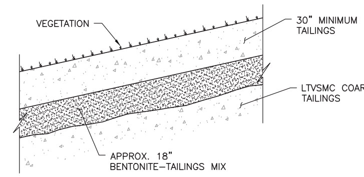


5 DETAIL: BENTONITE AMENDED POND BOTTOM
NTS



6 DETAIL: DAM SLOPE BENTONITE AMENDED COVER
NTS

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SIGNATURE Thomas J. Radue
DATE 5/12/17 LICENSE# 20951

DRAWN: CAD
CHECKED: TJR
BARR PROJECT NO.: 23/69-0C29
SCALE: AS SHOWN

PLANT DRAWING NUMBER:

FLOTATION TAILINGS BASIN CLOSURE PLAN

POLYMET MINING

POLY MET MINING, INC.
NORTHMET PROJECT
HOYT LAKES, MINNESOTA

BARR

BARR ENGINEERING CO.
4300 MARKETPOINTE DRIVE
SUITE 200
MINNEAPOLIS, MN.
Ph: 1-800-632-2277

DWG. NO. FTB–024
REV A

CADD USER: Cristian A. Diaz FILE: K:\DESIGN\23690C29.10\PERMIT_NMT-02-CS-024.DWG PLOT SCALE: 1:2 PLOT DATE: 5/12/2017 9:56 AM

Review of PolyMet's Tailings Basin Permit Application: Tailings Basin Dam

Reviewers: Dirk Van Zyl, Steve Gale/Nate Lichty - Gale Tec Engineering, Inc. and Stu Grubb/Cecilio Olivier - Emmons Olivier Resources, Inc.

#	Page	Section or Table Number	Comment/Concern	PolyMet Response	Final Comment	Recommendation: Address Pre-Permit	Recommendation: Address Post-Permit & Make Condition of Permit	Recommendation: Address Pre-constr.	Recommendation: Condition of Permit Recommendation
1	Geotech Report-page 123 Mgmt. Plan - page 5 Mgmt. Plan - page 34	Section 9 - Operat. & Mainten. Section 2.1- Flotation Tailings Charact. Section 6.3 - Adaptive Mgmt.	The Management Plan calls for the design and/or the operation to be modified based on operational experience using the Observational Method. We recommend that this approach be defined in the Permit similar to that included in a paper "Liquefaction of Tailings Dams" by Solseng, P.B. - Barr Engineering Company presented/published for a "Liquefaction of Mining Tailings" symposium in Cleveland, Ohio - 1997. The Barr paper details that the Observational Method concept design should include: 1) Predict behavior with detailed calculations, 2) design with contingencies, 3) construct with monitoring and 4) compare measurements with predictions and redesign if necessary. The Geotechnical Report Section 2.1-page 5 states that this method is used for all MDNR-Permitted Tailings Basins. If the Observational Method is to be permitted, we recommend that the plan include a design at the time of permitting and identify what instrumentation will be installed, where the instrumentation will be installed and what the instrumentation will monitor (e.g. excess pore water pressures and tailings dam deformations). If the Observational Method is permitted, we recommend that the permit require stability evaluations be submitted at least yearly with the annual Dam Safety Report. If a significant design change is required, we recommend that the company apply for a permit amendment.	Further clarification on the details of the Observational Methods were requested.	The Observational Method (Peck, R.B., Geotechnique, No. 2, 1969) is based on assessing potential geotechnical failure modes that may result during/post construction as well as conditions and events that could instigate instability. An example condition could be a previously undiscovered layer of soft soil beneath the dike alignment. An example event may be a large rainfall that causes increased seepage and slope toe erosion. After this assessment is complete and critical failure modes and conditions/events are identified and analyzed, contingency plans should be developed for each critical failure mode. We recommend this analysis be performed prior to construction. With the analysis results in mind, a monitoring system (geotechnical instrumentation, site reviews, etc.) should be developed and implemented during construction to monitor dike performance. The monitoring system would be used to confirm assumptions made during original design or to change operations/design if field observations and adverse measurements are recorded. We recommend that to adequately use this method for dike construction, that a geotechnical instrumentation and monitoring plan should be developed based on the results of the dike stability analysis that considers conditions/events that could result in localized or complete dike instability. Contingency plans should be developed for each critical condition. The instrumentation and monitoring plan should include 1) a list of geotechnical instruments that will be installed, where they will be installed and what they will be measuring, 2) how often the instrumentation readings be taken, 3) who will review the instrumentation readings, 4) what the typical values will be and what the thresholds will be that indicate “adverse conditions” that will require a change in operation or design. The contingency plan should include a list of potential adverse conditions that may occur and what would be observed if that condition occurred. The plan should include different operational/design options to address the adverse conditions.	X	X		The importance of a well defined Observational Method is paramount. It is the preference of the reviewers that this key issue be addressed as part of the permit application. Either as a pre-permit or as a condition of the permit, the following items need to be incorporated: 1) Adverse conditions/events that could lead to localized/global dike instability. 2) An instrumentation and monitoring plan that includes those items presented in "Final Comment" section. 3) A contingency plan that includes those items presented in "Final Comment" section.

Review of PolyMet's Tailings Basin Permit Application: Tailings Basin Dam

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2	Mgmt. Plan - page 10	Section 2.2.4 - Dam Construct.	Cement deep soil mixing (CDSM) shear walls are shown to be needed to satisfy stability of the north tailings dam as a result of liquefaction of buried slimes. The Geotechnical Report text states that a Construction Quality Assurance Plan will be developed. Since this CDSM structural feature is such a critical aspect of the plan, we recommend that the permit require bench-scale testing, test columns and field validation using such techniques as coring and wet sampling and geophysical testing (e.g. Ps logging and/or electromagnetic testing methods). The Federal Highway Administration (FHWA) has a design manual for Deep Mixing for Embankment and Foundation Support - October, 2013. This manual includes guidance for CDSM installation and integrity testing.	Post-permitting & pre-construct. bench scale testing and in-field validation testing is already incorporated in the construction specifications (FTMP, Attach. G, Section 313200). A Dec. 30, 2016 memo suggested that the CDSM be eliminated.	The Barr specifications included in the Basin Management Plan contain reasonable QA/QC procedures for CDSM construction.				This issue can be closed if a larger buttress will replace the CDSM.
	Geotech Report - page 75, Mgmt. Plan - page 10	Section 6.3.2.4 - Cement Deep Soil Mixing Zone							
3	Geotech Report - page 8	Section 3.2 - Tailings Basin Develop.	The Report describes various peat layer thicknesses and various slime layer thicknesses beneath the Cell2E North perimeter dam. Sitka Corporation identified typical standard penetration resistance value (blow/foot) for the slimes was 5 or less and for the fine tailings was in the range of 15-20. We recommend that the layer thicknesses and the continuity of the layers be further investigated and a sensitivity analysis be performed based on the thickness, continuity and the liquefied shear strength values. A USSR liq=0.10 is included in Table 5-10 (page 41) for the LTVSMC fine tailings/slimes and further alludes to this value being a minimum to be used for design by the Engineering and Design Manual - Coal Refuse Disposal Facilities published by U.S. Department of Labor - MSHA. Further documentation should be provided for this value: and a sensitivity analysis should be performed in conjunction with the previously described parameters. Sitka Corporation found remolded vane shear strength values of the slimes to be in the range of 100 - 300 pounds per square foot. These low remolded vane shear strength values could indicate a USSR liq. less than 0.10. These lower values could result in a factor of safety of less than 1.1.	Slope stability sensitivity analyses to evaluate variation in material strength has been performed and reported in GDP Vol 1, Sections 6.6 and 7.3.8. Affirmation of selected strength parameters will be performed following acquisition of additional strength data during post-permit installation of instrumentation.	The additional subsurface exploration and instrumentation & monitoring plan should be developed based on the results of the analysis performed as part of the Observational Method process Part 1. The plan should include what instrument type is required, its location, depth and expected range of values that will be obtained during basin construction. This plan should be incorporated into the submittal discussed as part of Comment 1.	X	X		The additional subsurface exploration, performed post permit, and development of the Instrumentation and Monitoring Plan should be based on the analysis of critical failure modes as associated with Comment 1
	Geotech Report - page 41	Section 5.2.3 - Shear Strength of LTVSMC Tailings and Table 5-10							

Review of PolyMet's Tailings Basin Permit Application: Tailings Basin Dam

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4	Geotech Report - page 8	Section 3.2 - Tailings Basin Develop.	The Report describes a layer of peat over a deposit of glacial till beneath the Cell 2E North perimeter dam. During the retreat of the glaciers approx. 10,000 years ago, depressions were formed in which lacustrine clay and peat were deposited. The Geotech. Report, however, does not reference any lacustrine clay layers, only peat over glacial till. Table 5-24 (page 64) identifies peat with a USSR yield = 0.23. This value may be appropriate for a fibrous peat but not for a decomposed amorphous peat or a high plasticity lacustrine clay. The soil types should be further investigated and sensitivity analysis performed for a range of shear strengths. Geotech. Report - page 49, Section 5.4.2.2, states that previous testing by Sitka resulted in higher permeability values for peat than that obtained from samples during the most recent 2014 investigation. This may indicate a different type of peat at various locations.	Same as Recommendation for Comment 3	The additional subsurface exploration and instrumentation & monitoring plan should be based on the results of the analysis performed as part of the Observational Method process Part 1. The results of this analysis should be used to develop the basin's instrumentation and monitoring plan. The plan should include what instrument type is required, its location, depth and expected range of values that will be obtained during basin's construction. This plan should be incorporated into the submittal discussed as part of Comment 1.	X	X		The additional subsurface exploration and instrumentation plan should be developed based on the analysis of critical failure modes as associated with Comment 1
5	Mgmt. Plan - page 22-24	Section 4.2 - Transport and Deposit. Plan	It appears that the stability analysis was based on maintaining a beach length of 625 feet between the inside crest of the dam and the edge of the water within the tailing basin. The water pocket could, at sometime during the operation, be closer to the dam than the 625 feet. Stability and exit seepage should be evaluated considering the water pocket closer or in contact with the tailings dam.	Addressed - have reviewed high pond conditions as shown in GDP Vol 1, Section 7.3.3.2 and supporting Sections	It appears that the analysis included a 4ft head increase, while still keeping the water pond at a 625ft distance from the crest of the perimeter dike. It is recommended that a water pocket distance of closer than 625ft be analyzed as a event/condition associated with the Observational Method approach.	X	X		A water pocket distance from the perimeter dike of closer than 625ft should be analyzed as part of the Observational Method and be part of the submittal associated to Comment 1.
6	Mgmt. Plan - page 34	Section 7.3 - Structure Removals	The Management Plan is vague regarding abandonment of existing structures within the tailings basin and assumes that the previous owner properly abandoned all pipes within the basin which could be a conduit for water which could create erosion conditions which could then act as a trigger for liquefaction and induce a flow failure. Specifically, the 9 foot diameter drop inlet decant structure constructed in Basin 2W and the approximate 2000 lineal feet of 40 inch diameter spiral pipe extending into Basin 1E should be addressed.	This will be addressed post-permitting; prior to reactivation of the basin	If not investigated pre-permit, we recommend that the dam safety permit include language that requires all existing pipes/structures to be investigated and properly abandoned to ensure dike stability is maintained.			X	

Review of PolyMet's Tailings Basin Permit Application: Tailings Basin Dam

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7	Geotech Report - page 90	Section 6.6.1 - Range and Distrib. of Shear Strength Values	The Report identifies that sensitivity analyses were performed for the USSR properties for most of the soils using either a normal or log-normal distribution. However, a sensitivity analysis was apparently not performed for liquefied shear strength ratio (USSR) for the slimes. The Report identifies that based on previous geotechnical workshops, a single estimate of that particular strength was chosen. Apparently, the chosen ratio is 0.10. Using this ratio, 40 feet of overburden would result in a liquefied shear strength of 600 pounds per square foot. Residual vane shear testing has shown slime values as low as 100 - 300 pounds per square foot, which would result in a ratio of less than 0.10. We recommend that this issue be further explored.	Affirmation of selected strength parameters will be performed following acquisition of additional strength data during post-permit installation of instrumentation.	The additional subsurface exploration and instrumentation & monitoring plan should be based on the results of the analysis performed as part of the Observational Method process Part 1. The results of this analysis should be used to develop the basin instrumentation and monitoring plan. The plan should include what instrument type is required, its location, depth and expected range of values that will be obtained during basin construction. This plan should be incorporated into the submittal discussed as part of Comment 1.	X	X		The additional subsurface exploration and monitoring plan should be included and analyzed as part of the Observational Method and be as part of the submittal associated with Comment 1
8	Mgmt. Plan - page 37	Section 7.2 - Final Reclamat.	The Plan identifies approximately 3% bentonite by dry weight to be added to the fine tailings beach to a depth of 18 inches and then overlain by 30 additional inches of tailings and then vegetated. The 3% by dry weight addition should be further investigated based on field trials, not laboratory testing in which very controlled conditions exist. Closure of the pond bottom refers the Geotechnical Report reader to the Adaptive Water Management Plan - Version 7. The effectiveness of injecting bentonite through the pond water is subject to concern with regard to reliability of the infiltration reduction.	Pilot testing/field tests are already incorporated in closure construction specifications (FTMP, Attachment G, Section 03100)	A plan should be developed that requires test sections be constructed on both the pond bottom and tailings dike side slope to evaluate the chosen means for bentonite inclusion. The test section evaluation should consider: onsite water chemistry, potential for ice scour along the shoreline, oxidation of sulfide bearing rock within side slopes, and other concepts which may impact the permeability of the bentonite amended tailings. The Adaptive Water Management Plan, Section 5, states 3 methods on how the Tailing Pond bottom could be amended at the time of closure: 1) broadcasting granulated or pelletized bentonite on the pond surface and allowing it to settle to the pond bottom, 2) direct injection of bentonite into the pond bottom or 3) placing a GCL on the pond bottom. We understand that the PolyMet tailings are not available as yet for lab or field trials. But, if bentonite/tailing mixing (methods 1 or 2) is the preferred method of application, a preliminary material and installation specification should be developed and a protocol should be prepared for both a laboratory and a field pilot study as part of the permit application. The protocol (including the design calculations for 1 or 2) should include a degree of variability on which the acceptance criteria is based. The specification should also address how durability to ice heave on the side slopes and freeze-thaw degradation will be addressed.	X	X		Perform test sections for each bentonite application technology prior to tailings dike closure. A report should be submitted with test results and a QA/QC program demonstrating that the bentonite-tailings mixture has adequate permeability.

Review of PolyMet's Tailings Basin Permit Application: Tailings Basin Dam

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#	Page	Section or Table Number	Comment/Concern	PolyMet Response	Final Comment	Recommendation			
						Address Pre-Permit	Address Post-Permit & Make Condition of Permit	Address Pre-constr.	Condition of Permit Recommendation
9	Geotech Data Package, Vol. 1, Attach. C, page 19	Section 3.0 - Drained Shear Strength Paramet.	The shear strength data for the different materials was evaluated by considering laboratory shear strength data plus interpreted field shear strength data from various tests as appropriate. The 33rd percentile of the resulting data was then selected for the stability analyses. In the case of the drained shear strength of the LTVSMC coarse tailings, the shear strength ranges are: laboratory testing 28 to 47 degrees, SPT testing 26 to 50 degrees and CPT testing 39 to 46 degrees (outliers below 39 degrees, to as low as 32 degrees were excluded, Figure A-3). The resulting value selected for stability analysis from the statistical analysis is 38.5 degrees. This value seems on the high side as lab testing and SPT testing values in the high 20's are included in the evaluation while lower values of the CPT testing were excluded. Furthermore, the drained shear strength selected for the coarse tailings is higher than that selected for glacial till - typically a well graded material that is very dense. The angularity of the coarse tailings particles might have played a role in the selection of this higher value. It is recommended that the stability analysis should also be done with a lower shear strength value, say 36 degrees, for the coarse tailings as part of a sensitivity analysis. It is recognized that this may not change the outcome very much, however this sensitivity analysis is an important aspect of developing further confidence in the effective strength stability results.	A sensitivity analysis will be performed to review the effect of the lower friction angles on dike stability. Strength data will also be further investigated during instrumentation installation.	The Dec. 30, 2016 Barr Memorandum identified no substantial reduction in the tailings dike global factor of safety by lowering the coarse tailings friction angle from 38.5 deg. to 36 deg. We question why some of the data was excluded from the statistical analysis and recommend that the coarse tailings friction angle be considered as a variable condition in the Observation Method process. At cross sections where lower friction angles result in lower factors of safety, the Observational Method would suggest enhanced instrumentation and monitoring at these locations. This analysis should be incorporated into the submittal discussed as part of Comment 1.	X	X		The apparent variability of the coarse tailings friction angle should be analyzed as part of the Observational Method and be a part of the submittal associated with Comment 1
10		Section 7.2 - Final Reclamat.	PolyMet is proposing a 20 year mine life and "wet closure" for the tailings basin. The proposed design is permittable and if permitted, would need to be managed in compliance with all rules and regulations including financial assurance. If permitted, the DNR should also require PolyMet to continually review the current state-of-the-practice for design techniques prior to starting any tailings basin closure activities. Information should be reviewed so that the decision on the best closure design option, accounts for current technologies, for environmental protections and considers the long term cost of operation. Continued study of tailings basin closure designs should also be considered as a permit condition. If a closure design change is required in the future, it must meet all environmental review and permitting standards.	Polymet will continue to evaluate potential project improvements during operations and at closure, one of which may be revisiting the tailings closure approach.	The review team is not ready to commit to a dry closure requirement. Wet closure will be more difficult and costly to manage for the long-term and it must be determined if this commitment is acceptable.			X	

Review of PolyMet's Tailings Basin Permit Application: Tailings Basin Dam

Reviewers: Dirk Van Zyl, Steve Gale/Nate Lichty - Gale Tec Engineering, Inc. and Stu Grubb/Cecilio Olivier - Emmons Olivier Resources, Inc.

#	Page	Section or Table Number	Comment/Concern	PolyMet Response	Final Comment	Recommendation			
						Address Pre-Permit	Address Post-Permit & Make Condition of Permit	Address Pre-constr.	Condition of Permit Recommendation
11		Barr Memo Dec. 30, 2016 on Tailings Basin Cell 2E Buttress Design as Alternate to CDSM	The modified buttress design includes increasing the buttress height by 35 ft. to a total height of 84 ft above the surrounding grade. This increased height will require the buttress slope toe to extend approx. 100 ft more into the wetland than what was previously proposed (200-250 ft total). The stability analyses presented are limited to global failure planes through the entire tailings dike. Localized stability of the buttress toe constructed over the soft, swamp soils does not appear to have been evaluated. This localized failure could be significant in that it could result in a progressive failure of a greater portion of the perimeter dike. We recommend that a stability analysis be performed for the buttress toe and the design be developed considering that construction will be occurring further out over the peat/swamp soils. The results of the stability analysis should be used to determine buttress design recommendations considering embankment construction over soft ground. Potential adverse environmental effects associated with the buttress fill (e.g. wetland fill and geochemistry of the Area 5 material) will also need to be addressed.			X			

memorandum

Project Name	PolyMet Dam Safety Permit Application Review	**Date**	03/10/17
To / Contact info	Jason Boyle (DNR)		
Cc / Contact info	Joe Henderson (DNR) and Mike Kunz (DNR)		
From / Contact info	Dick Van Zyl, Steve Gale (Gale Tec Engineering, Inc.), Cecilio Olivier (EOR) and Stuart Grubb (EOR)		
Regarding	Review Team Comments		

Background

PolyMet submitted two permit applications to the DNR for Dam Safety Permits for the NorthMet project. One application was for the Flotation Tailings Basin and the other was for the Hydrometallurgical Residue Facility (HRF).

To supplement the review process, the DNR requested that a team of top experts (EOR Review Team) be assembled to assess and comment on the proposed design, operation and maintenance of the facilities. The review approach focused on key elements similar to tailings basin review panels required by law in Montana and other western states. The review process included the following tasks:

- Documents Review – Including PolyMet's Dam Safety Permits applications, related technical documents, and comment tracking sheets.

- Site Visit and Discussion - Trip to Hoyt Lakes to develop observations and take field notes at the LTV/PolyMet tailings basin and proposed HRF sites. Meet with PolyMet and the tailings basin hydro designers to ask questions and discuss the different design elements.

- Review Meetings – Internal review meetings between EOR Review Team and DNR to discuss initial findings, need for additional information and develop final comments and recommendations. Meeting with PolyMet, DNR and the EOR Review Team to discuss final findings.

- Draft and Final Report - Present a Draft Report of findings to DNR and PolyMet. Prepare a Final Report including a response to comments on the Draft Report.

EOR Review Team

EOR assembled a Review Team of experienced experts in mining geotechnical engineering. The Review Team included:

- ***Dirk van Zyl, PhD, PE***. Dirk is on the faculty of the University of British Columbia and consults with mining companies worldwide on tailings basin design. He was formerly on the faculty of the University of Nevada – Reno, and he has worked for several consulting companies. Dr. van Zyl has authored or co-authored over 120 papers on mining topics, including tailings basin management. He currently serves on several review panels in Montana and on the review panel that previously investigated the Mt. Polley dam failure.

- ***Steve Gale, PE.*** Steve is the President of Gale-Tec Engineering Inc. in Minneapolis, Minnesota. He has over 30 years of experience working as a geotechnical engineer. Mr. Gale and his company provide consulting services on all aspects of tailings basin design, management, and closure, including dam safety analysis and permitting. He has worked on many of the tailings basins on Minnesota's Iron Range.

Resumes are included in Attachment 1.

Review Process

The EOR Review Team went through the following documents:

- Technical Memorandum: NorthMet Geotechnical Data Package – Volume 1 (Flotation Tailings Basin) – Version 4 Modeling Outcomes Summary. Barr Engineering, April 2, 2013.
- NorthMet Dam Safety Permit Application: Flotation Tailings Basin. Barr Engineering, July, 2016.
- NorthMet Dam Safety Permit Application: Hydrometallurgical Residue Facility. Barr Engineering, July 2016.
- 2015 Tailings Basin Dam Safety Inspection Report. Barr Engineering, August 2016
- Technical Memorandum: DNR Review of PolyMet's Dam Safety Permit Application – Tailings Basin Comment 9 – LTVSMC Coarse Tailings Strength. Barr Engineering, December 30, 2016.
- Technical Memorandum: Tailings Basin Cell 2E North Dam – Modified Buttress as Alternative to Cement Deep Soil Mix Zone. Barr Engineering, December 30, 2016

The EOR Team (along with the DNR, PolyMet and Barr Engineering) conducted a site visit to the LTV tailings basin site and proposed HRF facility in September 29th, 2016. The EOR Review Team also met with PolyMet and Barr Engineering to discuss comments and questions on the proposed NorthMet project. A follow up meeting to discuss and review comments was held with the same participants at DNR headquarters on December 5th, 2016. The EOR Review Team and DNR met on several occasions to discuss the review's status .

Review Comments

The detailed EOR Review Team comments are presented in the review tables of Attachment 2. The columns on the tables include:

- *Comment/Concern* - These initial comments were written by the EOR Review Team, reviewed by DNR, and submitted to PolyMet in December, 2016.
- *PolyMet Response* - PolyMet provided these written and/or verbal responses to the initial comments.
- *Final Comments* - After considering PolyMet's response, the EOR Review Team prepared these comments contained in this column.
- *Recommendations* - The EOR Review Team recommends that the comments and issues be addressed as follows:

- *Address Pre-Permit* - These issues will require additional information before a permit can be issued. This may require resubmittal of the complete permit application.
- *Address Post-Permit & Make Condition of Permit* - These issues require additional information, but they are not likely to have a bearing on the DNR's decision to grant or deny the permit. They may affect future construction and operation of the facilities. Some of these comments can only be addressed while the facilities are operating. PolyMet must address these comments after the permit is granted.
- *Address Pre-Construction* - These issues also require additional information, but they are not likely to have a bearing on the DNR's decision to grant or deny the permit. PolyMet must provide more information before beginning construction of the facility.
- *Condition of Permit Recommendation* - The EOR Review Team provides elements and recommended language to be incorporated into the permit, either pre-permit or as a condition of the permit.

Comments on PolyMet's Design, Approach and Redevelopment of the LTV Tailings Basin

<u>Observational Method (Comments #1, #4, #5 and #7 in Attachment 2)</u>

The Observational Method is a well-documented and often-used approach to tailings dam construction and maintenance. The Observational Method steps are:

1) Predict behavior with detailed calculations,
2) Design with contingencies,
3) Construct with monitoring and
4) Compare measurements with predictions and redesign if necessary.

The EOR Review Team agrees that the Observational Method can and should be used during construction, but it is not a substitute for careful initial design. The EOR Team concluded that the permit application lacks the detail and description of contingencies for the Observational Method to be effective. If monitoring data indicate a potentially unsafe condition during construction, then the alternate construction methods and designs (contingencies) must be already in place so that they can be implemented immediately.

<u>Peat Layers and Slimes Layers (Comments #3, #4 and #7 in Attachment 2)</u>

The former LTV tailings basin was constructed over layers of peat in some areas. Layers of slimes (very fine-grained taconite tailings) were also included in the construction of the tailings basin dam. Both peat layers and slimes layers have very low shear strength, which could potentially contribute to a dam failure. The tailings basin can be designed to safely mitigate for these conditions, but the areas with peat and slimes must be well-defined and tested. The EOR Team commented that additional data should be gathered on the peat layers and slime layers, and that the design may need to be modified in the future in accordance with the Observational Method.

<u>Cement Deep Soil Mixing (CDSM) & Dam Toe Buttressing (Comments #2 and #11 in Attachment 2)</u>

In the permit application, PolyMet proposed constructing the dam with both CDSM and dam toe buttressing (reinforcement usually using waste rock). CDSM uses large-diameter drills to drill into the base of the tailings basin dam and mix Portland cement with the existing materials. Placing of these CDSM "pillars" close together in a line creates a kind of shear wall that increases the shear strength of the material. The construction needs to be carefully monitored in the subsurface to make sure that the pillars are constructed as designed. CDSM is often used in the construction of embankments and dams, but to our knowledge has not been used in a tailings basin.

Dam toe buttressing places heavy materials at the toe of the tailings basin dam to prevent the toe of the dam from sliding and causing a dam failure. The required size and weight of the buttress increase as the height of the dam increases.

The EOR Review Team commented that additional monitoring would be required during CDSM construction and during operations and closure to assess the effectiveness of the CDSM. Since then, PolyMet has removed CDSM from the design plans in favor of using larger dam toe buttresses. The design plans with additional buttresses will have several advantages:

- The technology is better understood on tailings basin dams,
- Construction and maintenance are above ground, so critical observation and monitoring can be done with greater confidence, and
- The buttress can be constructed incrementally over an extended period of time, whereas the CDSM must be fully completed prior to placing the basin into service.

Peat deposits should be removed near the toe of the existing tailings basin dam so that the new buttress will have a solid footing. If peat deposits are not fully removed, the EOR Review Team commented that additional analysis should be required to evaluate the stability of the buttress toe that may be constructed over localized soft soils. PolyMet indicated that buttress construction will specify the complete removal of peat soils. The EOR Review Team also recommended performing additional analysis for other potential impacts due to additional wetland fill or the geochemistry of the buttress material.

<u>Water Ponding (Comment #5 in Attachment 2)</u>
As currently designed, a pond of water will be maintained on top of the tailings basin in perpetuity. During mining operations, the residue from the processing plant (tailings) is pumped to the pond as slurry, and water is returned to the plant after the tailings settle out. PolyMet developed stability analysis models that show the volume and location of the pond at various times during the operating life of the tailings basin. This stability analysis was based on maintaining a beach length of 625 feet between the inside crest of the dam and the edge of the water within the tailings basin. This would minimize the potential for the water to rise and cause erosion at the edge of the basin.

The EOR Review Team commented that some of the model runs did not seem to correctly account for a potential rise in water levels, the location of the beach around the pond, and the distance to the edge of the tailings basin. PolyMet indicated that the design included a 4 feet head increase while still keeping the water pond at a 625 feet distance from the crest of the perimeter dike. The EOR Review Team recommended that a water pocket distance of less than 625 feet (or in direct contact with the tailings dam) be analyzed as an event/condition of the Observational Method approach.

Existing Structures (Comment #6 in Attachment 2)
The EOR Review Team commented that some of the existing structures associated with the existing tailings basin had not been specifically addressed in the plan for future construction. The EOR Team recommended that the permit includes language that requires all existing structures to be investigated and properly abandoned before construction to ensure that dike stability is maintained.

Bentonite Addition (Comment #8 in Attachment 2)
To minimize water seepage from the tailings basin, bentonite will be added to the soils at the top of the basin during the closure and reclamation process. The permit application only lists alternatives for placing the bentonite that will be pilot tested and field tested later. The EOR Review Team commented on specific elements that should be included in the field testing that would impact the permeability of the bentonite amended tailings. Once the preferred bentonite application method is selected, the EOR Review Team recommended developing material and installation specifications and a detailed protocol for both a laboratory and a field pilot study.

Statistical Analyses (Comment #9 in Attachment 2)
Geotechnical tests were performed to determine the shear strength of the tailings at hundreds of locations around the existing tailings basin. Statistical analyses are used to calculate the overall strength and stability of the basin. EOR Review Team commented that some of the geotechnical test results (i.e. low coarse tailings friction angles) were excluded from the statistical analyses. Because of their importance in the overall stability of the basin, the EOR Review Team recommended that coarse tailings friction angles be considered as a variable condition in the Observational Method process. This would also provide a consistent and proper procedure for future analyses.

It should be noted that including all the geotechnical results in the statistical analyses did not significantly reduce the global factor of safety. Nevertheless, the EOR Review Team recommended using the Observational Method to enhance instrumentation and monitoring at those discrete cross sections where lower friction angles could occur. If lower friction angles are observed, the statistical analysis must be rerun to verify that this localized factor of safety is still acceptable.

Wet Closure vs. Dry Closure (Comment #10 in Attachment 2)
Wet closure of the tailings basin is currently proposed, meaning that the top of the tailings basin will have a permanent pool of water on top of the basin. Wet closure has ongoing costs like; maintaining water levels to prevent flooding and drying out, erosion repair, treatment of discharged water and on-going monitoring. Dry closure (no water ponding) requires a greater initial investment, but has much lower ongoing maintenance costs and less long-term environmental risk.

The EOR Review Team did not proposed dry closure as a permit requirement at this time. The EOR Review Team recommended that if the wet closure is permitted, the DNR should require PolyMet to continually review the current state-of-the-practice for dry closure techniques prior to starting any tailings basin closure activities.

General Discussion of Issues – HydroMet Residue Facility

Stability of Underlying Soils (Comment #1 and #2 in Attachment 2)

The soft ground beneath the proposed residue facility consists of up to 30 feet of slimes, peat and tailings concentrate. This will not be an adequate foundation for the 80 foot high basin. Three potential remediation alternatives have been considered:

- Pre-loading the existing material with 50 feet of rock and soil to compress and consolidate the underlying material. This is the method currently proposed by PolyMet.
- Installing wick drains that will allow water to flow out of the existing material, thereby increasing its shear strength.
- Removing the existing material and any soft soils before constructing the basin.

The basin will have a geomembrane or geosynthetic liner. The liner could deform and fail if the existing underlying material cannot support the material added to the basin.

The EOR Review Team commented that the proposed pre-load design should be re-evaluated to determine if it will adequately surcharge and compress the existing material.

Geomembrane (Comment #3 in Attachment 2)

The EOR Review Team commented that more information was required in the permit application to evaluate the geomembrane liner system. Barr Engineering provided the information, so this issue has been closed.

James Kuipers, PE
Principal Consulting Engineer
jkuipers@kuipersassoc.com

Kuipers & Associates, LLC

PO Box 145
Wisdom, MT 59761
406-689-3464

February 23, 2018

To: Kevin Lee, Minnesota Center for Environmental Advocacy

From: Jim Kuipers PE, Kuipers & Associates

Re: **PolyMet NorthMet Mine Economic Analysis**

At your request I have developed an Excel spreadsheet which mimics the financial analysis that has been performed for the PolyMet NorthMet Mine project as identified herein. The spreadsheet is intended to be the same as the pro forma cash flow analysis to the extent possible given the data provided in the financial analysis for the project. The purpose of the development of the spreadsheet is not to confirm the company's financial analysis, but rather to use it to show how project economics might be affected by financial assurance requirements, and by options such as use of filtered tailings in lieu of slurry tailings as discussed in comments provided to you previously.

1. Pro Forma Cash Flow Economic Analysis

The technical basis for the NorthMet Project economic analysis performed by PolyMet to date consists of the following:

1. *Technical Report on the Results of a Definitive Feasibility Study of the NorthMet Project*, Report compiled from multiple sources under the guidance and supervision of D. J. Hunter C.Eng. CP (Mining), October 2006.
2. *Technical Report on the NorthMet Deposit, Minnesota, USA*, Wardrop report to Polymet Mining Corp, September 2007.
3. *PolyMet Updates Capital And Operating Costs, Revised Construction Plans Reduce Pre-Revenue Capital Costs And Time Line Project Development Update*, Hoyt Lakes, Minnesota, May 20, 2008 – PolyMet Mining Corp.
4. *Updated NI 43-101 Technical Report on the NorthMet Deposit*, Minnesota, USA, AGO Mining Consultants Inc. for Polymet Mining Corp, Amended Report Date, January 14, 2013.

All three technical reports were intended to be in conformance with National Instrument 43-101 and Canadian Institute of Mining, Metallurgy and Petroleum (CIM) guidelines for Mineral Resource Estimates. The 2006 Technical report was based on historical information for mineral resources collected to that date. The 2007 report was based on the inclusion of results from 30 diamond drill holes completed in early 2007. The 2013 report is based on the inclusion of results from 31 additional diamond drill holes completed between March 2007 and July 2007. Each report updates and to a significant extent relies on the results from the previous technical reports.

I have previously reviewed more than 100 project feasibility reports intended to be NI 43-101 compliant. In nearly all cases a printout is provided showing the cash flow analysis including all inputs identified in the study, as is the case with our own analysis performed herein. However, it is notable that in the case of the NorthMet project analysis the initial 2006 report provides the most detailed information for cash flow analysis purposes, although not in a manner that shows the entire pro forma analysis as noted in our comments below. The subsequent analysis provides only limited detailed information pertaining to the analysis, relying instead on discussion of results from the initial 2006 analysis. Therefore, any attempt to mimic their financial analysis necessitated using the initial 2006 analysis.

2006 Technical Report

The data from the 2006 Technical Report was identified and entered into an Excel spreadsheet. The data together with the source and corresponding calculations entered into the spreadsheet is contained in **Table 1 - 2006 Base Case** and **Table 2 - 2006 Market Case** (see Oversize Tables). The Base Case in the 2006 technical report used the approximate metals prices at that time, and the Market Case used the three-year rolling average at that time. The results for the Base Case and Market Case from the 2006 Technical Report and the spreadsheet are summarized and compared in Table 3.

Table 3 – Comparison of 2006 Technical Report and Spreadsheet Results

	Base Case		Market Case	
	2006 TR	**Spreadsheet**	**2006 TR**	**Spreadsheet**
Metal Prices				
Copper	$1.50		$2.25	
Nickel	$6.50		$7.80	
Cobalt	$15.25		$16.34	
Palladium	$225.00		$274.00	
Platinum	$900.00		$1,040.00	
Gold	$450.00		$540.00	
Financial Summary (Pre-Tax)				
Internal Rate of Return (IRR)	17.4%	18.6%	34.2%	36.9%
Present Value (5% Disc. Rate)	$450,643	$523,680	$1,210,792	$1,243,728
Present Value (7.5% Disc. Rate)	$298,807	$355,945	$910,978	$953,336

The results suggest that the spreadsheet is a reasonably accurate approximation of the results of the 2006 Technical Report based on the available data. Some of the difference in results may be due to revenue, with different values reported in the 2006 Technical Report Table 25-11 for the first 10 years, versus the values from Table 20-1 which were for all years used in the spreadsheet. In addition, although according to the report "…the costs of environmental impact mitigation and management have been included in DFS cost estimates along with an estimate of the cost of the mandated closure bond," no information identifying the actual costs was provided, therefore no costs were entered in the spreadsheet.

2007, 2008, 2013 Technical Reports

The 2007 Technical Report re-estimated the mineral resource estimates but did not contain any financial analysis. According to the report "Compared with the DFS estimate, grades in the Measured and Indicated categories drop slightly for all grade elements. Copper (Cu) decreases by 5.64%, nickel (Ni) by

4.61%, platinum (Pt) by 2.45%, palladium (Pd) by 6.55%, gold (Au) by 2.82% and cobalt (Co) by 0.39%. However, the contained metal value increases significantly for all elements upwards of 25% in the Measured and Indicated categories. Copper increased by 27.75%, nickel by 29.14%, platinum by 31.4%, palladium by 26.51%, gold by 33.0% and cobalt by 32.1%."

The 2008 Update was based on a revision to the operating plan that allowed for selling of concentrate during the construction and commissioning of new facilities. The report suggested capital costs had increased for the project by $222.1M since 2006, but the revised strategy would reduce the capital needed to $312.3M. In addition, costs were estimated to increase to $13.33 from $11.02/ton. The Update did not include any detailed cash flow information but suggested an increase in the after-tax rate of return from 26.7% to 30.6%.

The 2013 Technical Report recites the 2008 Update but does not provide any additional information or details related to economic analysis.

Due to the lack of detailed information in the 2007, 2008 and 2013 Technical Reports, no further refinement of the spreadsheet based on the 2006 Technical Report was performed. Given the differences mentioned in those reports, together with new developments such as the estimated cost of reclamation and closure and financial assurance requirements, the company should produce an entirely new Definitive Feasibility Study that hopefully is not based on the 2006 report in any manner, and that contains complete information so as to allow for independent verification of their economic analysis.

Due to the lack of information as well as the need to update the mineral resource estimate, capital costs, operating costs, and likely other aspects affecting project economics, the 2006 DFS and the spreadsheet developed based on it should not be taken to represent the actual project economics. However, since the information is the best available, it is useful and valid in the absence of the proponent producing more current information to compare the potential economics of the project given the proposed financial assurance requirements and if the project were to use filtered tailings instead of slurry tailings to eliminate the risk of catastrophic failure of the tailings storage facility, which are considered in the following sections.

2. Impact of Reclamation and Closure and Financial Assurance on Economic Feasibility

MDNR's Permit to Mine Draft Special Conditions address key aspects of reclamation and closure financial assurance including when various amounts and in what form would be required should the project go forward. Specifically, the following is required (from Attachment 2 to Draft Special Conditions, Financial Assurance):

> G. REQUIRED AMOUNTS OF FINANCIAL ASSURANCE
>
> 17. Prior to issuance of the Permit to Mine, the Permittee:
>
> a. Must provide to the DNR a total of $75,000,000 of financial assurance in the form of Surety or Reclamation Bonds, ILOCs, or cash for coverage of liabilities associated with (i) the construction of the project, and (ii) the legacy reclamation costs associated with the facilities within the former LTVSMC plant site and tailings basin acquired by Permittee from Cliffs Erie, L.L.C.; and
>
> b. Must deposit a minimum of $10,000,000 cash into the Trust Fund described in Appendix B. This $10,000,000 is part of the $75,000,000 financial assurance required under 17a.

> 18. For example, at the start of MY1, Permittee must provide the amount of required financial assurance for total expected liabilities in MY2. Based on the Permittee's current mining plan, the total of Reclamation Costs plus Long Term Costs for MY1 and MY2 are expected to be $544,000,000 and $588,000,000, respectively.

19. Beginning at MY1, the Permittee must contribute a minimum of $2,000,000 cash per year to the Trust Fund until MY9. Annual contributions must be made no later than December 31 each year.

20. Beginning no later than the start of MY9: a. Permittee must commence a ramp up of cash in the Trust Fund through contributions made on an annual basis through the end of MY18. Annual contributions must continue until the value of the Trust Fund has reached the calculated amount needed at MY19 to ensure that the Trust Fund will remain fully funded to cover the Long-Term Costs, assuming an effective discount rate of 2.9%. Based on Permittee's current mining plan, this calculated value at MY19 is expected to be $580,000,000.

current analysis indicates that the Trust Fund needs $580,000,000 at MY19 to ensure payment of all Long-Term Costs. If the ramp-up period begins at the start of MY9, then the Trust Fund would have a balance of approximately $26,000,000, and there would be 10 years of ramp-up to MY19. Permittee's minimum annual cash contribution would therefore be ($580M - $26M)/10 = $55.4 M that year.

Figure 1, from the Draft Special Conditions, provides a descriptive illustration of the financial assurance requirements showing how the maximum reclamation and long-term liability peaks in project year 12 at $1,039M, and then through concurrent reclamation conducted during the mine life decreases to $580M for long-term liability only. The financial assurance requirements from the Draft Special Conditions as illustrated in Figure 1 were entered into the spreadsheets based on the 2006 Technical Report and are shown in **Table 4 - 2006 Base Case with Financial Assurance** and **Table 5 - 2006 Market Case with Financial Assurance** (see Oversize Tables). The financial assurance (FA) estimate is shown separately for Reclamation and Long-Term Monitoring and Maintenance (LTMM) and operations. Also shown is the annual LTMM Trust Fund contribution together with the cumulative amount contributed to the Trust Fund. The Financial Assurance cost was determined using a rate of 1.5% ($0.015/$1.000) applied to the FA estimates minus the cumulative total of the trust fund. No costs for concurrent reclamation and closure are shown, but the spreadsheet shows the reclamation activities being conducted in the three years following the cessation of mining, reducing the LTMM Trust Fund to $474M post-reclamation. The results from the spreadsheets are compared in Table 6.

The results show that the impact of including reclamation and closure financial assurance requirements is significant, particularly in the event of lower metals prices as represented by the Base Case where the IRR was reduced by 10.1%. Of particular concern is the impact that the financial assurance requirements have on cash flow. With the inclusion of the trust fund contributions beginning in Year 9, in the Base Case a significant number of years have either low or negative cash flow in large part due to the large annual contributions ($55.4M) required. In the Market Case the contributions also have a significant impact on cash flow beginning in Year 9.

Figure 1 – Draft Special Conditions Financial Assurance and Trust Fund Requirements

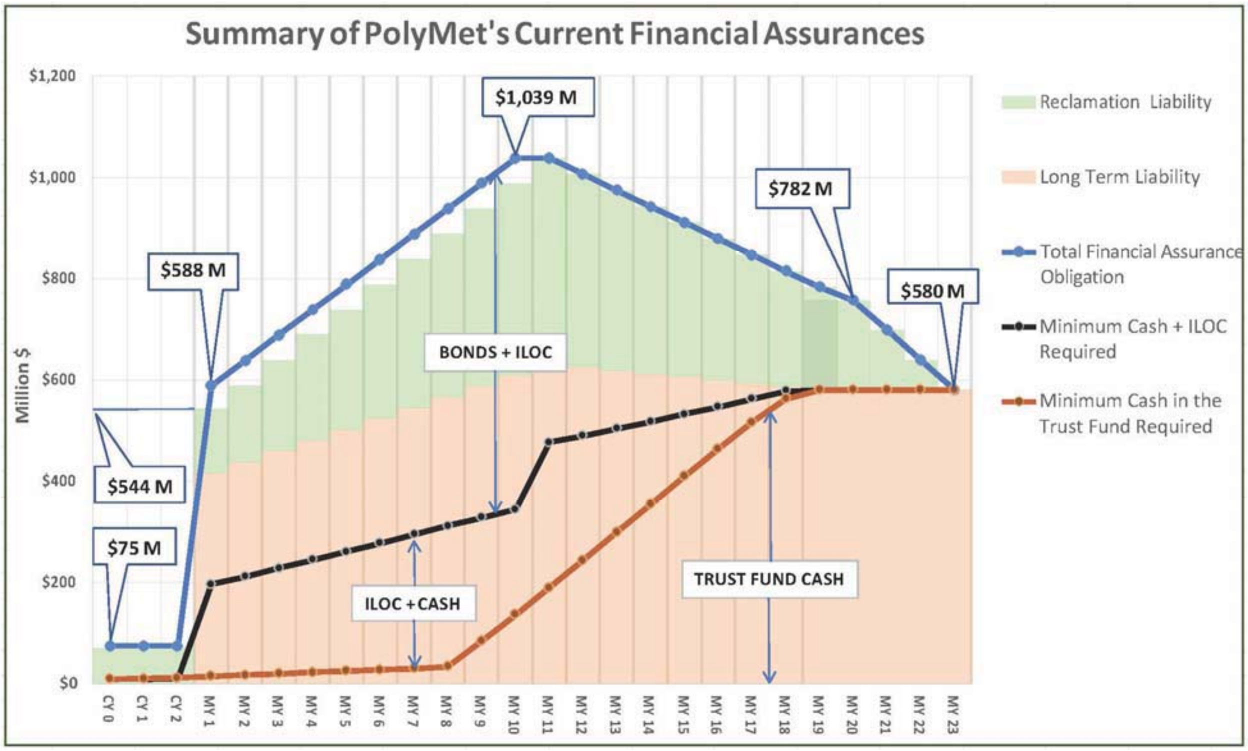

Table 6 – Comparison of 2006 Technical Report with and without Reclamation and Closure

	Base Case		Market Case	
	2006 TR Spreadsheet	Add Reclamation and Closure	2006 TR Spreadsheet	Add Reclamation and Closure
Metal Prices				
Copper	$1.50		$2.25	
Nickel	$6.50		$7.80	
Cobalt	$15.25		$16.34	
Palladium	$225.00		$274.00	
Platinum	$900.00		$1,040.00	
Gold	$450.00		$540.00	
Financial Summary (Pre-Tax)				
Internal Rate of Return (IRR)	18.6%	6.9%	36.9%	32.1%
Present Value (5% Disc. Rate)	$523,680	$110,773	$1,243,728	$934,086
Present Value (7.5% Disc. Rate)	$355,945	$43,884	$953,336	$702,374

The requirement by MDNR to only require an initial amount of $10M and additional amounts of $2M for the first eight years of operation provides for a significant break to the project proponent. However, given the requirement for other forms of financial assurance in lieu of the trust fund this appears to be a reasonable requirement from a regulatory standpoint. But, the analysis shows the end-loaded requirements will have a significant impact on project economics, particularly going forward from Year 9, which overall suggests the project is at significant risk of cessation beginning that year, particularly if metals prices were to become unfavorable. It will be particularly important for this reason for MDNR to pay close attention to the forms and ability to renew financial assurance to ensure it remains viable if the company were to undergo bankruptcy.

3. Impact of Filtered Tailings on Economic Feasibility

As we have discussed in previous comments, the Mount Polley Independent Engineering Review Panel (IERP) recommended that filtered tailings be considered as Best Available Technology (BAT) and recommended that a feasibility analysis be performed to determine the cost, although the IERP recommended that public safety be given the highest consideration. The project proponent has not provided a feasibility study, however MDNR has suggested filtered tailings is not technically or economically viable while the company has stated filtered tailings “were not found to have significant environmental benefit over the” existing plan.[1]

We have rejected the notion of technical viability as contained in our comments which we would summarize as the project proponent and the industry in general waiting to see who will first to undertake filtration at a large scale, given it is commonly used elsewhere in mining for tailings treatment.

MEND (2017)[2] notes that definitive capital costs are difficult to obtain, but provides indicative operating costs suggesting that unthickened conventional slurry tailings typically costs $1.20/tonne, whereas filtered tailings typically cost $5.20/tonne. Additional costs of $100M for estimated capital costs for filtration and additional costs of $4/ton were entered into the spreadsheets based on the 2006 Technical Report and are shown in **Table 7 - 2006 Base Case with Filtered Tailings** and **Table 8 - 2006 Market Case with Filtered Tailings** (see Oversize Tables). The results from the spreadsheets are compared in Table 9.

Table 9 – Comparison of 2006 Technical Report with and without Filtered Tailings

	Base Case		**Market Case**	
	2006 TR Spreadsheet	**Add Filtered Tailings**	**2006 TR Spreadsheet**	**Add Filtered Tailings**
Metal Prices				
Copper	$1.50		$2.25	
Nickel	$6.50		$7.80	
Cobalt	$15.25		$16.34	
Palladium	$225.00		$274.00	
Platinum	$900.00		$1,040.00	
Gold	$450.00		$540.00	
Financial Summary (Pre-Tax)				
Internal Rate of Return (IRR)	18.6%	-10.6%	36.9%	21.0%
Present Value (5% Disc. Rate)	$523,680	-$89,929	$1,243,728	$733,384
Present Value (7.5% Disc. Rate)	$355,945	-$146,092	$953,336	$512,398

[1] http://polymetmining.com/wp-content/uploads/2017/04/Fact-sheet-Tailings-Basin-Stability-2017.pdf
[2] Study of Tailings Management Technologies, MEND Report 2.50.1, October 2017.

The results show that the impact of using filtered tailings is likely to be significant, particularly in the event of lower metals prices as represented by the Base Case where the IRR was reduced to a negative return. However, the analysis only addresses the upfront costs, and not any reductions that would occur such as reduced reclamation and closure costs. The use of filtered tailings would allow for significant concurrent reclamation to occur and minimize the reclamation requirements at the end of the project life. The use of filtered tailings would also reduce the future costs for LTMM and water treatment operations.

The costs for filtered tailings used in this analysis are highly preliminary and a more definitive capital and cost operating estimate should be provided by the proponent and the result considered against the current economics. This should be done in a manner consistent with the recommendations of the IERP and in particular should be considered weighing public input from those persons whom might be directly impacted were a catastrophic tailings failure to occur. It is not possible to conduct an adequate feasibility study for filtered tailings without a complete feasibility study for the proposed project that reflects current conditions to compare the option of filtered tailings. Until this situation is rectified with respect to both an adequate analysis and public stakeholder involvement in the same, consistent with the current standard of care, PolyMet will not have demonstrated itself as a responsible mining company.

Oversize Tables

Table 1
CASH FLOW ANALYSIS - Polymet Northmet Project
Base Case (2006 Technical Report)

Line #	Description	Data Source	Total	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
				Year/Project Year																									
				0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Mining Operations																												
1	Ore Mined (kt)	2006 TR Table 20-1	226,706	78	6,469	11,935	13,903	10,470	12,692	12,599	12,729	9,879	11,080	14,013	11,121	12,736	12,443	10,360	4,083	9,334	10,231	8,467	8,894	7,598	9566	6026			
2	Waste Mined (kt)	2006 TR Table 20-1	336,370		25,436	20,212	21,564	17,280	14,598	21,857	13,520	21,383	17,350	17,122	14,207	15,608	13,883	12,178	10,950	9,099	6,956	8,842	11,944	14,128	14,128	14,128			
3	Total Material Mined (kt)	2006 TR Table 20-1	563,076		31,905	32,147	35,467	27,750	27,290	34,456	26,249	31,262	28,430	31,135	25,328	28,344	26,326	22,538	15,033	18,433	17,187	17,309	20,838	21,726	23,694	20,154			
4	**Process Plant Operations**																												
5	Ore Processed (kt)	2006 TR Table 20-1	227,607		6,307	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	9,344	9,344	9,344	9,344	8,246	8,246	8,246	7,346			
6	Ore Grade																												
7	Copper (%)	2006 TR Table 20-1	0.30%		0.32%	0.33%	0.39%	0.37%	0.29%	0.30%	0.31%	0.27%	0.25%	0.30%	0.29%	0.26%	0.27%	0.28%	0.24%	0.27%	0.34%	0.34%	0.36%	0.28%	0.43%	0.30%			
8	Nickel (%)	2006 TR Table 20-1	0.09%		0.09%	0.09%	0.10%	0.10%	0.09%	0.09%	0.09%	0.08%	0.08%	0.09%	0.08%	0.08%	0.08%	0.09%	0.07%	0.08%	0.09%	0.09%	0.09%	0.08%	0.11%	0.08%			
9	Cobalt ppm	2006 TR Table 20-1	74		76	71	82	79	76	74	72	71	72	73	70	71	73	83	69	73	78	77	77	71	75	69			
10	Palladium ppb	2006 TR Table 20-1	276		312	319	354	291	253	264	282	262	233	263	272	268	277	266	242	263	309	283	284	218	378	263			
11	Platinum ppb	2006 TR Table 20-1	79		80	90	108	79	67	71	76	71	69	74	77	74	74	74	69	78	102	84	83	70	106	83			
12	Gold ppb	2006 TR Table 20-1	39		39	43	51	41	35	37	39	35	32	35	36	36	37	37	35	38	45	42	42	36	57	41			
13	Ore Contained Metal																												
14	Copper (klbs)	2006 TR Table 20-1	1,405,141		41,402	78,771	108,443	77,478	73,614	75,594	78,920	53,347	55,400	84,078	64,502	66,227	67,192	58,016	19,598	50,404	69,571	57,576	64,037	42,549	82,268	36,156			
15	Nickel (klbs)	2006 TR Table 20-1	398,955		11,644	21,483	27,806	20,940	22,846	22,678	22,912	15,806	17,728	25,223	17,794	20,378	19,909	18,648	5,716	14,934	18,416	15,241	16,009	12,157	21,045	9,642			
16	Cobalt (klbs)	2006 TR Table 20-1	33,727		983	1,695	2,280	1,654	1,929	1,865	1,833	1,403	1,596	2,046	1,557	1,809	1,817	1,720	563	1,363	1,596	1,304	1,370	1,079	1,435	832			
17	Palladium (ozs)	2006 TR Table 20-1	1,860,417		58,854	111,020	143,516	88,844	93,635	96,990	104,672	75,475	75,281	107,467	88,206	99,530	100,506	80,358	28,813	71,583	92,186	69,872	73,655	48,300	105,441	46,214			
18	Platinum (ozs)	2006 TR Table 20-1	529,852		15,091	31,322	43,784	24,119	24,797	26,084	28,210	20,453	22,293	30,238	24,970	27,482	26,850	22,355	8,215	21,230	30,430	20,739	21,526	15,509	29,568	14,585			
19	Gold (ozs)	2006 TR Table 20-1	261,186		7,357	14,965	20,676	12,518	12,953	13,593	14,476	10,083	10,339	14,302	11,674	13,370	13,425	11,178	4,167	10,343	13,425	10,370	10,893	7,976	15,900	7,204			
20	Recovery																												
21	Copper (%)	2006 TR Table 25-9	92.3%		92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%			
22	Nickel (%)	2006 TR Table 25-9	70.3%		70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%			
23	Cobalt (%)	2006 TR Table 25-9	40.7%		40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%			
24	Palladium (%)	2006 TR Table 25-9	75.2%		75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%			
25	Platinum (%)	2006 TR Table 25-9	72.7%		72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%			
26	Gold (%)	2006 TR Table 25-9	67.0%		67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%			
27	Recovered Metal																												
28	Copper (klbs)	Calculated	1,296,945		38,214	72,706	100,093	71,512	67,945	69,773	72,843	49,239	51,134	77,604	59,535	61,128	62,018	53,549	18,089	46,523	64,214	53,142	59,106	39,273	75,933	33,372			
29	Nickel (klbs)	Calculated	280,465		8,186	15,103	19,548	14,721	16,060	15,943	16,107	11,112	12,463	17,732	12,509	14,325	13,996	13,110	4,018	10,499	12,946	10,714	11,254	8,546	14,795	6,778			
30	Cobalt (klbs)	Calculated	13,727		400	690	928	673	785	759	746	571	649	833	634	736	739	700	229	555	650	531	557	439	584	338			
31	Palladium (ozs)	Calculated	1,399,034		44,259	83,487	107,924	66,811	70,414	72,937	78,713	56,757	56,611	80,815	66,331	74,847	75,581	60,429	21,667	53,831	69,324	52,544	55,389	36,321	79,292	34,753			
32	Platinum (ozs)	Calculated	385,202		10,971	22,771	31,831	17,535	18,027	18,963	20,508	14,869	16,207	21,983	18,153	19,980	19,520	16,252	5,972	15,434	22,123	15,078	15,649	11,275	21,496	10,603			
33	Gold (ozs)	Calculated	174,994		4,929	10,027	13,853	8,387	8,679	9,108	9,699	6,755	6,927	9,582	7,822	8,958	8,995	7,489	2,792	6,930	8,995	6,948	7,298	5,344	10,653	4,827			
34	**Revenue**																												
35	Metals Prices																												
36	Copper ($/lb)	2006 TR Table 25-9	$1.50		$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50			
37	Nickel ($/lb)	2006 TR Table 25-9	$6.50		$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50			
38	Cobalt ($/lb)	2006 TR Table 25-9	$15.25		$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25			
39	Palladium ($/oz)	2006 TR Table 25-9	$225.00		$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00			
40	Platinum ($/oz)	2006 TR Table 25-9	$900.00		$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00			
41	Gold ($/oz)	2006 TR Table 25-9	$450.00		$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00			
42	Treatment and Refining Charges																												
43	Copper ($/lb)	2006 TR Table 19-6	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00			
44	Nickel ($/lb)	2006 TR Table 19-6	$1.63		$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63			
45	Cobalt ($/lb)	2006 TR Table 19-6	$6.10		$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10			
46	Palladium ($/oz)	2006 TR Table 19-6	$17.00		$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00			
47	Platinum ($/oz)	2006 TR Table 19-6	$18.00		$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00			
48	Gold ($/oz)	2006 TR Table 19-6	$9.50		$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50			
49	Revenue																												
50	Copper (k$)	Calculated	$1,945,417		$57,321	$109,058	$150,140	$107,268	$101,918	$104,660	$109,264	$73,858	$76,701	$116,406	$89,303	$91,692	$93,028	$80,323	$27,134	$69,784	$96,321	$79,713	$88,659	$58,909	$113,899	$50,058			
51	Nickel (k$)	Calculated	$1,367,268		$39,906	$73,625	$95,295	$71,764	$78,295	$77,721	$78,523	$54,171	$60,756	$86,444	$60,981	$69,837	$68,230	$63,909	$19,590	$51,182	$63,113	$52,231	$54,866	$41,663	$72,125	$33,043			
52	Cobalt (k$)	Calculated	$125,600		$3,662	$6,311	$8,491	$6,161	$7,184	$6,944	$6,826	$5,224	$5,942	$7,619	$5,798	$6,735	$6,765	$6,404	$2,098	$5,075	$5,944	$4,856	$5,101	$4,018	$5,344	$3,097			
53	Palladium (k$)	Calculated	$290,999		$9,206	$17,365	$22,448	$13,897	$14,646	$15,171	$16,372	$11,805	$11,775	$16,810	$13,797	$15,568	$15,721	$12,569	$4,507	$11,197	$14,419	$10,929	$11,521	$7,555	$16,493	$7,229			
54	Platinum (k$)	Calculated	$339,748		$9,676	$20,084	$28,075	$15,466	$15,900	$16,726	$18,088	$13,115	$14,295	$19,389	$16,011	$17,622	$17,217	$14,334	$5,268	$13,613	$19,512	$13,298	$13,803	$9,945	$18,959	$9,352			
55	Gold (k$)	Calculated	$77,085		$2,171	$4,417	$6,102	$3,694	$3,823	$4,012	$4,272	$2,976	$3,051	$4,221	$3,446	$3,946	$3,962	$3,299	$1,230	$3,053	$3,962	$3,060	$3,215	$2,354	$4,693	$2,126			
56	Net Revenue (k$)	Calculated	$4,146,117		$121,942	$230,861	$310,551	$218,249	$221,766	$225,233	$233,347	$161,149	$172,520	$250,888	$189,335	$205,399	$204,922	$180,839	$59,827	$153,903	$203,272	$164,089	$177,164	$124,443	$231,512	$104,905			
57	**Expenditures**																												
58	Capital Expenditures																												
59	Initial Capital (k$)	2006 TR Table 20-8	$379,640	$379,640																									
59	Sustaining Capital (k$)	2006 TR Table 25-11	$71,787		$ 11,238	$ 6,406	$ 7,686	$ 6,515	$ 8,184	$ 6,377	$ 7,296	$ 6,113	$ 4,899	$ 7,073															
60	Working Capital (k$)	2006 TR Table 25-11	$0	$ 14,991	$ 5,819																				$ (20,810)			
61	Total Capital Expenditures (k$)		$451,427	$394,631	$17,057	$6,406	$7,686	$6,515	$8,184	$6,377	$7,296	$6,113	$4,899	$7,073	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$20,810			
62	Operating Cost																												
63	Mining and Infrastructure ($/ton milled)																												
64	Railroad Operations ($/ton milled)																												
65	Metallurgical Operations ($/ton milled)																												
66	General and Admin ($/ton milled)																												
67	Power ($/ton milled)																												
68	Total Operating Cost ($/ton milled)	Calculated	$11.32		$14.26	$10.69	$11.13	$11.19	$10.95	$10.78	$10.95	$10.99	$11.16	$11.33	$10.98	$11.13	$10.91	$10.70	$11.76	$11.99	$12.32	$11.62	$12.52	$12.19	$12.30	$8.74			
69	Total Operating Cost (k$)	2006 TR Table 20-10	$2,576,372	$ 2,483	$89,948	$124,860	$130,040	$130,718	$127,891	$125,865	$127,876	$128,366	$130,305	$132,356	$128,204	$130,043	$127,453	$124,918	$109,866	$112,042	$115,133	$108,592	$103,253	$100,539	$101,452	$64,169	$0	$0	$0
70	Financial Assurance	Not identifiable																											
71	Reclamation and Closure	Not identifiable																											
72	Total All Expenditures	Calculated	$3,027,799	$397,114	$107,005	$131,266	$137,726	$137,233	$136,075	$132,242	$135,172	$134,479	$135,204	$139,429	$128,204	$130,043	$127,453	$124,918	$109,866	$112,042	$115,133	$108,592	$103,253	$100,539	$101,452	$43,359	$0	$0	$0
73	**Income**																												
74	Operating Income (k$)	Calculated	$1,118,319	-$397,114	$14,937	$99,595	$172,825	$81,017	$85,691	$92,992	$98,174	$26,670	$37,316	$111,459	$61,131	$75,356	$77,470	$55,921	-$50,039	$41,861	$88,138	$55,496	$73,910	$23,904	$130,061	$61,545	$0	$0	$0
75	Cumulative Cash Flow (k$)	Calculated		-$397,114	-$382,176	-$282,581	-$109,756	-$28,739	$56,952	$149,943	$248,118	$274,788	$312,104	$423,563	$484,694	$560,051	$637,521	$693,442	$643,403	$685,264	$773,402	$828,898	$902,809	$926,713	$1,056,773	$1,118,319	$1,118,319	$1,118,319	$1,118,319
76	**Economic Indicators before Taxes**																												
77	NPV @ 0%		0%	$1,118,319																									
78	NPV @ 5%	Calculated	5.0%	$523,680																									
79	NPV @ 7.5%	Calculated	7.5%	$355,945																									
80	IRR	Calculated		18.6%																									

Joint Petition Ex. 13

Table 2
CASH FLOW ANALYSIS - Polymet Northmet Project
Market Case (2006 Technical Report)

Line #	Description	Data Source	Year/Project Year																										
				2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
			Total	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Mining Operations																												
1	Ore Mined (kt)	2006 TR Table 20-1	226,706	78	6,469	11,935	13,903	10,470	12,692	12,599	12,729	9,879	11,080	14,013	11,121	12,736	12,443	10,360	4,083	9,334	10,231	8,467	8,894	7,598	9566	6026			
2	Waste Mined (kt)	2006 TR Table 20-1	336,370		25,436	20,212	21,564	17,280	14,598	21,857	13,520	21,383	17,350	17,122	14,207	15,608	13,883	12,178	10,950	9,099	6,956	8,842	11,944	14,128	14,128	14,128			
3	Total Material Mined (kt)	2006 TR Table 20-1	563,076		31,905	32,147	35,467	27,750	27,290	34,456	26,249	31,262	28,430	31,135	25,328	28,344	26,326	22,538	15,033	18,433	17,187	17,309	20,838	21,726	23,694	20,154			
4	**Process Plant Operations**																												
5	Ore Processed (kt)	2006 TR Table 20-1	227,607		6,307	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	9,344	9,344	9,344	9,344	8,246	8,246	8,246	7,346			
6	Ore Grade																												
7	Copper (%)	2006 TR Table 20-1	0.30%		0.32%	0.33%	0.39%	0.37%	0.29%	0.30%	0.31%	0.27%	0.25%	0.30%	0.29%	0.26%	0.27%	0.28%	0.24%	0.27%	0.34%	0.34%	0.36%	0.28%	0.43%	0.30%			
8	Nickel (%)	2006 TR Table 20-1	0.09%		0.09%	0.09%	0.10%	0.10%	0.09%	0.09%	0.09%	0.08%	0.08%	0.09%	0.08%	0.08%	0.08%	0.09%	0.07%	0.08%	0.09%	0.09%	0.09%	0.08%	0.11%	0.08%			
9	Cobalt ppm	2006 TR Table 20-1	74		76	71	82	79	76	74	72	71	72	73	70	71	73	83	69	73	78	77	77	71	75	69			
10	Palladium ppb	2006 TR Table 20-1	276		312	319	354	291	253	264	282	262	233	263	272	268	277	266	242	263	309	283	284	218	378	263			
11	Platinum ppb	2006 TR Table 20-1	79		80	90	108	79	67	71	76	71	69	74	77	74	74	74	69	78	102	84	83	70	106	83			
12	Gold ppb	2006 TR Table 20-1	39		39	43	51	41	35	37	39	35	32	35	36	36	37	37	35	38	45	42	42	36	57	41			
13	Ore Contained Metal																												
14	Copper (klbs)	2006 TR Table 20-1	1,405,141		41,402	78,771	108,443	77,478	73,614	75,594	78,920	53,347	55,400	84,078	64,502	66,227	67,192	58,016	19,598	50,404	69,571	57,576	64,037	42,549	82,268	36,156			
15	Nickel (klbs)	2006 TR Table 20-1	398,955		11,644	21,483	27,806	20,940	22,846	22,678	22,912	15,806	17,728	25,223	17,794	20,378	19,909	18,648	5,716	14,934	18,416	15,241	16,009	12,157	21,045	9,642			
16	Cobalt (klbs)	2006 TR Table 20-1	33,727		983	1,695	2,280	1,654	1,929	1,865	1,833	1,403	1,596	2,046	1,557	1,809	1,817	1,720	563	1,363	1,596	1,304	1,370	1,079	1,435	832			
17	Palladium (ozs)	2006 TR Table 20-1	1,860,417		58,854	111,020	143,516	88,844	93,635	96,990	104,672	75,475	75,281	107,467	88,206	99,530	100,506	80,358	28,813	71,583	92,186	69,872	73,655	48,300	105,441	46,214			
18	Platinum (ozs)	2006 TR Table 20-1	529,852		15,091	31,322	43,784	24,119	24,797	26,084	28,210	20,453	22,293	30,238	24,970	27,482	26,850	22,355	8,215	21,230	30,430	20,739	21,526	15,509	29,568	14,585			
19	Gold (ozs)	2006 TR Table 20-1	261,186		7,357	14,965	20,676	12,518	12,953	13,593	14,476	10,083	10,339	14,302	11,674	13,370	13,425	11,178	4,167	10,343	13,425	10,370	10,893	7,976	15,900	7,204			
20	Recovery																												
21	Copper (%)	2006 TR Table 25-9	92.3%		92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%			
22	Nickel (%)	2006 TR Table 25-9	70.3%		70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%			
23	Cobalt (%)	2006 TR Table 25-9	40.7%		40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%			
24	Palladium (%)	2006 TR Table 25-9	75.2%		75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%			
25	Platinum (%)	2006 TR Table 25-9	72.7%		72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%			
26	Gold (%)	2006 TR Table 25-9	67.0%		67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%			
27	Recovered Metal																												
28	Copper (klbs)	Calculated	1,296,945		38,214	72,706	100,093	71,512	67,945	69,773	72,843	49,239	51,134	77,604	59,535	61,128	62,018	53,549	18,089	46,523	64,214	53,142	59,106	39,273	75,933	33,372			
29	Nickel (klbs)	Calculated	280,465		8,186	15,103	19,548	14,721	16,060	15,943	16,107	11,112	12,463	17,732	12,509	14,325	13,996	13,110	4,018	10,499	12,946	10,714	11,254	8,546	14,795	6,778			
30	Cobalt (klbs)	Calculated	13,727		400	690	928	673	785	759	746	571	649	833	634	736	739	700	229	555	650	531	557	439	584	338			
31	Palladium (ozs)	Calculated	1,399,034		44,259	83,487	107,924	66,811	70,414	72,937	78,713	56,757	56,611	80,815	66,331	74,847	75,581	60,429	21,667	53,831	69,324	52,544	55,389	36,321	79,292	34,753			
32	Platinum (ozs)	Calculated	385,202		10,971	22,771	31,831	17,535	18,027	18,963	20,508	14,869	16,207	21,983	18,153	19,980	19,520	16,252	5,972	15,434	22,123	15,078	15,649	11,275	21,496	10,603			
33	Gold (ozs)	Calculated	174,994		4,929	10,027	13,853	8,387	8,679	9,108	9,699	6,755	6,927	9,582	7,822	8,958	8,995	7,489	2,792	6,930	8,995	6,948	7,298	5,344	10,653	4,827			
34	**Revenue**																												
35	Metals Prices																												
36	Copper ($/lb)	2006 TR Table 25-9	$2.25		$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25			
37	Nickel ($/lb)	2006 TR Table 25-9	$7.80		$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80			
38	Cobalt ($/lb)	2006 TR Table 25-9	$16.34		$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34			
39	Palladium ($/oz)	2006 TR Table 25-9	$274.00		$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00			
40	Platinum ($/oz)	2006 TR Table 25-9	$1,040.00		$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00			
41	Gold ($/oz)	2006 TR Table 25-9	$540.00		$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00			
42	Treatment and Refining Charges																												
43	Copper ($/lb)	2006 TR Table 19-6	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00			
44	Nickel ($/lb)	2006 TR Table 19-6	$1.95		$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95			
45	Cobalt ($/lb)	2006 TR Table 19-6	$6.54		$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54			
46	Palladium ($/oz)	2006 TR Table 19-6	$17.00		$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00			
47	Platinum ($/oz)	2006 TR Table 19-6	$18.00		$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00			
48	Gold ($/oz)	2006 TR Table 19-6	$9.50		$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50			
49	Revenue																												
50	Copper (k$)	Calculated	$2,918,126		$85,981	$163,588	$225,210	$160,902	$152,877	$156,990	$163,897	$110,788	$115,052	$174,609	$133,954	$137,537	$139,541	$120,485	$40,701	$104,676	$144,481	$119,570	$132,988	$88,363	$170,849	$75,087			
51	Nickel (k$)	Calculated	$1,640,722		$47,887	$88,350	$114,354	$86,117	$93,954	$93,265	$94,228	$65,005	$72,907	$103,732	$73,177	$83,804	$81,876	$76,691	$23,508	$61,418	$75,736	$62,678	$65,839	$49,995	$86,549	$39,652			
52	Cobalt (k$)	Calculated	$134,577		$3,924	$6,763	$9,098	$6,601	$7,698	$7,440	$7,314	$5,598	$6,366	$8,164	$6,213	$7,216	$7,249	$6,862	$2,248	$5,438	$6,369	$5,203	$5,465	$4,305	$5,726	$3,318			
53	Palladium (k$)	Calculated	$359,552		$11,374	$21,456	$27,736	$17,170	$18,096	$18,745	$20,229	$14,587	$14,549	$20,769	$17,047	$19,236	$19,424	$15,530	$5,568	$13,834	$17,816	$13,504	$14,235	$9,335	$20,378	$8,931			
54	Platinum (k$)	Calculated	$393,677		$11,212	$23,272	$32,532	$17,920	$18,424	$19,381	$20,959	$15,197	$16,564	$22,467	$18,553	$20,419	$19,949	$16,610	$6,104	$15,774	$22,610	$15,409	$15,994	$11,523	$21,969	$10,836			
55	Gold (k$)	Calculated	$92,835		$2,615	$5,319	$7,349	$4,449	$4,604	$4,832	$5,145	$3,584	$3,675	$5,083	$4,149	$4,752	$4,772	$3,973	$1,481	$3,676	$4,772	$3,686	$3,872	$2,835	$5,651	$2,561			
56	Net Revenue (k$)	Calculated	$5,539,487		$162,993	$308,748	$416,278	$293,160	$295,653	$300,652	$311,772	$214,756	$229,113	$334,824	$253,093	$272,964	$272,812	$240,151	$79,611	$204,816	$271,783	$220,050	$238,393	$166,356	$311,123	$140,385			
57	**Expenditures**																												
58	Capital Expenditures																												
59	Initial Capital (k$)	2006 TR Table 20-8	$379,640	$379,640																									
59	Sustaining Capital (k$)	2006 TR Table 25-11	$71,787		$ 11,238	$ 6,406	$ 7,686	$ 6,515	$ 8,184	$ 6,377	$ 7,296	$ 6,113	$ 4,899	$ 7,073															
60	Working Capital (k$)	2006 TR Table 25-11	$0	$ 14,991	$ 5,819																			$ (20,810)			
61	Total Capital Expenditures (k$)		$451,427	$394,631	$17,057	$6,406	$7,686	$6,515	$8,184	$6,377	$7,296	$6,113	$4,899	$7,073	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$20,810			
62	Operating Cost																												
63	Mining and Infrastructure ($/ton milled)																												
64	Railroad Operations ($/ton milled)																												
65	Metallurgical Operations ($/ton milled)																												
66	General and Admin ($/ton milled)																												
67	Power ($/ton milled)																												
68	Total Operating Cost ($/ton milled)	Calculated	$11.32		$14.26	$10.69	$11.13	$11.19	$10.95	$10.78	$10.95	$10.99	$11.16	$11.33	$10.98	$11.13	$10.91	$10.70	$11.76	$11.99	$12.32	$11.62	$12.52	$12.19	$12.30	$8.74			
69	Total Operating Cost (k$)	2006 TR Table 20-10	$2,576,372	$ 2,483	$89,948	$124,860	$130,040	$130,718	$127,891	$125,865	$127,876	$128,366	$130,305	$132,356	$128,204	$130,043	$127,453	$124,918	$109,866	$112,042	$115,133	$108,592	$103,253	$100,539	$101,452	$64,169	$0	$0	$0
70	Financial Assurance	Not identifiable																											
71	Reclamation and Closure	Not identifiable																											
72	Total All Expenditures	Calculated	$3,027,799	$397,114	$107,005	$131,266	$137,726	$137,233	$136,075	$132,242	$135,172	$134,479	$135,204	$139,429	$128,204	$130,043	$127,453	$124,918	$109,866	$112,042	$115,133	$108,592	$103,253	$100,539	$101,452	$43,359	$0	$0	$0
73	**Income**																												
74	Operating Income (k$)	Calculated	$2,511,689	-$397,114	$55,989	$177,482	$278,553	$155,927	$159,577	$168,411	$176,600	$80,278	$93,909	$195,396	$124,889	$142,922	$145,359	$115,233	-$30,255	$92,774	$156,650	$111,457	$135,139	$65,817	$209,671	$97,026	$0	$0	$0
75	Cumulative Cash Flow (k$)	Calculated		-$397,114	-$341,125	-$163,643	$114,910	$270,837	$430,414	$598,825	$775,425	$855,702	$949,611	$1,145,007	$1,269,896	$1,412,817	$1,558,176	$1,673,409	$1,643,154	$1,735,928	$1,892,578	$2,004,035	$2,139,175	$2,204,992	$2,414,663	$2,511,689	$2,511,689	$2,511,689	$2,511,689
76	**Economic Indicators before Taxes**																												
77	NPV @ 0%		0%	$2,204,992																									
78	NPV @ 5%	Calculated	5.0%	$1,243,728																									
79	NPV @ 7.5%	Calculated	7.5%	$953,336																									
80	IRR	Calculated		36.9%																									

Table 4
CASH FLOW ANALYSIS - Polymet Northmet Project
Base Case (2006 Technical Report) with Reclamation and Closure

Line #	Description	Data Source	Total	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
	Year/Project Year			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Mining Operations																												
1	Ore Mined (kt)	2006 TR Table 20-1	226,706	78	6,469	11,935	13,903	10,470	12,692	12,599	12,729	9,879	11,080	14,013	11,121	12,736	12,443	10,360	4,083	9,334	10,231	8,467	8,894	7,598	9566	6026			
2	Waste Mined (kt)	2006 TR Table 20-1	336,370		25,436	20,212	21,564	17,280	14,598	21,857	13,520	21,383	17,350	17,122	14,207	15,608	13,883	12,178	10,950	9,099	6,956	8,842	11,944	14,128	14,128	14,128			
3	Total Material Mined (kt)	2006 TR Table 20-1	563,076		31,905	32,147	35,467	27,750	27,290	34,456	26,249	31,262	28,430	31,135	25,328	28,344	26,326	22,538	15,033	18,433	17,187	17,309	20,838	21,726	23,694	20,154			
4	**Process Plant Operations**																												
5	Ore Processed (kt)	2006 TR Table 20-1	227,607		6,307	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	9,344	9,344	9,344	9,344	8,246	8,246	8,246	7,346			
6	Ore Grade																												
7	Copper (%)	2006 TR Table 20-1	0.30%		0.32%	0.33%	0.39%	0.37%	0.29%	0.30%	0.31%	0.27%	0.25%	0.30%	0.29%	0.26%	0.27%	0.28%	0.24%	0.27%	0.34%	0.34%	0.36%	0.28%	0.43%	0.30%			
8	Nickel (%)	2006 TR Table 20-1	0.09%		0.09%	0.09%	0.10%	0.10%	0.09%	0.09%	0.09%	0.08%	0.08%	0.09%	0.08%	0.08%	0.08%	0.09%	0.07%	0.08%	0.09%	0.09%	0.09%	0.08%	0.11%	0.08%			
9	Cobalt ppm	2006 TR Table 20-1	74		76	71	82	79	76	74	72	71	72	73	70	71	73	83	69	73	78	77	77	71	75	69			
10	Palladium ppb	2006 TR Table 20-1	276		312	319	354	291	253	264	282	262	233	263	272	268	277	266	242	263	309	283	284	218	378	263			
11	Platinum ppb	2006 TR Table 20-1	79		80	90	108	79	67	71	76	71	69	74	77	74	74	74	69	78	102	84	83	70	106	83			
12	Gold ppb	2006 TR Table 20-1	39		39	43	51	41	35	37	39	35	32	35	36	36	37	37	35	38	45	42	42	36	57	41			
13	Ore Contained Metal																												
14	Copper (klbs)	2006 TR Table 20-1	1,405,141		41,402	78,771	108,443	77,478	73,614	75,594	78,920	53,347	55,400	84,078	64,502	66,227	67,192	58,016	19,598	50,404	69,571	57,576	64,037	42,549	82,268	36,156			
15	Nickel (klbs)	2006 TR Table 20-1	398,955		11,644	21,483	27,806	20,940	22,846	22,678	22,912	15,806	17,728	25,223	17,794	20,378	19,909	18,648	5,716	14,934	18,416	15,241	16,009	12,157	21,045	9,642			
16	Cobalt (klbs)	2006 TR Table 20-1	33,727		983	1,695	2,280	1,654	1,929	1,865	1,833	1,403	1,596	2,046	1,557	1,809	1,817	1,720	563	1,363	1,596	1,304	1,370	1,079	1,435	832			
17	Palladium (ozs)	2006 TR Table 20-1	1,860,417		58,854	111,020	143,516	88,844	93,635	96,990	104,672	75,475	75,281	107,467	88,206	99,530	100,506	80,358	28,813	71,583	92,186	69,872	73,655	48,300	105,441	46,214			
18	Platinum (ozs)	2006 TR Table 20-1	529,852		15,091	31,322	43,784	24,119	24,797	26,084	28,210	20,453	22,293	30,238	24,970	27,482	26,850	22,355	8,215	21,230	30,430	20,739	21,526	15,509	29,568	14,585			
19	Gold (ozs)	2006 TR Table 20-1	261,186		7,357	14,965	20,676	12,518	12,953	13,593	14,476	10,083	10,339	14,302	11,674	13,370	13,425	11,178	4,167	10,343	13,425	10,370	10,893	7,976	15,900	7,204			
20	Recovery																												
21	Copper (%)	2006 TR Table 25-9	92.3%		92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%			
22	Nickel (%)	2006 TR Table 25-9	70.3%		70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%			
23	Cobalt (%)	2006 TR Table 25-9	40.7%		40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%			
24	Palladium (%)	2006 TR Table 25-9	75.2%		75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%			
25	Platinum (%)	2006 TR Table 25-9	72.7%		72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%			
26	Gold (%)	2006 TR Table 25-9	67.0%		67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%			
27	Recovered Metal																												
28	Copper (klbs)	Calculated	1,296,945		38,214	72,706	100,093	71,512	67,945	69,773	72,843	49,239	51,134	77,604	59,535	61,128	62,018	53,549	18,089	46,523	64,214	53,142	59,106	39,273	75,933	33,372			
29	Nickel (klbs)	Calculated	280,465		8,186	15,103	19,548	14,721	16,060	15,943	16,107	11,112	12,463	17,732	12,509	14,325	13,996	13,110	4,018	10,499	12,946	10,714	11,254	8,546	14,795	6,778			
30	Cobalt (klbs)	Calculated	13,727		400	690	928	673	785	759	746	571	649	833	634	736	739	700	229	555	650	531	557	439	584	338			
31	Palladium (ozs)	Calculated	1,399,034		44,259	83,487	107,924	66,811	70,414	72,937	78,713	56,757	56,611	80,815	66,331	74,847	75,581	60,429	21,667	53,831	69,324	52,544	55,389	36,321	79,292	34,753			
32	Platinum (ozs)	Calculated	385,202		10,971	22,771	31,831	17,535	18,027	18,963	20,508	14,869	16,207	21,983	18,153	19,980	19,520	16,252	5,972	15,434	22,123	15,078	15,649	11,275	21,496	10,603			
33	Gold (ozs)	Calculated	174,994		4,929	10,027	13,853	8,387	8,679	9,108	9,699	6,755	6,927	9,582	7,822	8,958	8,995	7,489	2,792	6,930	8,995	6,948	7,298	5,344	10,653	4,827			
34	**Revenue**																												
35	Metals Prices																												
36	Copper ($/lb)	2006 TR Table 25-9	$1.50		$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50			
37	Nickel ($/lb)	2006 TR Table 25-9	$6.50		$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50			
38	Cobalt ($/lb)	2006 TR Table 25-9	$15.25		$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25			
39	Palladium ($/oz)	2006 TR Table 25-9	$225.00		$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00			
40	Platinum ($/oz)	2006 TR Table 25-9	$900.00		$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00			
41	Gold ($/oz)	2006 TR Table 25-9	$450.00		$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00			
42	Treatment and Refining Charges																												
43	Copper ($/lb)	2006 TR Table 19-6	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00			
44	Nickel ($/lb)	2006 TR Table 19-6	$1.63		$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63			
45	Cobalt ($/lb)	2006 TR Table 19-6	$6.10		$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10			
46	Palladium ($/oz)	2006 TR Table 19-6	$17.00		$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00			
47	Platinum ($/oz)	2006 TR Table 19-6	$18.00		$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00			
48	Gold ($/oz)	2006 TR Table 19-6	$9.50		$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50			
49	Revenue																												
50	Copper (k$)	Calculated	$1,945,417		$57,321	$109,058	$150,140	$107,268	$101,918	$104,660	$109,264	$73,858	$76,701	$116,406	$89,303	$91,692	$93,028	$80,323	$27,134	$69,784	$96,321	$79,713	$88,659	$58,909	$113,899	$50,058			
51	Nickel (k$)	Calculated	$1,367,268		$39,906	$73,625	$95,295	$71,764	$78,295	$77,721	$78,523	$54,171	$60,756	$86,444	$60,981	$69,837	$68,230	$63,909	$19,590	$51,182	$63,113	$52,231	$54,866	$41,663	$72,125	$33,043			
52	Cobalt (k$)	Calculated	$125,600		$3,662	$6,311	$8,491	$6,161	$7,184	$6,944	$6,826	$5,224	$5,942	$7,619	$5,798	$6,735	$6,765	$6,404	$2,098	$5,075	$5,944	$4,856	$5,101	$4,018	$5,344	$3,097			
53	Palladium (k$)	Calculated	$290,999		$9,206	$17,365	$22,448	$13,897	$14,646	$15,171	$16,372	$11,805	$11,775	$16,810	$13,797	$15,568	$15,721	$12,569	$4,507	$11,197	$14,419	$10,929	$11,521	$7,555	$16,493	$7,229			
54	Platinum (k$)	Calculated	$339,748		$9,676	$20,084	$28,075	$15,466	$15,900	$16,726	$18,088	$13,115	$14,295	$19,389	$16,011	$17,622	$17,217	$14,334	$5,268	$13,613	$19,512	$13,298	$13,803	$9,945	$18,959	$9,352			
55	Gold (k$)	Calculated	$77,085		$2,171	$4,417	$6,102	$3,694	$3,823	$4,012	$4,272	$2,976	$3,051	$4,221	$3,446	$3,946	$3,962	$3,299	$1,230	$3,053	$3,962	$3,060	$3,215	$2,354	$4,693	$2,126			
56	Net Revenue (k$)	Calculated	$4,146,117		$121,942	$230,861	$310,551	$218,249	$221,766	$225,233	$233,347	$161,149	$172,520	$250,888	$189,335	$205,399	$204,922	$180,839	$59,827	$153,903	$203,272	$164,089	$177,164	$124,443	$231,512	$104,905			
57	**Expenditures**																												
58	Capital Expenditures																												
59	Initial Capital (k$)	2006 TR Table 20-8	$379,640	$379,640																									
59	Sustaining Capital (k$)	2006 TR Table 25-11	$71,787		$ 11,238	$ 6,406	$ 7,686	$ 6,515	$ 8,184	$ 6,377	$ 7,296	$ 6,113	$ 4,899	$ 7,073															
60	Working Capital (k$)	2006 TR Table 25-11	$0	$ 14,991	$ 5,819																			$ (20,810)			
61	Total Capital Expenditures (k$)		$451,427	$394,631	$17,057	$6,406	$7,686	$6,515	$8,184	$6,377	$7,296	$6,113	$4,899	$7,073	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$20,810			
62	Operating Cost																												
63	Mining and Infrastructure ($/ton milled)																												
64	Railroad Operations ($/ton milled)																												
65	Metallurgical Operations ($/ton milled)																												
66	General and Admin ($/ton milled)																												
67	Power ($/ton milled)																												
68	Total Operating Cost ($/ton milled)	Calculated	$11.32		$14.26	$10.69	$11.13	$11.19	$10.95	$10.78	$10.95	$10.99	$11.16	$11.33	$10.98	$11.13	$10.91	$10.70	$11.76	$11.99	$12.32	$11.62	$12.52	$12.19	$12.30	$8.74			
69	Total Operating Cost (k$)	2006 TR Table 20-10	$2,576,372	$ 2,483	$89,948	$124,860	$130,040	$130,718	$127,891	$125,865	$127,876	$128,366	$130,305	$132,356	$128,204	$130,043	$127,453	$124,918	$109,866	$112,042	$115,133	$108,592	$103,253	$100,539	$101,452	$64,169	$0	$0	$0
70	Reclamation and Closure Cost																												
71	Reclamation FA Estimate			$75,000	$125,807	$113,807	$148,828	$183,850	$218,871	$253,893	$288,914	$323,936	$358,957	$393,979	$429,000	$404,194	$379,389	$354,583	$329,778	$304,972	$280,167	$255,361	$230,556	$202,000	$134,667	$67,333	$0	$0	$0
72	LTMM & Operations FA Estimate				$418,193	$474,193	$489,283	$504,372	$519,462	$534,552	$549,641	$564,731	$579,821	$594,910	$610,000	$606,250	$602,500	$598,750	$595,000	$591,250	$587,500	$583,750	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000
73	Total FA Estimate			$75,000	$544,000	$588,000	$638,111	$688,222	$738,333	$788,444	$838,556	$888,667	$938,778	$988,889	$1,039,000	$1,010,444	$981,889	$953,333	$924,778	$896,222	$867,667	$839,111	$810,556	$782,000	$714,667	$647,333	$580,000	$580,000	$580,000
74	LTMM Trust Fund Annual Contribution		$580,000	$10,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400							
75	LTMM Trust Fund Cumulative			$10,000	$12,000	$14,000	$16,000	$18,000	$20,000	$22,000	$24,000	$26,000	$81,400	$136,800	$192,200	$247,600	$303,000	$358,400	$413,800	$469,200	$524,600	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000
76	Financial Assurance Cost		$185,895	$975	$7,980	$8,610	$9,332	$10,053	$10,775	$11,497	$12,218	$12,940	$12,861	$12,781	$12,702	$11,443	$10,183	$8,924	$7,665	$6,405	$5,146	$3,887	$3,458	$3,030	$2,020	$1,010	$0	$0	$0
77	Total Reclamation and Closure		$765,895	$10,975	$9,980	$10,610	$11,332	$12,053	$12,775	$13,497	$14,218	$14,940	$68,261	$68,181	$68,102	$66,843	$65,583	$64,324	$63,065	$61,805	$60,546	$59,287	$3,458	$3,030	$2,020	$1,010	$0	$0	$0
76	Total All Expenditures	Calculated	$3,793,694	$408,089	$116,985	$141,876	$149,058	$149,286	$148,850	$145,738	$149,391	$149,419	$203,465	$207,610	$196,306	$196,885	$193,036	$189,242	$172,930	$173,848	$175,679	$167,879	$106,712	$103,569	$103,472	$44,369	$0	$0	$0
77	**Income**																												
78	Operating Income (k$)	Calculated	$352,424	-$408,089	$4,957	$88,985	$161,494	$68,963	$72,916	$79,495	$83,956	$11,730	-$30,945	$43,278	-$6,971	$8,514	$11,887	-$8,403	-$113,104	-$19,945	$27,592	-$3,790	$70,452	$20,874	$128,041	$60,535	$0	$0	$0
77	Cumulative Cash Flow (k$)	Calculated		-$408,089	-$403,131	-$314,146	-$152,652	-$83,689	-$10,773	$68,722	$152,678	$164,408	$133,463	$176,741	$169,770	$178,284	$190,171	$181,768	$68,664	$48,720	$76,312	$72,522	$142,974	$163,848	$291,888	$352,424	$352,424	$352,424	$352,424
78	**Economic Indicators before Taxes**																												
79	NPV @ 0%		0%	$352,424																									
78	NPV @ 5%	Calculated	5.0%	$110,773																									
79	NPV @ 7.5%	Calculated	7.5%	$43,884																									
80	IRR	Calculated		6.9%																									

Table 5
CASH FLOW ANALYSIS - Polymet Northmet Project
Market Case (2006 Technical Report) with Reclamation and Closure

Line #	Description	Data Source	Total	Year/Project Year																									
				2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
				0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Mining Operations																												
1	Ore Mined (kt)	2006 TR Table 20-1	226,706	78	6,469	11,935	13,903	10,470	12,692	12,599	12,729	9,879	11,080	14,013	11,121	12,736	12,443	10,360	4,083	9,334	10,231	8,467	8,894	7,598	9566	6026			
2	Waste Mined (kt)	2006 TR Table 20-1	336,370		25,436	20,212	21,564	17,280	14,598	21,857	13,520	21,383	17,350	17,122	14,207	15,608	13,883	12,178	10,950	9,099	6,956	8,842	11,944	14,128	14,128	14,128			
3	Total Material Mined (kt)	2006 TR Table 20-1	563,076		31,905	32,147	35,467	27,750	27,290	34,456	26,249	31,262	28,430	31,135	25,328	28,344	26,326	22,538	15,033	18,433	17,187	17,309	20,838	21,726	23,694	20,154			
4	**Process Plant Operations**																												
5	Ore Processed (kt)	2006 TR Table 20-1	227,607		6,307	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	9,344	9,344	9,344	9,344	8,246	8,246	8,246	7,346			
6	Ore Grade																												
7	Copper (%)	2006 TR Table 20-1	0.30%		0.32%	0.33%	0.39%	0.37%	0.29%	0.30%	0.31%	0.27%	0.25%	0.30%	0.29%	0.26%	0.27%	0.28%	0.24%	0.27%	0.34%	0.34%	0.36%	0.28%	0.43%	0.30%			
8	Nickel (%)	2006 TR Table 20-1	0.09%		0.09%	0.09%	0.10%	0.10%	0.09%	0.09%	0.09%	0.08%	0.08%	0.09%	0.08%	0.08%	0.08%	0.09%	0.07%	0.08%	0.09%	0.09%	0.09%	0.08%	0.11%	0.08%			
9	Cobalt ppm	2006 TR Table 20-1	74		76	71	82	79	76	74	72	71	72	73	70	71	73	83	69	73	78	77	77	71	75	69			
10	Palladium ppb	2006 TR Table 20-1	276		312	319	354	291	253	264	282	262	233	263	272	268	277	266	242	263	309	283	284	218	378	263			
11	Platinum ppb	2006 TR Table 20-1	79		80	90	108	79	67	71	76	71	69	74	77	74	74	74	69	78	102	84	83	70	106	83			
12	Gold ppb	2006 TR Table 20-1	39		39	43	51	41	35	37	39	35	32	35	36	36	37	37	35	38	45	42	42	36	57	41			
13	Ore Contained Metal																												
14	Copper (klbs)	2006 TR Table 20-1	1,405,141		41,402	78,771	108,443	77,478	73,614	75,594	78,920	53,347	55,400	84,078	64,502	66,227	67,192	58,016	19,598	50,404	69,571	57,576	64,037	42,549	82,268	36,156			
15	Nickel (klbs)	2006 TR Table 20-1	398,955		11,644	21,483	27,806	20,940	22,846	22,678	22,912	15,806	17,728	25,223	17,794	20,378	19,909	18,648	5,716	14,934	18,416	15,241	16,009	12,157	21,045	9,642			
16	Cobalt (klbs)	2006 TR Table 20-1	33,727		983	1,695	2,280	1,654	1,929	1,865	1,833	1,403	1,596	2,046	1,557	1,809	1,817	1,720	563	1,363	1,596	1,304	1,370	1,079	1,435	832			
17	Palladium (ozs)	2006 TR Table 20-1	1,860,417		58,854	111,020	143,516	88,844	93,635	96,990	104,672	75,475	75,281	107,467	88,206	99,530	100,506	80,358	28,813	71,583	92,186	69,872	73,655	48,300	105,441	46,214			
18	Platinum (ozs)	2006 TR Table 20-1	529,852		15,091	31,322	43,784	24,119	24,797	26,084	28,210	20,453	22,293	30,238	24,970	27,482	26,850	22,355	8,215	21,230	30,430	20,739	21,526	15,509	29,568	14,585			
19	Gold (ozs)	2006 TR Table 20-1	261,186		7,357	14,965	20,676	12,518	12,953	13,593	14,476	10,083	10,339	14,302	11,674	13,370	13,425	11,178	4,167	10,343	13,425	10,370	10,893	7,976	15,900	7,204			
20	Recovery																												
21	Copper (%)	2006 TR Table 25-9	92.3%		92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%			
22	Nickel (%)	2006 TR Table 25-9	70.3%		70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%			
23	Cobalt (%)	2006 TR Table 25-9	40.7%		40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%			
24	Palladium (%)	2006 TR Table 25-9	75.2%		75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%			
25	Platinum (%)	2006 TR Table 25-9	72.7%		72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%			
26	Gold (%)	2006 TR Table 25-9	67.0%		67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%			
27	Recovered Metal																												
28	Copper (klbs)	Calculated	1,296,945		38,214	72,706	100,093	71,512	67,945	69,773	72,843	49,239	51,134	77,604	59,535	61,128	62,018	53,549	18,089	46,523	64,214	53,142	59,106	39,273	75,933	33,372			
29	Nickel (klbs)	Calculated	280,465		8,186	15,103	19,548	14,721	16,060	15,943	16,107	11,112	12,463	17,732	12,509	14,325	13,996	13,110	4,018	10,499	12,946	10,714	11,254	8,546	14,795	6,778			
30	Cobalt (klbs)	Calculated	13,727		400	690	928	673	785	759	746	571	649	833	634	736	739	700	229	555	650	531	557	439	584	338			
31	Palladium (ozs)	Calculated	1,399,034		44,259	83,487	107,924	66,811	70,414	72,937	78,713	56,757	56,611	80,815	66,331	74,847	75,581	60,429	21,667	53,831	69,324	52,544	55,389	36,321	79,292	34,753			
32	Platinum (ozs)	Calculated	385,202		10,971	22,771	31,831	17,535	18,027	18,963	20,508	14,869	16,207	21,983	18,153	19,980	19,520	16,252	5,972	15,434	22,123	15,078	15,649	11,275	21,496	10,603			
33	Gold (ozs)	Calculated	174,994		4,929	10,027	13,853	8,387	8,679	9,108	9,699	6,755	6,927	9,582	7,822	8,958	8,995	7,489	2,792	6,930	8,995	6,948	7,298	5,344	10,653	4,827			
34	**Revenue**																												
35	Metals Prices																												
36	Copper ($/lb)	2006 TR Table 25-9	$2.25		$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25			
37	Nickel ($/lb)	2006 TR Table 25-9	$7.80		$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80			
38	Cobalt ($/lb)	2006 TR Table 25-9	$16.34		$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34			
39	Palladium ($/oz)	2006 TR Table 25-9	$274.00		$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00			
40	Platinum ($/oz)	2006 TR Table 25-9	$1,040.00		$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00			
41	Gold ($/oz)	2006 TR Table 25-9	$540.00		$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00			
42	Treatment and Refining Charges																												
43	Copper ($/lb)	2006 TR Table 19-6	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00			
44	Nickel ($/lb)	2006 TR Table 19-6	$1.95		$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95			
45	Cobalt ($/lb)	2006 TR Table 19-6	$6.54		$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54			
46	Palladium ($/oz)	2006 TR Table 19-6	$17.00		$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00			
47	Platinum ($/oz)	2006 TR Table 19-6	$18.00		$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00			
48	Gold ($/oz)	2006 TR Table 19-6	$9.50		$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50			
49	Revenue																												
50	Copper (k$)	Calculated	$2,918,126		$85,981	$163,588	$225,210	$160,902	$152,877	$156,990	$163,897	$110,788	$115,052	$174,609	$133,954	$137,537	$139,541	$120,485	$40,701	$104,676	$144,481	$119,570	$132,988	$88,363	$170,849	$75,087			
51	Nickel (k$)	Calculated	$1,640,722		$47,887	$88,350	$114,354	$86,117	$93,954	$93,265	$94,228	$65,005	$72,907	$103,732	$73,177	$83,804	$81,876	$76,691	$23,508	$61,418	$75,736	$62,678	$65,839	$49,995	$86,549	$39,652			
52	Cobalt (k$)	Calculated	$134,577		$3,924	$6,763	$9,098	$6,601	$7,698	$7,440	$7,314	$5,598	$6,366	$8,164	$6,213	$7,216	$7,249	$6,862	$2,248	$5,438	$6,369	$5,203	$5,465	$4,305	$5,726	$3,318			
53	Palladium (k$)	Calculated	$359,552		$11,374	$21,456	$27,736	$17,170	$18,096	$18,745	$20,229	$14,587	$14,549	$20,769	$17,047	$19,236	$19,424	$15,530	$5,568	$13,834	$17,816	$13,504	$14,235	$9,335	$20,378	$8,931			
54	Platinum (k$)	Calculated	$393,677		$11,212	$23,272	$32,532	$17,920	$18,424	$19,381	$20,959	$15,197	$16,564	$22,467	$18,553	$20,419	$19,949	$16,610	$6,104	$15,774	$22,610	$15,409	$15,994	$11,523	$21,969	$10,836			
55	Gold (k$)	Calculated	$92,835		$2,615	$5,319	$7,349	$4,449	$4,604	$4,832	$5,145	$3,584	$3,675	$5,083	$4,149	$4,752	$4,772	$3,973	$1,481	$3,676	$4,772	$3,686	$3,872	$2,835	$5,651	$2,561			
56	Net Revenue (k$)	Calculated	$5,539,487		$162,993	$308,748	$416,278	$293,160	$295,653	$300,652	$311,772	$214,756	$229,113	$334,824	$253,093	$272,964	$272,812	$240,151	$79,611	$204,816	$271,783	$220,050	$238,393	$166,356	$311,123	$140,385			
57	**Expenditures**																												
58	Capital Expenditures																												
59	Initial Capital (k$)	2006 TR Table 20-8	$379,640	$379,640																									
59	Sustaining Capital (k$)	2006 TR Table 25-11	$71,787		$ 11,238	$ 6,406	$ 7,686	$ 6,515	$ 8,184	$ 6,377	$ 7,296	$ 6,113	$ 4,899	$ 7,073															
60	Working Capital (k$)	2006 TR Table 25-11	$0	$ 14,991	$ 5,819																					$ (20,810)			
61	Total Capital Expenditures (k$)		$451,427	$394,631	$17,057	$6,406	$7,686	$6,515	$8,184	$6,377	$7,296	$6,113	$4,899	$7,073	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$20,810			
62	Operating Cost																												
63	Mining and Infrastructure ($/ton milled)																												
64	Railroad Operations ($/ton milled)																												
65	Metallurgical Operations ($/ton milled)																												
66	General and Admin ($/ton milled)																												
67	Power ($/ton milled)																												
68	Total Operating Cost ($/ton milled)	Calculated	$11.32		$14.26	$10.69	$11.13	$11.19	$10.95	$10.78	$10.95	$10.99	$11.16	$11.33	$10.98	$11.13	$10.91	$10.70	$11.76	$11.99	$12.32	$11.62	$12.52	$12.19	$12.30	$8.74			
69	Total Operating Cost (k$)	2006 TR Table 20-10	$2,576,372	$ 2,483	$89,948	$124,860	$130,040	$130,718	$127,891	$125,865	$127,876	$128,366	$130,305	$132,356	$128,204	$130,043	$127,453	$124,918	$109,866	$112,042	$115,133	$108,592	$103,253	$100,539	$101,452	$64,169	$0	$0	$0
70	Reclamation and Closure Cost																												
71	Reclamation FA Estimate			$75,000	$125,807	$113,807	$148,828	$183,850	$218,871	$253,893	$288,914	$323,936	$358,957	$393,979	$429,000	$404,194	$379,389	$354,583	$329,778	$304,972	$280,167	$255,361	$230,556	$202,000	$134,667	$67,333	$0	$0	$0
72	LTMM & Operations FA Estimate				$418,193	$474,193	$489,283	$504,372	$519,462	$534,552	$549,641	$564,731	$579,821	$594,910	$610,000	$606,250	$602,500	$598,750	$595,000	$591,250	$587,500	$583,750	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000
73	Total FA Estimate			$75,000	$544,000	$588,000	$638,111	$688,222	$738,333	$788,444	$838,556	$888,667	$938,778	$988,889	$1,039,000	$1,010,444	$981,889	$953,333	$924,778	$896,222	$867,667	$839,111	$810,556	$782,000	$714,667	$647,333	$580,000	$580,000	$580,000
74	LTMM Trust Fund Annual Contribution		$580,000	$10,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400	$55,400							
75	LTMM Trust Fund Cumulative			$10,000	$12,000	$14,000	$16,000	$18,000	$20,000	$22,000	$24,000	$26,000	$81,400	$136,800	$192,200	$247,600	$303,000	$358,400	$413,800	$469,200	$524,600	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000	$580,000
76	Financial Assurance Cost		$185,895	$975	$7,980	$8,610	$9,332	$10,053	$10,775	$11,497	$12,218	$12,940	$12,861	$12,781	$12,702	$11,443	$10,183	$8,924	$7,665	$6,405	$5,146	$3,887	$3,458	$3,030	$2,020	$1,010	$0	$0	$0
77	Total Reclamation and Closure		$765,895	$10,975	$9,980	$10,610	$11,332	$12,053	$12,775	$13,497	$14,218	$14,940	$68,261	$68,181	$68,102	$66,843	$65,583	$64,324	$63,065	$61,805	$60,546	$59,287	$3,458	$3,030	$2,020	$1,010	$0	$0	$0
78	Total All Expenditures	Calculated	$3,793,694	$408,089	$116,985	$141,876	$149,058	$149,286	$148,850	$145,738	$149,391	$149,419	$203,465	$207,610	$196,306	$196,885	$193,036	$189,242	$172,930	$173,848	$175,679	$167,879	$106,712	$103,569	$103,472	$44,369	$0	$0	$0
79	**Income**																												
80	Operating Income (k$)	Calculated	$1,745,794	-$408,089	$46,009	$166,872	$267,221	$143,874	$146,802	$154,914	$162,382	$65,338	$25,648	$127,214	$56,787	$76,079	$79,776	$50,909	-$93,319	$30,969	$96,104	$52,171	$131,681	$62,787	$207,651	$96,016	$0	$0	$0
81	Cumulative Cash Flow (k$)	Calculated		-$408,089	-$362,080	-$195,208	$72,013	$215,887	$362,689	$517,603	$679,985	$745,322	$770,971	$898,185	$954,972	$1,031,051	$1,110,826	$1,161,735	$1,068,415	$1,099,384	$1,195,488	$1,247,659	$1,379,340	$1,442,127	$1,649,778	$1,745,794	$1,745,794	$1,745,794	$1,745,794
82	**Economic Indicators before Taxes**																												
83	NPV @ 0%		0%	$1,745,794																									
84	NPV @ 5%	Calculated	5.0%	$934,086																									
85	NPV @ 7.5%	Calculated	7.5%	$702,374																									
86	IRR	Calculated		32.1%																									

Table 7
CASH FLOW ANALYSIS - Polymet Northmet Project
Base Case (2006 Technical Report) with Filtered Tailings

Line #	Description	Data Source	Total	Year/Project Year																									
				2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
				0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Mining Operations																												
1	Ore Mined (kt)	2006 TR Table 20-1	226,706	78	6,469	11,935	13,903	10,470	12,692	12,599	12,729	9,879	11,080	14,013	11,121	12,736	12,443	10,360	4,083	9,334	10,231	8,467	8,894	7,598	9566	6026			
2	Waste Mined (kt)	2006 TR Table 20-1	336,370		25,436	20,212	21,564	17,280	14,598	21,857	13,520	21,383	17,350	17,122	14,207	15,608	13,883	12,178	10,950	9,099	6,956	8,842	11,944	14,128	14,128	14,128			
3	Total Material Mined (kt)	2006 TR Table 20-1	563,076		31,905	32,147	35,467	27,750	27,290	34,456	26,249	31,262	28,430	31,135	25,328	28,344	26,326	22,538	15,033	18,433	17,187	17,309	20,838	21,726	23,694	20,154			
4	**Process Plant Operations**																												
5	Ore Processed (kt)	2006 TR Table 20-1	227,607		6,307	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	9,344	9,344	9,344	9,344	8,246	8,246	8,246	7,346			
6	Ore Grade																												
7	Copper (%)	2006 TR Table 20-1	0.30%		0.32%	0.33%	0.39%	0.37%	0.29%	0.30%	0.31%	0.27%	0.25%	0.30%	0.29%	0.26%	0.27%	0.28%	0.24%	0.27%	0.34%	0.34%	0.36%	0.28%	0.43%	0.30%			
8	Nickel (%)	2006 TR Table 20-1	0.09%		0.09%	0.09%	0.10%	0.10%	0.09%	0.09%	0.09%	0.08%	0.08%	0.09%	0.08%	0.08%	0.08%	0.09%	0.07%	0.08%	0.09%	0.09%	0.09%	0.08%	0.11%	0.08%			
9	Cobalt ppm	2006 TR Table 20-1	74		76	71	82	79	76	74	72	71	72	73	70	71	73	83	69	73	78	77	77	71	75	69			
10	Palladium ppb	2006 TR Table 20-1	276		312	319	354	291	253	264	282	262	233	263	272	268	277	266	242	263	309	283	284	218	378	263			
11	Platinum ppb	2006 TR Table 20-1	79		80	90	108	79	67	71	76	71	69	74	77	74	74	74	69	78	102	84	83	70	106	83			
12	Gold ppb	2006 TR Table 20-1	39		39	43	51	41	35	37	39	35	32	35	36	36	37	37	35	38	45	42	42	36	57	41			
13	Ore Contained Metal																												
14	Copper (klbs)	2006 TR Table 20-1	1,405,141		41,402	78,771	108,443	77,478	73,614	75,594	78,920	53,347	55,400	84,078	64,502	66,227	67,192	58,016	19,598	50,404	69,571	57,576	64,037	42,549	82,268	36,156			
15	Nickel (klbs)	2006 TR Table 20-1	398,955		11,644	21,483	27,806	20,940	22,846	22,678	22,912	15,806	17,728	25,223	17,794	20,378	19,909	18,648	5,716	14,934	18,416	15,241	16,009	12,157	21,045	9,642			
16	Cobalt (klbs)	2006 TR Table 20-1	33,727		983	1,695	2,280	1,654	1,929	1,865	1,833	1,403	1,596	2,046	1,557	1,809	1,817	1,720	563	1,363	1,596	1,304	1,370	1,079	1,435	832			
17	Palladium (ozs)	2006 TR Table 20-1	1,860,417		58,854	111,020	143,516	88,844	93,635	96,990	104,672	75,475	75,281	107,467	88,206	99,530	100,506	80,358	28,813	71,583	92,186	69,872	73,655	48,300	105,441	46,214			
18	Platinum (ozs)	2006 TR Table 20-1	529,852		15,091	31,322	43,784	24,119	24,797	26,084	28,210	20,453	22,293	30,238	24,970	27,482	26,850	22,355	8,215	21,230	30,430	20,739	21,526	15,509	29,568	14,585			
19	Gold (ozs)	2006 TR Table 20-1	261,186		7,357	14,965	20,676	12,518	12,953	13,593	14,476	10,083	10,339	14,302	11,674	13,370	13,425	11,178	4,167	10,343	13,425	10,370	10,893	7,976	15,900	7,204			
20	Recovery																												
21	Copper (%)	2006 TR Table 25-9	92.3%		92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%			
22	Nickel (%)	2006 TR Table 25-9	70.3%		70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%			
23	Cobalt (%)	2006 TR Table 25-9	40.7%		40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%			
24	Palladium (%)	2006 TR Table 25-9	75.2%		75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%			
25	Platinum (%)	2006 TR Table 25-9	72.7%		72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%			
26	Gold (%)	2006 TR Table 25-9	67.0%		67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%			
27	Recovered Metal																												
28	Copper (klbs)	Calculated	1,296,945		38,214	72,706	100,093	71,512	67,945	69,773	72,843	49,239	51,134	77,604	59,535	61,128	62,018	53,549	18,089	46,523	64,214	53,142	59,106	39,273	75,933	33,372			
29	Nickel (klbs)	Calculated	280,465		8,186	15,103	19,548	14,721	16,060	15,943	16,107	11,112	12,463	17,732	12,509	14,325	13,996	13,110	4,018	10,499	12,946	10,714	11,254	8,546	14,795	6,778			
30	Cobalt (klbs)	Calculated	13,727		400	690	928	673	785	759	746	571	649	833	634	736	739	700	229	555	650	531	557	439	584	338			
31	Palladium (ozs)	Calculated	1,399,034		44,259	83,487	107,924	66,811	70,414	72,937	78,713	56,757	56,611	80,815	66,331	74,847	75,581	60,429	21,667	53,831	69,324	52,544	55,389	36,321	79,292	34,753			
32	Platinum (ozs)	Calculated	385,202		10,971	22,771	31,831	17,535	18,027	18,963	20,508	14,869	16,207	21,983	18,153	19,980	19,520	16,252	5,972	15,434	22,123	15,078	15,649	11,275	21,496	10,603			
33	Gold (ozs)	Calculated	174,994		4,929	10,027	13,853	8,387	8,679	9,108	9,699	6,755	6,927	9,582	7,822	8,958	8,995	7,489	2,792	6,930	8,995	6,948	7,298	5,344	10,653	4,827			
34	**Revenue**																												
35	Metals Prices																												
36	Copper ($/lb)	2006 TR Table 25-9	$1.50		$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50	$1.50			
37	Nickel ($/lb)	2006 TR Table 25-9	$6.50		$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50	$6.50			
38	Cobalt ($/lb)	2006 TR Table 25-9	$15.25		$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25	$15.25			
39	Palladium ($/oz)	2006 TR Table 25-9	$225.00		$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00	$225.00			
40	Platinum ($/oz)	2006 TR Table 25-9	$900.00		$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00	$900.00			
41	Gold ($/oz)	2006 TR Table 25-9	$450.00		$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00	$450.00			
42	Treatment and Refining Charges																												
43	Copper ($/lb)	2006 TR Table 19-6	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00			
44	Nickel ($/lb)	2006 TR Table 19-6	$1.63		$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63	$1.63			
45	Cobalt ($/lb)	2006 TR Table 19-6	$6.10		$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10	$6.10			
46	Palladium ($/oz)	2006 TR Table 19-6	$17.00		$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00			
47	Platinum ($/oz)	2006 TR Table 19-6	$18.00		$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00			
48	Gold ($/oz)	2006 TR Table 19-6	$9.50		$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50			
49	Revenue																												
50	Copper (k$)	Calculated	$1,945,417		$57,321	$109,058	$150,140	$107,268	$101,918	$104,660	$109,264	$73,858	$76,701	$116,406	$89,303	$91,692	$93,028	$80,323	$27,134	$69,784	$96,321	$79,713	$88,659	$58,909	$113,899	$50,058			
51	Nickel (k$)	Calculated	$1,367,268		$39,906	$73,625	$95,295	$71,764	$78,295	$77,721	$78,523	$54,171	$60,756	$86,444	$60,981	$69,837	$68,230	$63,909	$19,590	$51,182	$63,113	$52,231	$54,866	$41,663	$72,125	$33,043			
52	Cobalt (k$)	Calculated	$125,600		$3,662	$6,311	$8,491	$6,161	$7,184	$6,944	$6,826	$5,224	$5,942	$7,619	$5,798	$6,735	$6,765	$6,404	$2,098	$5,075	$5,944	$4,856	$5,101	$4,018	$5,344	$3,097			
53	Palladium (k$)	Calculated	$290,999		$9,206	$17,365	$22,448	$13,897	$14,646	$15,171	$16,372	$11,805	$11,775	$16,810	$13,797	$15,568	$15,721	$12,569	$4,507	$11,197	$14,419	$10,929	$11,521	$7,555	$16,493	$7,229			
54	Platinum (k$)	Calculated	$339,748		$9,676	$20,084	$28,075	$15,466	$15,900	$16,726	$18,088	$13,115	$14,295	$19,389	$16,011	$17,622	$17,217	$14,334	$5,268	$13,613	$19,512	$13,298	$13,803	$9,945	$18,959	$9,352			
55	Gold (k$)	Calculated	$77,085		$2,171	$4,417	$6,102	$3,694	$3,823	$4,012	$4,272	$2,976	$3,051	$4,221	$3,446	$3,946	$3,962	$3,299	$1,230	$3,053	$3,962	$3,060	$3,215	$2,354	$4,693	$2,126			
56	Net Revenue (k$)	Calculated	$4,146,117		$121,942	$230,861	$310,551	$218,249	$221,766	$225,233	$233,347	$161,149	$172,520	$250,888	$189,335	$205,399	$204,922	$180,839	$59,827	$153,903	$203,272	$164,089	$177,164	$124,443	$231,512	$104,905			
57	**Expenditures**																												
58	Capital Expenditures																												
59	Initial Capital (k$)	2006 TR Table 20-8	$379,640	$379,640																									
59	Sustaining Capital (k$)	2006 TR Table 25-11	$71,787		$ 11,238	$ 6,406	$ 7,686	$ 6,515	$ 8,184	$ 6,377	$ 7,296	$ 6,113	$ 4,899	$ 7,073															
60	Working Capital (k$)	2006 TR Table 25-11	$0	$ 14,991	$ 5,819																			$ (20,810)			
61	Total Capital Expenditures (k$)		$451,427	$394,631	$17,057	$6,406	$7,686	$6,515	$8,184	$6,377	$7,296	$6,113	$4,899	$7,073	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$20,810			
62	Operating Cost																												
63	Mining and Infrastructure ($/ton milled)																												
64	Railroad Operations ($/ton milled)																												
65	Metallurgical Operations ($/ton milled)																												
66	General and Admin ($/ton milled)																												
67	Power ($/ton milled)																												
68	Total Operating Cost ($/ton milled)	Calculated	$11.32		$14.26	$10.69	$11.13	$11.19	$10.95	$10.78	$10.95	$10.99	$11.16	$11.33	$10.98	$11.13	$10.91	$10.70	$11.76	$11.99	$12.32	$11.62	$12.52	$12.19	$12.30	$8.74			
69	Total Operating Cost (k$)	2006 TR Table 20-10	$2,576,372	$ 2,483	$89,948	$124,860	$130,040	$130,718	$127,891	$125,865	$127,876	$128,366	$130,305	$132,356	$128,204	$130,043	$127,453	$124,918	$109,866	$112,042	$115,133	$108,592	$103,253	$100,539	$101,452	$64,169	$0	$0	$0
70	Filtered Tailings																												
71	Capital Cost		$100,000	$100,000																									
72	Operating Cost ($/ton milled)				$2.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00			
73	Total Operating Cost		$897,814		$12,614	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$37,376	$37,376	$37,376	$37,376	$32,984	$32,984	$32,984	$29,384			
74	Total Filtered Tailings		$997,814	$100,000	$12,614	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$37,376	$37,376	$37,376	$37,376	$32,984	$32,984	$32,984	$29,384	$0	$0	$0
75	Total All Expenditures	Calculated	$4,025,613	$497,114	$119,619	$177,986	$184,446	$183,953	$182,795	$178,962	$181,892	$181,199	$181,924	$186,149	$174,924	$176,763	$174,173	$171,638	$147,242	$149,418	$152,509	$145,968	$136,237	$133,523	$134,436	$72,743	$0	$0	$0
76	**Income**																												
77	Operating Income (k$)	Calculated	$120,505	-$497,114	$2,323	$52,875	$126,105	$34,297	$38,971	$46,272	$51,454	-$20,050	-$9,404	$64,739	$14,411	$28,636	$30,750	$9,201	-$87,415	$4,485	$50,762	$18,120	$40,926	-$9,080	$97,077	$32,161	$0	$0	$0
78	Cumulative Cash Flow (k$)	Calculated		-$497,114	-$494,790	-$441,915	-$315,810	-$281,513	-$242,542	-$196,271	-$144,816	-$164,866	-$174,270	-$109,531	-$95,120	-$66,483	-$35,733	-$26,532	-$113,947	-$109,462	-$58,700	-$40,580	$347	-$8,733	$88,343	$120,505	$120,505	$120,505	$120,505
79	**Economic Indicators before Taxes**																												
80	NPV @ 0%		0%	$120,505																									
81	NPV @ 5%	Calculated	5.0%	-$89,929																									
82	NPV @ 7.5%	Calculated	7.5%	-$146,092																									
83	IRR	Calculated		-10.6%																									

Table 8
CASH FLOW ANALYSIS - Polymet Northmet Project
Base Case (2006 Technical Report) with Filtered Tailings

Line #	Description	Data Source	Total	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
				Year/Project Year																									
				0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Mining Operations																												
1	Ore Mined (kt)	2006 TR Table 20-1	226,706	78	6,469	11,935	13,903	10,470	12,692	12,599	12,729	9,879	11,080	14,013	11,121	12,736	12,443	10,360	4,083	9,334	10,231	8,467	8,894	7,598	9566	6026			
2	Waste Mined (kt)	2006 TR Table 20-1	336,370		25,436	20,212	21,564	17,280	14,598	21,857	13,520	21,383	17,350	17,122	14,207	15,608	13,883	12,178	10,950	9,099	6,956	8,842	11,944	14,128	14,128	14,128			
3	Total Material Mined (kt)	2006 TR Table 20-1	563,076		31,905	32,147	35,467	27,750	27,290	34,456	26,249	31,262	28,430	31,135	25,328	28,344	26,326	22,538	15,033	18,433	17,187	17,309	20,838	21,726	23,694	20,154			
4	**Process Plant Operations**																												
5	Ore Processed (kt)	2006 TR Table 20-1	227,607		6,307	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	11,680	9,344	9,344	9,344	9,344	8,246	8,246	8,246	7,346			
6	Ore Grade																												
7	Copper (%)	2006 TR Table 20-1	0.30%		0.32%	0.33%	0.39%	0.37%	0.29%	0.30%	0.31%	0.27%	0.25%	0.30%	0.29%	0.26%	0.27%	0.28%	0.24%	0.27%	0.34%	0.34%	0.36%	0.28%	0.43%	0.30%			
8	Nickel (%)	2006 TR Table 20-1	0.09%		0.09%	0.09%	0.10%	0.10%	0.09%	0.09%	0.09%	0.08%	0.08%	0.09%	0.08%	0.08%	0.08%	0.09%	0.07%	0.08%	0.09%	0.09%	0.09%	0.08%	0.11%	0.08%			
9	Cobalt ppm	2006 TR Table 20-1	74		76	71	82	79	76	74	72	71	72	73	70	71	73	83	69	73	78	77	77	71	75	69			
10	Palladium ppb	2006 TR Table 20-1	276		312	319	354	291	253	264	282	262	233	263	272	268	277	266	242	263	309	283	284	218	378	263			
11	Platinum ppb	2006 TR Table 20-1	79		80	90	108	79	67	71	76	71	69	74	77	74	74	74	69	78	102	84	83	70	106	83			
12	Gold ppb	2006 TR Table 20-1	39		39	43	51	41	35	37	39	35	32	35	36	36	37	37	35	38	45	42	42	36	57	41			
13	Ore Contained Metal																												
14	Copper (klbs)	2006 TR Table 20-1	1,405,141		41,402	78,771	108,443	77,478	73,614	75,594	78,920	53,347	55,400	84,078	64,502	66,227	67,192	58,016	19,598	50,404	69,571	57,576	64,037	42,549	82,268	36,156			
15	Nickel (klbs)	2006 TR Table 20-1	398,955		11,644	21,483	27,806	20,940	22,846	22,678	22,912	15,806	17,728	25,223	17,794	20,378	19,909	18,648	5,716	14,934	18,416	15,241	16,009	12,157	21,045	9,642			
16	Cobalt (klbs)	2006 TR Table 20-1	33,727		983	1,695	2,280	1,654	1,929	1,865	1,833	1,403	1,596	2,046	1,557	1,809	1,817	1,720	563	1,363	1,596	1,304	1,370	1,079	1,435	832			
17	Palladium (ozs)	2006 TR Table 20-1	1,860,417		58,854	111,020	143,516	88,844	93,635	96,990	104,672	75,475	75,281	107,467	88,206	99,530	100,506	80,358	28,813	71,583	92,186	69,872	73,655	48,300	105,441	46,214			
18	Platinum (ozs)	2006 TR Table 20-1	529,852		15,091	31,322	43,784	24,119	24,797	26,084	28,210	20,453	22,293	30,238	24,970	27,482	26,850	22,355	8,215	21,230	30,430	20,739	21,526	15,509	29,568	14,585			
19	Gold (ozs)	2006 TR Table 20-1	261,186		7,357	14,965	20,676	12,518	12,953	13,593	14,476	10,083	10,339	14,302	11,674	13,370	13,425	11,178	4,167	10,343	13,425	10,370	10,893	7,976	15,900	7,204			
20	Recovery																												
21	Copper (%)	2006 TR Table 25-9	92.3%		92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%	92.3%			
22	Nickel (%)	2006 TR Table 25-9	70.3%		70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%	70.3%			
23	Cobalt (%)	2006 TR Table 25-9	40.7%		40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%	40.7%			
24	Palladium (%)	2006 TR Table 25-9	75.2%		75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%	75.2%			
25	Platinum (%)	2006 TR Table 25-9	72.7%		72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%	72.7%			
26	Gold (%)	2006 TR Table 25-9	67.0%		67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%	67.0%			
27	Recovered Metal																												
28	Copper (klbs)	Calculated	1,296,945		38,214	72,706	100,093	71,512	67,945	69,773	72,843	49,239	51,134	77,604	59,535	61,128	62,018	53,549	18,089	46,523	64,214	53,142	59,106	39,273	75,933	33,372			
29	Nickel (klbs)	Calculated	280,465		8,186	15,103	19,548	14,721	16,060	15,943	16,107	11,112	12,463	17,732	12,509	14,325	13,996	13,110	4,018	10,499	12,946	10,714	11,254	8,546	14,795	6,778			
30	Cobalt (klbs)	Calculated	13,727		400	690	928	673	785	759	746	571	649	833	634	736	739	700	229	555	650	531	557	439	584	338			
31	Palladium (ozs)	Calculated	1,399,034		44,259	83,487	107,924	66,811	70,414	72,937	78,713	56,757	56,611	80,815	66,331	74,847	75,581	60,429	21,667	53,831	69,324	52,544	55,389	36,321	79,292	34,753			
32	Platinum (ozs)	Calculated	385,202		10,971	22,771	31,831	17,535	18,027	18,963	20,508	14,869	16,207	21,983	18,153	19,980	19,520	16,252	5,972	15,434	22,123	15,078	15,649	11,275	21,496	10,603			
33	Gold (ozs)	Calculated	174,994		4,929	10,027	13,853	8,387	8,679	9,108	9,699	6,755	6,927	9,582	7,822	8,958	8,995	7,489	2,792	6,930	8,995	6,948	7,298	5,344	10,653	4,827			
34	**Revenue**																												
35	Metals Prices																												
36	Copper ($/lb)	2006 TR Table 25-9	$2.25		$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25	$2.25			
37	Nickel ($/lb)	2006 TR Table 25-9	$7.80		$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80	$7.80			
38	Cobalt ($/lb)	2006 TR Table 25-9	$16.34		$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34	$16.34			
39	Palladium ($/oz)	2006 TR Table 25-9	$274.00		$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00	$274.00			
40	Platinum ($/oz)	2006 TR Table 25-9	$1,040.00		$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00	$1,040.00			
41	Gold ($/oz)	2006 TR Table 25-9	$540.00		$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00	$540.00			
42	Treatment and Refining Charges																												
43	Copper ($/lb)	2006 TR Table 19-6	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00			
44	Nickel ($/lb)	2006 TR Table 19-6	$1.95		$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95			
45	Cobalt ($/lb)	2006 TR Table 19-6	$6.54		$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54	$6.54			
46	Palladium ($/oz)	2006 TR Table 19-6	$17.00		$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00	$17.00			
47	Platinum ($/oz)	2006 TR Table 19-6	$18.00		$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00	$18.00			
48	Gold ($/oz)	2006 TR Table 19-6	$9.50		$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50	$9.50			
49	Revenue																												
50	Copper (k$)	Calculated	$2,918,126		$85,981	$163,588	$225,210	$160,902	$152,877	$156,990	$163,897	$110,788	$115,052	$174,609	$133,954	$137,537	$139,541	$120,485	$40,701	$104,676	$144,481	$119,570	$132,988	$88,363	$170,849	$75,087			
51	Nickel (k$)	Calculated	$1,640,722		$47,887	$88,350	$114,354	$86,117	$93,954	$93,265	$94,228	$65,005	$72,907	$103,732	$73,177	$83,804	$81,876	$76,691	$23,508	$61,418	$75,736	$62,678	$65,839	$49,995	$86,549	$39,652			
52	Cobalt (k$)	Calculated	$134,577		$3,924	$6,763	$9,098	$6,601	$7,698	$7,440	$7,314	$5,598	$6,366	$8,164	$6,213	$7,216	$7,249	$6,862	$2,248	$5,438	$6,369	$5,203	$5,465	$4,305	$5,726	$3,318			
53	Palladium (k$)	Calculated	$359,552		$11,374	$21,456	$27,736	$17,170	$18,096	$18,745	$20,229	$14,587	$14,549	$20,769	$17,047	$19,236	$19,424	$15,530	$5,568	$13,834	$17,816	$13,504	$14,235	$9,335	$20,378	$8,931			
54	Platinum (k$)	Calculated	$393,677		$11,212	$23,272	$32,532	$17,920	$18,424	$19,381	$20,959	$15,197	$16,564	$22,467	$18,553	$20,419	$19,949	$16,610	$6,104	$15,774	$22,610	$15,409	$15,994	$11,523	$21,969	$10,836			
55	Gold (k$)	Calculated	$92,835		$2,615	$5,319	$7,349	$4,449	$4,604	$4,832	$5,145	$3,584	$3,675	$5,083	$4,149	$4,752	$4,772	$3,973	$1,481	$3,676	$4,772	$3,686	$3,872	$2,835	$5,651	$2,561			
56	Net Revenue (k$)	Calculated	$5,539,487		$162,993	$308,748	$416,278	$293,160	$295,653	$300,652	$311,772	$214,756	$229,113	$334,824	$253,093	$272,964	$272,812	$240,151	$79,611	$204,816	$271,783	$220,050	$238,393	$166,356	$311,123	$140,385			
57	**Expenditures**																												
58	Capital Expenditures																												
59	Initial Capital (k$)	2006 TR Table 20-8	$379,640	$379,640																									
59	Sustaining Capital (k$)	2006 TR Table 25-11	$71,787		$ 11,238	$ 6,406	$ 7,686	$ 6,515	$ 8,184	$ 6,377	$ 7,296	$ 6,113	$ 4,899	$ 7,073															
60	Working Capital (k$)	2006 TR Table 25-11	$0	$ 14,991	$ 5,819																			$ (20,810)			
61	Total Capital Expenditures (k$)		$451,427	$394,631	$17,057	$6,406	$7,686	$6,515	$8,184	$6,377	$7,296	$6,113	$4,899	$7,073	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$20,810			
62	Operating Cost																												
63	Mining and Infrastructure ($/ton milled)																												
64	Railroad Operations ($/ton milled)																												
65	Metallurgical Operations ($/ton milled)																												
66	General and Admin ($/ton milled)																												
67	Power ($/ton milled)																												
68	Total Operating Cost ($/ton milled)	Calculated	$11.32		$14.26	$10.69	$11.13	$11.19	$10.95	$10.78	$10.95	$10.99	$11.16	$11.33	$10.98	$11.13	$10.91	$10.70	$11.76	$11.99	$12.32	$11.62	$12.52	$12.19	$12.30	$8.74			
69	Total Operating Cost (k$)	2006 TR Table 20-10	$2,576,372	$ 2,483	$89,948	$124,860	$130,040	$130,718	$127,891	$125,865	$127,876	$128,366	$130,305	$132,356	$128,204	$130,043	$127,453	$124,918	$109,866	$112,042	$115,133	$108,592	$103,253	$100,539	$101,452	$64,169	$0	$0	$0
70	Filtered Tailings																												
71	Capital Cost		$100,000	$100,000																									
72	Operating Cost ($/ton milled)				$2.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00	$4.00			
73	Total Operating Cost		$897,814		$12,614	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$37,376	$37,376	$37,376	$37,376	$32,984	$32,984	$32,984	$29,384			
74	Total Filtered Tailings		$997,814	$100,000	$12,614	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$46,720	$37,376	$37,376	$37,376	$37,376	$32,984	$32,984	$32,984	$29,384	$0	$0	$0
75	Total All Expenditures	Calculated	$4,025,613	$497,114	$119,619	$177,986	$184,446	$183,953	$182,795	$178,962	$181,892	$181,199	$181,924	$186,149	$174,924	$176,763	$174,173	$171,638	$147,242	$149,418	$152,509	$145,968	$136,237	$133,523	$134,436	$72,743	$0	$0	$0
76	**Income**																												
77	Operating Income (k$)	Calculated	$1,513,875	-$497,114	$43,375	$130,762	$231,833	$109,207	$112,857	$121,691	$129,880	$33,558	$47,189	$148,676	$78,169	$96,202	$98,639	$68,513	-$67,631	$55,398	$119,274	$74,081	$102,155	$32,833	$176,687	$67,642	$0	$0	$0
78	Cumulative Cash Flow (k$)	Calculated		-$497,114	-$453,739	-$322,977	-$91,144	$18,063	$130,920	$252,611	$382,491	$416,048	$463,237	$611,913	$690,082	$786,283	$884,922	$953,435	$885,804	$941,202	$1,060,476	$1,134,557	$1,236,713	$1,269,546	$1,446,233	$1,513,875	$1,513,875	$1,513,875	$1,513,875
79	**Economic Indicators before Taxes**																												
80	NPV @ 0%		0%	$1,513,875																									
81	NPV @ 5%	Calculated	5.0%	$733,384																									
82	NPV @ 7.5%	Calculated	7.5%	$512,398																									
83	IRR	Calculated		21.0%																									