Technical Memorandum

Twin Metals Mine and the Peter Mitchell Pit

Simulation of the Development of the Peter Mitchell Pit and Its Effects on the Proposed Twin Metals Tailings Impoundment

Prepared for: Northeastern Minnesotans for Wilderness

By: Tom Myers, Ph.D.; Hydrologic Consultant, Reno, NV

February 22, 2016

SUMMARY

Twin Metals Minnesota (Twin Metals) has proposed developing sulfide-ore copper-nickel deposits in the Rainy Headwaters watershed, which drains to the pristine Boundary Waters Canoe Area Wilderness (BWCAW) and other lands farther north. Twin Metals has proposed placing about half of the resulting tailings in facilities south of the Laurentian Divide and in the St. Louis River watershed, instead of within the area that drains toward the Boundary Waters. The Laurentian Divide, however, is not as definite a boundary between watersheds as previous thought due to the changing hydrogeology of the Peter Mitchel Pit (PMP). The PMP is a series of taconite mine pits that currently straddle the Laurentian Divide. All of the PMP pits will eventually be combined and the land barrier through the Laurentian Divide removed, forming a lake that spans the divide. Once this occurs, water and contaminants from south of the divide can enter the PMP and flow north to enter the Birch Lake watershed and Kawishiwi River to drain toward the BWCAW.

The numerical groundwater model developed to assess the effects of the proposed PolyMet Mine on the hydrogeology of the Partridge and Embarrass Rivers was revised to include the effects of developing and managing the PMP. Additionally, a contaminant source representing a proposed Twin Metals tailings impoundment in the Embarrass River watershed was added to the model to determine whether the PMP could draw contaminants south toward the PMP where it could cross the divide into the Rainy Headwaters.

Model simulations showed that from 25 to 50 years after the PolyMet Mine closes and the PMP is dewatered to levels far lower than at the potential Twin Metals tailings facility, there would be a significant contaminant flux through the topographic divide from the Embarrass River to the PMP, and thus into the Birch Lake and Kawishiwi River watershed. A slug of contaminants moves at deep levels through the bedrock to the PMP. The contaminant transport through the divide occurs because the PMP is drawn low enough to significantly increase the hydraulic gradient to the south. The change in gradient forces the groundwater divide to move northward to a point where contaminants from a potential Twin Metals tailings impoundment

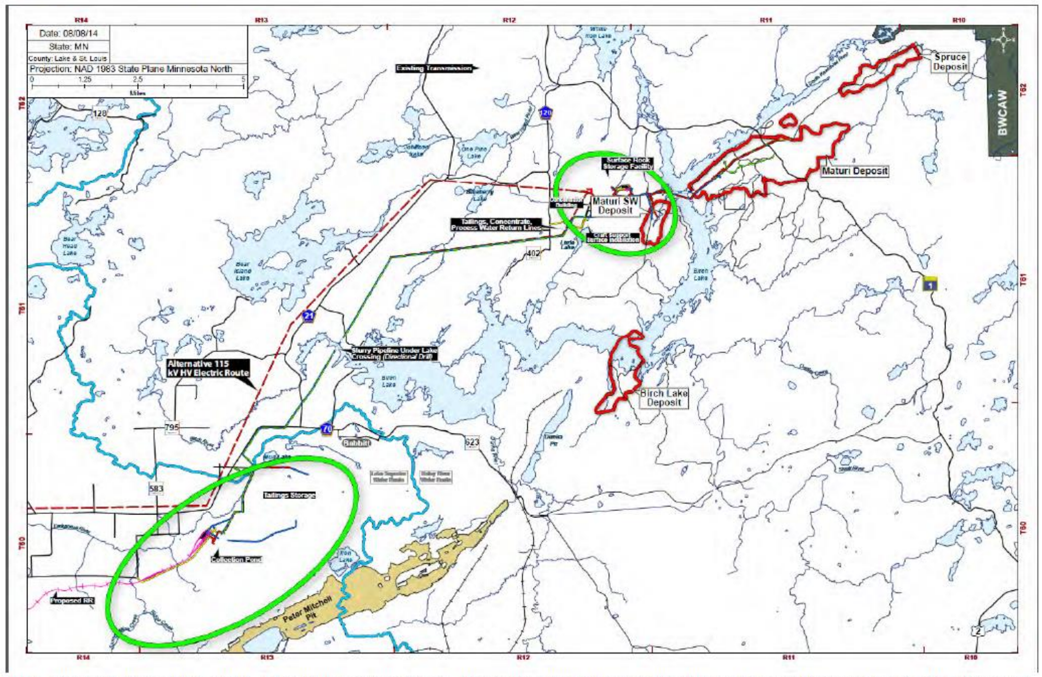
are captured and move southward. Simple groundwater flow, or advection, causes the contaminant to flow southward to the PMP. This is in addition to contaminants from the proposed PolyMet mine, which would drain into the PMP essentially in perpetuity.

INTRODUCTION

Duluth Metals, Inc. (Duluth), acquired in January 2015 by the Chilean mining company Antofagasta plc, controls approximately 56,000 acres of mineral interest over various federal, state, and private land parcels, including approximately 27,000 acres held under the name Twin Metals Minnesota LLC, a subsidiary of Duluth Metals, Inc. (the Twin Metals project). (AMEC 2015 Helmberger 2015). The Twin Metals project includes four delineated ore bodies, named Maturi, Maturi Southwest, Birch Lake, and Spruce Road. The Twin Metals' ore bodies are north and east of the Laurentian Divide, meaning they are in the watershed draining towards the Boundary Waters Canoe Area Wilderness (BWCAW).

AMEC (2014) indicated that most of the Twin Metals surface tailings impoundment will be located south of the divide, mostly in the Embarrass River headwaters, a portion of which is part of the St. Louis River watershed. AMEC (2014) presents no detailed designs for the tailings storage facilities, but at least three figures show the general location. AMEC (2014) Figure 18-5 (Figure 1) shows a broad area (green oval) just north and northwest of the PMP labeled as "proposed locations for the TSF." AMEC (2014) Figure 4-3 (Figure 2) shows a broad area of public land ownership in the same area labeled as "Tailing Storage Facility." AMEC (2014) Figure 18-4 (Figure 3) shows a relatively detailed outline of a tailings storage facility. The location of Highway 23 on Figure 3 helps to locate the proposed tailings impoundment.

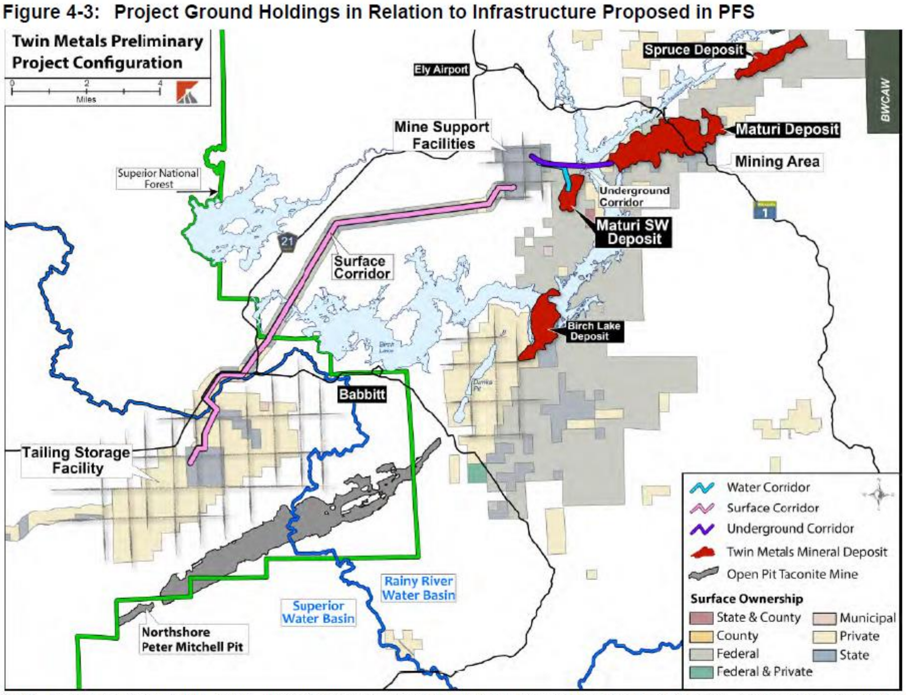
Figure 18-5: Utility Corridors



Note: Figure courtesy Duluth, 2014. Map north is to top of plan. Green areas highlighted on the plan are proposed locations for the TSF (lower left) and the concentrator and associated infrastructure (upper center).

Figure 1: Figure 18-5 from AMEC (2014) showing a broad area in green ovals that could contain tailings storage facilities for Twin Metals.

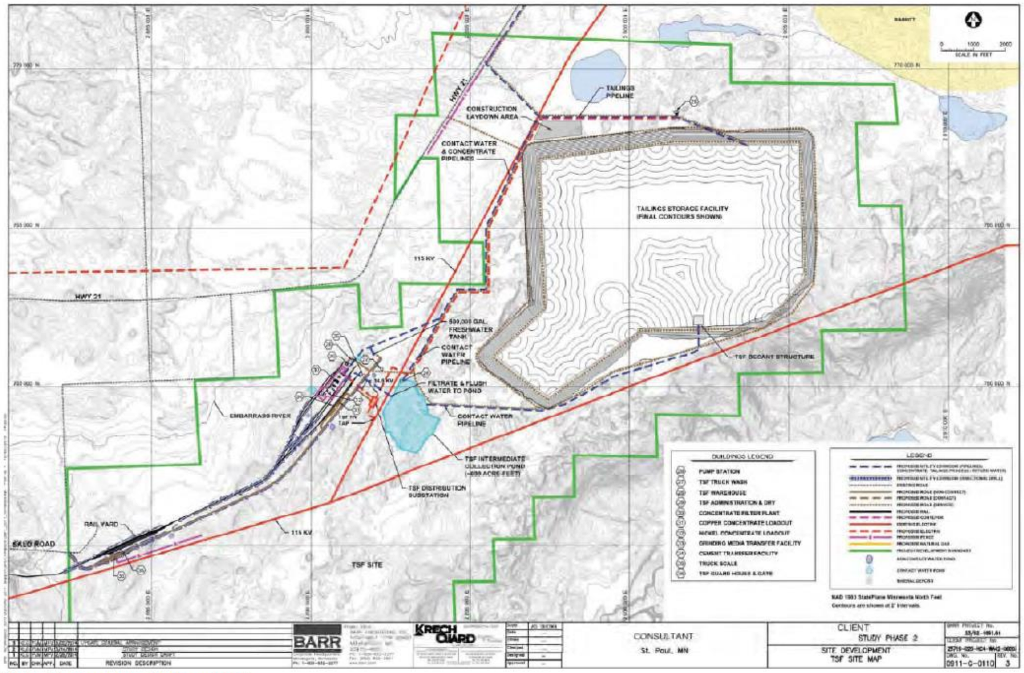
Figure 4-3: Project Ground Holdings in Relation to Infrastructure Proposed in PFS



Note: Figure courtesy Duluth, 2014. Infrastructure shown in the figure is proposed and not constructed. Spruce deposit noted on the figure is the Spruce Road deposit.

Figure 2: Figure 4-3 from AMEC (2014) showing a broad area of private land with a tailing storage facility label northwest of the Peter Mitchell Pit.

Figure 18-4: Tailings Storage Facility



Note: Figure prepared by Barr, 2014.

Figure 3: Figure 18-4 from AMEC (2014) showing the outline of a potential tailings storage facility.

Myers' PolyMet groundwater model (Myers 2014a, b, and c) extended north of PolyMet to the St Louis River/Rainy River Headwaters divide near Babbitt, but it truncated along the Embarrass River flowing west from its headwaters (Myers 2014b). The model included the Embarrass River as part of the simulation the plant site. The model was amended to include the PMP once it was realized that the PMP could create a gradient from PolyMet to the north and by virtue of breaching the Laurentian Divide could allow contaminants to pass into the Rainy River Headwaters watershed (Myers 2015). That report (Myers 2015) is attached to this memorandum as Attachment 1. The revised model showed that contaminants from PolyMet could flow northward to the PMP.

This memorandum describes adding the proposed Twin Metals' tailings storage facility as shown in Figure 3 to the revised Myers PolyMet groundwater model that includes the PMP. The objective is to determine whether contaminants, simulated as sulfate (SO_4), could drain from the proposed tailings impoundment site through the topographic divide to enter the PMP and potentially the Rain River Headwaters watershed.

DESCRIPTION OF STUDY AREA

The potential Twin Metals tailings storage facilities locations are north of a ridge between the Partridge River and Embarrass River drainages. The ridge is also north of the PMP. The topographic outline can best be seen in a columnar transect from the Myers model. Figure 4 shows an up-down cross-section along model column 130 with groundwater contours from the steady state solution, or the solution that best represents background conditions. The plan shows a color gradation of elevation from the digital elevation model used to establish the top elevation for the model. The top of the ridge is about 550 m (1800 feet) above mean sea level (amsl). Elevations near the PolyMet mine site are about 490 m amsl, and at the Embarrass River on the north of the columns, elevations are about 440 m amsl. The long-term PMP lake elevation would be about 457 m amsl, but up to the year 2070, the PMP lake will be dewatered to as low as 396 m amsl.

Groundwater contours on Figure 4 are hard to read, but they do show a ridge in the groundwater under the topographic ridge, as would be expected. Thus, in natural or pre-mine conditions groundwater between the Embarrass and Partridge River watersheds do not mix.

Figure 5 shows similar profile information but shows the formations for layer 3 and in the profile. The figure captions describe the plan geology. The profile in Figure 5 shows that the granite extends south beneath the Virginia and Biwabik Formations, and the Duluth Complex. The PMP is in the higher-conductivity Biwabik Formation (the red). Myers (2015) found that much of the water during PMP dewatering comes from the Biwabik Formation, but it drew water and contaminants from the south as well over the long term. The PMP drew water from the south. Groundwater contour maps in Myers (2015) all show that the groundwater divide between the PMP and Embarrass River remains and that the contours to the southeast from the divide to the PMP are much steeper than to the north. This is due to the PMP being significantly lower than the divide and closer to it than is the Embarrass River to the north; there is more relief to drop over a shorter distance to the south. However, the groundwater divide extends north of the topographic divide. In 2070 at the projected end of mining in the PMP, the groundwater divide is at least 1 km north of the topographic divide (Figure 11, Myers 2015, Attachment 1). Therefore, if Twin Metals' tailings are deposited sufficiently close to the topographic divide, seepage from the tailings impoundment could be drawn southward to the PMP.

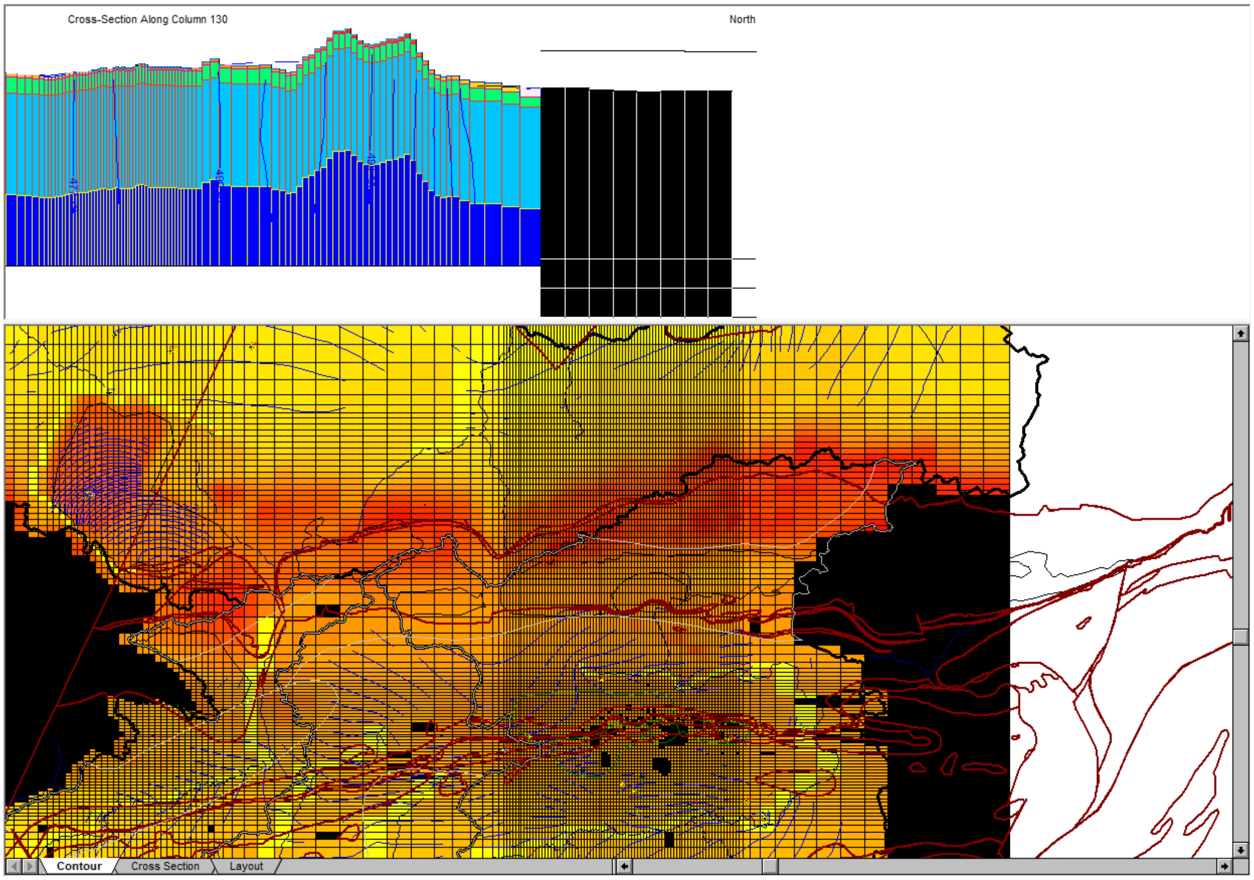


Figure 4: Cross-section along column 130 from the Myers (2014a, b, and c) groundwater model, steady state solution. The plan view is layer 1, in which the yellow cells are drain boundaries for streams and color gradation is for elevation. The red-orange in the middle is higher elevations, which rise to about 550 m (1800 feet). The section lies about 3/5ths of the way from the left edge to the right edge. The contours are two meters and the purple represents dry or unsaturated model cells.

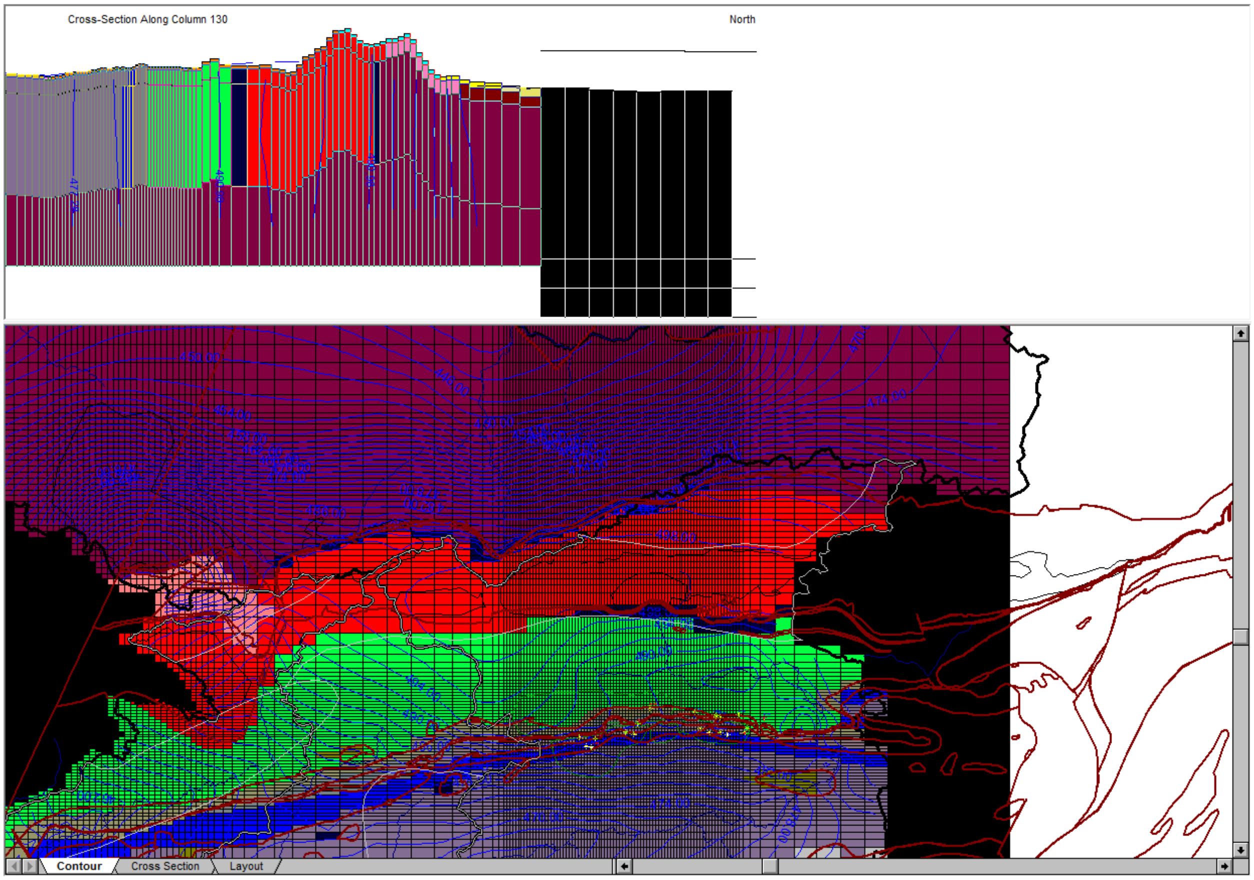


Figure 5: Cross-section along column 130 from the Myers (2014a, b, and c) groundwater model. The plan view is in layer 3 and shows the various formations. See Myers (2014a, b, and c) for details, but in general the northern dark red is granite, the red in the middle is the Biwabik Formation, the green is the Virginia formation, and below that is the Duluth Complex which includes several stratigraphic layers. The Biwabik Formation in general has the highest conductivity. The columnar section lies about 3/5ths of the way from the left edge to the right edge. The contours are two meters, and the purple represents dry or unsaturated model cells.

METHOD OF ANALYSIS

To determine whether contaminants would report south to the PMP from a potential Twin Metals tailings impoundment, I added a potential source of contaminants representing a potential Twin Metals tailings impoundment to the PolyMet model as revised to include the PMP (Myers 2015). I imported the tailings storage facility outline from Figure 3 into a GIS file used for the PolyMet modeling (Figure 6). The proposed tailings storage facility would be less than three quarters of a kilometer from the topographic divide between the Embarrass and Partridge Rivers and about 2.5 km from the PMP (Figure 6).

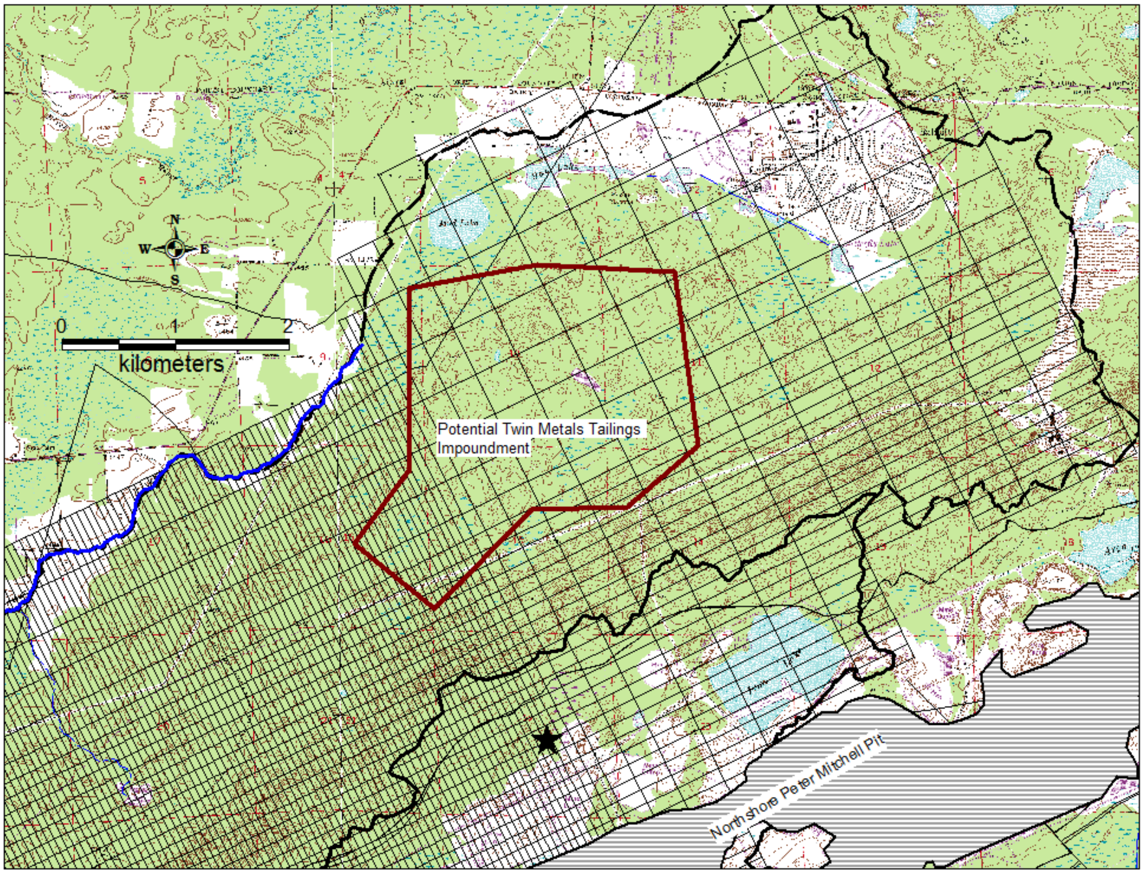


Figure 6: Site of the potential Twin Metals tailings impoundment north of the Peter Mitchell Pit. The facilities are imposed on the groundwater model grid. The star is the simulated monitoring point between the PMP and the potential Twin Metals tailings facility.

Contaminant transport of sulfate occurs in this model based on advection and dispersion. Advection is the movement of contaminants with the groundwater flow, accounting for the fact that pore volume is much less than the total aquifer volume. Particles move faster than the average flow velocity. Dispersion is the spreading of contaminants due to the tortuosity of the pathways the actual particles travel through. Transport through pores is not along a straight line, and therefore a contaminant plume spreads along and perpendicular to the flow path. The model does not consider attenuation or geochemical reactions because sulfate often transports conservatively (Myers 2016).

Seepage from the potential tailings impoundment was simulated as a specified flux boundary, (recharge boundary), which means that the seepage rate is specified. Because the impoundment would be new, it would presumably be lined, unlike the existing impoundment to be used at PolyMet. The impoundment would seep at rates less than natural recharge, and for this model test, I have chosen to use the predicted seepage rate from the PolyMet tailings impoundment (1.144×10^{-3} m/d) as an upper limit with a sulfate concentration similar to a Category 1 waste rock dump, or 2,500,000 ug/l (2500 mg/l). This concentration is used to provide a comparison with estimates for the PolyMet Mine and to simply determine whether a plume extends from the potential Twin Metals tailings impoundment to the PMP.

It is unlikely that tailings would be placed before the end of proposed mining at PolyMet (20 years from the present) so the tailings seepage was added to the model simulations beginning at that time (2035). Three stress periods—6, 4, and 26 years long with 122- and 243-day periods per year—are used to simulate the years to 2070 when the PMP stops dewatering. After 2070, the model runs for 100 years as the PMP recovers naturally to 457 m. See Myers (2015) for details.

RESULTS AND DISCUSSION

The results are best presented with a series of contour maps showing sulfate and head concentrations (Figures 7-12). Six years after the assumed placement of Twin Metals tailings with seepage commencing over the impoundment shown in Figure 6, concentrations have not extended far south (Figure 7). The PMP maintains relatively high water levels at this time (Myers 2015) so there has been no significant southward hydraulic gradient developed (not shown). The lowest sulfate concentration contours (to 0.1 ug/l) begin to extend beneath the topographic divide (Figure 7), likely driven by dispersion. At the time of maximum drawdown in the PMP, sulfate concentration contours as high as 1000 ug/l have extended through the divides to the PMP (Figure 8). The concentration contours also form a divide between the PMP and potential Twin Metals tailings storage facility (Figure 8). At deeper levels, model layer 3, the plume has extended even farther south (Figure 9). However, redevelopment of the pit lake at the PMP has allowed a gap to redevelop in the sulfate concentrations through the divides, indicating that sulfate from a Twin Metals tailings impoundment would no longer extend to the PMP (Figure 10).

The simulated groundwater head contours show clearly the reasons for sulfate not reaching the PMP except when the PMP is most drawn down (Figure 11). By the year 2070 when the PMP is most drawn down, the head contours develop a groundwater ridge north of the topographic divide and very near the southern boundary of the potential Twin Metals tailings impoundment (Figure 11). The groundwater ridge, which had coincided with the topographic divide, shifted north and increased the area drawn to the PMP because of the much deeper groundwater to match the PMP lake levels. However, the low point along the groundwater, or saddle to use a topographic analogy, is west of the low point in the concentration contours. Effectively, dispersion caused some contaminants to cross the groundwater divide where they then can be drawn by gradient-driven advection south to the PMP. By 2070, the groundwater model simulation shows the flux crossing the divide to the southeast of the PMP is 1118 m^3/d, based on the water balance for the model domain shown in Figure 13 (Table 1)[1]. One hundred years later, the groundwater divide shifts south to coincide with the topographic ridge, which shuts off the source of contaminants from the north (Figure 12). The flux southward decreases to 310 m^3/d by 2170, but as noted no longer carries contaminants.

Both groundwater contour figures (11 and 12) show relatively steep contours to the west, or towards the Embarrass River. The Embarrass River is up to several tens of meters lower than PolyMet, and the PMP is lower when it is fully drawn down for mining prior to 2070. After 2070 the pit lake would develop in the PMP to levels higher than the Embarrass River, although as noted it takes a long time for the pit water level to recover. However, it is noteworthy that inflow from storage exceeds 7000 m^3/d for both periods. This reflects the changes in groundwater contours and generally shows that the drawdown is occurring in the model domain due to the proposed Twin Metals tailings seepage being less than natural recharge because liners can minimize seepage. The decrease in seepage to the Embarrass River (drain outflow, Table 1) reflects the decreased seepage due to the tailings impoundments. This demonstrates an unusual negative effect of mining – large sized tailings storage facilities with low seepage can significantly affect the total recharge to the area and decrease discharge to the rivers, thereby reducing available surface water.

Hydrographs of sulfate concentration (Figure 14) for a simulated monitoring well between the facilities (Figure 6) show that sulfate concentrations begin to rise about 25 years after PolyMet ceases operations and return to base levels 25 years later. The potential Twin Metals tailings storage facility, as simulated, would cause contaminants to cross the topographic divide to the PMP for about 25 years based on the current plans for the PMP. The high concentrations in layer 4 reflect the plume extending south faster, as shown in Figure 9. It is likely the plume in layer 4 (Figure 9) discharges into the base of the PMP. Groundwater levels reach a nadir at about the time of peak sulfate concentration (Figure 15). The period of rising and falling concentrations does not center on the nadir due to lag time created by transport due to advection, strictly hydraulic gradient driven, and dispersion. Contaminants remain after the groundwater level has risen at least 15 m above the point at which contaminants first break through at the monitoring because they remain sufficiently far south after the groundwater divide begins to shift south. The moving divide could cause some contaminants to move back northward.

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[1] Ymin in Table 1 is the south side of the water balance boundary (Figure 12), while Ymax, Xmin and Xmax are north, west, and east respectively.

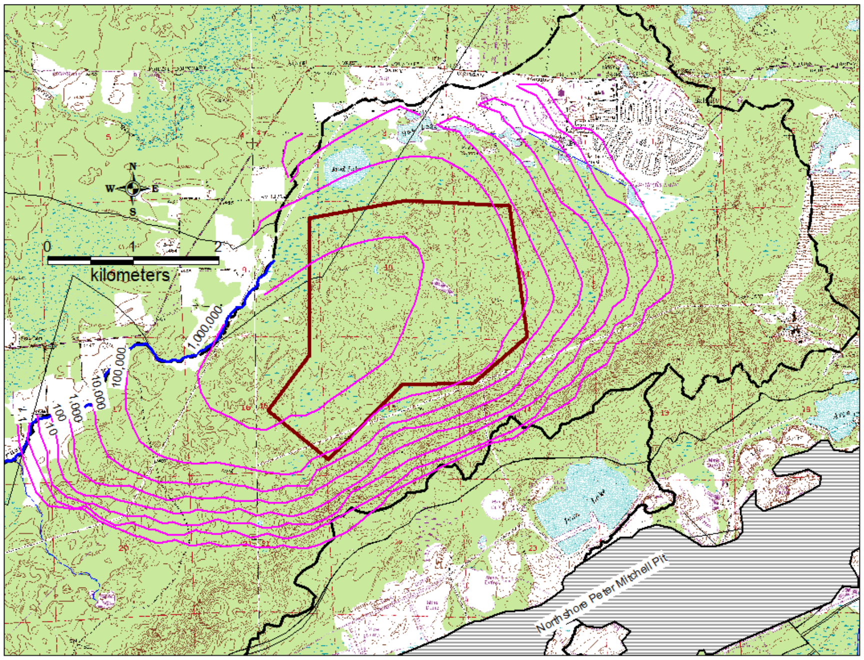

Figure 7: Simulated sulfate concentrations from a potential Twin Metals tailings impoundment. Six years after the end of proposed PolyMet Mine, c. 2042. Model layer 3.

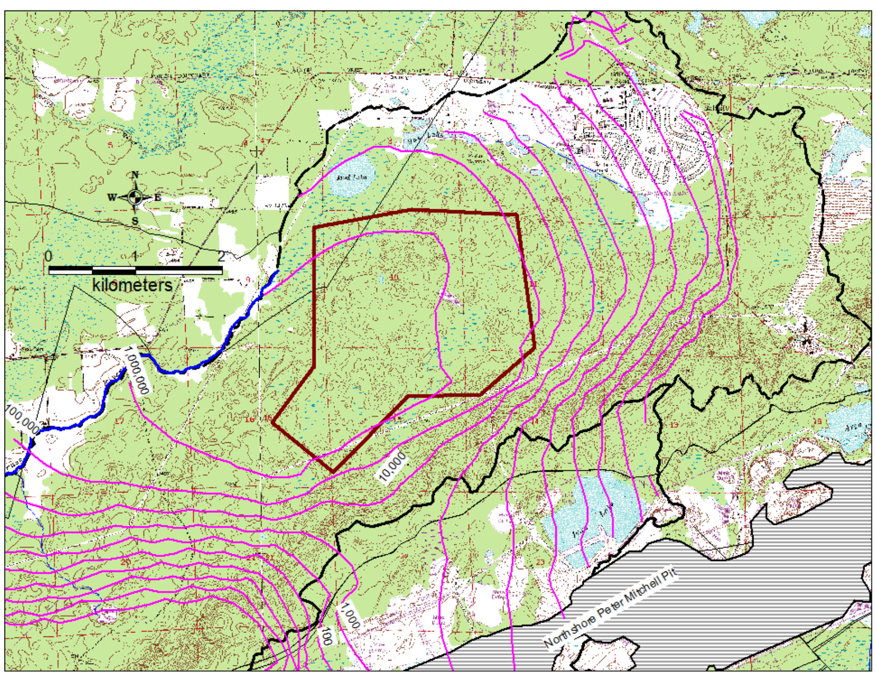

Figure 8: Simulated sulfate concentrations from a potential Twin Metals tailings impoundment, at the end of proposed Peter Mitchell Pit mining, c. 2070. Model layer 3.

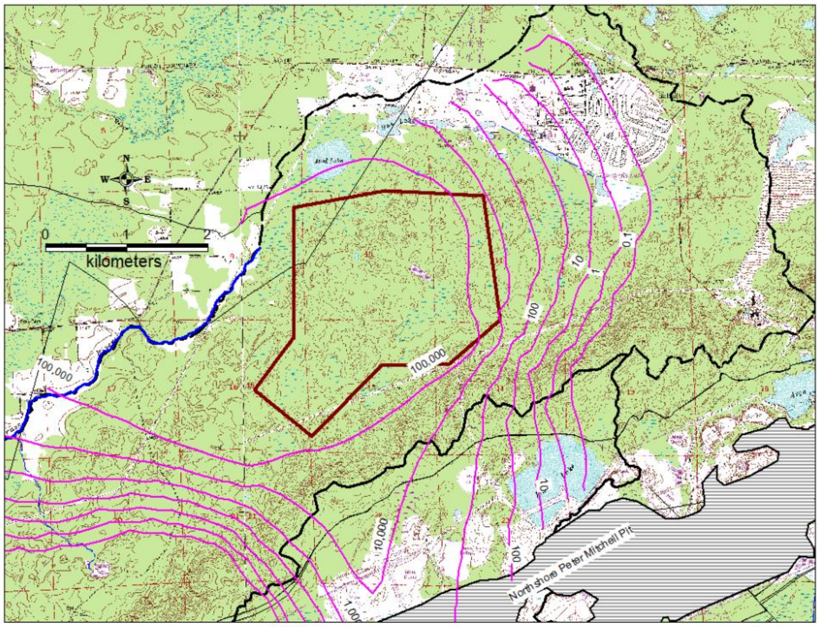

Figure 9: Simulated sulfate concentrations from a potential Twin Metals tailings impoundment, at the end of proposed Peter Mitchell Pit mining, c. 2070. Model layer 4.

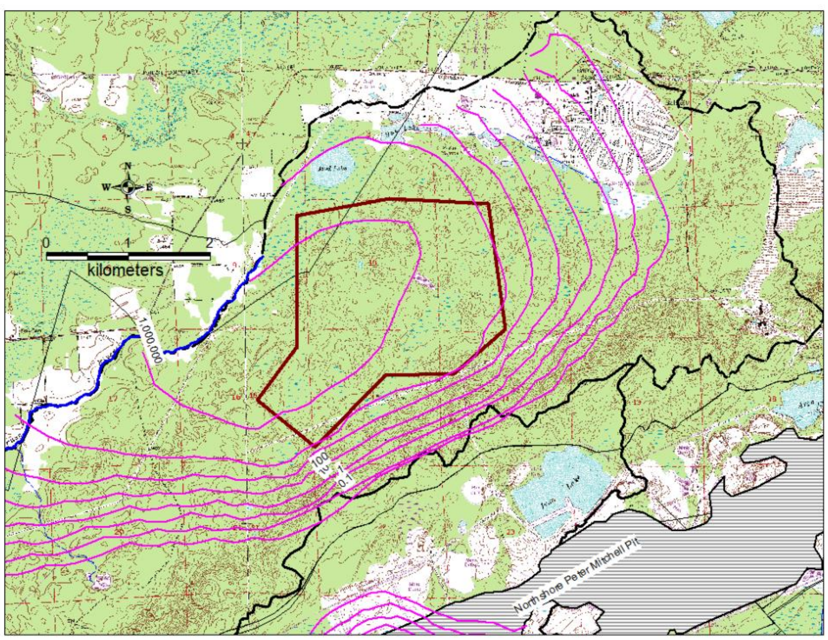

Figure 10: Simulated sulfate concentrations from a potential Twin Metals tailings impoundment, 100 years after the end of proposed Peter Mitchell Pit mining and 136 years after the end of proposed PolyMet Mine, c. 2170. Model layer 3.

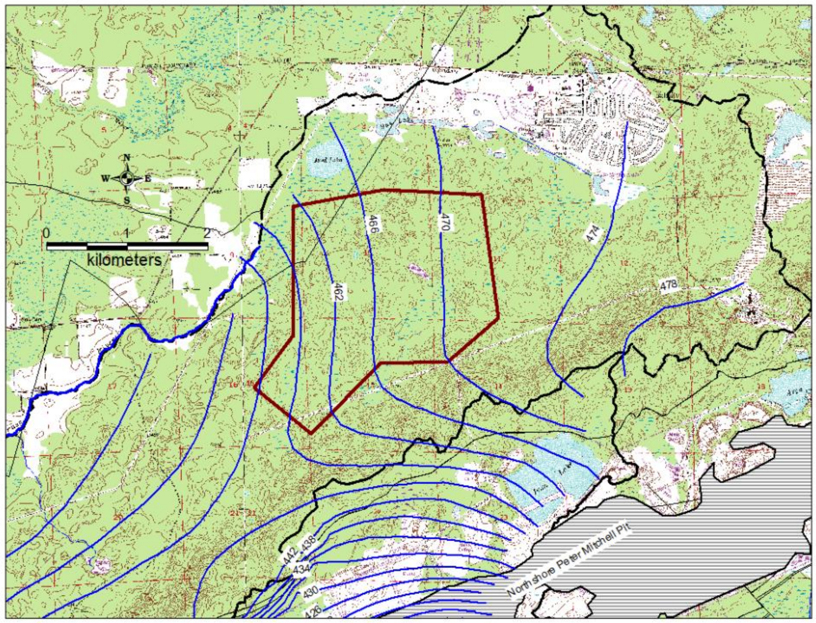

Figure 11: Simulated groundwater head contours with a potential Twin Metals tailings impoundment at the end of proposed Peter Mitchell Pit mining and 36 years after the end of proposed PolyMet Mine, c. 2070. Model layer 3.

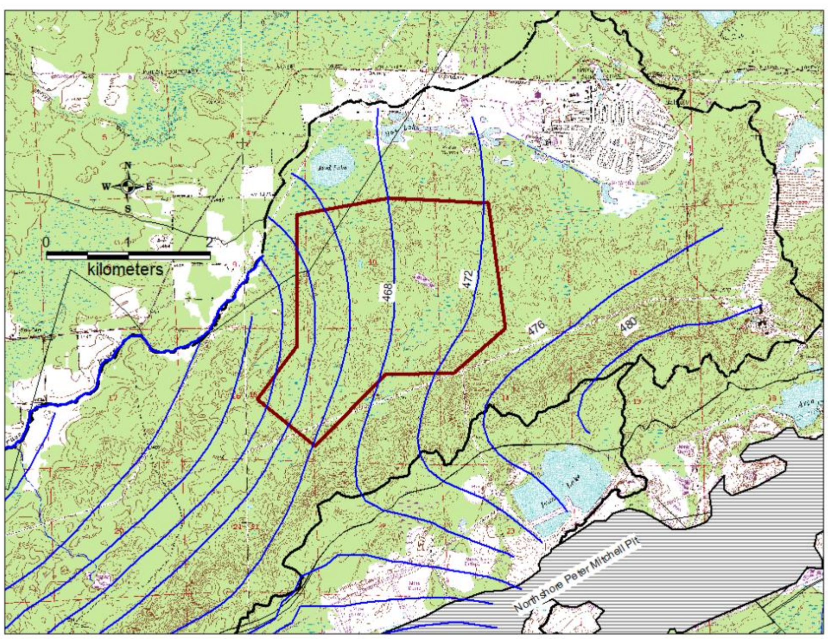

Figure 12: Simulated groundwater level contours from a potential Twin Metals tailings impoundment, 100 years after the end of proposed Peter Mitchell Pit mining and 136 years after the end of proposed PolyMet Mine, c. 2170. Model layer 3.

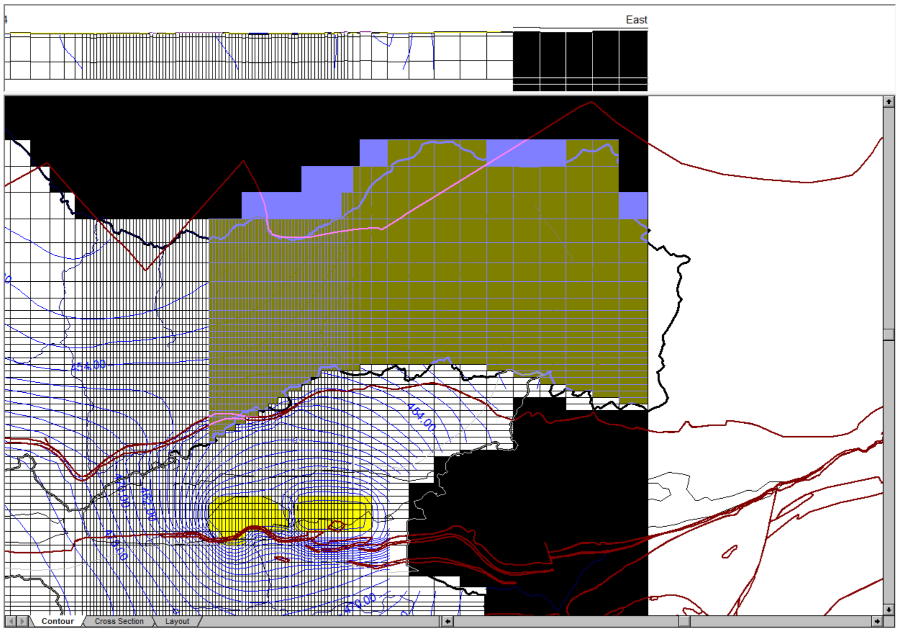

Figure 13: GWVistas screenshot showing portion of model domain included in the water balance for the upper Embarrass River.

Table 1: Water balance (m^3/day) for model domain in the east end of the Embarrass River watershed, shown in Figure 12. Discharge to the Peter Mitchell Pit (PMP) is total discharge to the dewatering operations or to the pit lake.

	2070 - End of PMP Mining		2170 - PMP Full pit lake	
	Inflow	Outflow	Inflow	Outflow
Storage	7556	3	7322	0
X min	261	1009	87	5108
X max	24	201	86	66
Y min	1118	1389	310	137
Y max	0	0	10	4
Drain	0	12567	0	9711
Recharge	7211		7211	
Total	15171	15170	15027	15027
Discharge to PMP		11575		6200
Discharge to PMP is the sum of flow to the model drain cells in 2070 and to storage in the domain beneath the drain cells in 2170 since the pit lake has not fully recovered. The model does not simulate surface water inflow so this could be an underestimate.				

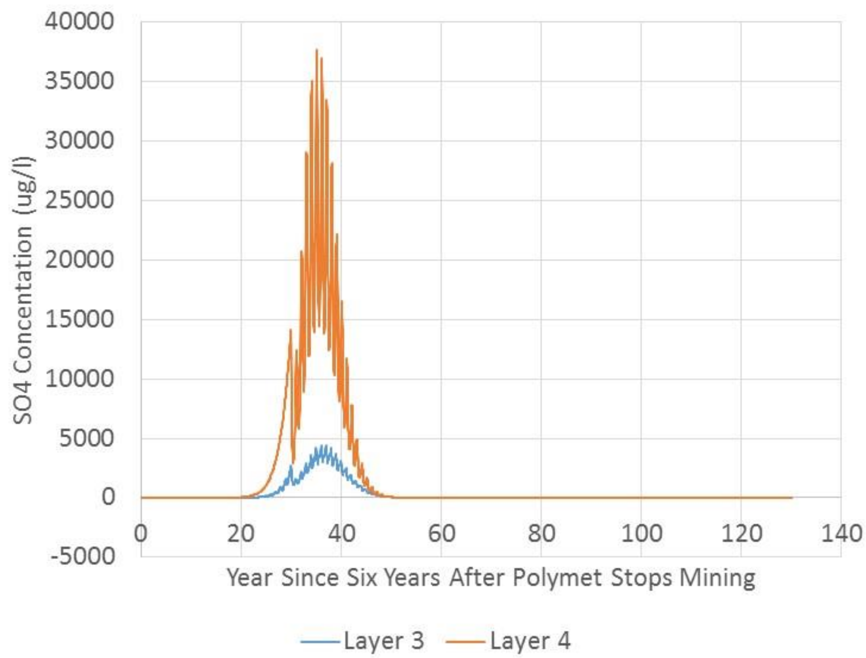

Figure 14: Simulated hydrograph of sulfate concentration for a monitoring point south of the topographic ridge between PMP and the potential Twin Metals tailings storage facility, as shown in Figure 6.

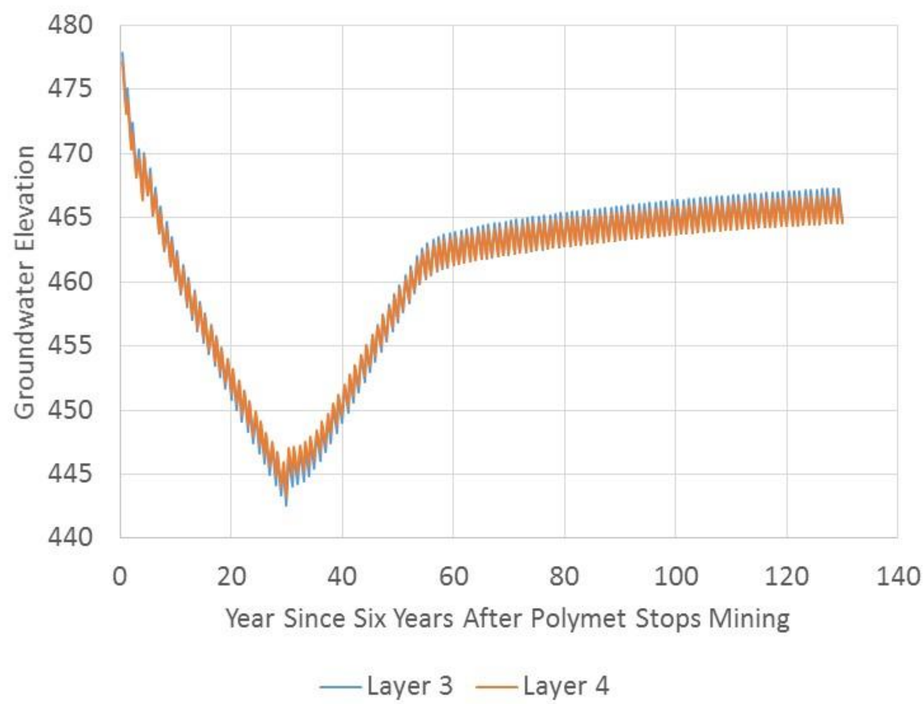

Figure 15: Simulated hydrograph of sulfate concentration for a monitoring point south of the topographic ridge between PMP and the potential Twin Metals tailings storage facility, as shown in Figure 6.

The groundwater table is much flatter in the upper portion of the Embarrass River watershed, near Babbitt, and as much as 15 meters higher than the long-term water level for the PMP. If Twin Metals placed its tailings closer to the divide, south or southeast of Babbitt but still in the Embarrass River watershed, there could be contaminant pathways directly south to the PMP. The PMP would have breached the Laurentian Divide and the pit lake water level (and subsequent groundwater levels) would be the same on both sides of the divide. Contaminant pathways from tailings placed farther to the east could cross the Laurentian Divide and enter the eastern end of the PMP. The Myers (2015, 2014a, b, and c) PolyMet model does not include any domain east of the Laurentian Divide (Figure 6), so simulations of such a connection are not possible without adding domain to the model. Based on the current findings, however, it is likely that tailings deposited farther east in the Embarrass River watershed would seep through the divide to the PMP and the BWCAW.

CONCLUSION

Model simulations showed that from 25 to 50 years after the PolyMet Mine closes and the PMP is dewatered to levels far lower than at the potential Twin Metals tailings facility, there would be a significant contaminant flux through the topographic divide from the Embarrass River to the PMP, and thus into the Birch Lake and Kawishiwi River watershed. A slug of contaminants moves at deep levels through the bedrock to the PMP. The contaminant transport through the divide occurs because the PMP lake is drawn low enough to significantly increase the hydraulic gradient to the south. The change in gradient forces the groundwater divide to move northward to a point where contaminants from a potential Twin Metals tailings impoundment are captured and move southward. Simple groundwater flow, or advection, causes the contaminant to flow southward to the PMP. If Twin Metals placed its tailings closer to the divide, contaminant pathways would develop even more directly south to the PMP. This is in addition to contaminants from the proposed PolyMet mine, which would drain into the PMP essentially in perpetuity.

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ATTACHMENT A

Technical Memorandum

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Prepared for: Minnesota Center for Environmental Advocacy

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December 15, 2015

Summary and Conclusion

The Peter Mitchell Pit north of Polymet will affect the groundwater flow near the proposed Polymet project more than disclosed in the Polymet FEIS. These effects are separate from the discharge of PMP dewatering water which affects flow in the Partridge River and is not considered in this memorandum. The PMP is actually three pits which have been variously mined and dewatered since the 1950s. The PMP into the future will be dewatered until 2070, with the three pits eventually being combined to form one pit, to water levels more than 200 feet lower than those at Polymet. After 2070, a permanent pit lake will form with an outlet 75 feet lower than levels at Polymet. The combined pits will cut through the Laurentian divide effectively mixing waters from the St Louis and Rainy Headwaters watersheds, meaning that contaminants from south of the divide can pass to the northern watershed by passing through the PMP lake.

Current PMP effects on groundwater other than very near the PMP are not that significant because the formations surrounding the PMP and separating it and Polymet have low conductivity so changes in the PMP propagate slowly. Calibration of Polymet-area groundwater models (both Polymet and Myers (2014a, b, and c)) are little affected by the PMP because both considered water levels in that area that were close to the natural groundwater level.

Myers' model simulated water levels at the PMP for steady state calibration equal to that observed in 2003 but did not simulate flux from the model. This technical memorandum shows that neither of three different ways of including the PMP in the calibration of the Myers model made a substantial difference in the observed head values, other than directly at the PMP, nor in the model-wide fluxes. When the West PMP pit is full and the East PMP pit is being dewatered, much of the dewatering water comes from the West PMP.

Polymet's model maintained the PMP at the calibration level into the future rather than simulating the long-term dewatering at the PMP until 2070 and establishing a pit lake up to 100 feet lower than the water levels at Polymet. This conceptualization does not comport with descriptions of the future expected water levels at PMP. Polymet's model essentially established a permanent gradient from the PMP to the south and prevented the water level north of Polymet from being drawn down due to Polymet dewatering and also prevented contaminants from flowing northward from Polymet to and beyond the Partridge River. Polymet's ignoring of the PMP future levels biased the model results and prevents the FEIS from considering contaminant pathways to the north.

This technical memorandum presents a detailed analysis using the Myers model of the potential for the PMP to affect groundwater levels and contaminant transport into the future. The model assumes the West Pit will be a lake and the East Pit will be dewatered for the 20 years of the proposed Polymet mine plan. After that time, mine dewatering lowers water levels through the entire PMP to levels more than 200 feet below the Polymet area. Having tested several conceptual models in steady state for calibration, the pit lake was modeled using the high conductivity, high porosity method with recharge set equal to net precipitation on open water. The East Pit being dewatered was simulated with head-controlled flux boundaries that only allow flow to discharge from the model domain (MODFLOW DRAIN boundaries) to lower the pit water levels to 2070 levels. Beyond 2070, the combined pits' lake was simulated using the high conductivity, high porosity method to the specified discharge level of 1500 feet.

The Myers model simulated the proposed Polymet mine with three transient stress periods corresponding to the construction and backfill of the three pits with concomitant waste rock dump construction and reclamation. The model then simulated the closure period including the development of a pit lake in the West Pit with period lengths based on water levels rising into different model layers to ease the simulation of resaturation of shallow model layers. I added the PMP as described above to the original simulation of the Polymet mine. The third closure period shortened to 26 years because of the closure of the PMP and the commencement of pit lake development. I added a fourth closure period to simulate changed in the groundwater for 100 years.

Groundwater contours control the flow direction and divide in the groundwater separates groundwater flow directions among aquifers just as a topographic ridge divides runoff between watersheds. There is a divide between the PMP and Polymet because there is recharge in the area, but its location varies with time as water levels in PMP and at Polymet vary. At the end of proposed Polymet mining, the divide lies north of Polymet and prevents flow northward by that time. In 35 years after the end of proposed Polymet mining, the divide shifts and diverts groundwater flow from much of the Category 1 waste rock dump and from the Central and West Pit northward toward the PMP; this is the time of maximum drawdown at PMP. One hundred years later, water levels at the PMP have recovered to their proposed long-term level and the groundwater divide has shifted slightly northward but still lies under the Cat 1 waste rock dump and on the north side of the Central and East Pits. Simulating the closure conditions in perpetuity as steady state moves the divide further south so that more of the Cat 1 waste rock dump and Central and East Pits flows northward.

Cross-section analysis shows that northward flow occurs primarily at depth, through the deepest model layer, and discharges upward into the bottom of the PMP. The FEIS should consider bedrock pathways from Polymet to the PMP as part of its contaminant analysis. Depending on the exact source location, the time period for transport from the pits to the PMP varies from less than 20 to a little more than 100 years. Pathways from the Cat 1 waste rock to the upper reaches of the Partridge River vary from about 60 to 100 years.

The conclusion of the analysis of the Peter Mitchell Pit is that its long-term dewatering and pit lake development will affect groundwater flow patterns at the proposed Polymet project. It will create pathways at depth from the Central and East Pits to the PMP. Contaminants could reach the PMP in less than 100 years. Also, the flow patterns allow contaminants from the Cat 1 Waste rock dump to reach the upper end of the Partridge River. The FEIS has failed to disclose these impacts by artificially treating the PMP as having a water level far above the Polymet area. This failure has caused the FEIS to not consider pathways to the north in the modeling. The FEIS' assurance that contaminants will not reach the Rainy Headwaters, the upper portion of the watershed draining into the Boundary Waters Canoe Area Wilderness, is inappropriate.

The water quality modeling for the minesite for the FEIS should be redone to consider a pathway from the Polymet pits to the PMP and from the Cat 1 waste rock dump to the upper reaches of the Partridge River. The FEIS should be altered in other ways to provide mitigation against contamination reaching the Rainy Headwaters.

Introduction

Environmental studies completed for the proposed Polymet Mine rely on there being no potential for contaminants to flow northward from the minesite into the Rainy Headwaters watershed which includes the Boundary Waters Canoe Area Wilderness (BWCAW). This memorandum reviews the modeling completed by Polymet and the future plans for the Northshore Mine or Peter Mitchell Pit (PMP) just north of Polymet to assess whether the assumption is correct. This memorandum then presents a modification to the Myers simulation of the Polymet Mine (Myers 2014a, b, and c) to include the PMP. The purpose was to determine whether Polymet's assumption of no flow or transport to the north was legitimate and to estimate the magnitude of contaminant transport to the north, if it occurs.

Northshore Mine and the Peter Mitchell Pit

The various pit lakes which make up the PMP will be combined by removing the ore along the divide (Barr Engineering 2010) (Figure 1). Final topography at closure near 2070 will establish a final pit lake elevation of 1500 feet amsl and include littoral zones with depth up to 30 feet and shallow marsh wetland with depth up to 6 feet (Barr Engineering 2010) (Figure 2). This final sculpting of pit lake depths would be achieved by in-pit waste disposal. The outflow elevation is the proposed rim elevation, over which flow would be north into the Dunka River which is part of the Rainy Headwaters. Removing the dike from the middle of the PMP will clearly mix water from both sides of the divide and cause water from south of the divide, which would otherwise drain to Lake Superior, to drain north into the Rainy Lakes and beyond.

The current water level in the pit on the St. Louis River side of the divide is 124 feet higher than the future water level of 1500 feet after the current pit segments are mixed. If Polymet contaminants reach the PMP, there will clearly be an interbasin transfer of contaminants along with the water. MNDNR relies on various factors to assume that Polymet contaminant transport will not be to the north.

Barr estimated a PMP lake water balance that includes undisturbed area runoff, mine feature runoff, groundwater inflow to pit, and direct net precipitation (Barr Engineering 2008). Total inflow to the PMP when it is full ranges from 21.4 to 17.9 cubic feet per second (cfs) (52,357 to 43,794 cubic meters per day (m^3/d)) and the groundwater inflow from 12.4 to 5.1 cfs depending on various assumptions (Barr Engineering 2008, p 18)[2]. These groundwater inflow rates are based on a range of 2.56 to 1.04 cfs/mile^2 for mining-disturbed land (Barr Engineering 2008, p 17). These rates translate to 35 to 14 in/y of recharge through mining-disturbed area which suggests the groundwater inflow estimate to the PMP

[2] This memorandum does not review the methodology used to estimate this inflow nor endorse the accuracy of the estimate.

may be much too high. Barr Engineering based these rates, when the PMP is full, on rates observed during dewatering which may be inaccurate due to the different gradient; when full the groundwater flow gradient would be low whereas during dewatering there is a several hundred foot water level drop into the pit which would cause a much higher dewatering rate.

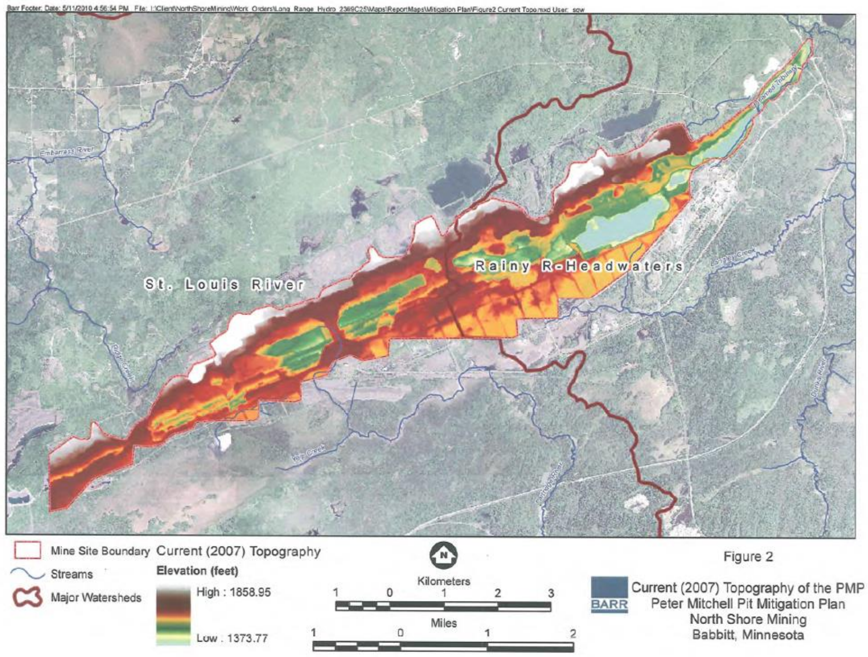

Figure 16: Snapshot of Figure 2 from Barr Engineering (2010) showing current topography. The dike of unmined ore between the St Louis River and Rainy Headwaters is evident along the divide.

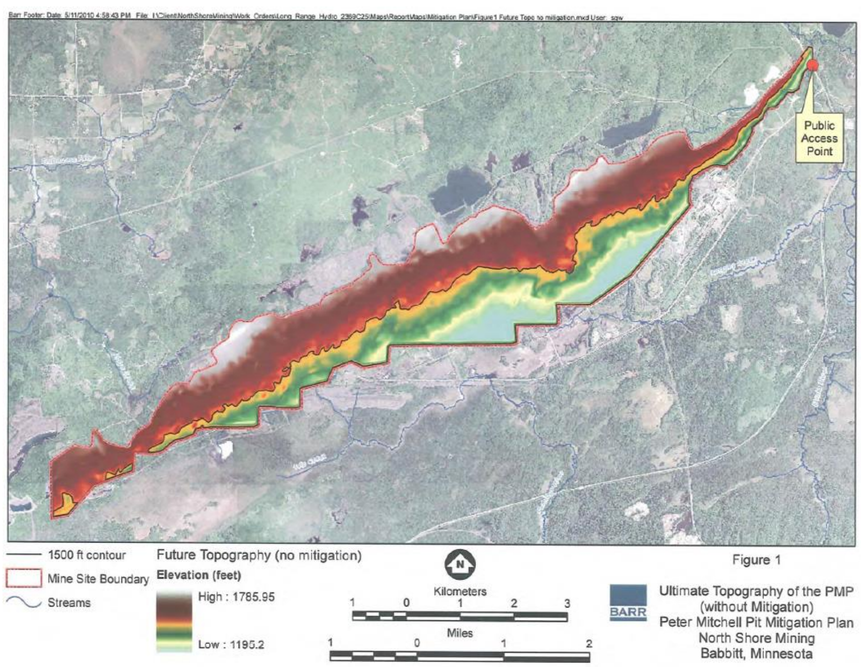

Figure 17: Snapshot of Figure 1 from Barr Engineering (2010) showing ultimate pit topography. Comparison with Figure 1 shows that the topography will involve some movement of waste rock

within the pit and backfilling to create a lake. The low contours (green) extend through the divide connecting water north and south.

The PMP as shown in Figure 1 has about 12 miles of shoreline. Barr Engineering (2010) shows cross-sections which suggest an average depth of about 150 feet. The lake will be long and narrow and not have a broad flat bottom due to the creation of littoral zones. An accurate but coarse estimate of conductivity (K) based on 12 miles and 150 feet thickness with the range in groundwater estimated above is 0.05 to 0.11 ft/d. These values are about an order of magnitude less than that in the calibrated Myers model, which found horizontal K (Kh) to equal 0.22 and 0.1 m/d in the Biwabik and Virginia formations, respectively (Myers 2014b).

Jimenez et al (2015a) provide a table suggesting that the west, east, and area 002 of the PMP will be at 1350, 1300, and 1250 feet amsl in 2070 and all will be at 1500 feet amsl in 2080+, suggesting it should take more than 10 years to fill up to 250 feet. Current PMP water surface levels are 1624, 1568 and 1380 feet amsl, respectively. These long-term water levels are significantly below long-term projected water levels at Polymet.

The FEIS effectively claims there can be no flow to the north from Polymet to the PMP because a topographic divide, the presence of the Partridge River, and due to a mound forming in the groundwater due to recharge. I review the first two details in my review of the FEIS. However, the mound argument resulted from a discussion provided to refute arguments from Coleman (2015) regarding flow to the north (Jimenez et al. 2015a). The "evidence" of there being no northward flow partly contradicts the expectation that a mound may form. Jimenez et al (2015b) report there is no apparent response in monitoring wells near Polymet and no apparent effects on lakes and wetlands near the Northshore pits in response to dewatering those pits. The lack of response in bedrock monitoring wells either raises a question of where the water comes from for dewatering at PMP or indicates there is a rapid response in water draining from surface aquifers in response to drawdown in the bedrock. However, the lack of response in nearby lakes suggests much of the surface water is perched. The area in the 100 Mile Swamp may not drain at all, suggesting there is very little recharge through this area which would prevent a mound from forming. In other words, evidence regarding the potential for northward flow is inconclusive but there is no evidence from local data that suggests no flow occurs.

Polymet Modeling of PMP

Polymet modeled the PMP as a constant head boundary (Pint and Mohr 2015), for which the user sets the exact water level at a point. This type of model boundary maintains the specified water level regardless of the stresses, such as pumping or changed recharge, applied to the model. The model boundary essentially allows an unlimited amount of groundwater to enter or leave the model domain as necessary to maintain the specified head. The K of the surrounding formations controls the gradient very near the boundary.

Polymet's model calibration assumed the PMP water level was constant about 5 meters above the level of the upper Partridge River even though the PMP in 1986-88, the period for which baseflow was set, was actually below the elevation of the river (Pint and Mohr 2015). This caused the model to simulate flow from the PMP to the river when in fact flow would have been in the other direction (Id.). Pint and Mohr (2015) explained that the PMP locations were based on 2003 aerial photograph and that the “[h]eads for the pit lakes were assigned based on data from the DNR Mesabi Elevation Project, which was from 1996”. They did not consider the variable water surface elevations that occur in the PMP.

A general problem with calibrating the Polymet mine model (or the Myers’ model) while accounting for PMP is that there is not really a period since the PMP started mining that represents steady state conditions. There have been several pits with different and frequently changing water levels since the 1960s. Dewatering discharge has been to different streams, such that baseflow in those streams is also a poor indicator of groundwater discharge. Due to the temporally variable recharge (changes with season) in a relatively small-scale watershed there is no correct steady recharge or baseflow. Polymet’s model reports do not provide simulated or measured fluxes from the PMP boundary (Myers 2014d) so it is difficult to assess the effect that the Barr’s handling of the PMP had on the calibration.

Myers (2014 b and c) modeling did not account for the PMP because the long-term water level would have been higher than the pre-mine groundwater level due to a net inflow of runoff and precipitation. Digital elevation model data used by Myers (2014b) set the PMP elevation at about 494.2 meters (1620 feet amsl), or 120 feet higher than expected at closure. Groundwater level observations between Polymet and the PMP did not fluctuate to reflect PMP lake levels or dewatering.

If there are not compensating factors, having the PMP have a lake level equal to 1500 feet would cause groundwater to flow northward toward the PMP. Downward leakage, or recharge from the surface, would form a groundwater mound on the water table in the underlying bedrock aquifers and could be a compensating factor. If recharge is zero and the aquifer properties are homogeneous, the water table will approximate a straight line with flow from the higher to the lower point. The line bulges upward as percolation reaches it because the percolation changes flow rates which require a changed gradient (Toth 1962). If the percolation rate is low, the mound will not cause a flow reversal. Jimenez et al (2015a) estimated that a mound would develop for an average leakage of 2.3 in/y or greater, a value much less than most estimates of recharge in the area (see Myers 2014a). This suggests that a mound could occur between the PolyMet mine and the PMP, but a model testing these conditions would provide a more accurate assessment. Based on the projected future water levels at the PMP, the pit lake water levels would be from 75 to 95 feet lower than Polymet (Jimenez et al 2015a, Table 1). Depending on the percolation rate, flow from Polymet to the PMP could occur. Interestingly, the Polymet model had a very low recharge (Myers 2014d) so that model should allow northward flow if the boundary condition is low enough. Coleman (2015) ran simulations with the Polymet model and found that indeed there would be flow to the north.

The Polymet MODFLOW model was designed to estimate dewatering rates at Polymet and only secondarily used to estimate contaminant flow paths. “The MODFLOW model was primarily designed to predict groundwater flow rates to the NorthMet mine pits, and was also used to evaluate groundwater flow directions for definition of GoldSim groundwater flow paths. The model is well-suited and appropriate for these purposes” (Pint and Mohr 2015, p 3). The details of the PMP were not important and do not appear to have even been considered. The agencies acknowledge that setting “artificially high Northshore pit lake elevations … would lead to conservatively high groundwater inflows to the proposed NorthMet pits (Jimenez et al. 2015a, p 1). Simulating the PMP as a constant head boundary forced the gradient to be downward towards the south, as done by Barr, with the objective of conservatively estimating pit lake inflows at Polymet, effectively hard-wires the contaminant flow paths. With the PMP set above Polymet and the Partridge River, it is not possible that the model would have estimated a flow path from Polymet to the PMP. The only way to estimate contaminant flow paths using the MODFLOW model is to simulate the Polymet mine development with the changing PMP water levels to estimate whether there is an impact. Contrary to claims (Pint and Mohr 2015, p 3), if done appropriately, the Polymet's MODFLOW model could provide accurate flow paths for different PMP conditions. The necessary change would be the actual head values in the boundary condition.

Revising Myers Model to Simulate PMP

The Northshore Mine lies north of the proposed Polymet Mine. That mine has developed the series of pits known as the Peter Mitchell Pit. Currently the PMP is two pit lakes west of the Laurentian Divide and one east of the divide (Figure 1). These pits have been variously mined since before the 1970s so they have alternated between being pits and lakes. The level of the bottom of the pits when dry and the level of the pit lakes when full is poorly known. The mapping of current topography clearly shows two pits west of the divide and a larger pit lake area east of the divide. A current photo (Figure 3) shows only the western pit full of water. A small-scale current photo shows a string of water bodies to the west and southwest; these are mostly shallow lakes associate with mining (Figure 4). The tailings impoundment to be used by Polymet is visible as are several pit lakes associated with that mining. Other water bodies are natural lakes.

My previous modeling of this area did not include a boundary for the PMP because the pits are primarily hosted in the Biwabik formation which has higher K than the Virginia Formation and Duluth Complex south of PMP. Also, the lake elevation was never stable for a sufficient time to consider that elevation appropriate for steady state calibration. The original steady state calibration simulated head values near the lake level as estimated from the digital elevation model used to populate ground surface elevations for that modeling effort (Myers 2014). There was no information regarding future water levels at the PMP, so the lake was not modeled as a factor for future groundwater elevations.

This model update adds the PMP to the model in several ways described below. First, there were some minor changes to the K parameters. The steady state calibration showed some high groundwater levels in layer 2 coincident with some very low Ks in parameter zones 15 and 21. Also, K in zone 14 caused a groundwater ridge between the PMP and Polymet. Several increases in were made to eliminate these groundwater peaks (Table 1). For example, increasing Kv14 from 0.002 to 0.007 m/d decreased the crest of the groundwater ridge from 509 to 502 m. Due to the vertical dip in the formations, simulating Kv larger than Kh is consistent with the idea that K is higher along the bedding plane, which has been dipped to closer to vertical. The recalibration slightly improved test statistics (Table 2).

Table 2: Select K values from Myers (2014) and as revised herein. See figures in Myers (2014b) for the parameter zones. Kh is horizontal K, Kv is vertical K.

Zone	Kh orig	Kv orig	Kh new	Kv new
14	0.002	0.002	0.002	0.007
15	0.0008	0.0008	0.008	0.01
21	0.000265	0.00318	0.00265	0.0318
22	0.00043	0.00043	0.00043	0.0043

Table 3: Calibration statistics for the original, revised, PMP1 and PMP2 steady state scenarios.

Statistic	Original	New calibration	PMP1	PMP2
SSR	336	325	375	332
RMS Error	2.33	2.29	2.46	2.31
Scaled res Std Dev	0.043	0.042	.045	.042
Scaled abs mean	0.033	0.034	.037	.034
Scaled RMS	0.043	0.042	.046	.043
Maximum	5.01	5.35	5.26	5.39
Minimum	-4.48	-4.41	-4.99	-4.37
Original is steady state calibration from Myers (2014) New calibration is minor changes to parameters values described here. PMP1 is the addition of a constant head boundary for the west PMP and drain for the east PMP. PMP2 is the addition of a constant head boundary for the entire PMP.				

Figure 18: Google Earth image of the Northshore Mine. The westernmost pit has water while pits to the east are dewatered.

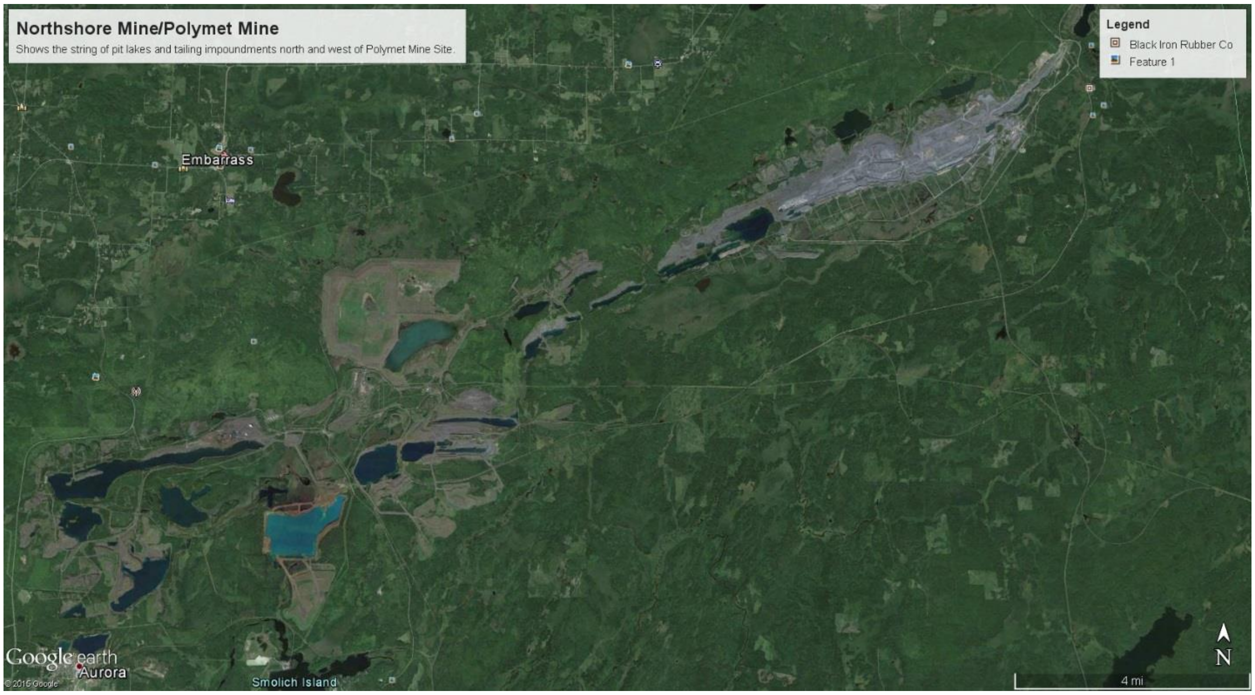

Figure 19: Google Earth Image showing Northshore Mine in the upper right and the trend of pit lakes, tailings impoundments and natural lakes ranging to the south of Embarass. The proposed Polymet site is just south of Northshore Mine.

The various pit lakes which make up the PMP will be combined by removing the ore along the divide (Barr Engineering 2010) (Figure 2). Final topography at closure near 2070 will establish a final pit lake elevation of 1500 feet amsl and littoral zones with depth up to 30 feet and shallow marsh wetland with depth up to 6 feet (Barr Engineering 2010). This final sculpting of pit lake depths would be achieved by in-pit waste disposal. The outflow elevation is based on the proposed rim elevation. Flow would be north into the Dunka River which flows into the Rainy Headwaters. Any contaminants which reach the PMP would therefore discharge north into the Rainy Headwaters and the BWCAW.

Jimenez et al (2015a) provide a table suggesting that the west, east, and area 002 of the PMP will be at 1350, 1300, and 1250 feet amsl (411.6, 396.3, and 381.1 m) in 2070 and all will be at 1500 feet amsl (457.3 m) in 2080+, suggesting it should take more than 10 years to fill up to 250 feet (76.2 m). Current PMP water surface levels are 1624, 1568 and 1380 feet amsl, respectively (495.1, 478.0, and 420.7 m).

The PMP after closure as shown in Figure 2 would have about 12 miles of shoreline. Barr Engineering (2010) shows cross-sections which suggest an average depth of about 150 feet (45.7 m). The lake will be long and narrow and not have a broad flat bottom due to the creation of littoral zones. Any model boundary designed to simulate the PMP beyond 2080 should include a water surface elevation of 457.3 m and depth of 45.7 m.

The effect of the PMP on the steady state calibration was tested in three ways, with the modified steady state calibration run described above becoming the base case. Figure 5 shows that without the PMP (the original calibration (Myers 2014) with changes described above) the groundwater contours slope to the south from the area of the PMP (the boundaries representing the PMP in Figure 6 show the location of the PMP). The contours converge at the Partridge River, as shown with the line just south of the 490 contour label. The groundwater table near the PMP is very flat at about 498 which indicates that without PMP calibration there is a small amount of artesian pressure in the area of the PMP.

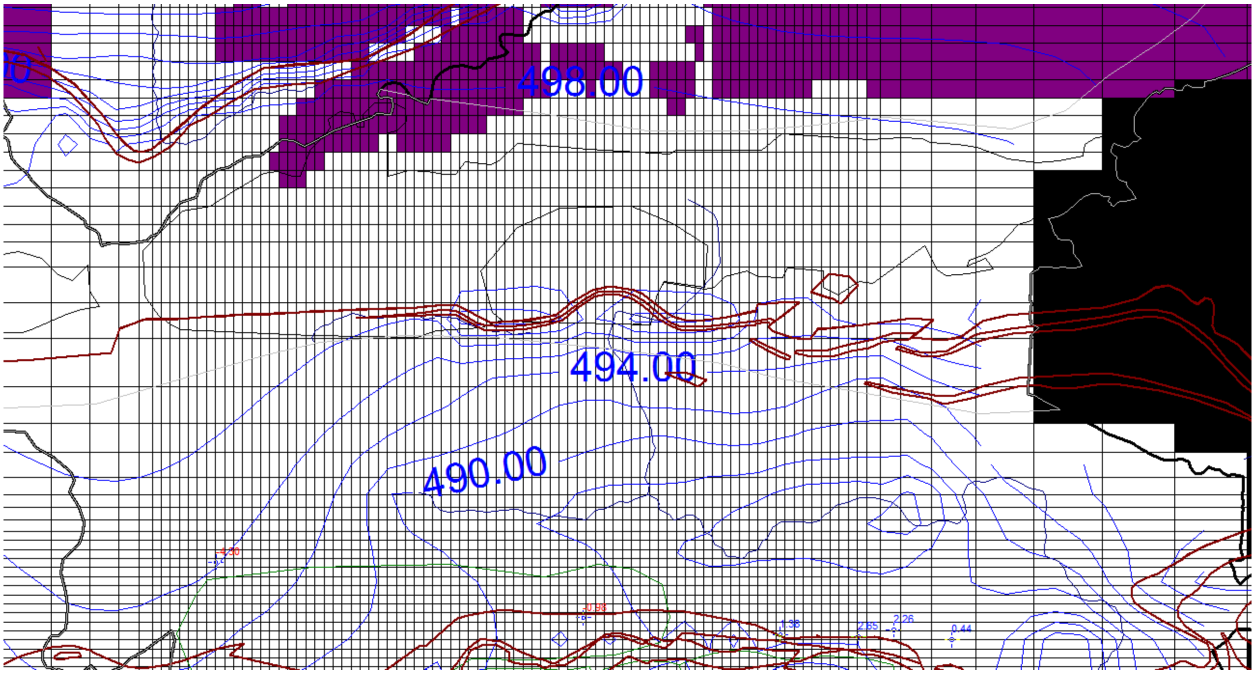

Figure 20: Steady state contours and residuals in layer 2 for the area near and south of the Peter Mitchell Pit for the minor recalibration.

The first scenario treated the far west pit as a constant head (CH) boundary with head set at 494 m amsl and the eastern lake as a drain with head set at 477 m amsl to simulate dewatering that one down to the level observed when the DEMs were observed (blue and yellow, respectively, in Figure 6). The model was run in steady state to assess how it changes the calibration and because steady state takes the effects to their limit. The groundwater contours mostly changed north of the geologic formations splitting the figures between north and south (Figure 6). The pit causes a general low gradient slope from the west to the PMP area to form. Between the pits, the groundwater flows directly from the CH to the drain, indicating that much of the dewatering in the East Pit is of water draining from the West Pit. If the West Pit level remains constant, inflow from precipitation and groundwater must offset the flow to the East Pit. The ridge in the groundwater table above elevation 494 (Figure 6) has lowered 4 to 6 m due to the pit boundaries, but further south the general slope, albeit slightly lower, is to the Partridge River. For this scenario, approximately 3331 m^3/day entered the model domain, while 205 m^3/day exited the domain into the pit lake through the CH (Table 3). The drain representing the drawn down pit lake had 3918 m^3/day discharge to it (Table 3). Dewatering the active mine mostly draws water from the pit lake with an additional 20% drawn from surrounding groundwater. Discharge to the Partridge River decreased about 5% due to the decreased gradient in the water table slope to the river (Table 3). The test statistics were not as good as those for the revised calibration, but are still well within usual standards (Table 2). The change in sum of squared residuals from 325 to 375 is relatively minor.

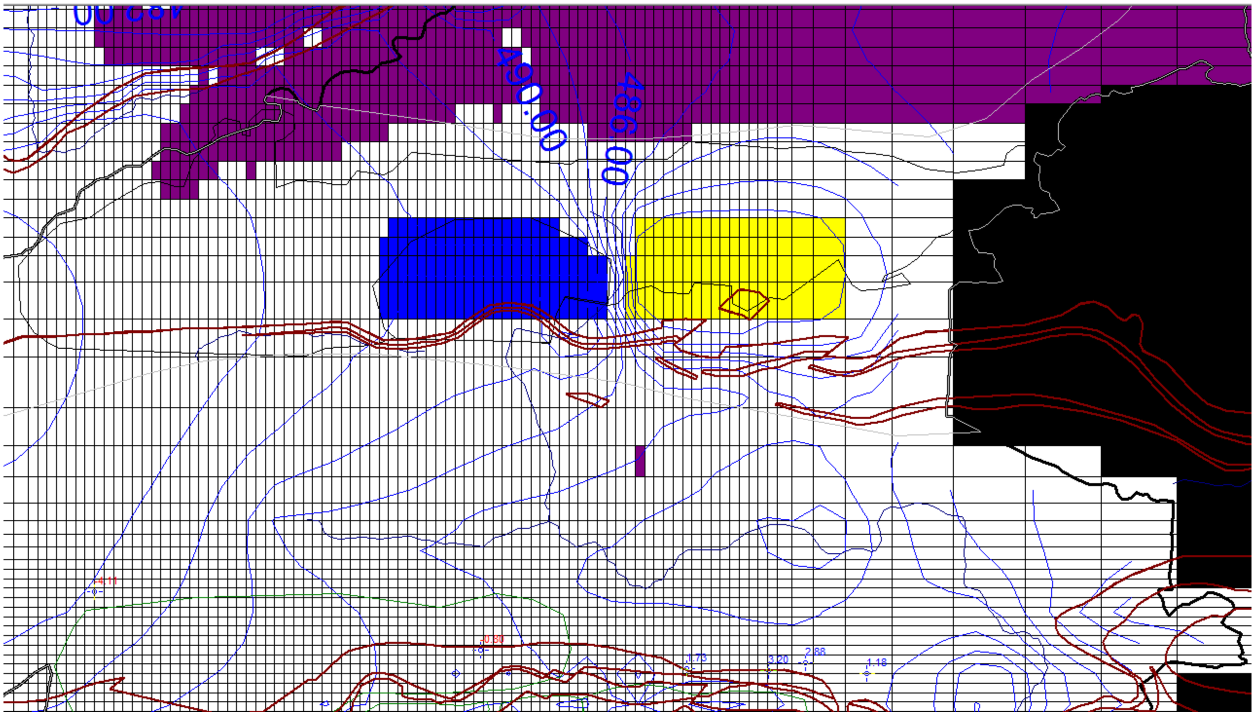

Figure 21: Steady state contours and residuals in layer 2 for the area around the Peter Mitchell Pit for the PMP1 scenario, with the west pit simulated as a constant head and the east pit as a drain boundary. See the text for the details.

The second scenario treated both pits as a CH with head level at 494, similar to the scenario used by Barr for their calibration runs. There is little apparent change in contours as compared to the without pit scenario except the groundwater ridge just south of PMP is gone (Figure 7). The pits actually remove more groundwater than discharge into it (Table 3) because the contours mostly slope to the pits. The changes in the water table cause a small reduction in discharge to the Partridge River (Table 3). The calibration statistics barely changed at all, meaning the pit lake simulated as a constant head boundary had no effect on the calibration (Table 2). Of course, there were no observation wells near the PMP, so there were no wells that could have been affected significantly by the changes.

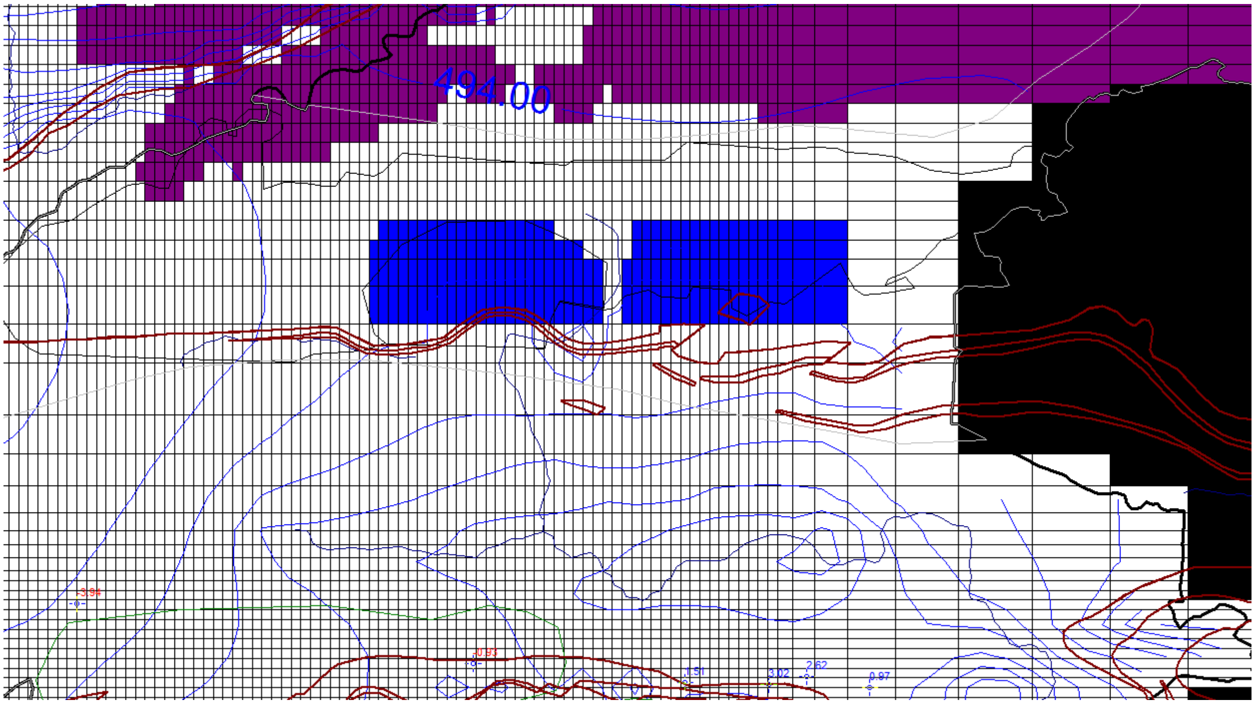

Figure 22: Steady state contours and residuals for the area around the Peter Mitchell Pit in layer 2 for the PMP2 scenario with both pits simulated as a constant head boundary. See the text for the details.

Table 4: Select water budget components for the revised steady state calibration (without PMP) and for the PMP1 and PMP2 scenarios. All flows in m^3/day.

Component	Without PMP	PMP1		PMP2		PMP457	
		In	Out	In	Out	In	Out
Model Inflow	97,495	100,612		97,215		97,062	
CH		3331	205	153	554		5981
PMP CH layer 1		334	79	50	235		
PMP CH layer 2		328	19	7	54		636
PMP CH layer 3		2668	107	96	264		5345
PMP Drain			5151				
PMP Drain layer 1			441				
PMP Drain layer 2			792				
PMP Drain layer 3			3918				
Partridge River, R5	21,420		20,188		20,972		18,312
Without PMP: revised steady state calibration PMP1: Peter Mitchell Pit simulated as a constant head and drain boundary PMP2: Peter Mitchell Pit simulated as a constant head boundary PMP457: Peter Mitchell Pit simulated as a constant head boundary with head set to equal 457 m.							

The third scenario treated both pits as a CH with head level at 457 m to simulate the proposed 1500 ft elevation for year 2080. I used CH boundaries to emulate Barr's conceptualization. This steady state run cause a huge change in groundwater contours. Much of layer 1 north of the Partridge River became dry as the water table was drawn into layer 2. The water table slopes to the Partridge River from

Polymet as for the other scenarios but the water table slopes downward to the north away from the river to the point the layer becomes dry (Figure 8). In model layer 2, the water table slopes from Polymet to the PMP, with the slope being much steeper near but south of PMP (Figure 9) due to the low K formations separating the areas. The total flow through the model does not change much because the PMP CH does not contribute flux to the model. Rather, more than 5000 m^3/d discharges to the boundary (Table 3). This rate would discharge from the PMP to the Dunka River and north into the Rainy Headwaters watershed. Discharge to the Partridge River decreases about 12% because of the change in water level near the river's drain boundary decreased the gradient to the drain. Both discharges, to the PMP and to the Partridge River, would require an infinite time period to actually become established because the model runs were in steady state. Therefore, transient simulations of the changes in the PMP with time would have discharges to these boundaries approach these flow rates but never quite reach them. These flow rates could be compared to the predicted transient discharges to estimate how far from the maximum discharges the simulation has reached.

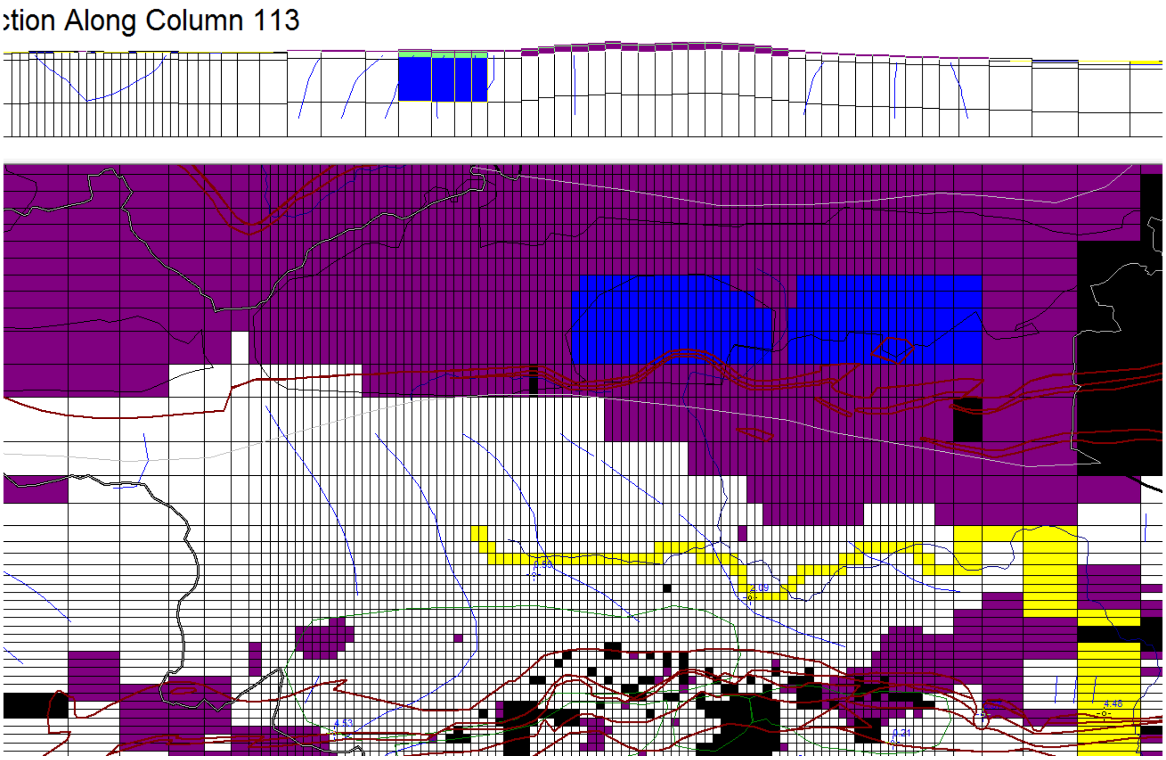

Figure 23: Steady state solution for layer 1 for scenario PMP457, for which the CH boundary head is 457 m.

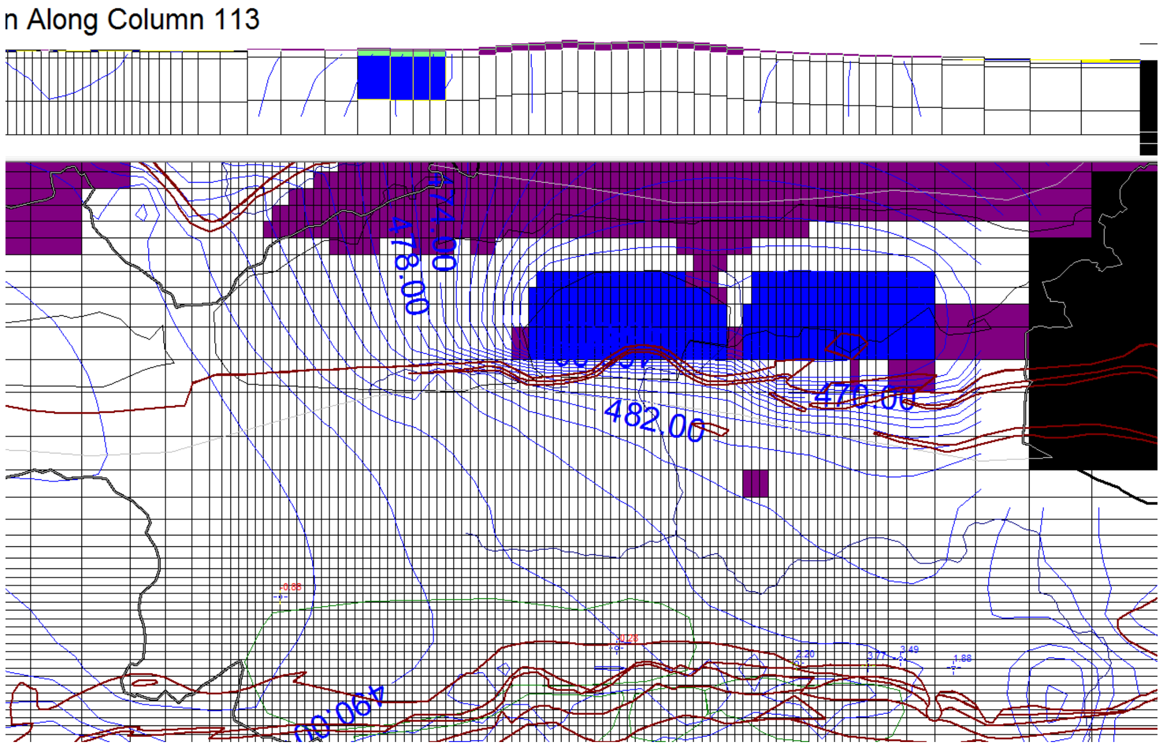

Figure 24: Steady state solution for layer 2 for scenario PMP457, for which the CH boundary head is 457 m.

Simulating PMP in Transient Mode

I added the PMP to the existing simulations (Myers 2014c) for the Polymet Mine for the "with pumping" scenario which involved pumping water into the West Pit (at Polymet) to fill it quicker, Polymet's proposed action. Myers (2014c) used six periods to simulate Polymet mine management strategies. During the first 20 years, three periods simulated the different periods of pit development and backfill (periods 3, 4, and 5 were 11, 3, and 6 years, respectively). For closure, there were also three periods for 6, 4, and 101 years. The first two shorter periods were based on the time to fill the West Pit through various model layers with pumping.

These time frames form the basis for the simulation herein with the PMP added to the Polymet simulation from now until the years 2080 and beyond, as described above. The 101-year period was replaced with a 26-year period until 2070 when mining the PMP is due to cease and then followed by a 200-year period to track a longer term evolution of head distribution and plume dispersion with details in Myers (2014c). I imposed the PMP management and closure onto the existing model files as described herein.

I simulated the PMP pit lakes (West and East) using the high K, high storage coefficient method (Anderson et al 2002) as at the West Pit at Polymet. Backfill K was set at 100 m/d, many orders of magnitude higher than the surrounding bedrock, which allows the water level to essentially be flat as in a lake. The storage coefficient was set equal to 1.0 in the layers which contained the lake surface and to 0.0001 in lower layers being simulated as confined. The use of a low specific storage allows groundwater entering at depth to displace lake water upward which occurs with this conceptualization in that pressure increases in lower layers are offset by head increases in the upper layer. The head increase in an unconfined aquifer is the water table and in this method of simulating lakes the water table is the lake surface. Pit lakes do not have vertical side walls and may not extend completely through a layer, so I adjusted the specific yield and porosity accordingly. For layer 3 under the West PMP, the lake would be 45.7 m deep whereas the layer is 200 m thick, therefore the Sy and n is 0.24 (allowing for additional minor adjustment for the sloping pit wall). Layer 3 in the West Pit had been set at 0.7 (Myers 2014c). As pit lakes are drained, the layers above the DRAIN were also simulated with the high porosity method so that the DRAIN would have to remove all of the water in the pit lake above it.

Initial water levels at the East and West PMP are the current observed level, with the West PMP being a pit lake and the East PMP being empty and mined. I use the high K/storativity method on the West PMP with recharge equaling the net precipitation, or 12 in/y (0.000484 m/d) because it is precipitation or pit wall runoff onto an open lake, until the pit lake is drained for mining as I assume it would be due to lowering to 1350 by year 2070 (Jimenez et al. 2015a). I simulated the West PMP therefore as a lake for 20 years, allowing the water level to adjust if conditions warrant; this means that the water level adjusts according to dewatering with the DRAIN in the East PMP and as replenished with recharge. After 20 years, I simulate it with a DRAIN to lower it to 1350 feet at year 2070. The rate of water level decline is linear by year. I simulated the East PMP with a DRAIN with steadily decreasing head from as observed at present (1568 ft, 478 m) to the 2070 level (1300 ft, 396.3 m); the head declined steadily through periods 3 through 8 (year 2070). In contrast to Barr's method and the tests I performed in steady state, I used DRAIN cells for mine dewatering because a DRAIN has a conductance parameter which controls the rate of water discharge; a CH boundary can provide water to the model domain but more importantly during dewatering it can remove as much water as necessary to lower the groundwater to the specified level immediately.

Beginning in period 6 when the West Pit is simulated with a DRAIN, the backfill is still simulated as a large pore space because it will be drained by dewatering down to the specified level. Dewatering in the East Pit continues without simulating a lake because the dewatering is not of a lake. After 2070, the end of period 8, for the recovery, the pits combine with a steady state DRAIN elevation of 457 m (1500 ft) to allow the pit lake to recover naturally to that level. Recharge for the entire area equaled the net precipitation/runoff reaching the pit lake surface as simulated before, or 12 in/y (0.000484 m/d).

Previously (Myers 2014c), the initial head for each time period was set equal to the head for the previous time period except where an underlying layer had risen into a higher layer but the higher layer was unsaturated. Because the resaturation routine works very poorly, the initial head in overlying layers was set equal to the head in the lower layer if that head were above the bottom elevation of the higher layer. For this simulation, the initial head was set a minimum of 0.1 m above the layer bottom, a setting which would apply only if the cell would be dry otherwise. If the underlying cell was above the bottom of the overlying cell, the head value would adjust quickly to the value of the underlying cell. Otherwise it would go dry in the first step if the underlying cell head was below the bottom of the layer.

During Polymet mine operations the West PMP is assumed to be a lake so recharge is 12 in/y, the difference between precipitation and evaporation. After Polymet closure until PMP closure in 2070, the West PMP has been assumed to be dewatered so the regular seasonal recharge was applied (meteoric waters infiltrating through the pit bottom). As the pit lake, now combined with the East PMP, refilled with water, the net meteoric precipitation was applied to the forming pit lake.

Results of Simulating PMP

The simulation starts with the East PMP being dewatered and the West PMP full of water. The head in the East PMP is 17 m below that of the West and becomes even greater, 47 m, over the 20-year Polymet period. This dewatering causes a high gradient from west to east, as may be seen in the groundwater contours (Figure 10). The approximate dewatering rate from the East Pit exceeds 12,000 m^3/d with flow coming from all directions. Flow from west to east into the East Pit was about 7700 m^3/d. Little water flowed into the West pit and with a recharge of just 514 m^3/d, the water lost from storage was over 9000 m^3/d. Water levels in the West Pit after 20 years were about 493 m while the East Pit had been dewatered to the 455 m level.

The groundwater divide between the PMP and Polymet is south and west of the West PMP and then trends more southeastward south of the East PMP so that it is almost directly below the Partridge River (Figure 10). Most advective flow, transporting contaminants, would be toward Polymet rather than toward PMP at this point.

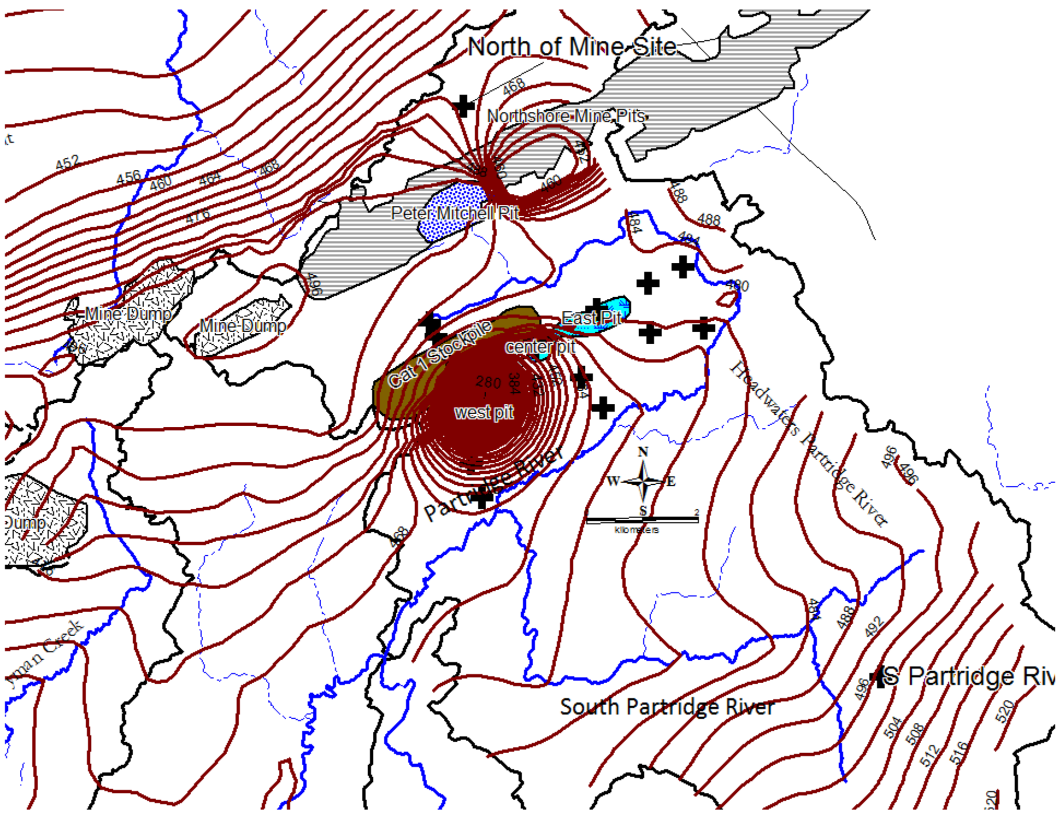

Figure 25: Polymet Mine simulation with pumping the West Pit and with the PMP, layer 3, year 20, end of mining at Polymet

Going forward from year 20, the end of mining at Polymet, both PMP pits have declining water levels to simulate mine dewatering to levels specified for the year 2070. This significantly changes the groundwater head from the end of Polymet Mining (Figure 11) to year 2070, the end of PMP mining

(Figure 11). Initially, the East Pit is significantly lower than the West PMP and all of the dewatering occurs from that pit; groundwater levels are beneath the specified DRAIN level in the West Pit and the DRAINs in the East Pit draw water from the West Pit. The contour map shows that the groundwater divide separating PMP from Polymet shifts south so that most of the Cat 1 waste rock dump is north of the divide. Most of the east end of the West Pit, and much of the Central and East Pit are also in the capture zone of the PMP as the detailed map (Figure 12) shows. At some point before 2070, contaminants seeping from that dump and all three pits will begin to flow north to the PMP.

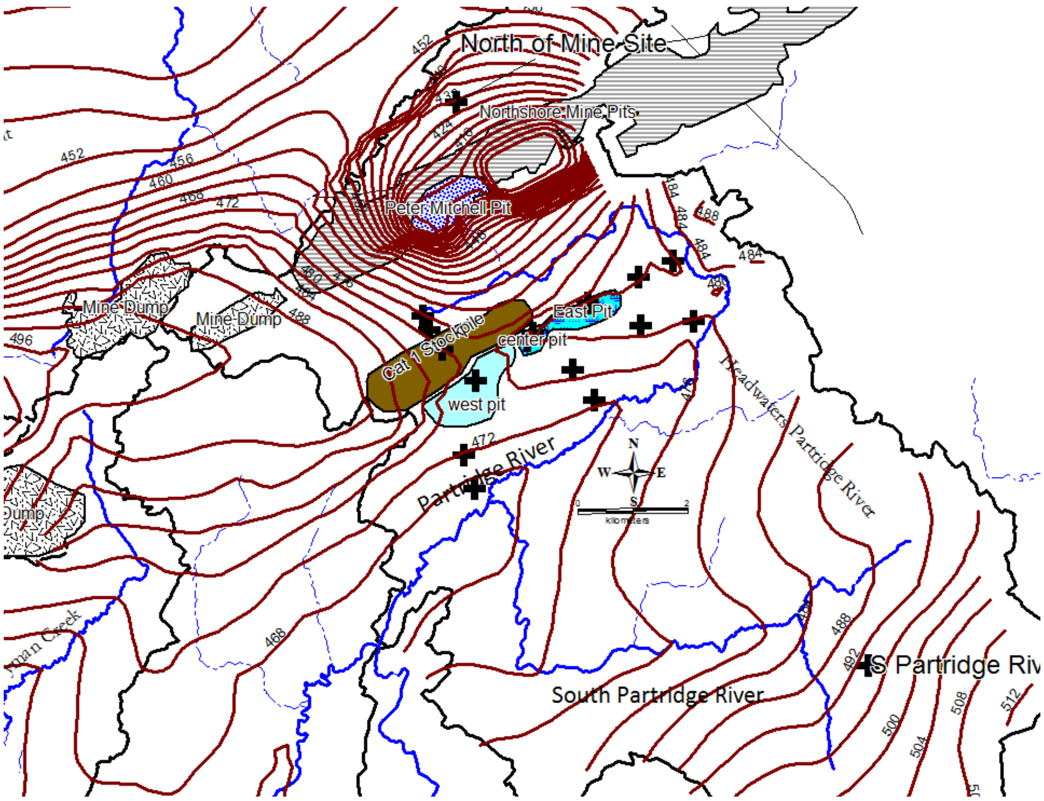

Figure 26: Polymet Mine simulation with pumping the West Pit and with the PMP, layer 3, year 2070, during Polymet closure at end of mining at PMP.

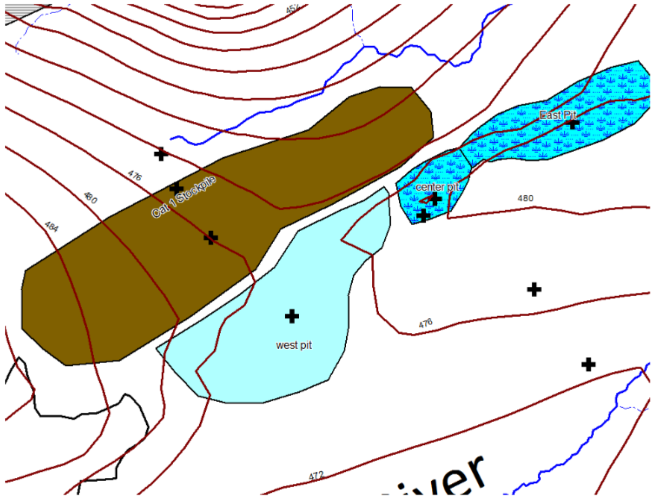

Figure 27: Close-up near the Polymet Pits and Cat 1 waste rock dump. Polymet Mine simulation with pumping the West Pit and with the PMP, layer 3, year 2070, during Polymet closure at end of mining at PMP.

Current plans are that the PMP will close by 2070 and refill after 2080. I did not simulate details of the pit lake development but set a DRAIN cell at the elevation expected to be the outlet from the lake, or 1500 feet (457 m). After a 100-year simulation period with the DRAIN at that specified elevation, the gradient toward the PMP decreased because the water level in the PMP increased. The higher PMP water levels (than in 2070 when the pit was fully dewatered (Figure 13)) allowed the groundwater divide to move slightly north and encompass less of the Cat 1 waste dump. The groundwater divide goes through the north edge of the East Pit however so some contaminants remaining there will still be flowing north 100 years after the PMP lake forms. The pit lake in the West Pit remains south of the divide, so any contaminants escaping from it drain south to the Partridge River.

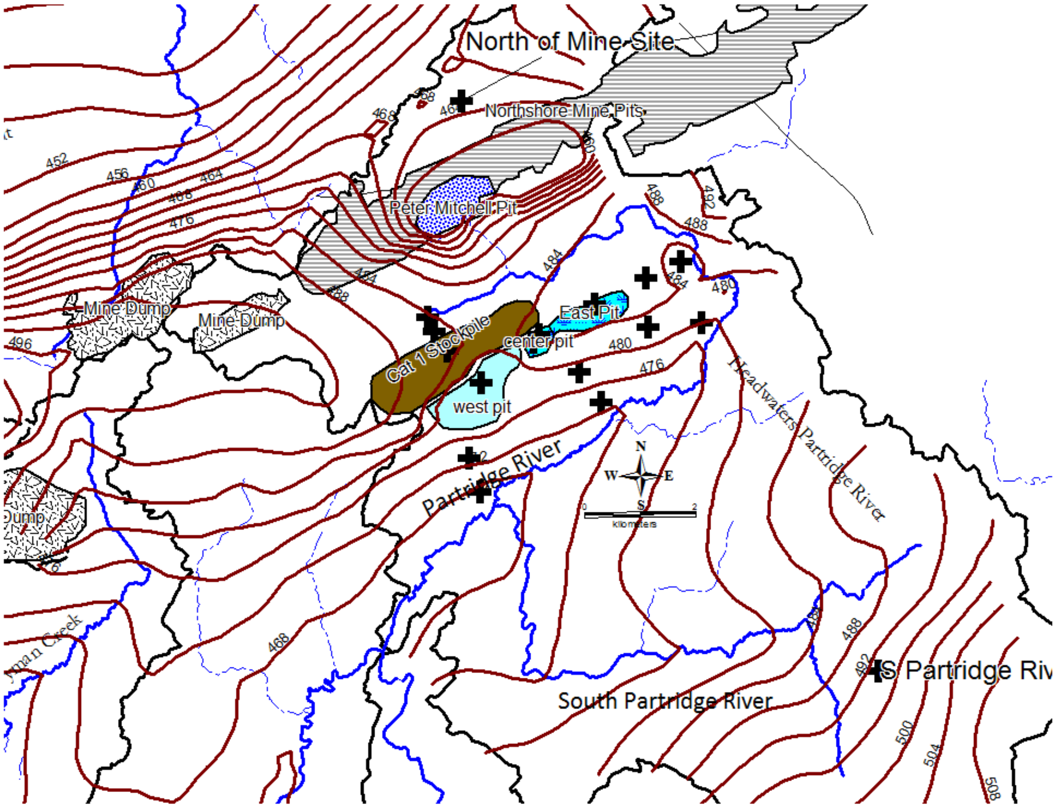

Figure 28: Polymet Mine simulation with pumping the West Pit and with the PMP, layer 3, year 2170, 100 years after PMP began recovery.

Steady state conditions represent those essentially in perpetuity. Groundwater contours at steady state near the PMP are very steep and flatter south toward Polymet (Figure 14). The groundwater level rises about 8 m from PMP to the Cat 1 Waste Dump. The groundwater divide at steady state is under the Cat 1 waste dump and goes through the Central and East Pit which are backfilled so that the groundwater divide can develop. About a third of the pits are north of the divide, so contaminants would move northward from the pits toward the PMP in perpetuity.

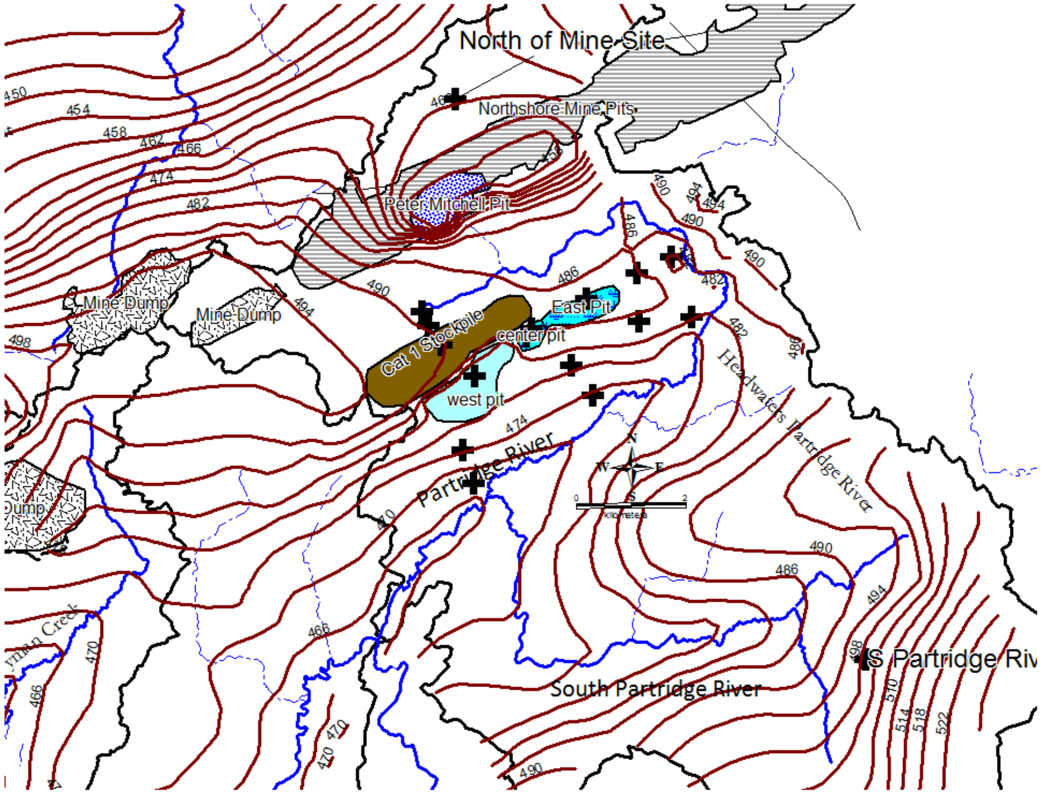

Figure 29: Polymet Mine simulation with the PMP at 1500 ft (457 m), steady state, layer 3.

Particle Tracking

Groundwater contours show there will be a gradient to the north from part of the Polymet Minesite (Figures 10 through 14), therefore I completed particle tracking to estimate pathways that contaminants would follow from the minesite to the PMP. For this analysis, I used the PMP457 scenario, with the PMP lakes simulated as a DRAIN boundary with constant head at 457 (contours as shown in Figure 14). The PMP with head significantly below the Partridge River would likely change flow paths for contaminants discharging from the Polymet project so that some would flow northward and if deep enough pass the Partridge River to reach the PMP. To test this, paths were determined using the PMP457 steady state model and the MODPATH model, as used by Myers (2014c). Particles were injected at the water table in layer 1 for the waste rock pile north of the West Pit and at the middle of layers 2 and 3 for the three pits. MODPATH simply determines a flowpath from source, the particle placement, to a sink during steady state. Travel time cannot be estimated. Porosity was set to 0.15, 0.02, 0.001, and 0.0005 for layers 1 through 4 to reflect till, fractured bedrock in the upper portion of the bedrock layers, and relatively unfractured rock with depth, respectively.

In layer 1 pathways from the waste rock dump either reach the far upstream end of the Partridge River or go downward into layer 2 (Figure 15). Some layer 1 paths parallel the upper river for several model cells (Figure 15). Further downstream south of the pit, pathways head due south until they drop into layer 2. Further along, the pathways near the Partridge River are those that curved upward from layer 2 to discharge into the river.

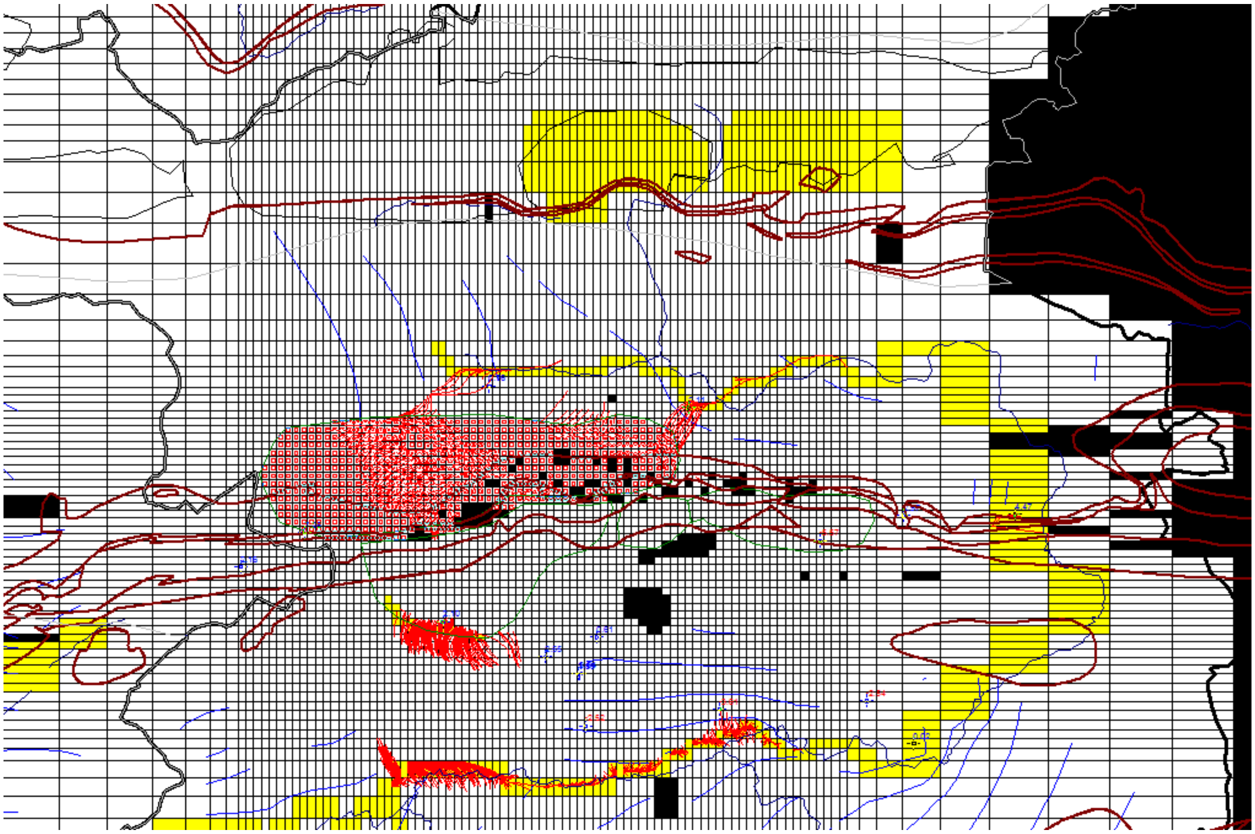

Figure 30: Particle tracking PMP simulated as drains, steady state, layer 1.

Pathways in layer 2 were mostly vertical so there was nothing to present in a map of layer 2 except for a plot of dots coinciding with the end of the layer 1 paths (Figure 15). In layer 3, the pathways north of Polymet are from southwest to northeast beginning under the Cat 1 waste rock dump (Figure 16). Other pathways commence at the south side of the West Pit and extend almost directly south of the West Pit (Figure 16). Further east, south of the Central and East Pit, there are pathways showing north to south pathways showing some transport in that layer south to the Partridge River.

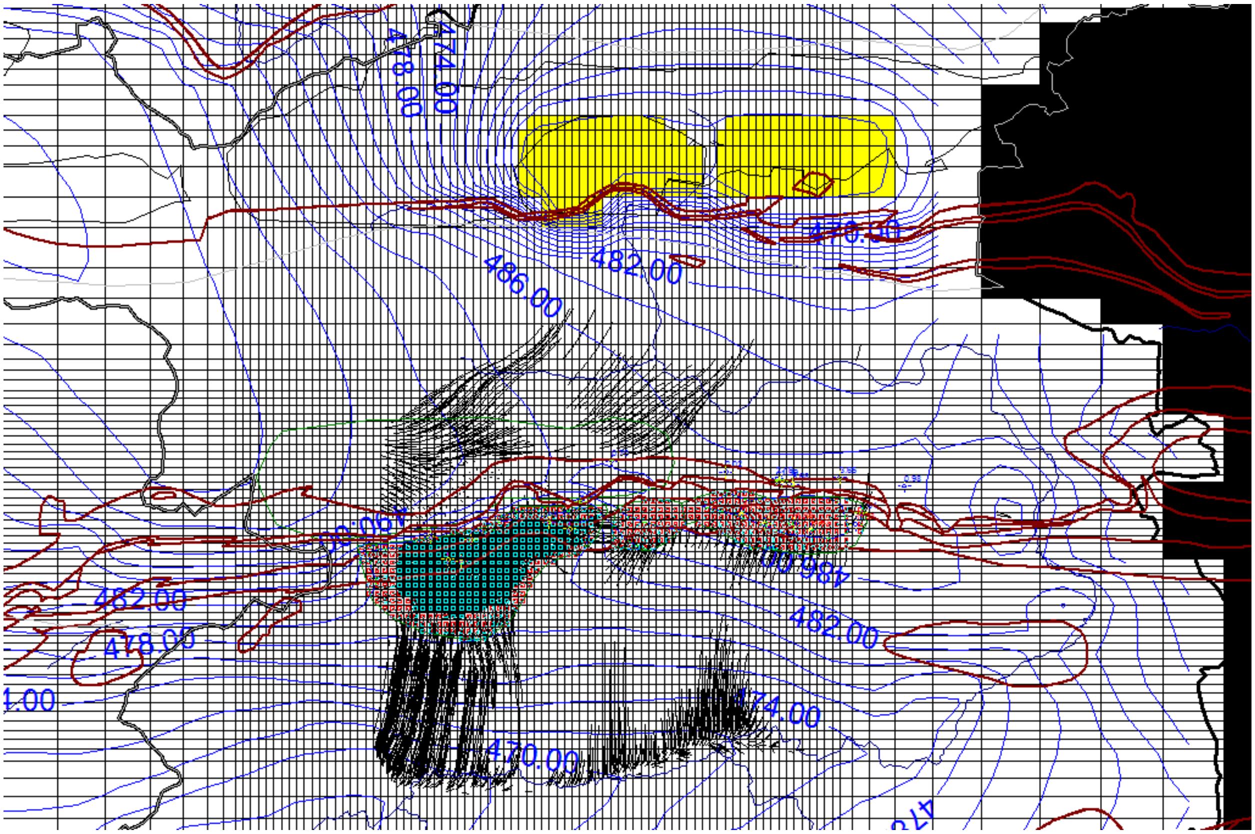

Figure 31: Particle tracking PMP simulated as drains, steady state, layer 3.

Some pathways emanating from the Central and East Pits in layer 3 do not appear on the map (Figure 16) because they plunge downward into layer 4 (Figure 17). In layer 4, pathways extend from just north of the minesite to the PMP and south to the Partridge River (Figure 17). The cross-section along column 137, north south through the East Pit, show clearly that pathways go downward from the surface through layers 2 and 3 and extend further through layer 4 to the discharge point (Figure 18). The northward pathways discharge upward into the bottom of the PMP (Figure 18), reflecting the upward gradient as demonstrated on Figure 12 and 13. The groundwater divide (Figure 14) divides the particle transport between north and southward directions.

The density of the pathways shows that a larger proportion of the particle transport is southward in layers 3 and 4 (Figures 16 and 17), which reflects that more of the source cells are south of the groundwater divide.

Flux Rates

The particle tracking shows there are pathways to the north in the long-term from both the Central/East Pits and from the Cat 1 waste rock dump. Using the digitizing feature of GWVistas, I determined the mass balance for model domain beneath the Cat 1 waste rock dump and for the Central/East Pits.

The total flow north from the Cat 1 waste rock dump was 154 m3/d (28 gpm) with 7, 3, 15, and 3 gpm in layers 1 through 4, respectively. The total flow to the south was 94 gpm. From the Central/East Pits, the total flow to the north was 12 gpm with 3, 1, 5, and 4 gpm through layers 1 through 4, respectively.

Total flow to the south was 39 gpm. For each feature, three quarters of the flow to the north was through bedrock layers, or 21 and 9 gpm from the Cat 1 waste rock dump and Central/East Pits, respectively. These rates exceed substantially those estimated for input to Goldsim for pathways to the south from the East Pit (Polymet 2015m). Estimated outflows to groundwater for the East Pit surficial and bedrock paths are 2.1 to 6.2 and 0.09 to 0.3 gpm for the P10 to P90 flows, respectively (Polymet 2015m, Table 6-6). Estimated outflow from the West Pit to the surficial flow path, bedrock flow path to SW004, and bedrock flow path to SW004a are 3.1 to 10.7, 0.03 to 0.1, and 0.05 to 0.16 gpm for the P10 to P90 flows, respectively (Polymet 2015m, Table 6-8).

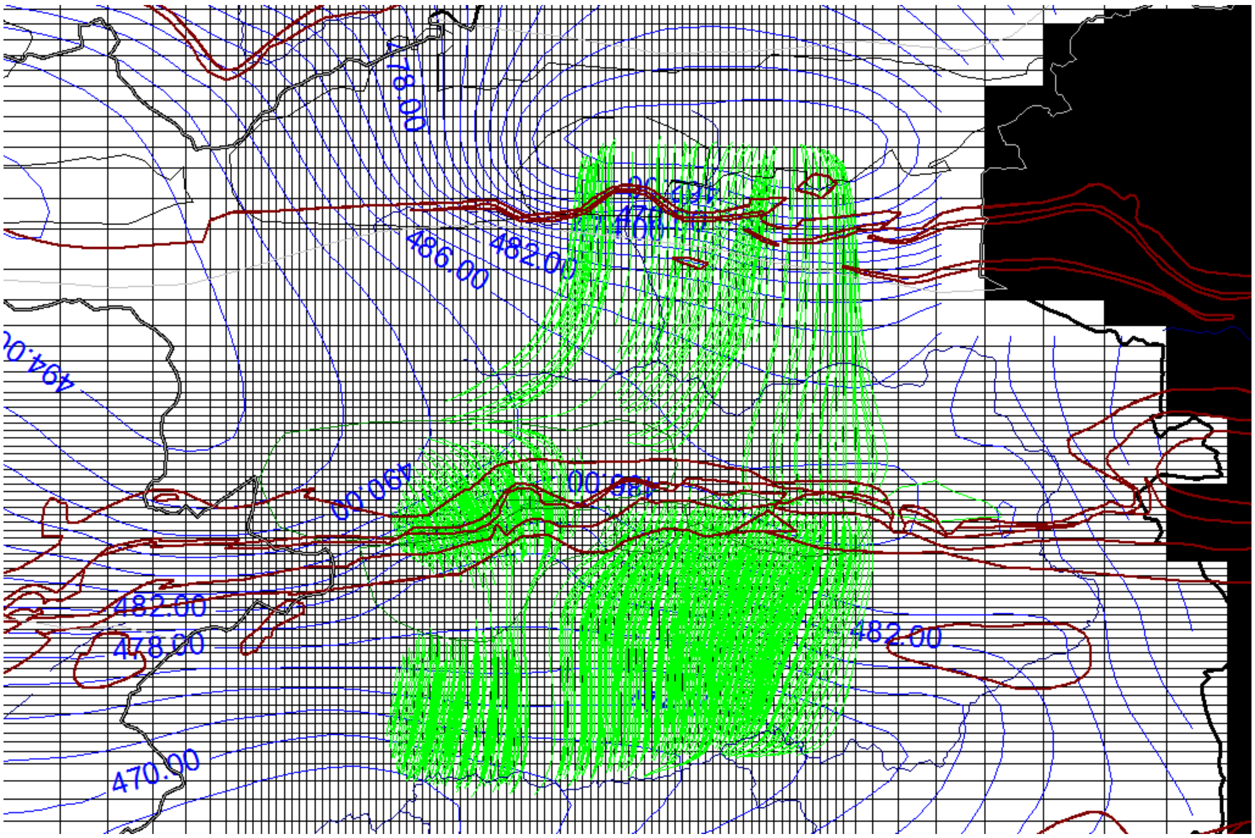

Figure 32: Particle tracking PMP simulated as drains, steady state, layer 4.

Conclusion

Consideration of the Peter Mitchell Pit clearly affects the groundwater flow paths in the area of the proposed Polymet Mine. Drawdown and long-term pit lake development at the PMP would cause the groundwater divide to be south of some of the Polymet mine features and would divert more flow northward than Polymet simulated in the Goldsim model as entering pathways draining to the south. Simulated flow rates northward exceed those used in Goldsim by up to three orders of magnitude. The higher flow rates to the north are primarily due to the gradient caused by dewatering at the PMP, although the low bedrock conductivity between Polymet and the PMP limits the flow. Because these flow rates exceed those considered with Goldsim for the Polymet FEIS, the model simulations must be recompleted to consider the PMP.

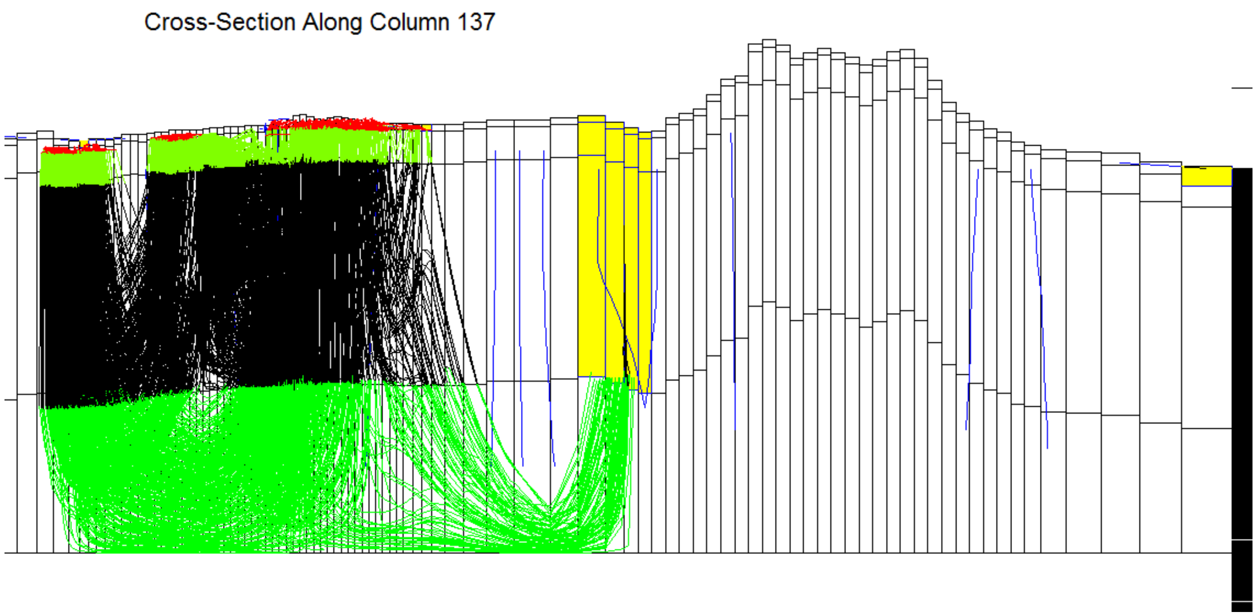

Figure 33: Cross-section showing particle tracking at steady state for PMP modeled as DRAINs with a sources in the East Pit. Paths extend north to the PMP and south to the Partridge River. Much of the pathway is in layer 4.

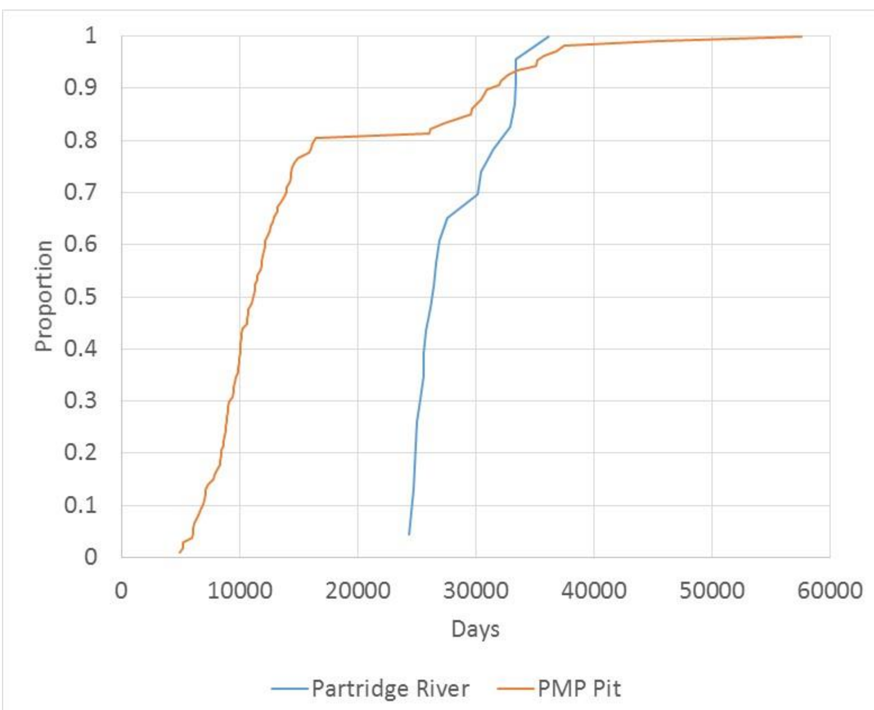

Figure 34: Proportion of particles flowing north from Polymet reaching the upper end of the Partridge River and the PMP Pit by a specified time.

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