United States Environmental Protection Agency

Analysis and Report on Sections 2 and 3 of the Comments of the Keweenaw Bay Indian Community (KBIC)—Final

Prepared for the United States Environmental Protection Agency – Region 5

By The Cadmus Group, Inc. under contract # EP-C-08-015

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Table of Contents

1 Introduction

The Keweenaw Bay Indian Community (KBIC) submitted a document entitled "Comments of the Keweenaw Bay Indian Community in Opposition to the Issuance of an Underground Injection Control Permit to Kennecott Eagle Minerals Company" (KBIC, 2009; hereafter referred to as the KBIC Comments) to the U.S. Environmental Protection Agency (EPA) in January, 2009. This report was prepared by KBIC's consultants, Stratus Consulting Inc. and Integrated Hydro Systems. In light of the concerns raised by the KBIC Comments, EPA has requested that the Cadmus Group, Inc. (Cadmus) evaluate Chapters 2 and 3 of the KBIC Comments and the *Kennecott Closing Argument and Proposed Findings of Fact and Conclusions of Law* dated October 15, 2008 associated with Kennecott Eagle Mineral Company's (KEMC's) application for a Treated Water Infiltration System (TWIS) permit. In performing this review, Cadmus has used additional data submitted to EPA by KEMC on the wastewater treatment plant inflows and processes as well as bedrock hydrogeology and associated modeling (Foth and Van Dyke, 2006a; Foth Infrastructure and Environment, 2007; Golder Associates, 2005a & b; Golder Associates, 2006a; Golder Associates, 2006b).

2 Kennecott Eagle Mineral Company Wastewater Management

KEMC will collect wastewater generated during operation and closure of the Eagle Project mine and ancillary facilities in contact water basins (CWB). The wastewater will be treated at the wastewater treatment plant (WWTP) and discharged to ground water by the treated water infiltration system. Sources of wastewater will be mine discharge water, temporary development rock storage area (TDRSA) drainage water, and storm water runoff from the main operations area.

3 Quantity and Quality of Inflow to the Mine and WWTP

According to KEMC's Class V Permit Application (Foth Infrastructure and Environment, 2007), KEMC estimated the flows and contaminant concentrations for the mine drainage water and TDRSA contact water with hydrogeologic tests such as flow logging and packer tests within the boreholes, static tests on the different types of rock in and around the mine, and kinetic tests - primarily on the development rock to be stored in the TDRSA. Flows for the truck wash and crusher contact waters were based on typical values in similar mining operations. The contaminant concentrations for the truck wash and crusher contact waters were estimated to be equivalent to those of the mine drainage water.

3.1 Estimating Quantity of Mine Inflow

KBIC's consultants have raised a number of concerns regarding the placement of bedrock boreholes and the aquifer hydraulic testing. One concern raised by KBIC's consultants is that there may be hydraulic communication between the bedrock aquifer and the Quaternary deposits, which would lead to greater quantities of wastewater entering the mine. They claim that in the continuous slug test conducted in upper bedrock well 04EA-107, there was a response in the Quaternary aquifer well QAL023.

A review of the results provided by Golder Associates (2005a) shows that during the first of two slug tests performed in bedrock borehole 05EA-107, there were no responses in Quaternary deposit wells QAL023, QAL043, or QAL044. In the second slug test using borehole 05EA-107, there was only a response in QAL023. Testing using borehole 04EA-084 revealed no responses in QAL023, QAL043, or QAL044.

In Golder Associates (2005a), bedrock aquifer testing using boreholes 04EA-47, 04EA-73, and 04EA-83 also showed no responses in Quaternary well QAL023. Testing in bedrock borehole 04EA-84 did produce a response in QAL023. This response was attributed to packer bypass, which is a reasonable interpretation.

Cadmus agrees that responses in the Quaternary deposits appear to be a localized and sporadic occurrence. The weight of evidence from the hydraulic testing suggests that hydraulic communication between the bedrock and the Quaternary deposits is not likely to be a major factor in ground water flow into the mine. Additional issues related to the quantity of mine inflow are discussed in Section 4, below.

3.2 Estimating Quantity of WWTP Inflow

KBIC's consultants claim that the influent volume for the WWTP will be one order of magnitude higher than predicted by KEMC, and that the WWTP is not designed to accommodate this likely increase in flow. If influent flows to the WWTP were to be as large as KBIC's consultants claim, it is likely that the WWTP could not accommodate such an increase, based on the proposed design capacity.[1,2] However, KEMC has contingencies in place to address periodic increases in flow from the mine prior to water entering the WWTP. According to Foth and Van Dyke (2006a), the contact water storage basins have an operating capacity of 7.8 million gallons (taking into account freeboard and sediment buildup). They were designed to handle the 50-year combined peak snow melt and rain event (that occurs over multiple days). It is noted that this operating capacity exceeds the 100-yr, 24-hr precipitation event (4.7 million gallons). The contact water storage basins are also capable of holding 15 days of mine discharge water (7.56 million gallons at 350 gpm) to allow for maintenance of the WWTP. In the unlikely case that a runoff event exceeds the capacity of the CWBs, excess water will be routed to the composite-lined TDRSA for emergency temporary storage. As an additional contingency, water can be pumped into vacant underground mine workings for additional temporary storage of water in the

[1] The issue of higher than predicted WWTP inflow quantity was discussed in Section 3.3 of KBIC, 2009.

[2] The issue regarding predicted influent flows is further discussed in Section 4, below.

event ample storage is not available at the TDRSA. KEMC considers this to be extremely unlikely – and Cadmus agrees - given the very conservative design of the CWBs.

3.3 Estimating Quality of WWTP Inflow

KBIC's consultants assert that the influent water quality will be worse than expected due to an underestimation of the concentration of contaminants in the mine drainage water, and that this could result in exceedances of standards in ground water and contamination of the underground sources of drinking water (USDW). KBIC's consultants state that "like other similar mined deposits around the world, water quality characteristics from leached Eagle ore, host and country rock show that high metal concentrations and low pH values are likely to result from mining of the Eagle deposits." In addition, KBIC's consultants state that the type of neutralizing material present in the rocks is not likely to counteract the acid produced over long periods of time.[3]

KEMC has conducted numerous static and kinetic tests to estimate the quality and quantity of the WWTP inflow. These tests were conducted on ore (mineralized rock that has a defined economic value) and development rock (rock removed to develop access to the ore body). According to the *Kennecott Proposed Findings and Conclusions of Law*, the static tests indicated that the sample rocks had varying degrees of acid generating potential, but also significant potential to self-neutralize acid generated. KEMC acknowledges that the high-sulfide content ore will be acid-generating. However, KEMC's Mine Permit Application (Foth and Van Dyke, 2006b) indicates that the ore will be quickly removed from the mine site and not stored long-term on the surface, minimizing the amount of acid mine drainage generated from the ore.

KBIC's consultants assert that the Eagle deposit ore contains more sulfide than KEMC estimated, and that KEMC did not use the high sulfur rock in the kinetic tests; thereby resulting in mine drainage water that was less acidic.[4] Kinetic tests are dynamic tests of repeated weathering cycles intended to assess the potential for acid generation and metal leaching under long-term field conditions (Blowes, et al., 2005). Acid mine drainage does not occur until the mine rock is exposed to air and water, allowing oxidation to occur. Because the ore will be exposed to air and water for a short time and it will not be stored on the surface long-term, it is appropriate to focus the kinetic tests on the rock in the TDRSA that will be exposed to air and precipitation for a long time. The rock in the TDRSA is development rock that will be used to backfill the mine at the end of the project. The static tests showed that the development rock has low sulfur content.

In addition, KBIC's consultants conducted their own model predictions of mine water quality using the same approach as KEMC but with different assumptions and conditions. KBIC's

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[3] The issue of the influent water quality being worse that KEMC predicted was noted in Section 2.3.1 and Section 3.4 of KBIC, 2009.

[4] The issue of the ore containing more sulfide was noted in Section 2.3.2 of KBIC, 2009.

consultants generated higher concentrations for many metals than KEMC. However, it appears that KBIC's consultants may not have taken secondary mineral solubility control into account during their modeling. Morin and Hutt (1997) reported that kinetic test release rates are higher than field release rates because the kinetic test releases reflect the dissolution rate of primary minerals alone, while mine site components release rates reflect chemical loadings resulting from the dissolution of primary minerals and the subsequent precipitation of secondary minerals. Secondary minerals, such as iron hydroxides and hydrous iron sulfates, will form as the primary sulfide minerals are dissolved by exposure to oxygen and water. These secondary minerals can incorporate heavy metals, reducing the net release of heavy metals into the ground water (Moncur, et al., 2009; Sidenko and Sherriff, 2005).

KBIC's consultant also claimed that the number of samples KEMC used for testing was much lower than recommended by Price and Errington (1994). They state that KEMC conducted acid-base accounting (ABA) tests on only 11 samples of ore and, in KBIC's opinion, they should have tested more than twice that number.[5] Price and Errington (1994) stated that the number of samples taken from a particular material depends on their variability and the questions being asked. If this project-specific information is not known, then Price and Errington suggested using the recommended *minimum* number of samples. Based on the amount of ore to be mined by KEMC (4 million tonnes), the minimum number of samples to be used for testing, as suggested by Price and Errington, would be at least 26. However, KEMC chose to conduct ABA tests on only 11 samples of ore because the ore will be removed quickly from the mine site and not stored long-term on the surface, minimizing the amount of acid mine drainage generated from the mine. For those reasons, KEMC chose to focus its testing on rock types representative of the development rock that is to be stored at the surface, and which would thus be more likely to generate ARD.

KBIC's consultants stated that KEMC did not use the most recent results from the kinetic tests in their water quality modeling.[6] According to the *Kennecott Proposed Findings and Conclusions of Law*, the kinetic tests showed that the sample rocks generated significant ARD from week 26 to week 80, and reached steady-state by 100 weeks. Price (1997) stated that kinetics tests should be run until the weekly reaction rates become relatively stable (steady state); this could require testing for periods of 40 weeks to more than a year. KEMC did not use the steady-state data generated at 100 weeks; they used the 70 week data (Foth Infrastructure and Environment, 2007). Although the kinetic test data from 100 weeks may have contained higher concentrations of metals than the test data at 70 weeks, it does not change the conclusion that mitigation is needed. KEMC will be amending the rock in the TDRSA with limestone, covering the TDRSA

[5] The issue of KEMC not conducting ABA tests on enough ore samples was noted in Section 2.3.2 of KBIC, 2009.

[6] The issue of KEMC not using the most recent kinetic test results for their modeling was noted in Section 2.3.2 of KBIC, 2009.

to prevent water from infiltrating through the rock pile, and constructing the TDRSA with double liners and redundant leachate collection systems. In addition, KEMC continues to monitor the ongoing kinetic tests to obtain a preview of the ARD potential of the rock masses in the mine and in the TDRSA.

KBIC's consultants claim that KEMC's prediction of contaminant concentrations in the TDRSA is underestimated because KEMC neglected small size fractions in the development rock that will leach higher concentrations of metals and that they did not account for a realistic amount of ore being present in the development rock.[7] The rock samples used for the kinetic tests were small in size to fit into the laboratory equipment. In the field, the rock material stored in the TDRSA will be much larger. KEMC scaled up the rock material size for the water quality model and assumed that the rock material stored in the TDRSA will average 10 cm in size. Cadmus believes this is a conservative assumption considering that much of the rock material will be 10 to 100 times larger than 10 cm.

KBIC's consultants believe that some of the disseminated ore with high sulfur content (up to 10%) will be left behind in the mine or end up in the TDRSA as a significant potential source of ARD.[8] KEMC's mining permit application (Foth and Van Dyke, 2006b) identifies disseminated ore as ore and plans to remove the disseminated ore from the mine site with the host rock ore. In addition, using pre-mining predictions and modern mining methods reduces the likelihood that a significant portion of the disseminated ore will be left behind in the mine or in the TDRSA.

KBIC's consultants claim that KEMC underestimated the concentrations of contaminants in the mine discharge water because their modeling did not take into account a thicker crown pillar (87.5 meter) and the ore that will be left in the crown pillar.[9] A thicker crown pillar is not likely to generate significantly more ARD than a thinner crown pillar because oxygen cannot penetrate the crown pillar in any significant quantity to create an ARD reaction. The sections of the crown pillar that can generate ARD are those exposed to ambient air and to fractures and faults that allow oxygen to diffuse into the rock formation. Oxygen is not likely to diffuse very far into the rock; therefore, the thickness of the crown pillar does not have an effect on the distance of oxygen diffusion. Two examples of oxygen diffusion provided in Morin and Hutt (1997) reference fractures oxidized 10 to 15 meters from the mine wall.

While fractures and faults in the crown pillar provide additional reactive surfaces and allow oxygen to diffuse into the rock, they are accounted for by estimating an available surface area. The available surface area includes the geometric surface area plus surface areas from natural

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[7] The issue of KEMC neglecting small size fractions of development rock in their prediction was noted in Section 2.3.3 of KBIC, 2009.

[8] The issue of disseminated ore being left behind in the mine was noted in Section 2.3.3 of KBIC, 2009.

[9] The issue of the thicker crown pillar was noted in Section 2.3.3 of KBIC, 2009.

fracturing and faulting and the effects of blasting that may contribute to ARD generation. According to KEMC's consultants, the water quality modeling of the mine discharge water conservatively assumed that the available surface area of the mine will be 100 times the apparent geometric surface area (Foth Infrastructure and Environment, 2007). KEMC's consultants state that this assumption comes from Morin and Hutt (1997), who have compiled data showing that the available surface area may vary from about 20 to about 125 times the apparent geometric surface area. Cadmus' review of Morin and Hutt found one reference to published minewall studies that indicate the average estimated ratio for reactive surfaces varied from 27:1 to 161:1. Note that this is only one of the many studies compiled by Morin and Hutt (1997), but the estimated ratios are similar to the ratio used by KEMC consultants. Cadmus believes KEMC's assumption is a reasonable estimation of the available surface area and it takes into account the distance of oxygen diffusion and the additional reactive surfaces within the crown pillar.

KBIC's consultants stated that KEMC overlooked the tonnage of development rock to be stored in the TDRSA in its water quality modeling.[10] KEMC agreed with KBIC's consultants but indicated that using the correct value for tonnage of development rock to be stored in the TDRSA increased the metals concentrations by 50% and did not change any of the conclusions and recommendations. In the water balance of the mine site, the wastewater generated by the TDRSA accounts for 5 to 6% of the total inflow to the WWTP; therefore, an increase in the metals concentration of the TDRSA wastewater will not have a significant impact on the WWTP inflow.

4 Review of Kennecott's FEFLOW Bedrock Modeling

KEMC used the ground water flow modeling software FEFLOW to quantify the effects of mine dewatering and predict mine inflow volumes as part of the mining permit application, (Golder Associates, 2006b). The bedrock hydrological modeling includes a preliminary and revised numerical model of ground water flow. The intent of the model is to provide conservative estimates of the rate of ground water inflow to the mine. KBIC's consultants have presented a number of criticisms of this modeling, including claims of a lack of inclusion of the quaternary sediments, overly simplistic boundary conditions, failure to include saline water, and poor model calibration. KBIC's consultants have also made modifications to KEMC's FEFLOW model and tested six scenarios, one of which produced a mine inflow estimate two orders of magnitude greater than that predicted by KEMC. Below is a review of KEMC's FEFLOW model and the sections of KBIC's comments that are relevant to bedrock flow modeling efforts. As part of this review, Cadmus prepared a model using SWIFT, a 3-dimensional modeling program for ground water flow and transport. SWIFT is a good selection for simulating ground water flow in the

[10] The issue of there being more development rock in the TDRSA was noted in Section 2.3.2 of KBIC, 2009.

mine area because of its ability to simulate flow through fractured media and to incorporate variable density fluids.

Overall the FEFLOW modeling analysis by KEMC was found to be technically sound. However, the model lacks adequate quantifiable certainty in the rate of mine inflow predictions because of the incompleteness of the hydrogeologic characterization.[11] The model application has several elements of “model misuse” as defined by Mercer and Faust (1981). These elements include improper conceptualization, improper model parameter selection, disregard of geological evidence, insufficient regional geologic data, and undocumented mass balance. Furthermore the analysis lacks many of the required quality assurance elements for model application (EPA, 2002). The model is solely a predictive model and lacks the requirements of being a calibrated model (Hill and Tiedeman, 2007). In summary, the model is uncalibrated,[12] was constructed using selective geologic data, and no uncertainty analysis was performed.[13] Nevertheless, KEMC’s FEFLOW modeling provides some insight regarding the general mine inflow rates. Although it should not be relied on alone, it has value because it provides one possible scenario of how ground water may be flowing into the mine.

Bear, et al. (1992) described the generally-accepted procedure that the modeling process begins with formulation of the objective, followed by the conceptualization, iteration loops to incorporate more data and improve the conceptual model, leading to predictive runs and an uncertainty analysis, as show in Figure 1.

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[11] Note that this conclusion is consistent with KBIC’s consultants’ comments in Section 2.1 of KBIC, 2009.

[12] The issue of the lack of model calibration was noted in Section 2.2.1 of KBIC, 2009.

[13] The issues of selective geologic data being used, and of the lack of an uncertainty analysis, relate to issues raised in Section 2.2.2 of KBIC, 2009.

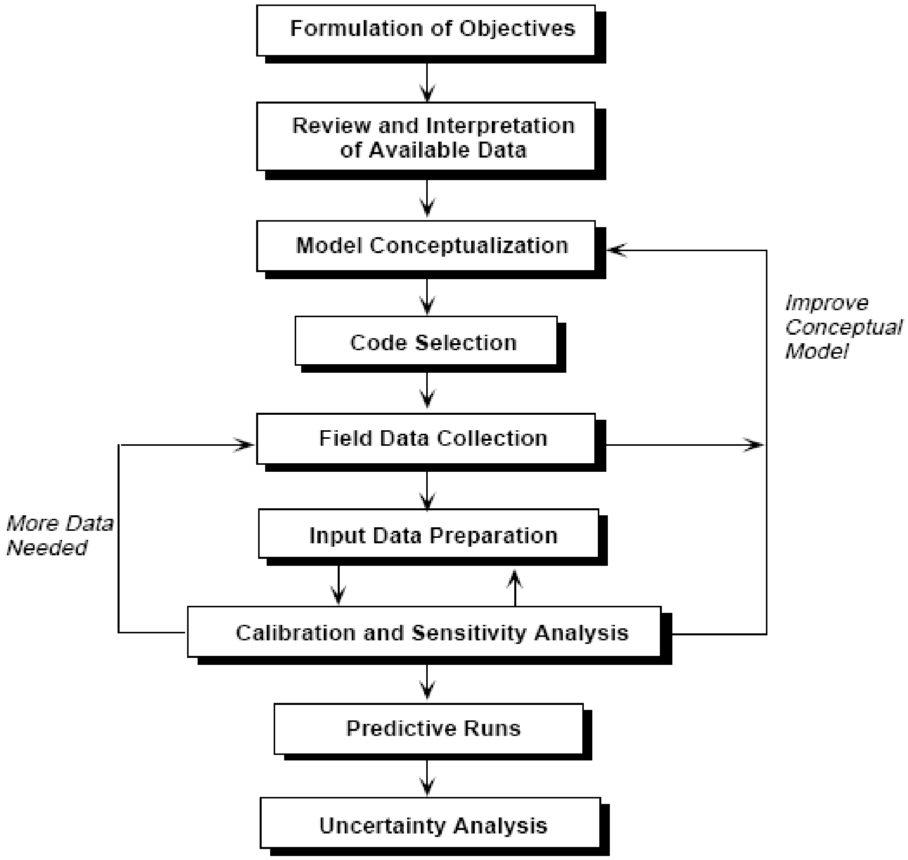

Figure 1: Conceptualization of Modeling Process. From Bear, et al., 1992, Figure 2.1-1.

The modeling objective, as defined in (Golder Associates, 2006b), for the bedrock hydrologic modeling at this site is to "provide a reliable predictive tool for mine inflows". Based on Cadmus' review and analysis, this objective is not achieved in that while mine inflows are calculated, the results cannot be considered reliable.

Nevertheless, the model analysis does follow the iteration loop of improving the conceptual model by incorporating data from the 2005 Phase II bedrock investigation. Specifically incorporating the 04EA-84 pumping test greatly enhances the model credibility. However, the credibility of the predicted mine inflow rates is not robust because the modeling does not include an uncertainty analysis. In summary, KEMC's modeling results cannot be disproven at this time, but there is no evidence that KEMC's model is more valid than KBIC's conceptual model. The SWIFT model, used as an independent check on KEMC's FEFLOW modeling results, produced results that were generally consistent with KEMC's modeling results, despite several differences in the numerical implementation and conceptual model. This indicates that KEMC's model results are plausible. Other conceptual models can be conceptualized that are equally plausible.

4.1 Review of Bedrock Geology

The bedrock features include faults, dikes, and inferred lineaments as shown in Figure 2, but these are only mapped for about one half of the modeled area. The faults include those by Kennecott Exploration Corporation (2005), fault zones inferred by Klasner, et al. (1979), and the AMEC fault (described in Golder Associates, 2006b). This figure and those following were generated by scanning reports and georeferencing to a consistent base map using GIS tools. The motivation is twofold. The first objective is to present information collectively and display the geologic structures at different scales with reference to previous modeling work. The second is to prepare digital GIS files for the construction of an independent numerical bedrock ground water flow model.

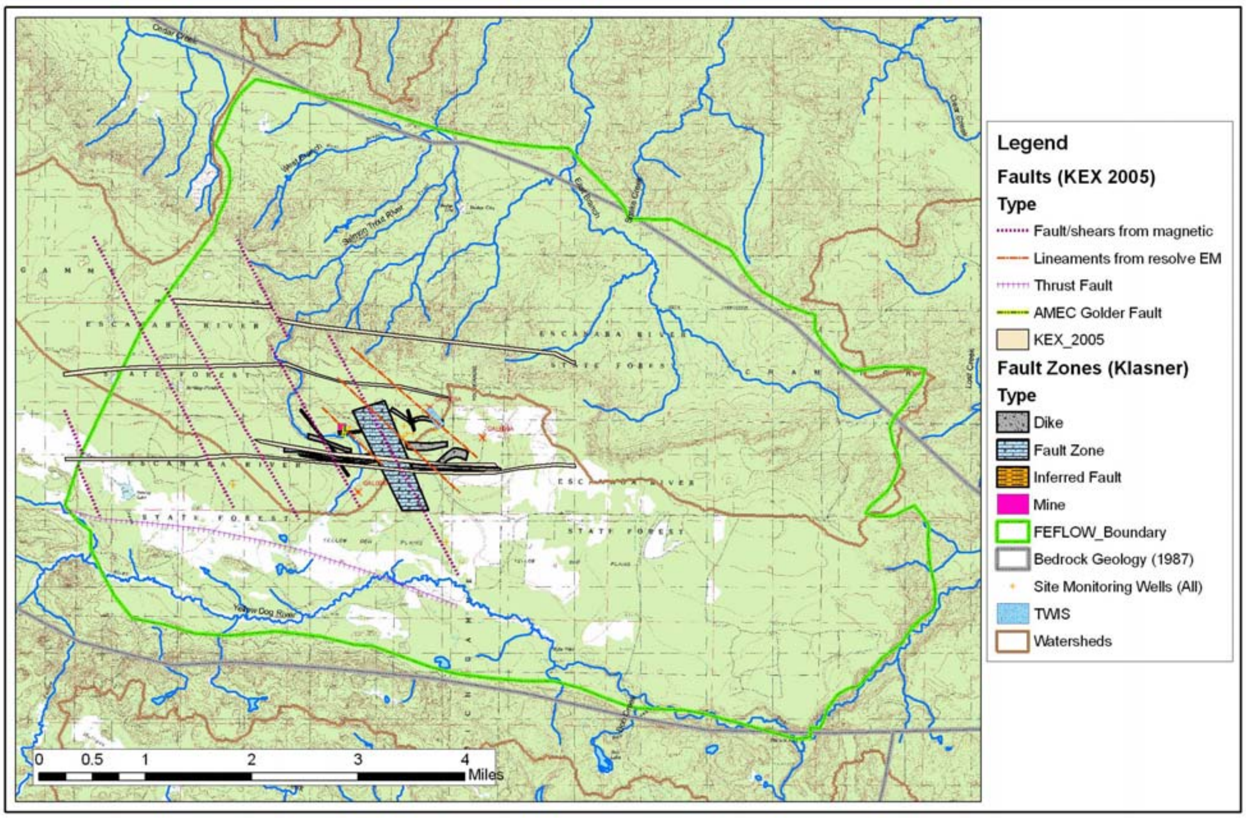

Figure 2. Bedrock faults, dikes, and lineaments within the model area.

In Figure 3, a closer examination is presented, and the modeled vertical fractures included in the FEFLOW model are superimposed (Figure 5-3, Golder Associates, 2006b).

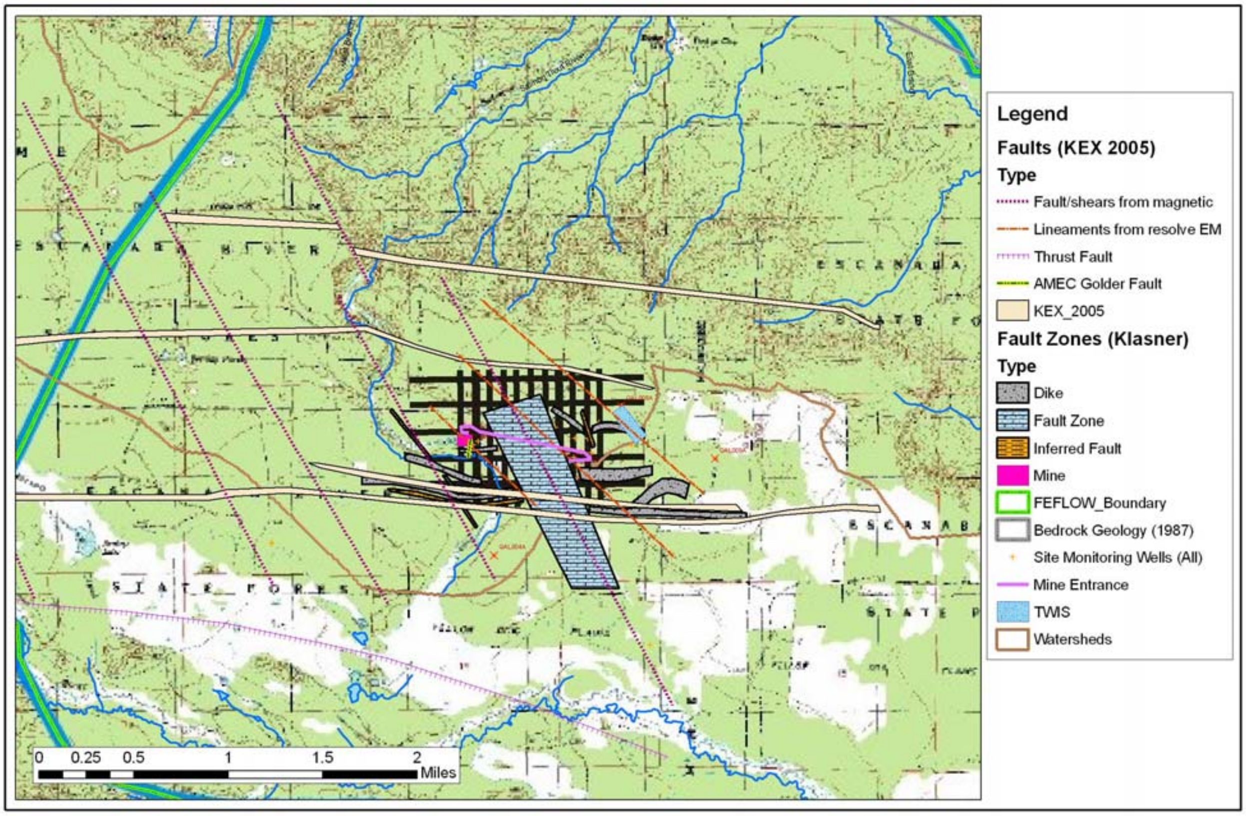

Figure 3. Bedrock faults, dike, and lineaments, and modeled FEFLOW fractures.

The region about 2 miles across the faults shown in Figure 4a is similar to that presented by KBIC (2009) (KBIC's Figure 2-1; Figure 4b below).

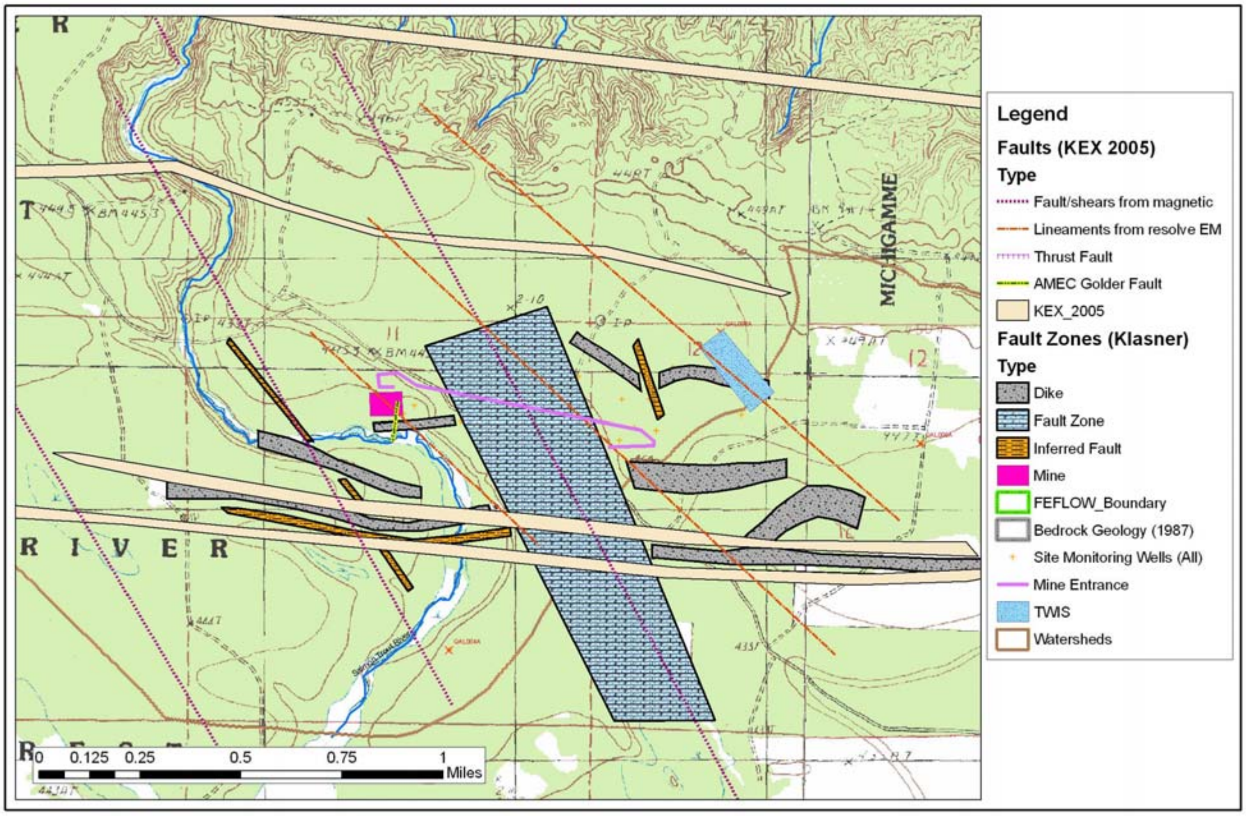

Figure 4a. Bedrock faults, dike, and lineaments. The mapped area is within the FEFLOW model area.

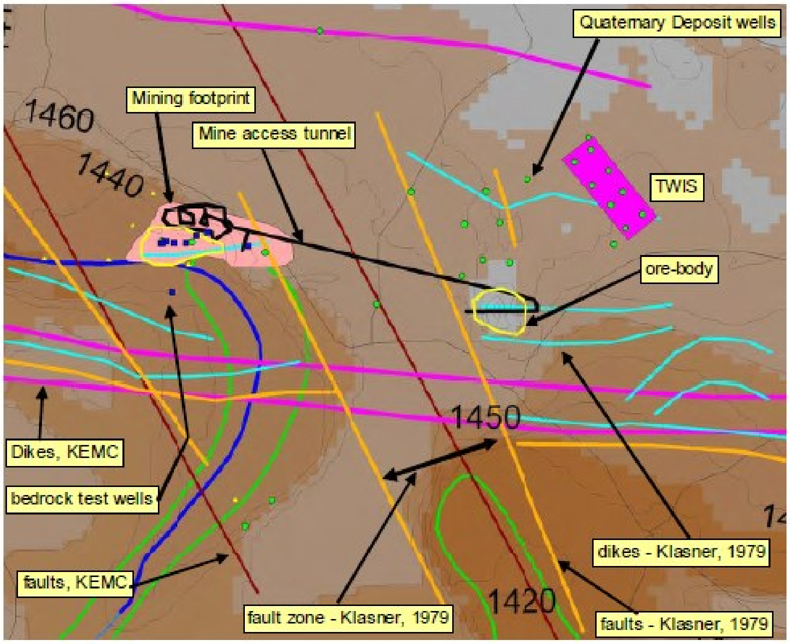

Figure 2.1. Location of bedrock test wells (blue squares) relative to major structural features (dikes and faults labeled), mining footprint, access tunnel, and Salmon Trout River (dark blue line). Light gray lines represent surface elevations (in feet). The curved green lines delineate wetland areas.

Source: Klasner et al., 1979.

Figure 4b. Locations of wells and structural features as shown by KBIC (2009).

In Figure 5, the AMEC fault as presented in Golder (2006b) is included, shown on a scale similar to that of Figure 4a.

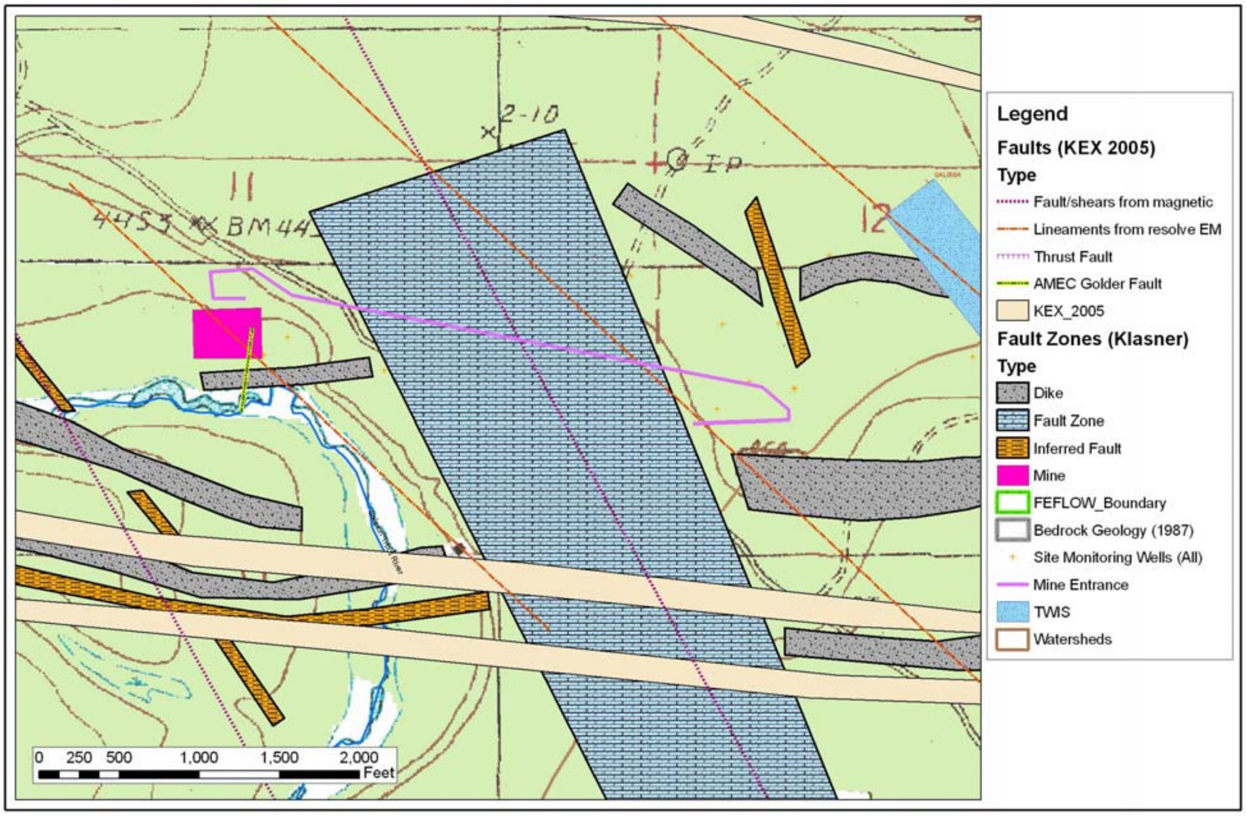

Figure 5. Bedrock faults, dike, and lineaments. (Note the mine area is a coarse approximation.) The mapped area is within the FEFLOW model area.

4.2 Review of the FEFLOW Model

The model covers an area approximately ten kilometers by eight kilometers. Vertically, the model extends from the top of bedrock down to the elevation of minus 250 meters, which is 400 meters below the lowermost mine level.

In Figure 6, the model predictions of hydraulic head (Golder Associates, 2006b, Figure 9-2) are shown. The modeled extent of the depressurization predictions is inconsistent with the presence of the fault, dikes, and lineaments. Dikes are typically very low permeability and one would not expect pressure changes to cross these features.[14]

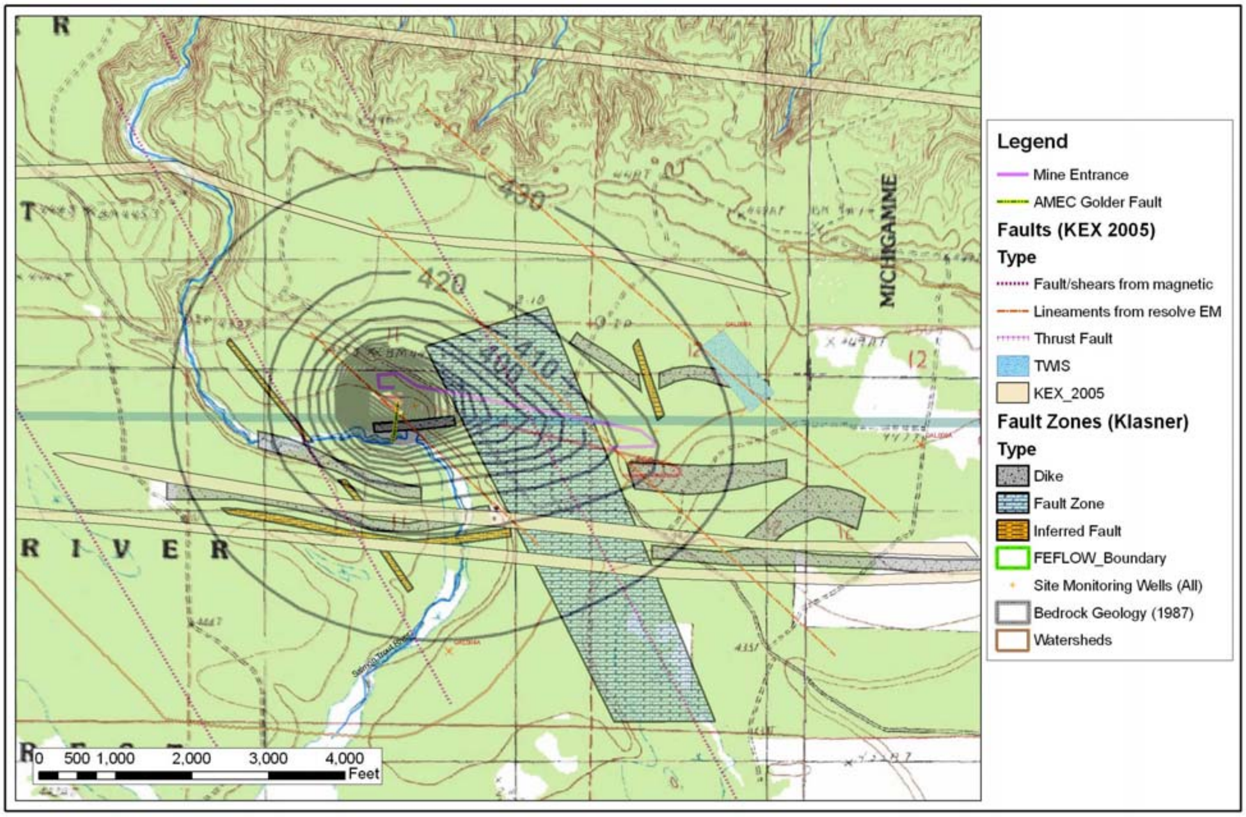

Figure 6. Site geology, and hydraulic heads predicted for when mining has ceased, using revised base case (Golder Associates, 2006b, Figure 9.2). The mapped area is within the FEFLOW model area.

The fault zone, dikes, and lineaments were essentially ignored in the characterization of the bedrock flow system used to develop the FEFLOW model.[15] Cadmus finds that this is a major shortcoming in the ability of the model to accurately represent ground water flow patterns during

[14] This issue of the permeability of the dikes was discussed in Section 2.1.1 KBIC, 2009.

[15] This issue was raised in Section 2.1.1 of KBIC, 2009.

mine operations and to predict mine inflow rates. As noted above, KEMC's modeling results cannot be disproven at this time. However, there is no evidence that KEMC's conceptual model is more valid than KBIC's conceptual model. Without further review and incorporation of geologic data, various alternate representations of fracture flow can easily be conceptualized, resulting in significant variation in the predicted mine inflow rate.

KEMC did include vertical fractures, but only in the lower bedrock. It is unclear why the fractures were not included in the upper bedrock. Cadmus finds that this assumption does not appear to be supported.[16]

Furthermore, these fractures were inferred as a uniform grid pattern spaced 120 and 226 meters apart. The KEMC report only describes hydraulic conductivity of the upper and lower bedrock without regard for vertical or horizontal components. [17] The vertical fractures (water conductive features) are designated as having a transmissivity of 3×10^{-6} m^2/s in Figure 3-1 and a hydraulic conductivity of 3×10^{-6} m/s in Table 5.1, with a width of 1 meter. Assuming the hydraulic conductivity and width description to be correct, one can calculate an equivalent vertical hydraulic conductivity for a block 226 x 100 meters as $(226 + 120) * 1 * 3 \times 10^{-6}$ m/s / $(226*120) = 3.8 \times 10^{-8}$ m/s. This is 76 times greater than the bulk hydraulic conductivity of 5×10^{-10} m/s. In other words, there is a 1:76 horizontal to vertical hydraulic conductivity ratio. Such a large ratio appears to be somewhat unreasonable in that the model offers significant vertical movement with little vertical head resistance than might be expected. This anisotropy is neither noted by KEMC, nor evaluated by KEMC as to its importance.

Furthermore, Cadmus found that there are inconsistencies in the FEFLOW report. For example, the upper bedrock is reported to be in layers 1 and 2 in Figure 5.4, but is shown as layers 1, 2 and 3 in Figure 5.2. The text on page 10 describes the lower bedrock in layers 3 to 14.

Because input data sets are in binary format, the information contained in the FEFLOW input data sets could not be used directly by Cadmus without access to the software program. The cost for a software license for FEFLOW is $3,500 for 3D flow, and a copy was not acquired for this review effort. No digital CAD files were available for this review. The 2005 Geotechnical Database, discussed in Golder Associates (2005b), with details from 92 exploratory boreholes was also not available.

Many of the above Cadmus review comments are similar to those in KBIC (2009). In that report, the same basic FEFLOW model was used as the basis for alternate scenario evaluation. The analysis resulted in predicted potential mine inflow a hundred times greater when the fracture

[16] This issue was raised by KBIC's consultants in Section 2.1.1 of KBIC, 2009.

[17] Section 2.1.1 of KBIC (2009) discusses the characterization of the upper and lower bedrock.

permeability was assumed to be a hundred times greater. As an independent evaluation, Cadmus constructed a similar model using SWIFT, as described in the next section, with similar results.

4.3 Development of Bedrock Ground Water Flow Model for this Review using SWIFT

A three-dimensional model of ground water flow in the bedrock, similar to the Kennecott model, was constructed by Cadmus using the SWIFT model (Reeves et al, 1986a and b). This numerical model was originally designed specifically for the analysis of waste injection flow and transport. The model has been updated and adopted for use on desktop PC's (Earthward Consulting, 2002). Originally designed for the analysis of nuclear waste flow and transport, SWIFT has been extensively verified and validated (Ward et al., 1984). This model was chosen because it offers variable fluid density and discrete fracture or dual porosity representation (transient model only) options.

Several additional software tools were used in conjunction with SWIFT. The model grid layout, georeferencing of structure maps, and final plates were accomplished using a desktop GIS package ArcView 9.3.1 from ESRI (www.esri.com). Model data set preparation and contouring and export of shapefiles to the GIS were accomplished through Groundwater Vistas, version 3.5 from ESI (www.groundwatermodels.com).

SWIFT Modeling Objective

The bedrock was modeled by Cadmus using SWIFT to better understand the FEFLOW model analysis. The objective was not to correct the deficiencies of the FEFLOW analysis, but rather to test certain aspects of the FEFLOW model. No additional data were used to calibrate the model, nor was an uncertainty analysis performed, per se.

Gridding

A finite-difference grid was developed using cell dimensions of 100x102 meters near the extremities of the modeled area and 25x25 meters near the proposed mine (Figure 7). There are 114 rows and 144 columns. The model contains a total of 229,824 cells, of which 159,530 are active. This is comparable to the 180,000 triangular elements in the FEFLOW model. The model origins are E427213 m and N5172869 m (UTM NAD1983, Zone 16N).

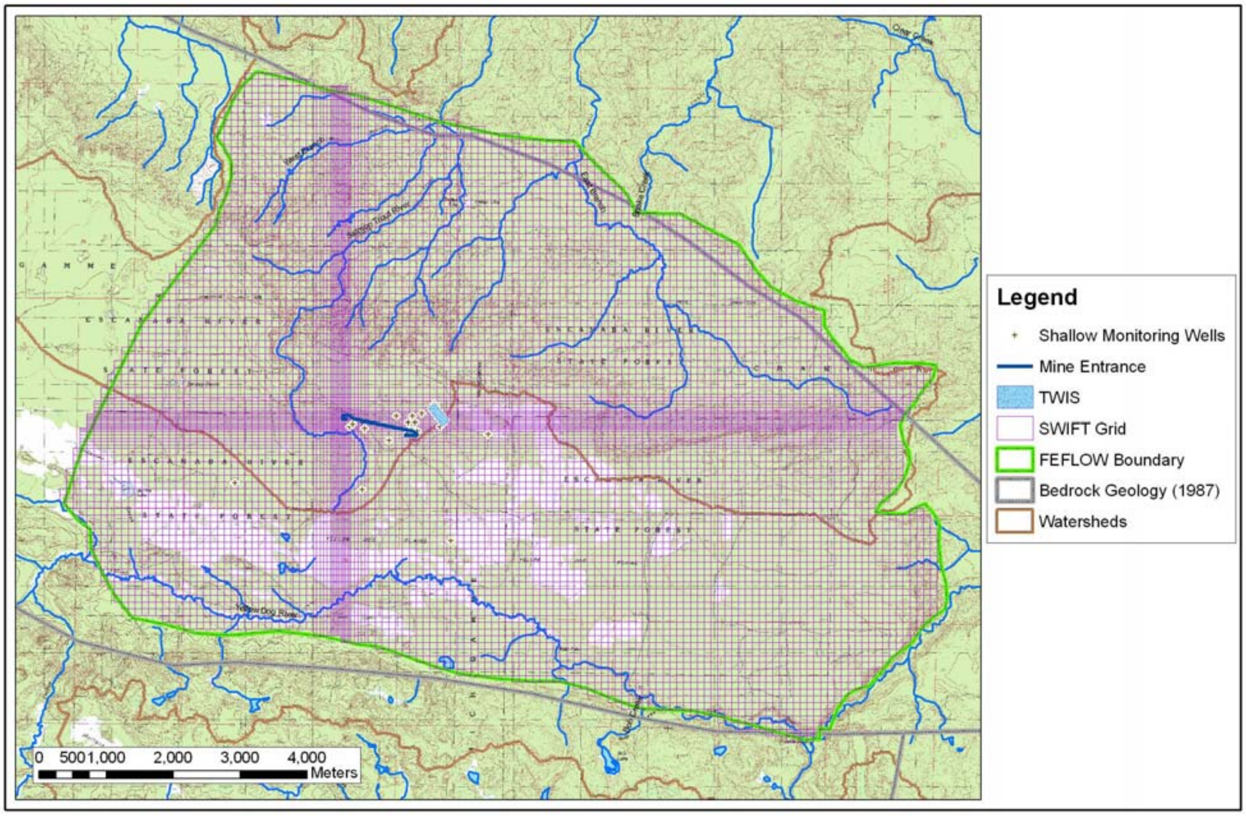

Figure 7. SWIFT finite difference grid.

The vertical grid in the SWIFT model was identical to that in the FEFLOW model. As previously noted, it is unclear whether model layer 3 represents upper bedrock or lower bedrock. Both conceptualizations were examined and found to have a significant effect on the predicted mine inflow rate.

Boundary Conditions

The same boundary conditions were developed for the SWIFT model as had been used in the FEFLOW model. No flow boundaries were used in all 14 layers around the perimeter and base of the model. Along the entire top of the model, which corresponds to the alluvium and upper bedrock interface, a constant pressure was assigned, which corresponds to a hydraulic head of 433 meters. This is the same as was done in the KEMC model and corresponds to the average water table elevation in the overburden above the proposed mine.

Hydrogeological Parameters

The same values of hydraulic conductivity used in the FEFLOW model (Table 5.1, Golder Associates, 2006b) for the upper and lower bedrock were used in the SWIFT model. The water conductive fractures are described in the section below.

Representation of Mining Operations

The mining operations were not modeled in SWIFT with the level of detail used in FEFLOW. The proposed mine configurations were not readily available in digital format. Furthermore, it was found that there was little need for this level of detail as other uncertainties in the overall hydrogeological characterization overshadowed this issue. To represent the mine operations, cells were assigned a pressure of zero for each layer where the proposed mine activities will take place. Several simulations were executed with varying mining elevation configurations.

Variable Density

KBIC's consultants stated that the effects of saline water in the mine and resulting density-dependent flow were ignored by KEMC.[18] Using the density profiles (Golder Associates, 2006a, Figure 10-2) and the density calculator (Maidment, 1993), the bounding fluid densities for the SWIFT model are 999.88 kg/m^3 at C=0 and 1010.48 kg/m^3 at C=1. These are the fluid densities used to define the dimensionless "brine" concentration in the model. The temperature profile ranged from 8.0°C at top of the model (elevation = 413 m) to 19.5°C at the base of the model with a depth of 633 m (elevation = -250 m). As noted below under "Importance of Variable Density," inclusion of variable density was not found to be of great significance to the model analysis. Thus, KEMC's FEFLOW model application using constant density assumptions is a valid simplification, and KBIC's critique is not relevant.

Discrete Fracture

The SWIFT model offers both discrete fracture (one-dimensional) and dual porosity options for pressure, heat, brine, and contaminant transport. These options were not used as the modeling analysis was performed in steady-state mode only. If data from the 04EA-84 pump test were used in model calibration, the discrete fracture or dual porosity options could be invoked. This task would further the evaluation of the FEFLOW model. However, incorporating localized fractures in the model would provide little change to the predicted mine inflow rates, as these would quickly drain and not provide long-term mine inflow. As shown in Figure 9.1 in Golder Associates (2006b), the inflow rates stabilize in days for the base case and within a year for the upper bounding case. Therefore, there is little need to incorporate the transient effects of fracture storage when the net permeability can be incorporated through equivalent porous media.

[18] The issue of density-dependent flow was discussed in Section 2.2.1 of KBIC, 2009.

Representation of Vertical Fracture Network

Rather than discrete vertical planar fracture elements on a grid basis, the vertical hydraulic conductivity of the lower bedrock can be adjusted to incorporate these flows as was done in FEFLOW. As described above, a vertical hydraulic conductivity (K_z) of 3.8 x 10^{-8} m/s produces the equivalent effect of the fracture system.

While the vertical fractures provide a vertical connection in the lower bedrock, they also enhance the net horizontal hydraulic conductivities in the X and Y directions. One can calculate the net X direction (K_x) hydraulic conductivity as 3 x 10^{-6} / 120 = 2.5 x 10^{-8} m^2/s and in the Y direction (K_y) as 3 x 10^{-6} / 226 = 1.33 x 10^{-8} m^2/s. These values are reasonable for a fractured bedrock setting.

The region of vertical fractures is shown in Figure 8 with the preliminary fracture work used in FEFLOW (Figure 5.3 of Golder Associates, 2006b). The region is more comparable to the revised FEFLOW model. Figure 9 shows the region of fractures modeled in the lower bedrock in relation to the various geologic features (faults, dikes, and lineaments) that were also shown in Figures 3, 4a, and 5.

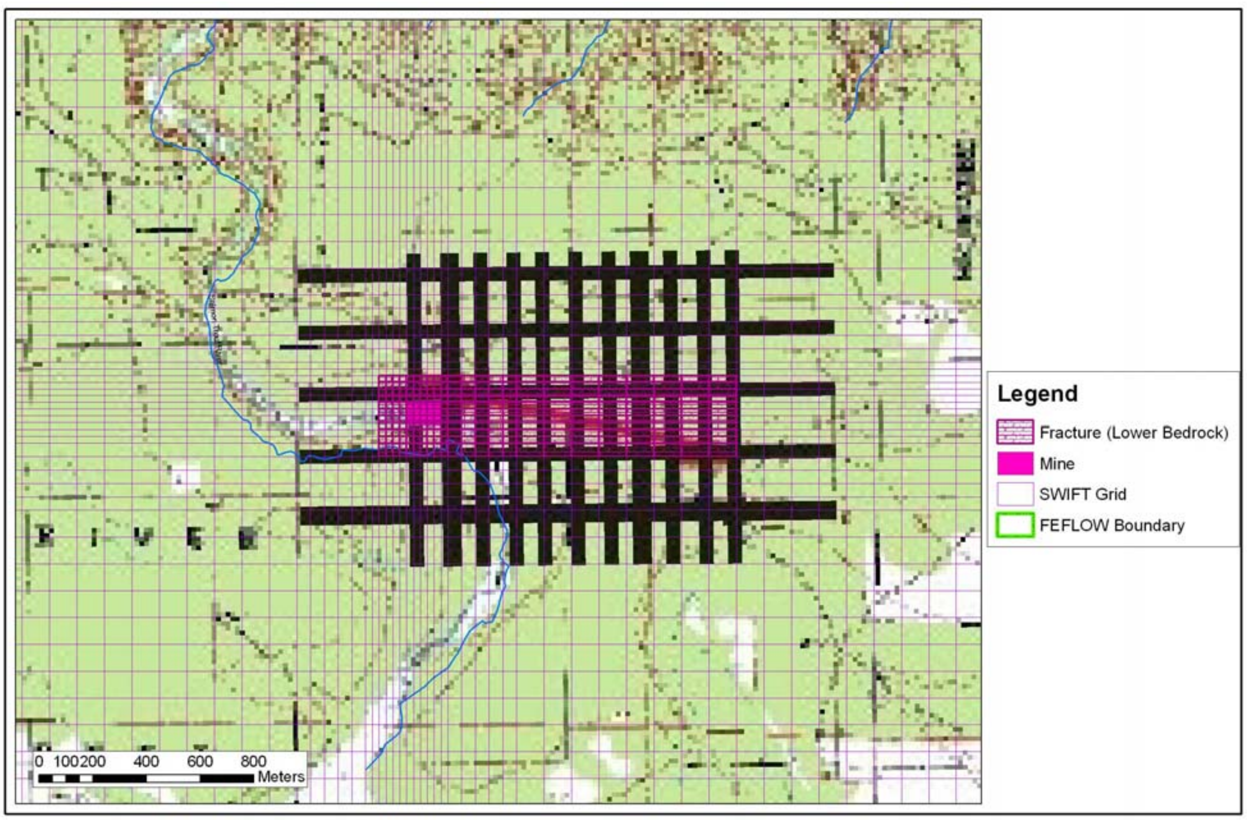

Figure 8. Assumed zone of lower bedrock fractures. This zone can also be viewed relative to the other geological data in Figure 9. The mapped area is within the FEFLOW model area.

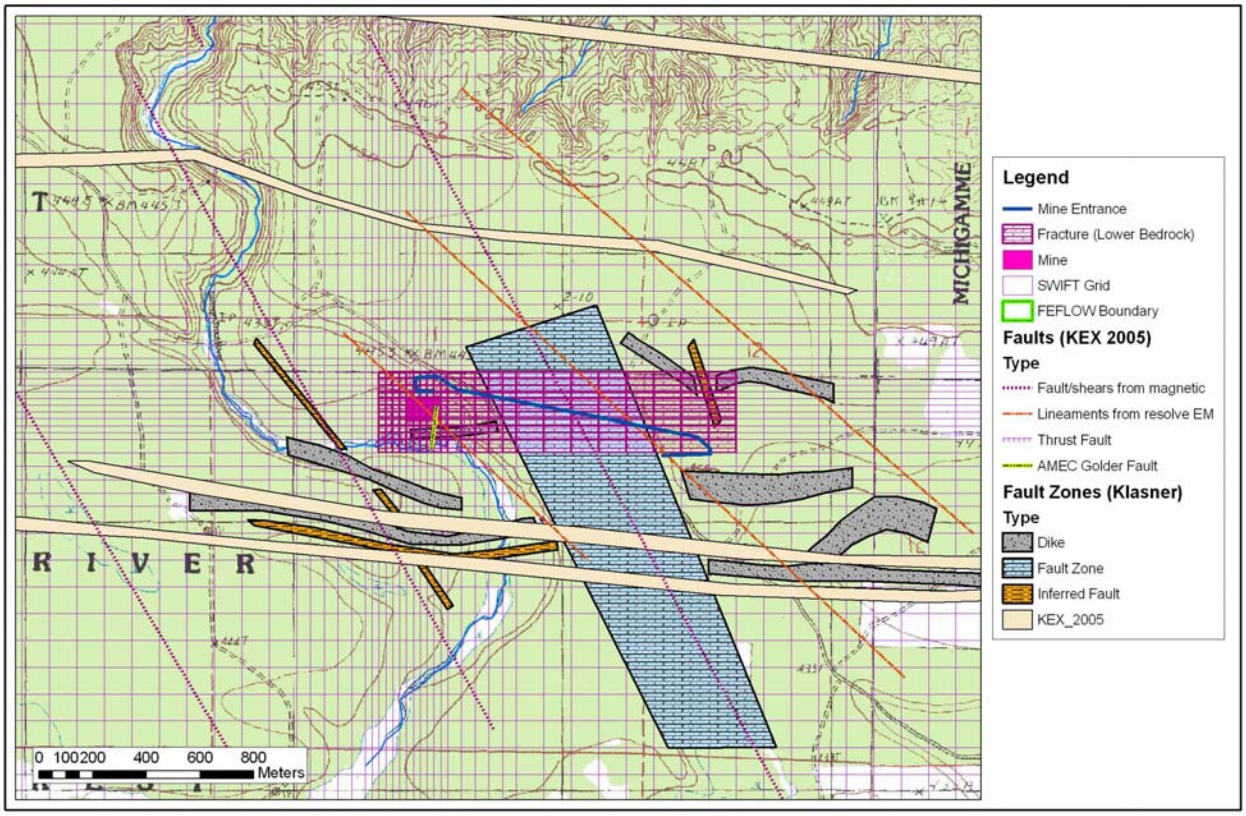

Figure 9. Modeled zone of lower bedrock fractures in relation to faults, dikes, and lineaments. The mapped area is within the FEFLOW model area.

Simulations

Several simulations were executed to match the work done by Golder Associates (2006b) and KBIC (2009).

Run Number	Fracture in Lower Bedrock	Mine Inflow (gpm)	Mine Inflow (cu m/day)	Description
41	None	13	72	Included to demonstrate importance of fractures in lower bedrock
46	Limited to near mine area (col 36-61, rows 49-71)	78	423	Most similar to preliminary FEFLOW model where inflow = 110 cu m/d
47	Limited to near mine area (col 45-67, rows 56-66)	46	253	Most similar to revised base case FEFLOW model where inflow = 410 cu m/d
48	Limited to near mine area (col 45-67, rows 56-66)	123	670	Most similar to revised Upper Bound FEFLOW model where in flow = 1,180 cu m/d

Run Number	Fracture in Lower Bedrock	Mine Inflow (gpm)	Mine Inflow (cu m/day)	Description
49	Limited to near mine area (col 45-67, rows 56-66)	330	1,800	Most similar to KBIC Scenario 5 with 10x fault permeability where inflow= 3,100 cu m/d
50	Limited to near mine area (col 45-67, rows 56-66)	2,587	14,100	Most similar to KBIC Scenario 6 with 100x fault permeability where inflow= 30,146 cu m/d
51	Limited to near mine area (col 45-67, rows 56-66)	47	254	Constant density version of Run 47
52	Limited to near mine area (col 45-67, rows 56-66)	43	233	Same as Run 47 with addition of Klasner dikes

Results from Run 47, along with the predicted hydraulic heads from the revised base case (Golder Associates, 2006b, Figure 9.2) are shown in Figure 10. The SWIFT results are presented for layer 3 at the top of the lower bedrock and Layer 7 deeper into the mine level. In general, while not shown, the vertical distribution of predicted hydraulic heads displays a similar pattern with both models.

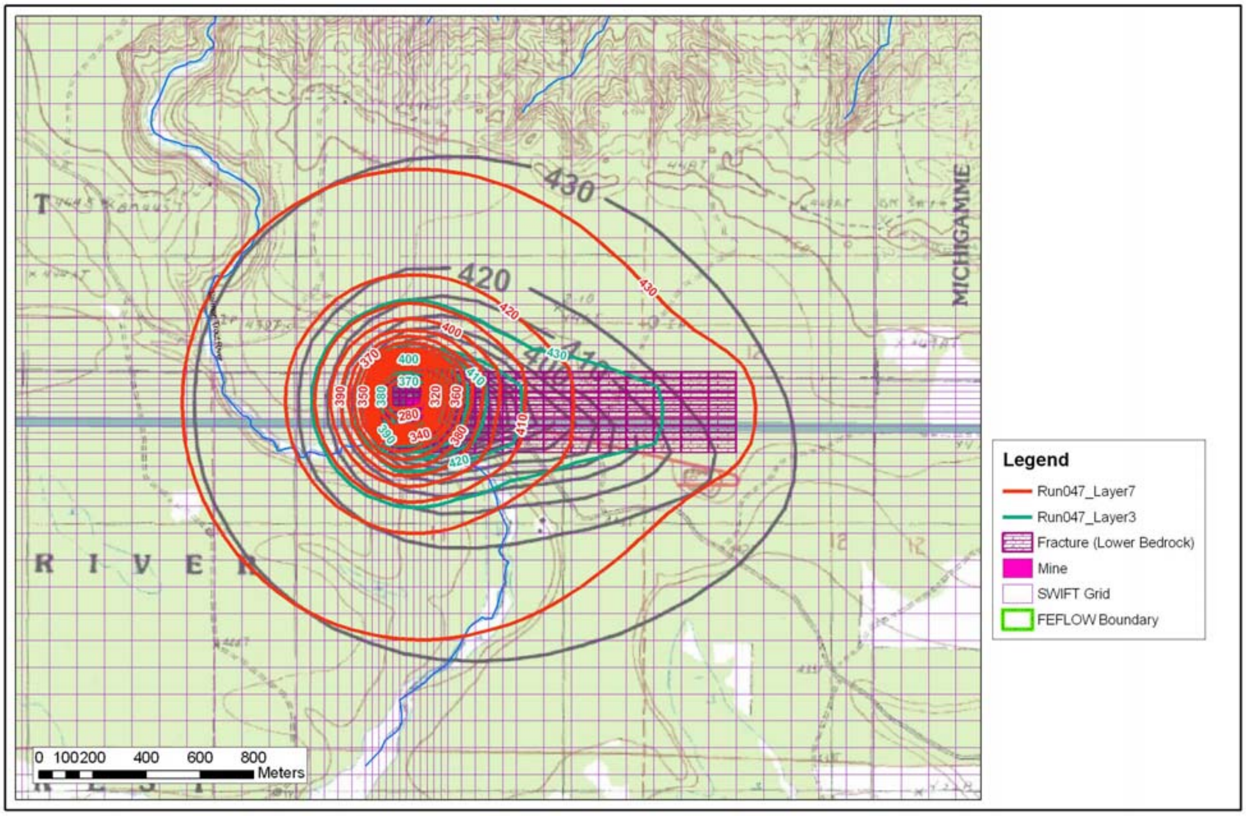

Figure 10. Predicted results for revised Base Case. The mapped area is within the FEFLOW model area.

With respect to representation of the vertical fracture network, in light of the model differences, the results from SWIFT are similar to those from FEFLOW. This confirms that the modeling analyses by KEMC, Cadmus, and KBIC are comparable.

Variation in Predictions

Because of uncertainty in the hydrogeologic characterization, it is reasonable to conduct simulations with variations in the fracture permeability. This is not the same as a true uncertainty analysis, but does provide insight regarding how the system responds to the unknown variability of localized fractures in the lower bedrock. A rigorous uncertainty analysis would provide quantitative statistics resulting from parameter uncertainty (Hill and Tiedeman, 2007). In Figure 11, the predicted hydraulic heads for KBIC Scenario 6, wherein the vertical conductivity is increased by a factor of 100, are shown. The more regular contours in Figure 11 are a reasonable result. Note that the extent of the depressurization increased slightly whereas the rate of mine inflow increased by a factor of over 50.

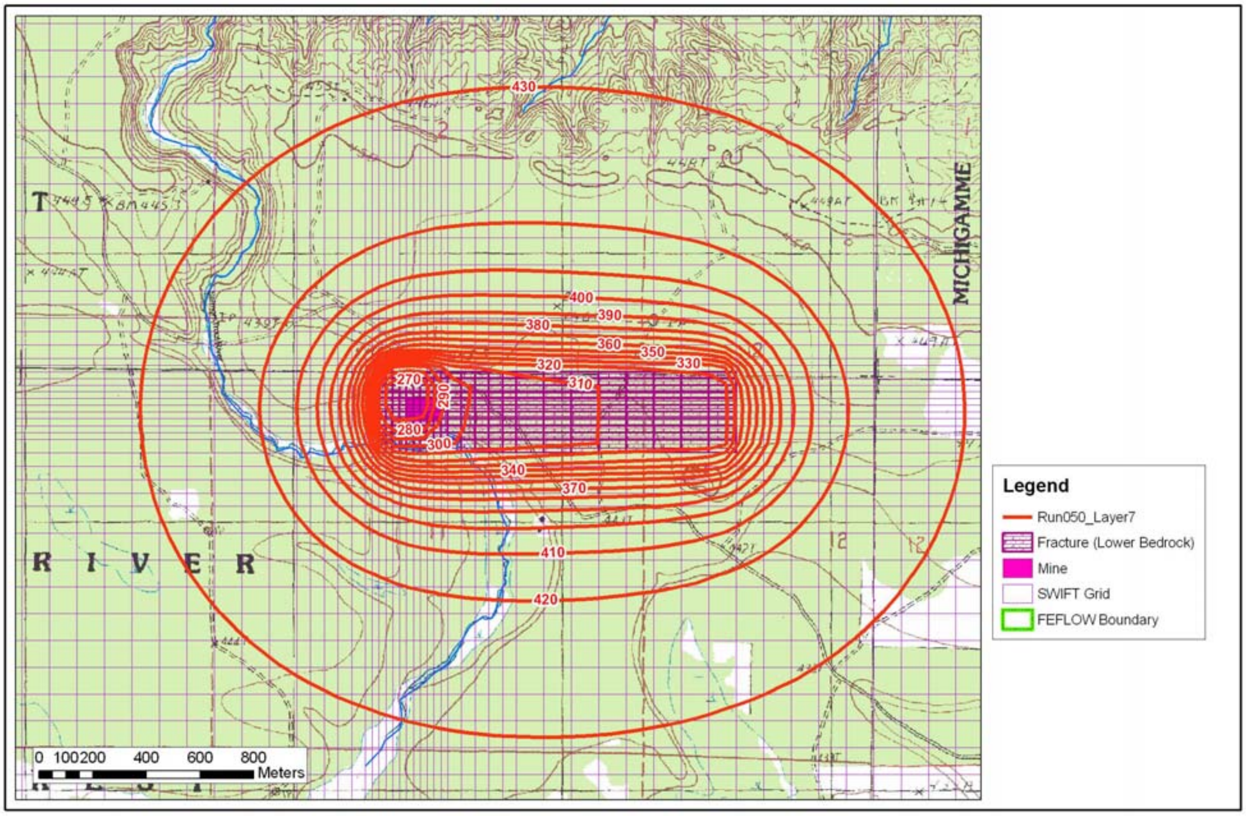

Figure 11. Predicted results for revised KBIC Scenario 6 (100x fault permeability). The mapped area is within the FEFLOW model area.

Importance of Variable Density

To assess the importance of variable density fluid, Run 51 was simulated using constant density conditions. The results are very similar to Run 47. Therefore the FEFLOW model application using constant density assumptions is a valid simplification.[19]

Importance of Dikes

Given the uncertainty of the geologic characterization, an evaluation simulation (Run 52) was conducted in which the dikes as presented by Klasner et al. (1979) were included. For simplicity, the dikes were represented as no-flow cells that are completely impermeable. In Figure 12, the predicted equipotential lines are interrupted by the dikes. The contours are discontinuous because the no-flow cells representing the dikes in SWIFT are inactive cells. (Note that these inactive cells are represented as blue cross-hatched areas labeled "SWIFT No flow dikes (Run52)" in Figure 12.) The small gaps are due to the interpolation technique, in which contour lines are stopped prematurely within the active cells and cannot be extended to the inactive cells. Overall,

[19] The issue of variable density was raised by KBIC's consultants in Section 2.1.1 of KBIC, 2009.

the extent of the depressurization is similar to the base case (Run 47), as shown in Figure 10. Thus, the absence of the dikes in KEMC's model is a reasonable simplification.[20]

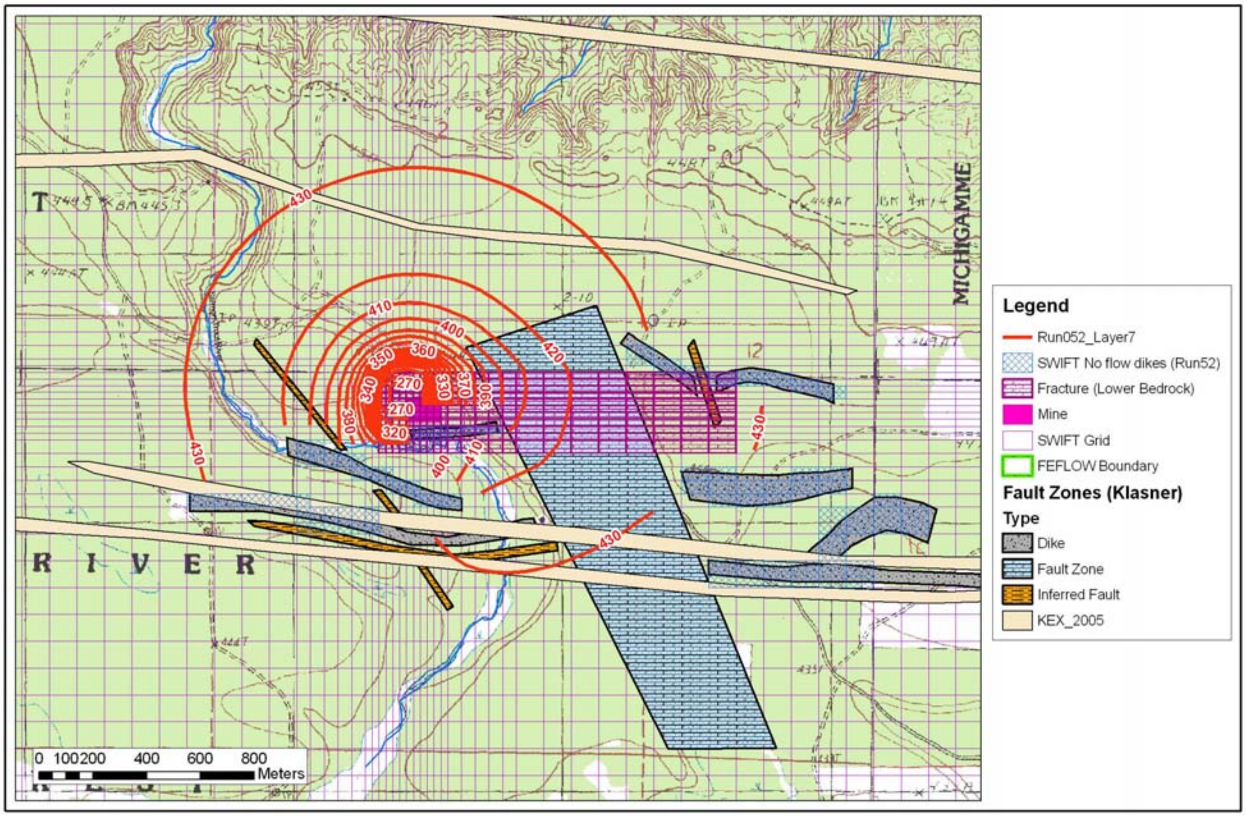

Figure 12. Predicted results including hypothesized no-flow dikes. The mapped area is within the FEFLOW model area.

Check on Water Influx from Alluvium

As a check on the conceptual model, an evaluation was made of the magnitude of the water influx through the top of the model. This is the water drawn into the bedrock from the alluvium as a result of the mining. For the base simulation (Run42), the maximum water influx through the top of the bedrock is 0.032 in/year. This is small compared to the net recharge to the alluvium, which is on the order of 15 in/yr. Therefore, the assumption to represent leakage from the alluvium using constant pressure or a head-dependent boundary condition appears to be reasonable. If, however, the leakage rate simulated was nearing the net infiltration from precipitation, this would have undermined the conceptual model. In summary, after checking the

[20] This issue of the permeability of the dikes was discussed in Section 2.1.1 KBIC, 2009.

reasonableness of the water influx from the alluvium, the KEMC's simplified conceptual bedrock model is not unreasonable.[21]

Mass Balance

Mass balance is a common quality assessment metric, with low errors being one indication of high quality modeling. In all of the SWIFT simulations, the mass balance errors were less than 1%, and they were typically less than 0.1%. Because SWIFT includes variable density, two or three iterations were performed to achieve fluid density convergence. The resulting low mass balance errors demonstrate that the simulations exhibit the numerical accuracy required for a defensible model application.

5 Wastewater Treatment Plant

KEMC has designed a treatment system to treat the wastewater associated with mining operations. Mine water, TDRSA water, and storm water runoff from the main operations area will be collected in the CWB and treated at the wastewater treatment plant prior to being discharged to ground water by the treated water infiltration system. The CWBs will provide wastewater storage and equilibrate the concentrations of contaminants in the wastewater. Wastewater will be pumped from these basins to the WWTP, which has been designed to include the following general processes:

- Wastewater storage
- Main wastewater treatment
- Concentrate reduction
- Sludge handling
- Evaporation/crystallization

5.1 Main Wastewater Treatment Plant

The treatment processes consist of metals precipitation/sedimentation with polymer addition as needed, filtration via a sand filter, a double pass reverse osmosis (RO) system, and numerous pH adjustments.

5.1.1 Complexity of the Treatment Process

KBIC's consultants state that the design of the treatment is overly complex and is an untested and unconventional system in the industry. They add that untested systems are usually fraught with start-up problems and do not initially perform to meet expectations.[22]

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21 Communication between the alluvium and the bedrock was discussed in Section 2.1.2 of KBIC (2009).

22 The issue of the overly complex treatment process proposed by KEMC was discussed in Section 3.2 of KBIC, 2009.

The main WWTP has been designed to provide a level of treatment sufficient to ensure consistent compliance with Michigan's Part 22 Groundwater Quality Standards (Michigan Part 22 Standards, undated). The treatment processes that comprise the WWTP are well established technologies that have been successful in treating the contaminants for which they are designed. Each process targets specific contaminants to ensure that effluent levels meet MDEQ standards. Lime precipitation specifically targets the reduction of heavy metals. The use of lime to neutralize mine drainage and precipitate metals has been the automatic treatment choice for many years (McGinnis, 1999). Once the optimal precipitation is established, the settling process is often accelerated by the addition of polymer, which gathers the insoluble metal compound particles into a coarse floc that can settle rapidly by gravity (EPA, 2000). KEMC's process will employ polymer addition, as needed, to further optimize the solids sedimentation process (Foth and Van Dyke, 2006a). In addition, reverse osmosis systems have been applied for treatment of mine-waste effluents or for polishing the effluent from facilities that use lime treatment (Blowes, et al., 2005). Polishing is defined as an advanced wastewater treatment step, applied after primary treatment and aimed at further reducing concentrations of contaminants. In KEMC's process, the RO treatment system will be used as a polishing step to reduce the concentrations of contaminants not removed by the primary treatment process (lime precipitation).

KBIC's consultants also commented that the Ground Water Discharge Permit Application (GWDPA) (Foth and Van Dyke, 2006a) describes the first step in the treatment process as "either lime softening or lime precipitation."[23] KBIC added that if lime precipitation was the treatment objective, more lime would be required and could result in issues for the RO treatment process.

Regarding which treatment process will be used, the GWDPA (Foth and Van Dyke, 2006a) describes the first step in the treatment process as metals precipitation/sedimentation using lime (calcium hydroxide). KBIC's consultants may be confusing the first step in the main WWTP with the discussion of softening/metals precipitation in the Concentrate Reduction Process (CRP).

The treatment objective for metals precipitation is to remove divalent and trivalent metals such as nickel, cadmium and aluminum. The treatment objective for lime softening is to remove hardness ions such as calcium and magnesium. KEMC will employ both metals precipitation and lime softening treatment in the Concentrate Reduction Process discussed in Section 5.1.6. Concerns regarding the RO treatment process and the lime requirements are discussed in Section 5.1.4.

[23] The issue regarding which type of treatment was being employed was discussed in Section 3.2 of KBIC, 2009.

5.1.2 Lack of Testing and Data

KBIC's consultants make the statement that KEMC has never submitted a treatability or pilot test to demonstrate the effectiveness of its novel, complex system.[24] They also commented that there are no actual data on treatment of Eagle Project wastewater, only theoretical predictions that are based on existing data that most likely used new RO membranes and water that did not resemble the combination of acid drainage and brine that will be generated by the Eagle Project.

According to the *Kennecott Closing Argument and Proposed Findings of Fact and Conclusions of Law* document (2008), "a treatability study was performed to confirm that the WWTP effluent would meet the more restrictive surface water standards set by MDEQ rather than the ground water standards. The results of the treatability study indicated that the treatment processes proposed for the WWTP worked as expected and exceeded Kennecott's projections regarding the WWTP's capacity to meet the Permit's discharge standards."

While predicting effluent concentrations through scientific calculations is common practice in designing any treatment facility, a treatability study is necessary to ensure that the technologies proposed will perform as predicted using water that is comparable in quality to the water that will require treatment. KEMC hired consultants (Siemens Water Technologies) to conduct a treatability study in the form of bench-scale tests. Bench-scale tests were conducted to simulate the main WWTP process and the CRP. A bench test was not conducted to simulate the Evaporation/Crystallization process. For this reason, the bench-scale study and full-scale design differ as follows:

- Concentrate from the CRP RO process and regenerate from the boron ion exchange process were routed to the beginning of the CRP in the bench-scale tests but are routed to the Evaporation/Crystallization process in the full-scale design.
- Filtrate from the filter press and overflow from the sludge storage tank, which are both part of the Evaporation/Crystallization process, are routed to the beginning of the CRP in the full-scale design but were not accounted for in the bench-scale process.

The results from the main WWTP process and CRP bench tests showed effluent concentrations that met the Groundwater Quality Standards of Part 22 (Michigan Part 22 Standards, undated). However, due to a laboratory error, the tests could not confirm that mercury would be removed at levels sufficient to meet Michigan's Part 201 Groundwater Residential Drinking Water Criterion for mercury of 2 parts per billion (ppb).[25] According to the Treatability Test Report (Siemens, 2007), mercury levels of 2.5 parts per trillion (ppt) in the CRP RO permeate were

[24] The issue regarding the lack of a treatability study was discussed in Section 3.2 of KBIC, 2009.

[25] A standard for mercury is not listed in the Part 22 standards presented in the Treatability Test Report (Siemens, 2007).

above the performance criteria of 2 ppt. However, when combined with the RO permeate from the main WWTP, the overall criteria for mercury were met. The Report added that testing was underway to evaluate the use of mercury selective resin to further polish the CRP RO permeate prior to blending with the main WWTP RO permeate. Because the permit application was submitted to EPA prior to the completion of the treatability study, it is unclear if mercury is an issue and if it will be specifically addressed in the full-scale process. Nevertheless, the predicted WWTP influent concentration for mercury of 0.041 ppb (Foth and Van Dyke, 2006a) is below the Federal maximum contaminant level (MCL) of 2 ppb.[26]

It should be noted that the treatability study consisted of only bench-scale and not pilot-scale testing. A pilot-scale test would provide a better representation of the full-scale treatment process as well as the effluent concentrations that could be expected. Although the pilot test would be advantageous, conducting a pilot-scale test would be challenging since a large volume of "make-up" or simulated influent water would be needed to perform testing because the mine currently does not exist. KEMC did modify the initial treatment process design based on bench-scale results by adding ammonia treatment via breakpoint chlorination to the full-scale design in the CRP to ensure discharge limits for ammonia are met.

5.1.3 Crucial aspects of the treatment process are not finalized

The KBIC Comments claim that KEMC has not finalized crucial aspects of the treatment process and provide boron as an example. Specifically, they state that KEMC has not decided on the approach for removing boron and refer to the treatment notes on the process flow diagram provided with the UIC Class V permit application (Foth Infrastructure and Environment, 2007) that say "an ion exchange system (for boron removal) may be added in lieu of caustic addition prior to the second pass RO unit."[27]

KEMC is not undecided on how they will address boron removal, but rather they may consider an alternative process (ion exchange using boron selective resin) and, as stated in the UIC Class V permit application (Foth Infrastructure and Environment, 2007), the "final selection will be based on economic and technical considerations at the time of final engineering." KEMC also states that, in terms of boron removal, ion exchange using boron-selective resin is comparable to the proposed RO system.

Both technologies are viable options for boron removal. A two-pass RO system under alkaline conditions is effective at removing boron (Dydo et al., 2005). Also, studies have shown that boron removal using boron-selective media can be 98 percent or greater (Demirçivi and Nasün-Saygılı, 2008).

[26] 40 CFR 141.62(b).

[27] The issue of whether the proposed treatment process can remove boron was discussed in Section 3.2 of KBIC, 2009.

KBIC's consultants also state that the removal efficiency estimate for boron is overly optimistic and, even under the optimistic view, the expected effluent boron concentration (174 μg/L) is close to the MDEQ permit limit (285 μg/L). The MDEQ permit limit of 285 μg/L for boron is well below EPA's Ten-Day Health Advisory for Children of 3000 μg/L, Longer-term Health Advisory for Children of 2000 μg/L, and Longer-term and Lifetime Health Advisory for adults of 5000 μg/l (EPA, 2008).

According to the UIC Class V permit application (Foth Infrastructure and Environment, 2007), the removal efficiency used for boron was 96.1 percent based on the membrane manufacturer's predictions. The KEMC treatability study indicates that compliance with permit discharge requirements will be achievable.

The treatability study consisted of bench-scale tests that simulated the main WWTP process and the CRP with a few exceptions as discussed in Section 5.1.2. Test results showed that each process can meet Michigan's Part 22 Groundwater Quality Standards for boron (Michigan Part 22 Standards, undated). Incidentally, boron removal was accomplished in the main WWTP simulated bench test using second pass RO under alkaline conditions and not ion exchange with boron-selective media.

5.1.4 Membrane Damage due to Poorer Influent Water Quality

KBIC's consultants state that if the inflow water quality is poorer than predicted, or if water quality is variable, the addition of lime will be more complicated and will probably result in damage to the membranes.[28] When the KBIC Comments refer to "damage to the membranes," it is assumed that they are referring to scaling of the membranes which can occur if precipitates of calcium are present in the RO feed.[29]

Inflow water to the WWTP will come from the contact water storage basins. These basins will equilibrate the inflow water (so that variations over time in the concentrations of wastewater constituents are averaged prior to the water entering the WWTP), and allow some of the suspended solids to settle prior to entering the WWTP. Lime addition should not be more complicated with an increase in contaminants in the inflow because process control measures will be in place to ensure adequate lime addition to maintain the pH between 9 and 11. As stated in the UIC Class V application (Foth Infrastructure and Environment, 2007), calcium precipitates will then be flocculated in the clarifier and allowed to settle out. After the metal precipitation/clarification process, the pH will be adjusted to between 6.5 and 7.5 with sulfuric

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[28] The issue of influent water quality being poorer than predicted and variable was discussed in Section 3.1 and Section 3.2 of KBIC, 2009.

[29] The issue of membrane damage due to the poorer influent water quality was discussed in Section 3.2 of KBIC, 2009.

acid to minimize the potential for scaling of the RO membranes. The reduction in pH will redissolve the calcium precipitates not removed in the clarification process.

5.1.5 Polymer, anti-scalant, and biocides are unspecified

KBIC's consultants state that the polymer to be used in the wastewater treatment system's metal precipitation/ sedimentation process and the anti-scalant(s) and biocide(s) to be used in the system's RO desalination process have not been specified in either KEMC's MDEQ permit or their UIC Class V permit application.[30] Because chemicals used in a treatment system may be present in the effluent, an industrial wastewater discharge permit application typically includes information on the chemicals to be used in the proposed treatment process, including those chemicals used in maintaining the treatment system (e.g., for microbiological control [biocides] and equipment cleaning). This information is typically found in the state permit fact sheet. In this case, the effluent would include the concentrated RO reject stream and sludge from the metal precipitation process. Information provided usually includes, but is not limited to, Material Safety Data Sheets (MSDSs) and chemical manufacturers' product data sheets. The manufacturer's product sheets provide information on the concentrations and properties of constituent chemicals found in a product, proposed dosage rates, and chemical concentrations in the chemical feed stream (particularly if a specific product is fed to the wastewater treatment in a diluted form of the neat chemical).

KBIC's consultants also state that the efficiency of removal of the biocide proposed for use in the wastewater treatment systems' RO process has not been examined by KEMC. The wastewater discharge application typically provides a profile of the anticipated wastewater discharge, including residual pollutant concentrations and residual concentrations of chemicals added as part of the treatment process. This wastewater discharge profile provides the permitting agencies with the data necessary to determine any impact the proposed wastewater discharge may have on the receiving water/environment.

Cadmus recommends that EPA consider including in the permit a condition that KEMC provide pertinent information regarding polymers, anti-scalant, or biocides (e.g., material safety data sheets (MSDSs), expected flow rates, etc.) to EPA prior to adding them to the wastewater.

5.1.6 Concentrate Reduction Process (CRP)

KBIC's consultants assert that there are no details presented regarding the Concentrate Reduction Process (CRP) and that the largest fouling problems will likely be encountered in the CRP.[31]

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[30] The issue with KEMC not specifying which polymer, anti-scalant, or biocide chemical they plan to use was discussed in Section 3.2 of KBIC, 2009.

[31] The issue of KEMC not providing details regarding the CRP process was discussed in Section 3.2 of KBIC, 2009.

According to the UIC permit application, the CRP will consist of:

- Breakpoint chlorination
- Softening and metals precipitation
- Microfiltration
- pH adjustment
- Ion Exchange
- RO
- pH adjustment
- Ion exchange

The UIC Class V permit application (Foth Infrastructure and Environment, 2007) also contains detailed descriptions of each of the above processes and Table 1-1 includes estimated effluent concentrations for two of the CRP processes.

KBIC's consultants do not specify what they perceive to be the cause of membrane fouling (e.g., scaling, biological growth, etc.). The WWTP is designed with several pretreatment processes that will minimize the potential for scaling. The softening/metals precipitation/microfiltration process will precipitate metals, calcium and magnesium salts, and silica, all of which can contribute to fouling. A pH reduction of the microfiltration permeate will put the remaining calcium and metal salts into solution. After the microfiltration step, the next process is ion exchange. The ion exchange process is designed to further reduce the level of heavy metals and inorganic cations (e.g., calcium). Reducing the concentration of these constituents will reduce the potential for membrane fouling.

5.1.7 Sludge Management

KBIC's consultants remarked that KEMC does not have a plan for how the precipitated sludge or the evaporation/crystallization residue will be managed.[32]

KEMC has stated that the waste solids from the sludge handling system and the evaporator/crystallizer system will be managed in accordance with applicable regulations. They will be stored in temporary covered and contained storage areas. Sludge management is outside the authority of the federal UIC program. However, KEMC should consider developing a sludge management plan that identifies how they will handle RCRA and non-RCRA waste.

5.1.8 WWTP Contingencies

The KBIC Comments claim that KEMC does not have a contingency plan for treatment of higher than expected volumes of water or water with substantially higher contaminant concentrations.[33]

[32] The issue regarding the lack of a sludge management plan was discussed in Section 3.5 of KBIC, 2009.

On the contrary, Cadmus notes that KEMC has contingencies built in to their designs. They have conservatively estimated the contaminant concentrations for the truck wash and crusher contact washers. In addition, periodic increases of inflow can be stored at the contact water storage basins. According to the GWDPA (Foth and Van Dyke, 2006a), the contact water storage basins are designed to hold 14 days of mine discharge water. The large volume of the contact water storage basins will allow for temporary maintenance of the WWTP equipment. Excess water from a rain or snow melt event that exceeds the design capacity of the contact water storage basins will be routed to the TDRSA for emergency temporary storage. Also, WWTP effluent will be continuously monitored for key indicator parameters to verify the proper operation. Any effluent not meeting design discharge standards will be pumped back to the contact water storage basins for re-treatment.

5.1.9 WWTP Quality Assurance Measures

The KBIC Comments state that KEMC does not have a clear plan for quality assurance of the treatment process.[34] Many of the concerns that KBIC's consultants have with regard to quality assurance (e.g., membrane cleaning frequency) will be addressed in the WWTP operations and maintenance manual that will be generated after the WWTP is built. KEMC does provide key components of their quality control system. These key components include:

- A **certified** WWTP operator experienced in the operation and maintenance of the treatment processes and equipment used in the wastewater water treatment system.
- Standardized routine operation and maintenance procedures.
- Instrumentation systems designed to allow remote operator monitoring of all critical WWTPs operations.
- Standardized procedures for routine calibration of all wastewater system instrumentation devices such as flow meters, pH meters, Oxidation/Reduction Potential (ORP) meters, conductivity meters, etc.
- Standardized procedures for storage and handling of wastewater treatment chemicals.
- Standardized procedures for approved alternate modes of operation in the event that an individual treatment process is out of operation.
- Standardized procedures for responding to WWTP alarm conditions, including immediate shutdown of all WWTP components if effluent quality may be compromised by the event triggering the alarm.
- Routine testing of raw wastewater, final effluent, and effluent from intermediate treatment processes as required to verify proper and consistent system performance.

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[33] The issue regarding the lack of a contingency plan for treating higher than expected volumes was discussed in Section 3.5 of KBIC, 2009.

[34] The issue regarding the lack of a quality assurance plan was discussed in Section 3.5 of KBIC, 2009.

- Standardized procedures for routing treated water from the effluent storage tank back to the CWBs in the event that the effluent quality does not meet the design discharge standards.
- Wastewater laboratory personnel certified in all analyses required for monitoring of the WWTP.
- Standardized wastewater sample collection, sample analysis, and analysis reporting procedures.
- Implementation of a laboratory quality assurance/quality control plan (Foth Infrastructure and Environment, 2007).

5.1.10 MDEQ Discharge Permit

KBIC's consultants claim that the MDEQ discharge permit for the WWTP effluent does not have numeric effluent limits for key contaminants that are difficult to remove.[35]

The MDEQ discharge permit limits are outside of federal authority; however, Cadmus recommends that EPA consider including limits in their permit for the federally-regulated contaminants.

6 Underground Mine Source Control

There are many techniques available to control water drainage in an underground mine. Two of these techniques are grouting and backfilling. Grouting is the injection of a slurry or grout into the subsurface. The grout fills cracks and voids and is used to strengthen the ground or to make it more water resistant. Loofbourow (1979) suggests that ground water may be diverted by grouting with cement slurries or chemical grouts. Grout and waste in which the sand has been removed can be used to plug solution channels, and clay can be used to plug pores or fractures.

A project conducted under the U.S. EPA Mine Waste Technology Program (EPA, 2005) demonstrated the ability of a polyurethane grout material to reduce the quantity and improve the quality of the drainage from an abandoned mine site. After application of the grout material, the flow was reduced by approximately 77% and the metal loadings were reduced by at least 50%.

Backfilling is the process of pumping or hauling granular material, typically with a small amount of cement, into underground mines to stabilize or seal openings. KEMC will be backfilling the mined out stopes concurrent with the mining of new stopes. The primary stopes will be backfilled with cemented aggregate. The secondary stopes will be backfilled with limestone amended development rock or other aggregate fill material (Foth and Van Dyke, 2006b). KEMC's purpose for backfilling is to provide mine stability and prevent surface subsidence.

[35] The issue regarding the lack of effluent limits for key contaminants in the MDEQ discharge permit was discussed in Section 3.6 of KBIC, 2009.

According to Morin and Hutt (1997), while one common purpose of backfill is to physically stabilize the mine walls, another benefit of backfilling is that it can also control mine drainage by isolating the mine workings from air or water.

7 Conclusions of the Review by Cadmus

This review has entailed examining KEMC's permit application materials and KBIC's comments concerning several key water quality and quantity issues associated with the proposed mining project: the quantity of water that will enter the mine (and ultimately the WWTP), the quality of water that will enter the WWTP, and the operation of the WWTP itself.

As part of the evaluation of water quality expected in the WWTP influent, KEMC conducted extensive static and kinetic tests on the various rock types to determine the potential for ARD generation. This is a common approach to predict the quality of wastewater to be generated from mine components. KEMC has appropriately used these test results to predict the quality of the wastewater generated from the mine and the TDRSA.

Hydrologic modeling is a crucial component of the water quantity evaluation, enabling the generation of quantitative estimates of mine inflow. As part of this review, the SWIFT model was used as an independent check on KEMC's and KBIC's FEFLOW modeling results. The results of the SWIFT modeling are generally consistent with those of the FEFLOW models, even though there are several differences in the numerical implementation and conceptual models. The results are similar responses in the predicted flow. However, without further review and incorporation of geologic data, various alternate representations of fracture flow can easily be conceptualized, resulting in significant variation in the predicted mine inflow rate. Other conceptual models can be conceptualized that are equally plausible.

Based on the information provided by KEMC, the proposed WWTP is designed to provide a level of treatment sufficient to ensure consistent compliance with Michigan's Part 22 Groundwater Quality Standards (Michigan Part 22 Standards, undated). The treatment processes that comprise the WWTP are well established technologies that have been successful in treating the contaminants for which they are designed. In addition, the treatability study conducted by a consultant of KEMC, in the form of bench-scale tests, showed that the Part 22 Standards could be met. However, the study revealed a possible issue with mercury that should be further examined.

References

Bear, J, Beljin, M, & Toss, R. (1992). *Fundamentals of ground-water modeling*. EPA/540/S-92/005. Retrieved from http://www.epa.gov/tio/tsp/download/issue13.pdf.

Blowes, D, Ptacek, C, Jambor, J, & Weisener, C. (2005). The Geochemistry of acid mine drainage. *Environmental Geochemistry*, 9(Chapter 5).

Demircivi, P & Nasun-Saygili, G. (2008). Removal of boron from waste waters by ion exchange in a batch system. *World Academy of Science, Engineering and Technology*, 47, 95-98.

Dydo, P, Turek, M, Ciba, J, Tojanowska, J, & Kluczka, J. (2005). Boron removal from landfill leachate by means of nanofiltration and reverse osmosis. *Proceedings of the European Desalination Society Conference on Desalination and the Environment*.

Earthward Consulting, Inc. (2002). *Data input guide for swift 2002*. Retrieved from http://www.earthwardconsulting.com/swift/usersmanual/.

EPA. (2008). *Drinking water health advisory for boron.* [EPA/822/R-08/013]. Retrieved from http://www.epa.gov/safewater/ccl/pdfs/reg_determine2/healthadvisory_ccl2-reg2_boron.pdf

EPA. (2005). *Underground mine source control demonstration project, EPA mine waste technology program.* [EPA/600/R-05/071]. Retrieved from http://www.epa.gov/nrmrl/pubs/600r05071/600r05071.pdf.

EPA. (2002). *Guidance for quality assurance project plans for modeling.* [EPA/240/R-02/007]. Retrieved from http://www.epa.gov/quality/qs-docs/g5m-final.pdf.

EPA. (2000). *Wastewater technology fact sheet chemical precipitation.* [EPA/832/F-00/018]. Retrieved from www.epa.gov/npdes/pubs/chemical_precipitation.pdf.

Foth and Van Dyke and Associates. (2006a). Eagle project groundwater discharge permit application. *State of Michigan department of environmental quality*. Retrieved from http://www.deq.state.mi.us/documents/deq-ogs-land-mining-metallicminingGWtxt.zip and http://www.deq.state.mi.us/documents/deq-ogs-land-mining-metallicminingGWfig.zip.

Foth and Van Dyke and Associates. (2006b). Eagle project mine permit application. *State of Michigan department of environmental quality.* Retrieved from http://www.deq.state.mi.us/documents/deq-ogs-land-mining-metallicmining-EagleAppWeb.pdf.

Foth Infrastructure and Environment. (2007). Eagle project Class V permit application: appendix b and c. *State of Michigan department of environmental quality.* Retrieved from http://www.epa.gov/r5water/uic/kennecott/pdf/kemc_application/1_permit_application.pdf.

Golder Associates. (2005a). Eagle project bedrock hydrologic investigation mining application, volume 2, appendix b-2. *State of Michigan department of environmental quality*. Retrieved from http://www.deq.state.mi.us/documents/deq-ogs-land-mining-metallicmining-EagleAppWeb.pdf.

Golder Associates. (2005b). Eagle project geotechnical study mining application, volume 1, appendix c-2. *State of Michigan Department of environmental quality*. Retrieved from http://www.deq.state.mi.us/documents/deq-ogs-land-mining-metallicmining-EagleAppWeb.pdf.

Golder Associates. (2006a). Eagle project phase II bedrock hydrogeologic investigation mining application, volume 2, appendix b-3. *Michigan Department of environmental quality*. Retrieved from http://www.deq.state.mi.us/documents/deq-ogs-land-mining-metallicmining-EagleAppWeb.pdf.

Golder Associates. (2006b). Bedrock hydrogeological modeling to assess inflow to proposed eagle project mining application, volume 2, appendix b-4. *Michigan Department of environmental quality*. Retrieved from http://www.deq.state.mi.us/documents/deq-ogs-land-mining-metallicmining-EagleAppWeb.pdf

Hill, M, & Tiedeman, C. (2007). *Effective groundwater model calibration: with analysis of data, sensitivities, predictions, and uncertainty*. Hoboken, New Jersey: Wiley-Interscience.

KEMC. (2008). Proposed findings of fact and conclusions of law. State of Michigan, State Office of Administrative Hearings and Rules.

Kennecott Exploration Corporation. (2005). Eagle project mining permit Application: geology of the eagle nickel-copper deposit, appendix c-1.

Keweenaw Bay Indian Community. (2009). Comments of the Keweenaw Bay Indian Community in opposition to the issuance of an underground injection control permit to Kennecott Eagle Minerals Company. [Application No. MI-103-5W20-0002]. Retrieved from http://www.epa.gov/r5water/uic/kennecott/pdf/stratus_uic_eagleproject_report.pdf

Klasner, J, Snider, D, Cannon, W, & Slack, J. Michigan Department of Natural Resources, Geological Survey Division. (1979). *The Yellow Dog Peridotite and a Possible Buried Igneous Complex of Lower Keweenawan Age in the Northern Peninsula of Michigan* (Report of Investigation 24).

Loofbourow, R. (1979). Controlling mine water. *Proceedings of the first international mine drainage symposium* (848 pp.). Miller Freeman Publications, Inc., San Francisco.

Maidment, D. (1993). *Handbook of hydrology*. McGraw Hill, New York. Retrieved from http://www.earthwardconsulting.com/density_calculator.htm

McGinnis, S. (1999). Treatment of Acid Mine Drainage. Research Paper 99/10. Science and Environment Section. House of Commons Library. UK

Mercer, J & Faust, C. (1981). *Ground Water Modeling*. National Ground Water Association (NGWA), Worthington, Ohio. 60 pp. Retrieved from http://www.ngwa.org.

Michigan Part 22 Standards. (Undated). Available on the Internet at: http://www.michigan.gov/documents/deq/wb-groundwater-P22Standards_248179_7.pdf. Accessed on March 8, 2010.

Moncur, M, Jambor, J, Ptacek, C, & Blowes, D. (2009). Mine drainage from the weathering of sulfide minerals and magnetite. *Applied Geochemistry*, 24(12), 2362-2373.

Morin, K & N Hutt. (1997). Environmental Geochemistry of Minesite Drainage: Practical Theory and Case Studies. MDAG Publishing. Vancouver, BC

Price, W. April 1997. *Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia*, Reclamation Section, Energy and Minerals Division, Ministry of Employment and Investment, BC.

Price, W & J. Errington. (1994). ARD policy for mine sites in British Columbia. *Proceedings of the International land reclamation and mine drainage conference and the third international conference on the abatement of acidic drainage.* Pittsburg. Retrieved from http://www.techtransfer.osmre.gov/nttmainsite/Library/proceed/intl1994/vol4part6.pdf.

Reeves, M, Ward, D, Johns, N, & Cranwell, R. (1986a). *Data input guide for SWIFT- II, the sandia waste-isolation flow and transport model for fractured media, release 4.84.* [NUREG/CR-3162, SAND83-0242]. Albuquerque, NM: Sandia National Laboratories.

Reeves, M, Ward, D, Johns, N, & Cranwell, R. (1986b). *Theory and implementation for SWIFT-II, the sandia waste-isolation flow and transport model for fractured media, release 4.84.* [NUREG/CR-3328, SAND83-1159]. Albuquerque, NM: Sandia National Laboratories.

Sidenko, N & Sherriff, B. (2005). The attenuation of Ni, Zn and Cu, by secondary Fe phases of different crystallinity from surface and ground water of two sulfide mine tailings in Manitoba, Canada. *Applied Geochemistry*, 20, 1180-1194.

Siemens Water Technology. (2007). Treatment test report (Prepared for Foth Infrastructure and Enviroment, LLC. Report No. JWM0726). Houston, TX.

Ward, D., Reeves, M, & Duda, L. (1984). *Verification and field comparison of the sandia waste-isolation flow and transport (SWIFT) model.* [NUREG/CR- 3316, SAND83-1154]. Albuquerque, NM: Sandia National Laboratories.

Attachment 1: The Bedrock at the Site as an Underground Source of Drinking Water

According to Underground Injection Control regulations (40 CFR 144.3), an underground source of drinking water (USDW) is an aquifer or its portion (as long as it is not an exempted aquifer):
(1) Which supplies any public water system; or
(2) Which contains a sufficient quantity of ground water to supply a public water system; and
 (i) Currently supplies drinking water for human consumption; or
 (ii) Contains fewer than 10,000 mg/L total dissolved solids.

The bedrock at the site contains a sufficient quantity of ground water to supply a public water system. A constant rate pumping test was conducted on Well 04EA-84 at a rate of 1 gallon per minute. Transmissivity was calculated to be $3.14 \times 10^{-6}\ m^2/s$ (Golder Associates, 2005a). No problems were encountered with the constant rate of pumping at 1 gallon per minute. This is sufficient to qualify the bedrock as a USDW in terms of quantity of ground water (i.e., condition (2)(i) is met).

According to Table 6.2 of Golder Associates (2005a), total dissolved solids concentrations in five samples from the bedrock were as follows: 124, 128, 272, 210, and 1590 mg/L. This indicates that condition (2)(ii) is met, and the bedrock is indeed a USDW.