Comments on Responses to Request for Additional Information (Class V Treated Water Infiltration System Application): Final Report

Prepared for:

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Task 4.1(a). Assessment of Adequacy of Responses

The following are Cadmus' comments on Kennecott's responses to EPA's request for additional information (UIC Permit Application No. MI-103-5W20-0002). Text from Kennecott is in italics. Comments from Cadmus are in plain type and generally follow responses from Kennecott.

EPA Comment No. 2

EPA Comment No. 2: App. A, Section 2.2.4, Hydraulic Characteristics of Quaternary Formations (p. 15): "At this location, the average D zone transmissivity is about 6,100 gpd/ft and is generally consistent throughout most of the pumping area." What is the basis for this assertion?

Kennecott Response to Comment No. 2: *Section 2 of Appendix A in the UIC application provides background data collected as part of the environmental baseline study (EBS). The hydraulic testing results referred to in this section were completed as part of the EBS, prior to the supplemental hydrogeological study performed for the proposed groundwater discharge area. The discussion of the D zone transmissivity refers to the results obtained for a multi-well pumping test performed as part of the EBS.*

The applicant does not describe the basis for assertion that the transmissivity is consistent throughout the pumping area; the response only mentions that the pumping test was done as part of the initial EBS. Also, the size of the pumping area is not clear.

This test was located south of the area proposed for discharge. The test was completed in a glacial outwash formation of very similar depositional environment, lithology, and grain size characteristics as those present beneath the proposed discharge area. Further discharge area-specific testing was then performed within the saturated portion of this formation beneath the proposed discharge area, as reported in Section 4.3.3 of Appendix A in the UIC application.

The use of the transmissivity value of 6,100 gpd/ft is not relevant for this report. In the hydrogeologic study (Appendix A), Kennecott states that the transmissivity "is likely lower, however, to the north-northeast and south-southeast…." Kennecott notes in their response that the initial test was located south of the proposed discharge area and that additional testing has been done beneath the proposed discharge area. Data for this additional testing are provided in Appendix C (Aquifer Hydraulic Testing Data). A specific capacity test at well QAL031D resulted in transmissivity estimates of 1,230 gpd/ft (pumping) and 1,888 gpd/ft (recovery) (also discussed in section 4.3.3 of Appendix A). These estimates are substantially lower than 6,100 gpd/ft.

EPA Comment No. 3

EPA Comment No. 3: App. A, Section 3.1: Double ring infiltrometer tests are only useful for measuring soil properties for the first few meters below ground surface. Given the thickness of the injection zone at this site (at least 70 feet or 21 meters) and the heterogeneity and anisotropy of soil properties at this site, larger scale tests would be more appropriate for providing a realistic infiltration rate under operating conditions for the TWIS. Permeability should be measured via monitoring wells screened in the unsaturated zone. (Cadmus, p. 5) Please provide data justifying use of the value measured by the double ring infiltrometer to the entire injection zone.

Kennecott Response to Comment No. 3: *The design hydraulic loading or TWIS application rate was set by Michigan R 323.2233(4)(a)(v):*

The design hydraulic loading or application rate, whether daily, monthly, or annual, shall not be more than 7% of the permeability of the most restrictive soil layer within the solum over the area of the discharge as determined by the saturated hydraulic conductivity method or 12% of the permeability as determined by the basin infiltration method. The design annual hydraulic loading rate shall not be more than 3% of the permeability of the solum when determined by either the cylinder infiltration method or air entry permeameter test method. The methods referenced in this paragraph for determining soil permeability are adopted by reference in these rules and are contained in the publication entitled "Methods of Soil Analysis, Part 1, Physical and Mineralogical Properties," Second Edition, American Society of Agronomy, 1986. The publication may be purchased from the American Society of Agronomy, 677 South Segoe Road, Madison, Wisconsin 53711-1086, or the Michigan Department of Environmental Quality, Waste Management Division, P.O. Box 30241, Lansing, Michigan 48909, at a cost at the time of adoption of these rules of $65, plus shipping and handling. A discharger, if utilizing published information, shall determine the methodology used to measure the reported hydraulic conductivity. If published information is utilized and if it is given as a range of expected values, then a discharger shall use the minimum value given the most restrictive soil layer within the solum when calculating the hydraulic loading or application rate.

The solum is defined as soil from the ground surface to a maximum depth of 60 inches.

The infiltrometer tests were performed in accordance with the Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer (ASTM D 3385-03), under constant head conditions. Due to the relatively high infiltration rates, open-topped 55-gallon drums fitted with outflow gate valves and tubing were used to introduce water to the infiltrometers in place of standard volume Mariotte tubes specified in the ASTM Standard. The ASTM standard is very similar to the ASA method referenced in R 323.2233(4) and the MDEQ has accepted the test results submitted as part of the Groundwater Discharge Permit Application. The measured infiltration rates ranged from 24-38 in./h (48-76 ft/d), and 3% of the infiltration ranged from 1.4 to 2.3 ft/d. For reference, 3% of the average measured infiltration rate (62 ft/d) would be 1.8 ft/d.

Measured hydraulic conductivities for the A-zone ranged from 44-61 ft/d (horizontal) and 7% of 44 ft/d is 3.1 ft/d. The application rate was conservatively set to 0.5 ft/d. With conservative selection of TWIS loadings and aquifer hydraulic parameters, the results of various analytical and numerical mounding models (including verification of the analytical modeling by Cadmus) showed that mounding is not expected to be a problem.

It is important to note that, while there is some apparent anisotropy, and a minor finer-grained layer (silty sand or clay) at depths of 60 feet or more, it is clear that infiltration behavior at the TWIS site will be dominated by the reasonably homogeneous sand for much of the depth below ground surface. This was one of the reasons the TWIS was sited in this location.

The infiltrometer results do not provide the necessary information at depth, in general, and in the vicinity of the clay layer, in particular. If the clays observed in the borings from the site are continuous, then they, not the sands, will dominate infiltration behavior at the site. The continuity of the clay layer should be explored. To do this, we suggest constructing a 3-D model using a program such as RockWorks or Target to better visualize the configuration of clay at this location. The cross-sections in the report are insufficient for determining the continuity of the clays.

There are several reasons why a larger-scale infiltration test at the TWIS site is not needed:
♦ Design infiltration rates (0.5 ft/d) were already reduced by more than a factor of 100 from the average of measured infiltration rates (62 ft/d) which were measured at 8 separate locations (North Jackson Co., "Supplemental Hydrogeological Study for Groundwater Discharge," Prepared for Kennecott Minerals Company, January 2006).

Flow from gravel to clay can drop hydraulic conductivity by far more than two orders of magnitude. A design infiltration rate of only two orders of magnitude less than 62 ft/d may not be conservative enough.

♦ In terms of assessing site variability, providing infiltration tests at eight locations is generally preferable to providing larger diameter tests at fewer locations.
♦ The measured rates ranged from 48 to 76 ft/d, and the measured variation over 8 locations does not indicate a significant degree of heterogeneity.
♦ The designed infiltration at scale will not be dictated significantly by the lower measured infiltration rates, since water will flow in the path of least resistance. This will generally lead to a higher-than-average rate of infiltration at scale.

This is not true if the clay layers are continuous. The flow would be dominated by the lower-permeability units.

♦ The sealed double-ring infiltrometer (SDRI) had an inner and outer diameter of 12 inches and 24 inches, respectively, and flows were approximately 1 gpm. Much larger SDRI diameters would lead to much higher flow rates and, in our judgment, would lead to some experimental difficulty in supplying enough water for the tests, since the tests generally last for several hours.

The significance of flow resistance under unsaturated conditions is likely minimal. Given that the design infiltration rate (0.5 ft/d) is considerably less than the measured infiltration rate of 62 ft/d, it is unlikely that a fully saturated condition would be satisfied near the surface. However, the flow-versus-time data record from the infiltration tests shows that a steady flow rate is achieved relatively quickly. If there was a large resistance from unsaturated conditions, there would be a noticeable lag period as the infiltration rate increased to a near-saturated condition.

EPA Comment No. 6

EPA Comment No. 6: App. A, Section 4.4.2 Groundwater Quality: We are concerned about possible reaction between introduced water and the native groundwater in this area. Table 5 presents data about pH but not Eh or dissolved oxygen: have these properties been measured? How will these parameters in the effluent compare to the background values of the water in the aquifer? What will be the impact of adding this volume of water with these characteristics to the aquifer? Please provide information about the mineralogic composition of the injection zone. Do these sediments contain significant concentrations of metals available for mobilization? (Cadmus pp.8-9)

General Comment from Cadmus: The applicant has provided partial responses to Comment No. 6. Kennecott does not present information on dissolved oxygen or Eh directly in the proposed discharge area, although there are two monitoring wells located in the discharge area (QAL031D and QAL041D). The applicant also did not directly compare the effluent and the groundwater compositions. Chemical and mineralogic data have been provided about the aquifer sediments, but the information is incomplete (see below).
Specific comments are noted below:

Kennecott Response to Comment No. 6: *KEMC has assembled all major- and trace-element analyses of soil samples from the proposed TWIS injection zone. The soils are Quaternary glacial outwash that is primarily poorly-graded sand, with minor components ranging from silt to cobbles.*

In the project area, the hydrogeologic report mentions a surface soil layer that is generally less than 1 ft thick and is black, with organic material and tree litter. The description of the glacial outwash in this response (referred to by the applicant as “soil”) seems to refer to the aquifer sediments. It is not clear if the samples listed in Attachment 2 were taken from the surface soil layer or from the deeper aquifer sediments?

The soils are slightly acidic, ranging form soil pH of 4.2 to 6.6, with a mean of 5.1. Table 1 included as Attachment 2, assembles the data and presents the descriptive statistics for the chemically analyzed soils.

Table 2 is not formatted so as to be clearly readable. It lacks a title and the data in the columns do not line up with the column titles. The sample locations are not provided on a map, and their depths are not indicated. We cannot, therefore, determine how representative these samples are of the sediments in the discharge zone. It is also not clear whether they represent the surface soil layer or the sediments at depth. There is no information given on how the samples were taken, prepared, and analyzed.

This table also compiles data on average concentrations of elements in rocks of the upper continental crust from Rudnick, R.H., and S. Gao, 2003, Composition of the Continental Crust, in R.L. Rudnick (ED). The Crust, Volume 3 of H.D. Holland and K.K. Turekian (Eds.), Treatise on Geochemistry. New York: Elsevier, p. 1-64 (Rudnick and Gao, 2003).
Because the table is jumbled, it is not clear which numbers refer to data taken from the various textbooks.

Attachment 3 includes Table 5 from Appendix A of the Class V Permit Application, which presents the shallow (i.e. QAL004A) and deep (i.e. QAL004D) water chemistry form (sic) four groundwater monitoring wells in the vicinity of the proposed injection zone.

QAL004A/D is located approximately 4,800' from the proposed discharge area (see Figure 15 in the hydrogeologic study). It is outside of the Eagle Project, not in the vicinity of the discharge area. Also Attachment 3 includes data from six wells (QAL004A, QAL004D, QAL005A, QAL005D, QAL006A, and QAL006D), not four. QAL005A/D and QAL006A/D are farther from the proposed discharge area than QAL004A/D. Monitoring wells exist in the proposed discharge area (QAL031D, QAL041D). Groundwater chemistry data from these wells would be most directly applicable to the questions being posed by EPA.

Attachment 4 is a report of sediment mineralogy prepared for KEMC by Dr. Rodney C. Johnson in 2008 called Mineralogy of Till Samples from Hole QAL-041. Petrographic Report KEMC 08-003.

This report notes that the sediments were washed to remove fines. It does not state how the sediments were washed. Furthermore, two of the four sediment samples lost at least 20% of their weight due to the washing. Clay-sized particles are geochemically significant in many systems and should not be disregarded. Therefore, the mineralogic information presented is incomplete and not sufficient and cannot support further assessment of water-rock interactions.

Because meteoric precipitation (rain and snowmelt) is always very dilute as stated in Berner, E.K. and R.A. Berner, 1996. Global Environment: Water, Air and Geochemical Cycles, Upper Saddle River, NJ: Prentice Hall[1], solutes in groundwater must derive predominantly from water-rock interactions that occur after infiltration. To understand the potential, if any, for generation of adverse water-quality due to water-rock interaction, it is appropriate to consider the chemistry and mineralogy of the injection zone.

It is commonly understood that precipitation is dilute, and a discussion of meteoric water is not relevant for this report; the groundwater entering the proposed discharge area will have already undergone water-rock interactions. We suggest additional sampling of groundwater within the proposed discharge area.

The most recent authoritative compilation of crustal abundances of elements is that of Rudnick and Gao (2003). In their Tables 1 and 2 (p. 5-6), they compile and critically evaluate data for the upper continental crust, the most appropriate general comparison for purposes of a site like Eagle. Because the glacial sediments derive from the Canadian Shield geologic province and represent a large-scale homogenization of heterogeneous sources from which the parent materials were plucked before transport and re-deposition, it is reasonable that the glacial outwash sediments closely resemble average upper-crustal rocks.

Values compiled in Attachment 2, Table 1, show that the Eagle Project's intrusive rocks are, on average, comparable to, though generally lower in essentially all elements than are average upper continental crustal rocks.

It is unclear which intrusive rocks are being referred to. In the previous paragraph, it is noted that the glacial deposits derive from heterogeneous sources in the Canadian Shield. Are the samples that were analyzed in Attachment 2 (Table 1) from the glacial outwash sediments? If so, they would not represent material from the mafic intrusive rocks referred to in the hydrogeologic report. Furthermore, they cannot be lower in *all* elements than average upper continental crustal rocks; if they are lower in some, they must be higher in others. Does this statement perhaps refer to trace elements?

*Because the mean and median values for the sediment samples are very close to the same, we can consider that it is likely that the populations form (sic) which the samples were drawn is approximately normally distributed, which also is reasonable given the general homogeneity of the sediments. If the normal-distribution assumption is a good approximation, then one can consider the 95th-percentile confidence interval as defined by Student's-t distribution. There are 17 samples, so there are 16 degrees of freedom, and the critical-t value for 16 degrees of freedom is 2.120, as stated in Wonnacott, T.H. and R.J.H. Wonnacott, 1977. Introductory Statistics for Business and Economics, 2nd Ed., New York, John Wiley & Sons. For all measured parameters, even Se in this data set, the average continental crust value falls within the 95th percentile range around the mean value (i.e., mean +/- 2.120*StDev) of the data set. Thus, we can conclude that there are no elemental anomalies in the sediments to serve as significant sources of potential adverse impact to groundwater.*

The question posed by EPA does not concern elemental anomalies or a comparison between the sediment samples and the average continental crust. The question involves the potential for the sediments to release metals into the groundwater. Groundwater samples from monitoring wells outside of the project area contained sporadic low concentrations of arsenic, barium, and mercury. If one were to base a prediction of groundwater trace metal concentrations solely on the similarity between the sediment analyses and average upper crustal composition, these occurrences of trace metals would not have been anticipated.

The ambient groundwater chemistry of the shallow system into which treated water would *discharge is dilute, with most parameters less than detection (Attachment 3, Table 5).*

Again, this statement appears to apply to trace elements as the major ions are certainly detectable. Also, as noted above, the wells in Table 5 are not located in the proposed discharge area.

This is consistent with the elemental chemistry of the solids. Although the soil pH is less than 7 and it also is likely that rainwater has a pH of 5.5 or less (the Minnesota sample cited in footnote 1 had a pH of 4.67), the injection-zone sediments clearly contain some available alkalinity, because the shallow groundwater pH values range from 5.4 to 9.1, with a single value (summer base-flow in QAL006A) less than pH 5. Well QAL004A evidently has a carbonate mineral in the matrix, because it produces titratable carbonate alkalinity ranging form (sic) 40 to 50 mg/L as HCO3- and discernable concentrations of Ca and Mg in solution. In the other two shallow groundwater wells, titratable alkalinity is low to undetectable, but the pH (except for the single base-flow value) is as high or higher than the probable pH of the precipitation. Because rain water and snow melt are very poorly buffered solutions, this small difference in pH indicates that the rock samples are essentially inert in acid-base terms.

The relevance of meteoric water is unclear. This answer does not make a clear linkage between the buffering capacity of the aquifer sediments and concerns about metals release or interactions between the groundwater and treated discharge water.

The dissolved-oxygen concentrations of the shallow zone indicates that the ambient groundwater is well oxygenated and therefore oxidizing; this is confirmed by comparing the ferrous-ion to the total iron concentrations in the shallow completions.

The dissolved oxygen has not been measured directly in the proposed discharge zone. The one sample available in the hydrogeologic report for the discharge zone (QAL031D) did not have a value for dissolved oxygen. However, the water did not contain significant ferrous iron (<0.1 mg/L), suggesting that the water may not be anoxic; this could be easily verified by field measurement. Other D-zone wells to the south and southwest of the project area have low or no measurable dissolved oxygen. The redox status of the groundwater in the proposed discharge zone should be verified.

The mineralogy of the shallow glacial outwash sediments is very simple and entirely consistent with provenance from the grantic terrain of the Canadian Shield: quartz, potassium feldspar and plagioclase, with minor mica and amphibole and trace levels of simple, mechanically-resistant oxides (magnetie-hematite-ilmenite-zircon) and apatite. The mineral grains are subrounded to subangular, in keeping with the geologic history of the deposits. Scanning electron microscopy of the sediments show no significant evidence of secondary ferric hydroxides or oxyhydroxides that could serve as a reservoir for adsorbed metals (such as) that might be mobilized if a new water enters the slow system; this is confirmed by the energy-dispersive spectrometry.

Anoxic groundwater from some of the D zone wells have dissolved iron. It is surprising that there is no evidence of secondary ferric hydroxides or oxyhydroxides in the SEM analysis given that the sandy sediments in the proposed discharge area are consistently described in the logs as having a reddish-brown color. No information was provided on how the sediments were washed prior to SEM analysis and whether the washing would have affected the surfaces of the minerals.

It is possible that the distribution of iron in the sediments in the region is variable. The weathered surfaces of the small amounts of hematite and ilmenite could also serve as a reservoir for adsorbed metals. Furthermore, the fines removed during the washing prior to SEM analysis may have contained iron-bearing phases and/or trace elements. Fines were apparently minimal for two of the four samples. The other two samples lost approximately a quarter of their weight when washed. Thus, the mineralogic analysis is incomplete.

The simple mineralogy and lack of secondary sinks for trace metals are consistent with the low concentrations of trace metals seen in the water chemistry of Attachment 3, Table 5. Finally, the available information on the water-treatment system indicates that the discharge water also will be well oxygenated and circumneutral. Therefore the thermodynamic tendency would be for the new water to move the heterogeneous system closer to stability with respect to ferric oxides. The chemical potential gradients would maintain any sorbed and co-precipitated metals or metalloids in the solid phase, and in fact provide a potential for further control of dissolved metals in solution.

Because (a) the injection-zone sediments have a simple and chemically-stabel (sic) mineralogy and (b) concentrations of elements in the glacial sands of the injection-zone are overwhelmingly lower in concentration than are average crustal rocks, there is no basis to suppose that the sediments could produce solutions that have elevated concentrations with respect to commonly observed ranges in any water:rock reaction. This is confirmed by ambient conditions across a range of naturally-occurring pH from 4.4 to 9.1. The injected solution will be compatible with the pH and Eh of the ambient groundwater, and is very unlikely to cause increased geochemical reactions of any sort.

The concern regarding possible reactions between the TWIS discharge water and the native groundwater is an appropriate consideration, which may be best judged by the characteristics of the treated discharge and the native groundwater. The discharge is planned in an area with a relatively thick and conductive glacial outwash of fine sands, exposed by thousands of years of rainfall and snowmelt. The water quality in the Quaternary aquifer is excellent, with low hardness, low alkalinity, low organic content, low salinity, and low concentrations of trace metals. Water quality results are shown in Table 5 (Appendix A of the UIC Application). Most trace metals in the A-zone wells have been consistently below detection limits. In some A-zone wells, low levels of barium (< 30 ug/L), low level mercury (<0.4 ng/L), and dissolved iron (< 400 ug/L) have been detected. The water has a low alkalinity and hardness, like the discharge. Although deeper, some D-level wells show trace levels of arsenic (< 10 ug/L), these wells are located significantly upgradient of the mine site and TWIS.

Data for groundwater are limited in the discharge zone, and it is unknown if arsenic is present in the sediments in the proposed discharge zone. Distance between the areas where arsenic was detected and the proposed TWIS area is no guarantee that arsenic is not present in the TWIS area. If small amounts of arsenic are present (perhaps associated with small amounts iron oxyhydroxide phases that may not have been detected in the samples that were analyzed), the anticipated oxygenated nature of the TWIS water should minimize the chance for release. Problems with other trace metals are not anticipated.

Since the water is very high quality and the geologic history has included thousands of years of rainfall and snowmelt through the sands, the sands are not expected to contain high levels of trace metals that would be mobilized by the operation of the TWIS.

It should be noted that monitoring plan for the TWIS will include monitoring of the nearby groundwater for trace metals. Trends in the concentrations of trace metals will be tracked carefully.

The mineralogic analysis of the samples from the proposed discharge area does indicate a relatively simple mineralogy (predominantly quartz and feldspar). The highly weathered nature of the regional glacial outwash sediments and the general lack of trace elements in the groundwater samples from other wells in the region suggest a low likelihood of problems with metals in the groundwater due to interactions between the aquifer materials and the treated discharge water. Based on groundwater data from wells outside of the project area, arsenic would be the main trace metal of concern. It was detected primarily in anoxic samples from the D zone, albeit at concentrations less than 10 µg/L. Because the discharge water from the TWIS would not likely be anoxic, it is not expected to promote liberation of any arsenic present in the sediments due to reductive dissolution of iron-bearing phases.

Release of arsenic from sediments may also occur due to elevated pH (>8). The final pH adjustment stage of the water treatment plant would adjust the pH to 6.5-7.5; water from the TWIS would be unlikely to cause arsenic desorption because the pH would be similar to or lower than the ambient groundwater. However, given the incomplete nature of the information regarding the groundwater and sediments in the proposed discharge area, it is recommended that careful groundwater monitoring be done in the TWIS area and downgradient. The applicant acknowledges that groundwater monitoring would take place, although the specific wells to be monitored, their screened intervals, and a sampling schedule have yet to be determined.

EPA Comment No. 9

EPA Comment No. 9: App. D, Page 2, Section 2.2: 400 gpm * 60 min/hr * 24 hr/day * 0.13368 ft^3/gal = 77,000 ft^3/day. At 0.5 ft/day application, this requires 154,000 ft^2, not 153,000 ft^2. Sec. 2.3 has the area of the TWIS as 150 * 1020 = 153,000 ft^2. Please explain this discrepancy. Given that one of the five cells comprising the TWIS will be resting at any given time, in theory only 153,000 * 4/5 = 122,400 ft^2 will be available at any given time. If the need arises, can all five cells be used at once? What contingency plans have been made for periods when not all five cells are operable?

Kennecott Response to Comment No. 9: *The percent difference between 153,000 ft^2 and 154,000 ft^2 is less than 0.7%. The discrepancy is most likely due to precision used for units* *conversion. Considering that the precision of infiltration rates and discharge flows used in the calculation is implied at 10%, the difference is not significant. In addition, the influence of rotating the cells on mounding will be minimal, because the mounding depends mostly on the quantity of discharge over a specified time (which was conservatively selected) and the ability of the sands to distribute the mound, rather than the concentrated area of the mound. This is because the applied infiltration rate is much less than the infiltration capacity.*

The analytical mounding model (Appendix E, of the application) was used to check the influence of reducing the applied area to 4/5ths of the TWIS area. Instead of an infiltration rate of 0.50 ft/d, the infiltration rate would be 0.625 ft/d for the same 400 gpm discharge. The infiltration rate of 0.625 ft/d is approximately 100 times less than the average measured infiltration rate. Using the analytical model in same parameterization for the analytical mounding solution for Scenario 2 in Table 3 of Appendix E of the application, the maximum mounding expected increases from 29.6 feet to 31.5 feet. Since the application of the infiltration will be applied in 4 cells, but rotated over all five cells, the increase of mounding should be less.

It is important to note that the application uses a conservatively selected discharge rate of 400 gpm as the design outflow, even though the maximum discharge rate from the water treatment facility is limited to 350 gpm. Using 350 gpm, 4/5ths of the TWIS area, and (otherwise) the same parameterization for the analytical solution, the maximum mounding is 29.4 feet. Given these results, no contingency plan is needed for periods when not all five cells are operable.

We have rechecked the calculations, and the value of 153,000 ft2 is not a rounding error. Nevertheless, the difference between 153,000 and 154,000 is a small percentage of the total square footage.

The applicant has not answered the question as to whether all five cells can be used at once.

EPA Comment No. 11

EPA Comment No. 11: App. E, Golder Associates Report, page 9, Section 4.1, Infiltration Rate: Did modeling take into account the planned operation having only four cells active at any one time? If not, what effect would this have?

Response to Comment No. 11: *This question is similar to that raised in Comment 9. The modeling did not take into account a reduced area implied by rotating operation of the TWIS cells. Given results from the analytical solution, it is very unlikely that this would be a significant effect at scales relevant to the application.*

The applicant did not answer EPA's question about the effects on the **numerical** model of having only four cells active at one time.

EPA Comment No. 14

EPA Comment No. 14: App. E, Golder Associates Report, Fig. 19: This figure, particularly the 2 ft contour, is very different from Fig. 7 and Fig. 14 in the 2/06 Fletcher & Driscoll Report (App. B- 7 of Environmental Impact Assessment submitted to the Michigan DEQ). The first is a steady state 400 gpm simulation, the second a 10 year simulation apparently using 74.3 gpm base case and the third the upper bound case. Please discuss the significance of the differences.

Kennecott Response to Comment No. 14: *These and other modeling outcomes depend on different assumptions for boundary conditions, parameterization, and methods of calculation. It wouldn't be appropriate to compare solutions without first demonstrating similar solutions for similar inputs. However, the significance of deviations is considered minor. The same general conclusions were found for every mounding analysis conducted for the TWIS, that there is ample storage and flow within the Quaternary aquifer to transmit the discharge, so that mounding is not likely to be a problem.*

The applicant has not discussed the differences in assumptions and parameters or the rationales for choosing the different values in the different studies.

EPA Comment No. 15

EPA Comment No. 15: App. E, Golder Associates Report, Figs. 20 and 22 differ from Figs. 8 and 15 in the Fletcher and Driscoll report. Please discuss the significance of the differences.

Kennecott Response to Comment No. 15: *See response for comment 14.*

The applicant has not discussed the reasons for the use of different boundary conditions and parameters.

EPA Comment No. 16

EPA Comment No. 16: Please explain why additional sensitivity analyses were not provided or run more sensitivity analyses to respond to the concerns stated in the Cadmus report (pp. 18-19).

Kennecott Response to Comment No. 16: *Each modeling exercise for the TWIS was conducted with a parameter sensitivity analysis. Additional sensitivity analyses were not run, because the main conclusions regarding mounding and flow direction were not expected to change significantly. The review report by Cadmus provides the same conclusion. The Cadmus report states that, "Overall the level of sensitivity analysis is judged as being marginally adequate for the modeling purposes." In addition, Cadmus (3.2.3, p.18) states, "The analytical model parameters selected are generally conservative." Most importantly, the Cadmus report (p. 26) states in conclusion that:*

The model does provide reasonable evidence that the glacial deposits do provide adequate hydrogeologic capacity to assimilate the additional infiltration without inundating the site. In other words, the calculations show that a mound will be created raising the water table, and will probably maintain a significant unsaturated zone beneath the site.

The response addresses the first part of the question posed by EPA.

Although the reviewers indicated that the model provides "reasonable evidence" that the glacial deposits do provide adequate hydrogeologic capacity to assimilate the additional infiltration without inundating the site, this does not preclude the need for performing an adequate sensitivity analysis. A more reasonable rationale for the limited sensitivity might be because the model was never properly calibrated.

EPA Comment No. 17

EPA Comment No. 17: MODFLOW modeling: Please provide demonstrations of convergence of the solution, closure and mass balance and any other calculational checks that were performed. Was the water table option used? (Cadmus, pp. 22-25)

Kennecott Response to Comment No. 17: *MODFLOW 2000 was run within GMS (Aquaveo), using the Layer Property Flow (LPF) package and the preconditioned conjugate gradient (PCG2) solver. The maximum number of iterations was 50 for outer nodes and 75 for inner nodes. The convergence criteria for head was 0.05 feet and the residual criteria for flow was 0.1 cubic feet per day. Mass balance errors were -0.78 cubic feet per day (<0.01%) for the quasi-calibration run and -0.25 cubic feet per day (<0.01%) for the recharge (TWIS run) case. The model converged for each reported run case.*

Within the LPF package in GMS, the convertible (type 3) condition was applied, so that layers can switch between unconfined and confined conditions depending on the position of the piezometric surface and top layer surface. Except for the far southwest, constant-head boundary, the upper layer was always unconfined during the simulation and the outcomes for mounding heads represent the expected response to the water table.

The response addresses the question posed by EPA.

It is reassuring that for a water table (unconfined) simulation that the mass balance was less than 1%. This is an expected result and helps to ensure that sufficient iterations were performed. Because of the relative simplicity of the conceptual model, one would expect the numerical convergence to be easily achieved. In all likelihood a reduction in the convergence and residual criteria would not materially change the predicted results.

The selection of a type 3 (convertible with variable transmissivity) is an appropriate selection for the water table conditions.

EPA Comment No. 18

EPA Comment No. 18: Please provide information about the calibration of the numerical model. (Cadmus, p. 25)

Kennecott Response to Comment No. 18: *No formal calibration exercise was performed, as the conceptualization for the MODFLOW model was rather simple and the objective was to model principal components of the system to obtain a rational estimate of the infiltration response. Several features not modeled include natural infiltration, conductance features at the seeps and streams, return flow back to mine inflow, bedrock outcrops, and more complex boundary conditions. For these reasons, it may not be appropriate to simply allow a numerical calibration routine to optimize hydraulic conductivities, for example, to obtain a better fit to observed heads.*

The main hydraulic parameters (Table 1 of Appendix E) were selected from results of baseline studies and uniform boundary heads were assigned to generally match the observed heads. This was deemed adequate in terms of capturing the mounding response near the TWIS, and for capturing general flow directions. A sensitivity analysis was used to better understand model sensitivity (primarily in the amount of mounding) from changes in hydraulic conductivity and porosity parameters.

The response addresses the question posed by EPA.

The premise of the justification for not performing model calibration just because of the simplistic level of conceptualization is incorrect. The model should be calibrated regardless of the level of detail of sophistication.

"The best possible determination of model inputs based on directly related field data can produce model outputs that match the measured equivalents poorly. If the fit is poor enough that the utility of model predictions is questionable, then a decision needs to be made about how to proceed. The choices are to use the predictive model, which has been shown to perform poorly in the circumstances for which testing is possible, or to modify the model so that, at the very least, it matches the available measured equivalents of model results." From page 8 of Mary C. Hill, Claire R. Tiedeman, 2007. "Effective Groundwater Model Calibration: With Analysis of Data, Sensitivities, Predictions, and Uncertainty", Wiley.