Technical Memorandum

NorthMet Mine Site Water Modeling Work Plan

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This technical memorandum considers two aspects of the ongoing modeling for the proposed NorthMet Mine. First, it considers the conceptual model of how flow is being simulated through the proposed mine site. Because the modeling will be probabilistic, the theory behind how the probability distributions for various factors is part of the conceptual model. Second, it considers the parameters used in the modeling, with extra consideration given to how the parameters are chosen for the probabilistic modeling.

The Water Modeling Data Package describes groundwater and transport modeling as a combination of MODFLOW and GoldSim. MODFLOW would be used to establish the base groundwater flow paths, both in a regional and local sense. Optimal conductivity (K) would be estimated by calibrating the MODFLOW model. The calibration of the revised MODFLOW is to the measured well levels and to the estimated discharge of 0.76 cfs to the Partridge River at station SW-004. This calibration varies from that used for the 2008 DEIS in that baseflow is about half the value used then.

None of the documentation reviewed describes how a flow path is established. However, flow charts A-C in the Water Modeling Workplan suggest a flowpath starting at each significant source – a waste rock dump or a pit, for example – and ending at the Partridge River. Various parameters for the flowpaths are established with MODFLOW modeling (calibration) and varied using stochastic modeling within GoldSim. Stochastic modeling is accomplished with Monte Carlo sampling in which a parameter – such as hydraulic conductivity (K) - is chosen randomly from an established probability distribution and the basic equations for the flow path recalculated. Different prediction result from each iteration of the GoldSim model. The results are presented as a probability distribution of load or an envelope of hydrographs, for example.

Conceptual Model Issues for Flow through Minesite

The general conceptual model appears to be simple, and accurate. The Partridge River forms north of the study site, the proposed NorthMet Mine, and flows around the east end of the study site and then to the west south of the site. Recharge to the river's watershed discharges to the river as baseflow; the connection of the surface unconsolidated sediments and the underlying bedrock appears to be slight.

Original regional-scale groundwater modeling was not reviewed for this memo because it is considered a baseline for the continued modeling.

Recharge to the site must provide sufficient inflow to equal the baseflow in the river, based on the assumption that baseflow in the river is the discharge of local recharge. The local model has been recalibrated to reflect a change in the estimated discharge to the Partridge River since the 2008 DEIS modeling. The new calibration lowered the estimated recharge to 0.6 in/y. Based on my experience, this is a very low recharge rate. The Water Modeling Data Package does not discuss the new optimal value, other than to set a range of 0.3 to 1.5 in/y as the bound that should be considered reasonable for different conductivity values along a flow path.

It does not seem correct to recalibrate the local but not the regional model because a change in discharge from the local model area would change the flow distribution in the regional system. It is not acceptable to only recalibrate the local area model if there is an overall change in flux that leaves the system. The flux across the boundaries of the local system, which were determined with the regional model, would change.

MODFLOW would be used to determine the basic flow distribution around the site, and GoldSim would be used to simulate a suite of flows and contaminant concentrations at various points in the study area. GoldSim would use 1-dimensional (1-d) flowpaths through the site to discharge points at the river. The method is similar to the analytical element method sometimes used with MODFLOW in which a section of a model domain is simulated with the analytic equation rather than with the finite difference solution. The flow along the flow path would accumulate natural and minesite recharge and interflow along the pathway. The upper end of the flow path could be a groundwater divide, for which the flow would be zero, or could be the pits when full which would cause a discharge to the flowpath. The pits are clearly not terminal and are a source of contaminants to the flowpath and to the Partridge River. Head at the upper end of the flow path would be based on the MODFLOW modeling (Water Modeling Data Package, p 61). Gradient along the flowpath would depend on the upstream head and the head in the Partridge River.

Probabilistic simulations of flow along a flow path would be done with GoldSim randomly choosing a new K value for each simulation from the probability distribution with the proviso that the newly calculated recharge would range from 0.3 to 1.5 in/y, respectively (Water Modeling Data Package, p 61). This indicates they would change the recharge used in MODFLOW to fit within the gradient and K (new value) of the flowpath. This would change the flow in the flow path and the baseflow in the river. The modelers must consider whether the changed discharge from the flow paths cumulatively still equals the estimated baseflow in the Partridge River.

The conductivity values for the unconsolidated sediments and the bedrock are determined in part by calibrating MODFLOW (the detailed modeling has not been reviewed for this memorandum). There appears to be an assumption of little connection between the unconsolidated aquifer and the bedrock. The reports must consider with pump tests the connections between the aquifers, including between the unconsolidated aquifer and the bedrock, and between the Virginia and Duluth formation. The

MODFLOW simulation must consider this connection because the simplistic solution in the GoldSim model cannot do so.

All precipitation to the pit lake surface becomes inflow to the pit lake; all of the winter precipitation is assumed to accumulate and become input during the snowmelt month. Runoff to the pits is broken into RO_{wall} and RO which are presumably the pit wall and other contributory areas, respectively. Runoff from the pit wall would be considered as a percent of rainfall, based on a distribution with the mean equal to 0.41 and standard deviation equal to 0.117, based on the runoff to the river. The runoff proportion mean was 0.3 with a standard deviation equal to 0.092. Apparently GoldSim determines the amount of runoff from the simulated monthly precipitation value based on a normal distribution with the moments just described. This would not be appropriate because the proportion of precipitation that becomes runoff depends on the amount of precipitation, with a higher proportion occurring during wet months. The wetness of the preceding months, known as antecedent moisture, could also affect the runoff. The modeling should choose a proportion conditioned on the antecedent moisture rather than randomly. This would increase the runoff during wet periods. Failing to do this would decrease the predicted transport from pit lakes and decrease the flow to the pits during mining.

The process pond leakage rate is treated deterministically as 5 gpd/acre. The influence or importance of this leakage should be determined. If the amount of water or contaminant this adds to the water balance of a flow pathway is small, it should be ignored. If it is more than a few percent of the water balance, it should be considered probabilistically like the other inflows to consider the uncertainty in the estimate.

The water balance of waste rock dumps (Water Modeling Data Package, p 94) does not include storage. Rather the model assumes that all water entering the dump during a year also exits it. The authors acknowledge this to be a controversial idea. The assumption could limit the effect of big years, when leftover storage from the preceding year combines with infiltration during the current year to cause a larger of water reaching the liner or containment system.

The method for modeling evapotranspiration (ET) from bare and reclaimed stockpiles does not appear to be correct (Water Modeling Data Package, p 95, 96). The document says they need to "represent the <u>mean</u> fractional evapotranspiration for the stockpiles throughout time and across the entire stockpile footprint", therefore they need a "distribution for the uncertainty in the mean of the entire population (as opposed to the uncertainty in the range of possible observed values)". This suggests they will model the ET as a constant proportion of precipitation through time and only consider the variability around that. The data used to analyze the variability shows that the amount of precipitation that becomes ET varied substantially from year to year (Water Modeling Data Package, Table 6-1, reasons for the difference between FL6 and the others are not clear). The data shows clearly that the ET fraction does not depend simply on the annual precipitation, with the highest precipitation year (1982) not having the lowest proportion lost to ET. This means that ET is not simply a function of water availability. The better way to model this would be to select an ET proportion from the observations using the sample rather than population standard deviation.

Also, they are simulating an average open water evaporation to equal 20.8 in/y, with standard deviation of 1.3 in/y (p 54). If this is appropriate for open water evaporation, it should be appropriate for waste rock.

Inflow to the pits would be determined as a function of depth using MODFLOW and then adjusted for uncertainty based on a probability distribution shown in the following figure. The basis for this distribution should be described. If it is to be legitimate, it should be determined using a stochastic simulation within MODFLOW, as noted in the Recommendations section.

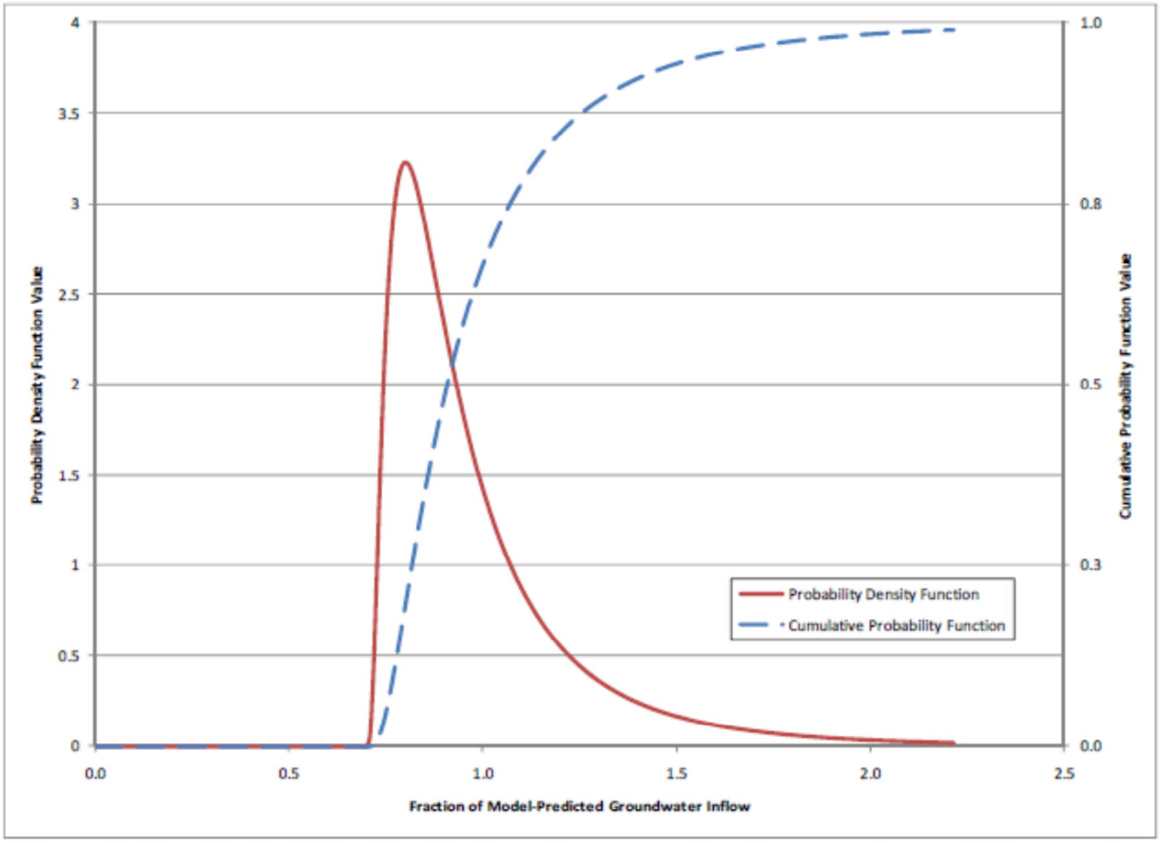

Figure 6-10 Probability distributions for uncertainty in groundwater inflow to pits

The simulated average infiltration in a reclaimed stockpile is 6.1 in/y (Water Modeling Data Package, p 99). It is not clear if this should be assumed to be recharge at that location. If so, it would exceed the calculated natural recharge by about ten times. Because the soil under the stockpile would control the natural recharge, it is unlikely that seepage through the stockpile could all become recharge. However, seepage reaches the soil slower than precipitation so more of it may become recharge.

The model treats sorption as deterministic, except for antimony for which it will be treated as probabilistic. One factor not considered is contact time. The rates of sorption depend on contact time and relative surface areas of the particles. If the surface area does not match that on which the sorption coefficients were based it could be incorrect. This drawback could be overcome by considering sorption coefficients probabilistically.

The GW quality input (background groundwater) is probabilistic only in the sense that a value will be determined as input from the aquifer, bedrock or surficial, for the entire model run. As stated, the "modeling approach utilizes mean bedrock groundwater concentrations that are homogenous across the modeled area and are constant through time, as was done for the surficial aquifer" (p 57). This means the concentration of a given parameter will be constant for the entire run. This ignores temporal variability due to which the concentration may spike for a period of time. Before this approach is accepted, the temporal variability should be considered; determine the standard deviation of the data temporally, if possible, to determine whether a stochastic input with time could result in periods with significantly higher or lower inflow concentrations. The decision, or justification, could also depend on the volume of inflow as compared with the pit volume.

Probability Estimates for Parameters

There are two parameters that generally need estimating for the modeling proposed herein – conductivity and dispersion length. Generally, conductivity values are set based on calibration so that modeled water level approximates the observed water levels and the modeled flux matches the estimated flux, here to the Partridge River. Pump tests and general understanding of the geologic formation also influences the choices for the conductivity values. There is no data with which to calibrate dispersivity.

Vertical conductivity or vertical anisotropy is not discussed in the modeling documents. This is probably because the GoldSim modeling is 1-d. It reflects an oversimplification involved in the GoldSim modeling.

The GoldSim modeling also apparently chooses conductivity values randomly to be used over each 1-d flow path; it is unclear whether there is a separate value for each flowpath. The documentation does not discuss conditioning of the value based on the chosen value for an adjacent flowpath. In other words, if it is strictly random then adjacent flowpaths could have widely different K which would be inappropriate. On the other hand, if one K value is chosen for all the flowpaths within the same aquifer type, the modeling would not be accounting for spatial heterogeneity at all.

GoldSim constructs flowpaths using adjacent cells and models the water balance simultaneously among each cell. It apparently utilizes one K for the entire flowpath. This assumption violates any realistic conceptual model of flow in the aquifers by ignoring heterogeneities. The K could vary along the flow path but the modeling as proposed here fails to account for that. If possible, the GoldSim modeling should use different K estimates for each cell.

Flux to the river depends on recharge and inflow to the model domain; simply this means that inflow equals outflow. It is possible that randomly chosen parameters, even if from realistic and proper probability distributions, will yield completely unrealistic predictions. Such combinations of parameters are not equally likely and should not be used. As stated, these combinations can result from random selections of reasonable parameter probability distributions.

The best to accommodate the uncertainty in K while maintaining spatial correlation is to use stochastic MODFLOW modeling; this would also accommodate changes in vertical conductivity, a factor apparently ignored by GoldSim. Each simulation should start with a set of K within MODFLOW from which the conditions for the 1-d simulation of transport could occur.

Dispersion length is the other parameter that controls concentrations reaching a discharge point. But the GoldSim modeling does not consider dispersion length as part of its probabilistic modeling. Rather, the model cells are set based on the dispersion length, and not adjusted among simulations. Transport calculations depend significantly on the dispersion length used in the calculation, but GoldSim fails to consider its variability. Within GoldSim, I am not aware of how the uncertainty in dispersion length could be considered.

The simplifications just described for dispersion length also render the calculation of vertical and lateral dispersion impossible. A plume becomes wider along its flow path, but that is not considered here. Plumes could overlap with the mass from an adjacent source. This modeling appears to ignore such a possibility.

Recharge rate also varies, but is not apparently chosen stochastically. It depends on the chosen K value (Water Modeling Work Plan, p 8). This is necessary probably because modeled water levels depend on recharge and K; if recharge is constant and K is chosen from the low-value end of the probability distribution, the water level could be much higher than observed.

Recommendations

Probabilistically-based results are preferable to a deterministic result based on the modeler's best guess. They provide a probability that a standard will be exceeded or that a system will fail. There is not a simple dichotomy resulting in a prediction that the project will not violate standards. In this case, the GoldSim model may oversimplify the groundwater quality predictions to a point where they are not useful. MODFLOW may be run using a Monte Carlo simulation to maintain the spatial correlation of parameters. The MODFLOW results could be the input to GoldSim, although the 1-d modeling may oversimplify the transport calculations.

Because MODFLOW results are being manipulated within GoldSim by changing the conductivity parameters, a detailed stochastic sensitivity should be completed within MODFLOW to understand how the Monte Carlo simulations, which will be performed within GoldSim, would affect the MODFLOW results. The sensitivity must include predictions of pit inflow to assess how realistic the GoldSim pit inflow assumptions are, whether the assumed log normal distribution for inflow is realistic. The sensitivity should also assess how the parameter distributions affect the discharge to the Partridge River. Because such discharge is a basis for the calibration, significant changes to the discharge would demonstrate that the GoldSim simulation will not be true to the MODFLOW calibration.