GoldSim Model Evaluation Work Plan
NorthMet Project, Minnesota

ERM Final
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1.0 Introduction

The NorthMet Project Supplemental Draft Environmental Impact Statement (SDEIS) will use GoldSim, a proprietary but publically available dynamic system model (DSM), to predict project effects on the quality of surface water and groundwater at designated evaluation locations within the Project Area. Two separate models are being developed for the NorthMet SDEIS. The first will evaluate the Mine Site, including mine facilities such as open pits, waste rock stockpiles, overburden storage areas, and waste water treatment plant (WWTP). The second will evaluate the Plant Site, including mine facilities such as process plants, ponds, WWTP, existing and future tailings basins, and groundwater collection wells.

Common to both models will be incorporation of hydrological processes including rainfall, evapotranspiration, surface water runoff, infiltration, surface water flow, groundwater flow, and groundwater storage. Chemical processes will include background water chemistry, chemical leaching from mine waste, groundwater solute transport, and seepage/mixing of groundwater into surface water. The water-quality models for the NorthMet Project are probabilistic, meaning that the uncertainty in the parameters describing the release and transport of chemicals is used to estimate uncertainty in the model predictions.

The model calculations incorporate processes and associated input parameters that affect the release and transport of chemicals from site facilities to natural systems beyond the site boundaries (such as perennial streams). During the period since models were first applied for the 2009 NorthMet Draft Environmental Impact Statement (DEIS), they have undergone extensive revision within an “Impact Assessment Planning” (IAP) process, a collaborative effort in which the project Co-lead agencies (MDNR, USACE, and USFS) plus the MPCA and technical representatives from the Cooperating Agencies (USEPA and the Tribes) who have met regularly to define water quality modeling needs. An important component in the IAP process has been to select ranges and probability distributions for model parameters.

The NorthMet water quality models will incorporate the range of transport processes and the uncertainty ranges of model parameters as agreed to by the Co-lead Agencies in IAP, Model Work Plan, and Model Calibration processes. Further, the models are largely transparent, meaning that all of the information on environmental behavior of the proposed NorthMet Project is presented in technical support documents provided by PolyMet and Barr Engineering. In particular, Mine Site and Plant Site Water Modeling Work Plans describe the conceptual models and list the input values and probability

distributions for all model parameters. Technical support for the selection of model parameters is presented in the Mine Site and Plant Site Water Modeling Data Packages.

The GoldSim software contains algorithms that perform unit conversions, simulate solute transport, most importantly, automate Monte Carlo simulations for predicting uncertainty. However, most of the governing equations used in the DSM will be programmed into the GoldSim software by PolyMet's consultant, Barr Engineering. This programming process may introduce computational errors caused by incorrect equations, incorrect conditional statements, or transcription errors.

This memo describes the review process for verifying that the GoldSim water quality models accurately implement the assumptions, inputs, and fate/transport calculations agreed upon by the Co-lead agencies. This verification will be performed by members of the ERM team who are independent of the Project sponsor (PolyMet) and the GoldSim modeler (Barr). This model evaluation work plan is part of a broader GoldSim Water Modeling Process as shown on the attached project flow diagram.

2.0 Review Process

This Model Evaluation Work Plan will be invoked several times during the GoldSim Water Modeling Process. The Plan includes two major tasks for model verification:

- Task 1 - Model Input Review will provide assurance that the approved guidance from the IAP process has been properly incorporated into the models

- Task 2 - Model Computation Review will include checking the model computations for chemical leaching, groundwater and surface water flow, solute transport, and mixing of groundwater into surface water

The review team will have a separate GoldSim license so the model can be operated independently of model developer. Barr will provide fully functioning versions of the site models for ERM evaluation.

For a model of this complexity, it is not feasible to apply *all* verifications to *all* components or calculations performed by the model. The general approach is to perform a reasonable number of initial verifications and then perform additional verifications to model components that are suspect. The verifications depend to some extent on the types of model components being evaluated. Water-related components are relatively straightforward, so emphasis will be placed on inputs, internal computations, and programmed equations. Chemical components are more complex and tend to involve multiple conditional statements in the programming. As a consequence, verification of the chemical components places emphasis on inputs, local/global mass balances, and comparing GoldSim predictions to cases where the results can be calculated independently.

Model components subjected to independent testing will be selected to include those components most likely to affect the predictions of water quality impacts. Specific examples include the Category 1 waste rock stockpile and the West Pit Lake (which will remain as permanent features after closure), the concentration caps applied to solutes in the waste rock (which may reduce predicted solute release), and solutes associated with the mine wastes that could possibly exceed water quality limits in the receiving environment (e.g., sulfate).

It is our understanding that Barr will provide a document presenting all equations that have been programmed into the GoldSim software. The model evaluation will assess the appropriateness of these equations given the model assumptions and where necessary, check that the equations are properly coded into the software. Resident algorithms in GoldSim, such as the Monte Carlo simulator and solute transport module, will not be reviewed. GoldSim has been extensively checked and debugged over its history of development and the resident algorithms are assumed to be correct.

2.1 Task I - Model Input Review

The Model Input Review focuses on checking for correct incorporation of input parameters into the GoldSim model. A Monte Carlo ***simulation*** will typically involve 500 to 1000 transient ***realizations*** (runs) of the water quality computational model, with each realization based on a suite of input parameters. Each realization uses a sequence one-month ***time steps*** to progress through simulated time. This leads to the following types of inputs:

- ***Simulation-deterministic*** parameters are set before the analysis begins (i.e., in the input files) and remain constant for all realizations and all time steps. An example of this type of input is the width of a groundwater flow path.

- ***Realization-uncertain*** parameters are randomly sampled at the beginning of a realization are used for all time steps in that realization. Using a random probability (between 0 and 1), the value for each input is sampled from the associated cumulative probability distribution at the beginning of the realization. An example of this type of input is the hydraulic conductivity of materials within a groundwater flow path.

- ***Time-step-uncertain*** parameters are randomly sampled from the associated cpd's at the beginning of a time step and are reset at the beginning of the next time step. An example of this input is watershed yield. Many of these inputs are randomly sampled on an annual basis (e.g., mean annual rainfall), in which case the sampled value applies to all twelve (monthly) time steps within a particular year.

Model input review takes advantage of GoldSim's ability to export tabulated summaries of model parameters, which can be formatted into Excel spreadsheets. Barr will be directed to program the GoldSim model to produce the following spreadsheets:

- ***Simulation Spreadsheet:*** tabulates all simulation-deterministic parameters used in the Monte Carlo simulation. This spreadsheet will "echo" the values listed in the GoldSim input files.

- ***Realization Spreadsheet:*** tabulates all realization-uncertain parameters. Each line of the spreadsheet will provide the values used for one realization, with the parameter values and associated random probabilities listed in columns. The overall spreadsheet will have 500 to 1000 lines.

- ***Time-Step Spreadsheet:*** tabulates time-step-uncertain inputs and associated random probabilities for a specified number of time steps chosen by the user. Each line of the spreadsheet will contain the uncertain input values and associated random probabilities used for one time step. As a working approach, inputs will be listed for 1000 time steps randomly extracted from the simulation.

Input review will involve checking the compiled spreadsheets and comparing the values with input descriptions provided in the approved final versions of the Mine Site Water Modeling Work Plan (including Tables 1-1 thru 1-34) and Plant Site Water Modeling Work Plan (including Tables 1-1 thru 1-50). For uncertain parameters, the random probability will be checked against the associated cumulative probability distribution to ensure that the associated input value was properly sampled.

If the initial check does not identify any problems with model inputs, the process may be ended at that stage. If problems are identified, additional checks will be performed and any deficiencies will be brought to the attention of the Co-leads and Barr. The review process will continue until the reviewers have reasonable confidence that GoldSim is correctly setting and using the model input values.

2.1.2 Task 1 Reporting and Schedule

It is anticipated that three separate Task 1 reviews will be conducted for each site. The first Task 1 review for a site will be conducted as part of the Model True-up process. A second review will be conducted after completion of the Model Results Check and will focus on changes to the model that occurred since the first review to verify that identified issues have been addressed. The third and final Task 1 review will be part of the Project Refinement process and will be comprehensive, much like the first review.

Each review will be performed after ERM receives a revised site work plan, revised data package, and associated spreadsheets (described above). ERM can complete each review in five work days or less. A summary memo describing the results of each review will be provided about one week after the review is completed.

2.2 Task 2 - Model Computation Review

The Task 2 Model Computation Review will provide a check of GoldSim calculations to ensure that model results are generated from mutually agreed upon equations and algorithms. Task 2 will focus on the internal computations to provide a greater assurance that the GoldSim models function as defined in the work plans, data packages, and approved CDFs. The Model Computation Review described below will be applied separately to both the Mine Site and Plant Site models.

Given the scope and complexity of each model, it is not feasible to check all internal calculations performed by the code. This work plan describes a strategy where the model reports internally computed numerical values and a multi-step verification process is used to assess the validity of those values. The verifications range from professional judgment to independent calculations that assess water/mass balances or attempt to reproduce the model computations in an exact or approximate manner. If the values are judged to be reasonably accurate, it is assumed that the model is performing its computations according to mutually agreed upon algorithms.

The starting point for this process is a detailed flow chart showing the model components and flow pathways between these components. General flow charts are provided in the Mine Site and Plant Site work plans. ERM will request that these general charts be expanded to provide more details regarding the model components and flow routing between components. The next step will be for the ERM to identify discrete points on the flow chart at which flows, concentrations, and/or storage amounts are to be evaluated. In this work plan, each of these is referred to as a ***Calculation Point*** (CP). The CPs will generally be associated with major mine facilities, on flow lines between facilities, and on flow lines between facilities and natural hydrologic features within the receiving environment (e.g., perennial streams). ERM will choose a sufficient number of CPs to provide an adequate sampling of the modeled system, but also limit the total number of CPs to provide efficiency in the Task 2 review.

After the CPs are identified, the GoldSim model will be modified by Barr to generate tabulated data files for each CP on a time step by time step basis. EXCEL spreadsheets are a convenient format for these data files, but other file structures may be agreed upon. For CPs on flow lines, the model output will be flow rates and chemical concentrations. For CPs associated with mine facilities, the model output will generally be stored water volume and chemical mass. The model output will be structured to report chemical concentrations and stored masses for any user-selected chemical constituent. The actual constituents evaluated during Task 2 will be determined by the Co-lead Agencies and communicated to Barr.

To focus on the effects that individual mine facilities could have on downgradient waters, the Task 2 review will consider transport of chemicals along ***Migration Pathways***, each representing a sequence of model connections that transport chemicals from a source (e.g., a waste rock facility) to ***Evaluation Locations*** where concentrations are compared against regulatory standards. The review will also

consider water and mass balances within mutually agreed upon ***Control Volumes*** (CVs). In this work plan, a CV is defined as a model component (or group of components) within which, water and chemical mass cannot be artificially created or lost. Some examples of control volumes are the Cat 1 stockpile, tailings basin cell 2W, and the West Pit. GoldSim operates by moving water and solutes between CVs in discreet steps through time. A mass balance accounts for mass inflow and outflow across the boundaries of the CV and the change of mass inside the CV.

The data files generated by GoldSim will allow the above checks to be made without relying on check-specific programming being added to the GoldSim model. This will insure that the Task 2 checks are performed independently from the GoldSim model developer. It is recognized that the requested data files will be large, but the programming used to create the files is relatively straightforward. In addition, each data set will be created for a single deterministic run, not from multiple realizations generated by the Monte Carlo simulations.

2.2.1 Task 2 Evaluation Process

The Task 2 review will consist of the following three steps:

Step 1. Professional screening evaluation of calculated values at all CPs.

Step 2. Evaluation of water and chemical mass balances for designated CVs throughout the simulation period.

Step 3. Verification of flows and concentrations along selected Migration Pathways at specific times during the simulation.

The ERM review team will conduct deterministic runs of the GoldSim model in order to generate the outputs necessary for Task 2 evaluation. One model run will be based on mean values for input variables. The additional runs may utilize minimums and/or maximums of certain input variables in order to test the model's logic algorithms for handling extreme values. For example, conditions may be simulated in one deterministic run to ensure that leach concentrations are controlled by concentration caps to evaluate this aspect of the model algorithm.

In addition to model outputs, the review team will require access to a complete copy of the GoldSim model to allow for calculation pathway tracing, model logic elucidation, and the ability to obtain additional specific values from model components as needed to complete the Task 2 review. The logic previously added to the GoldSim models for echoing input parameters (Task 1 review) will be retained through the Task 2 evaluation to provide the review team access to spreadsheet compilations of input values used in model calculations.

Specific requirements for each Task 2 evaluation step are described below.

Step 1: Professional evaluation of calculated values at the CPs

Step 1 will involve the use of professional judgment and simple calculations to screen results at CPs for evidence of unlikely values and improbable changes in values over time. While primarily a qualitative assessment, hand and spreadsheet calculations may be performed to provide a basis for judging the reported CP flows, concentrations, and chemical masses. For example, simple calculations may be performed to compute the possible maximum and minimum values for a parameter at a CP. If the GoldSim reported value falls outside this range, the portion of the model computing the value will be flagged for further evaluation. This step will provide a time-efficient way to screen the results of CPs and Migration Pathways for potential problems before progressing to more detailed verification of results determined by specific portions of the model.

Step 1 of the Task 2 evaluation will require Barr to deliver a working version of GoldSim that generates Excel-based time-series output files with flows and concentrations (or chemical masses) for the Agency-selected list of chemical constituents. The initial list of constituents considered in the Task 2 review will be based on professional judgment and mutual agreement between Barr and the Co-Lead Agencies. As the review proceeds, ERM and the Co-lead Agencies may modify the list to include additional chemical constituents of interest. For the constituents considered, the review team will assess the reasonableness of the reported mass flux and chemical concentrations over the course of the model simulation. If necessary, the review team may make additional requests for Barr to output other model values.

Step 2: Evaluation of water and chemical mass balances within selected CVs over the simulation period

Cumulative water volume and chemical mass balances will be used to determine if water and chemicals are properly tracked by the model. After definition of single and multi-component CVs within the model flow chart, water volume and chemical mass flows into and out of each CV will be computed by the review team based on flow and concentration values reported for the associated CPs as part of Step 1. To preserve independence, these calculations will be programmed in the EXCEL spreadsheets by the review team, not the model developer. In addition, the water volume and chemical mass stored within each CV will be accounted for. Water and chemical mass fluxes will be tracked as cumulative values over the course of a deterministic (rather than Monte Carlo) simulation. The resulting values will be used to confirm that the following relationship is maintained in each CV throughout the simulation for both water and chemical constituents:

$$\textit{initial mass} + \textit{cumulative mass in} - \textit{cumulative mass out} = \textit{remaining mass}$$

Output will be evaluated for several deterministic runs in order to confirm the mass balance for mean and extreme input values. A relevant example would be the mass balance of sulfate in Cat 1 waste rock facility, where at the end of a simulation the total amount of soluble sulfate produced by oxidation should equal the mass leached out by

meteoric water + the mass stored in the rock when pore water concentrations were above the concentration cap for sulfate. Results of the mass balances for selected CVs will be presented graphically to illustrate how accurately mass is tracked through the GoldSim model.

Some uncertain input parameters will be modeled to have a covariance structure using algorithms internal to GoldSim. The degree and nature of this relationship is described in GoldSim by a correlation coefficient ranging between -1 and 1. Consider for example two uncertain inputs, A and B, which are modeled to be covariant. While each parameter is statistically sampled from its associated cumulative probability distribution, covariance methods provide a tendency for higher values of A to be associated with higher values of B (positive correlation coefficient) or higher values of A to be associated with lower values of B (negative coefficient). If the values are uncorrelated and completely independent of one another, the correlation coefficient is zero and no algorithms are used in GoldSim to relate the two. As part of the Task 2 evaluation, uncertain inputs that are modeled to be covariance will be plotted on scattergrams to verify that the correlation coefficient used in the model is reflected in the slope of the data points.

Step 3: Independent verification of selected migration pathways at selected time points during the simulation

Step 3 will involve verification of certain model results through independent calculations by the review team. Several representative Migration Pathways will be selected for review. The review team will evaluate a sufficient number of Migration Pathways to provide reasonable assurance that the overall model is performing as proposed. This will be a quantitative assessment, the rigor of which will be assessed and modified during the process. Emphasis will be placed on pathways providing the greatest chemical flux that ultimately reaches the Evaluation Locations where chemical concentrations are compared with regulatory criteria. These pathways will be identified based on scoping calculations and the interim GoldSim model results. For example, in the Plant Site model, emphasis will likely be placed on seepage and chemical concentrations emanating from the Tailings Basin and in associated groundwater and surface water flow paths that carry chemical mass to the Embarrass River. It is anticipated that three or four major pathways will be identified in each site model.

The deterministic runs will be set up to test mean input values as well as extreme ranges of selected input parameters. For example, in tracking chemical migration, the model export process will obtain the values for oxidation rates in mine waste (which is related closely to release rates for most solutes) and the concentration caps (i.e., maximum dissolved concentrations of parameters in pore water) to ensure that the values for these critical parameters applied in the model accurately match the values set in the input. Hydrologic input variables along a Migration Pathway that are required to compute system flow rates (i.e., rainfall, evapotranspiration) will also need to be output to the Excel-based files.

For each selected Migration Pathway, the review team will perform independent calculations to track chemical migration from its source to the Evaluation Location. The calculations will independently compute the mass flux along the pathway and compare this with mass flux simulated in the model. The independent evaluation will be based on a combination of time-step calculations that attempt to reproduce the model computations, use of average conditions over certain time intervals, and min/max calculations that attempt to bracket the model results.

2.2.2 Task 2 Reporting and Schedule

It is anticipated that two Task 2 reviews will be conducted. The first will be performed after completion of the second Task 1 input review and will be part of the Model Results Check. The second will performed after the third Task 1 input review and will be part of the Project Refinement process. Depending on the number of issues identified, each Task 2 evaluation will require 10 to 15 work days of focused effort by two or three people. A summary memo will be competed about 1 week after each Task 2 review is completed.

For each Task 2 evaluation, the review team will document any model outputs that are judged to be unreasonable or that contradict independent calculations performed by the team. Possible discrepancies identified during Task 2 will be discussed with Barr and the Co-lead Agencies before they are identified in the formal record. At the completion of each Task 2 evaluation and after discussion with Barr and the Co-lead Agencies, a memo will be produced detailing all findings including any unresolved discrepancies or errors identified for Co-lead Agency review and comment. Along with the memo, any independent calculations produced by the review team to check model function will be documented in calculation sheets. The team will develop several standard forms to provide hardcopy results from each step in the Task 2 evaluation that can be reviewed by third parties. In many cases, the documented calculations will consist of calculation worksheets that show the input values, equations used, and results/comparisons with the GoldSim outputs.

2.3 Project Coordination

ERM will coordinate with Barr and the Co-lead Agencies to report and correct any input or computational errors uncovered. ERM will submit to the Co-Lead Agencies a summary memo reporting Task 1 results at the end of the Model True-up phase. Separate reports describing both Task 1 and Task 2 results will be provided at the end of the Model Results Check and Project Refinement phase.

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