~~Water~~ Dynamic System Model Evaluation Work Plans
NorthMet Project

Revised Draft
23 December 2011

1.0 Introduction

The NorthMet Project ~~SDEIS~~Supplemental Draft Environmental Impact Statement (SDEIS) will incorporate ~~is using~~~~using~~incorporates ~~computational~~ dynamic system models (DSM) to ~~estimate~~ predict the potential for pollutants ~~that~~ to leach from mine waste ~~to~~ and degrade the quality of surface water and/or groundwater. ~~The generic term for the type of models proposed for the NorthMet project water quality predictions is "dynamic systems models (DSM" (DSMs). These are~~ DSMs use computational tools that track the time-dependent movement of ~~material~~mass~~material~~ through a series of connected physical and chemical processes ~~various compartments~~. The ~~specific code used for the~~ NorthMet project is using GoldSim, a proprietary but publically available DSM. Two separate models are being developed for the NorthMet ~~DEIS~~SDEIS~~DEIS~~. The first will evaluate the Mine Site, including open pits, waste rock stockpiles, overburden storage areas, waste water treatment plant (WWTP), surface water flow, groundwater ~~containment~~storage~~containment~~, and offsite groundwater ~~migration.migration~~flow. The second will ~~cover~~ modelevaluate the Plant Site, including process facilities, ponds, WWTP, existing tailings basin, future tailings disposal, surface water flow, groundwater containment, and offsite groundwater migration. The water-quality models for the NorthMet project are probabilistic, ~~so thatthat~~and~~that~~ uncertainty in the parameters describing the release and transport of pollutants is used to estimate uncertainty in predictions.

The model calculations ~~are supported by~~Incorporate ~~extensive~~ site-specific measurements of pollutant concentrations in the waste and the rate at which these pollutants leach from these materials. ~~In~~ During the period since ~~the~~ models were first applied for the 2009 NorthMet Draft Environmental Impact Statement (DEIS~~,~~),~~,~~ they have undergone extensive revision ~~in~~within~~in~~ an "Impact Assessment Planning" (IAP) process—a collaborative effort in which the project ~~coco~~Co-~~lead~~ Lead agencies (~~MnDNRMnDNR~~MN DNR, USACE, and USFS)~~,~~ plus the MPCA and technical ~~experts~~ representatives from the cooperating ~~participating~~ agencies (USEPA and the tribes) ~~and tribes~~, met ~~repeatedly~~ regularly to define ~~refinement the~~ water quality ~~models~~modeling needs~~models~~. An important component in the IAP process was selecting ranges for model parameters that would contribute to the uncertainty predictions~~predictionprediction uncertainty~~.

The NorthMet water quality models ~~now~~ will incorporate the range of transport effects ~~that the IAP~~ teams~~team identified as important,~~ and the uncertainty ranges ~~in~~ of model parameters ~~spans the range~~ agreed upon by the IAP team. Further, the models are largely transparent, meaning that all of the information on environmental behavior of the proposed NorthMet Mine—sampling and analysis of materials, configurations of the mine facilities, assumptions about water flow and

Comment [ZW1]: What are the materials? Should this be mass?

Comment [ZW2]: What are 'compartments' referring to?

Comment [ZW3]: Should this be storage?

Comment [ZW4]: The measurements are far from extensive.

Comment [MO5]: Is this referring to the humidity cells? If so, please specify.

Comment [ZW6]: It is not clear how the model calculations are supported. The release rates and water quality measurements are being used to calibrate and operate the model.

Comment [MO7]: May want to specify the IAP workgroups that contributed.

Comment [ZW8]: What are the 'mine facilities' referring to?

solute transport—are presented in ~~the~~ technical support documents ~~for the SDEIS.SDEIS~~provided by PolyMet and Barr Engineering. In particular, the work plans developed for the water quality modeling describe in detail the conceptual models and present the ranges for all model parameters (PolyMet, 2011a and 2011b).

A disadvantage of this collaborative model-design process is that the models are ~~moderately~~ complicated. GoldSim contains modules that automate certain calculations, and ~~it does~~ incorporates~~incorporate~~ ~~automatically~~ mass balance tracking, unit conversions, and Monte Carlo ~~tools~~ simulations for ~~propagating~~ predicting uncertainty. ~~But~~ However, many of the governing equations specific to the NorthMet project had to be programmed into the model by PolyMet's consultant, Barr Engineering. In addition to potential errors in conceptualization, which can affect all predictive models, the configuration process for the NorthMet Mine could have introduced computational errors caused by incorrect logic, transcription mistakes, or other errors in the computer code. This memo presents a framework for evaluating whether or not the NorthMet Project ~~water quality modelsmodels~~DSMs accurately implement the ~~assumptions~~geochemical and physical relationships, equations~~assumptions and fate and transport calculationscalculations~~and model parameters agreed upon by the ~~coco~~Co-~~lead~~ Lead agencies.

2.0 Background

~~This~~ The evaluation framework proposed herein ~~is for a "high-level" review, in which the~~ compares GoldSim model ~~is evaluated by comparing model~~ predictions to targeted test cases where results can be calculated independently. This approach is ~~in contrast toto~~different from a more detailed review of computer code, which is generally impractical to ~~conduct~~ simulate for complicated models~~, and may be less reliable method for evaluating overall model accuracy~~.

~~Considering the mass balance~~ Each model calculation ~~component in a high-level review, each model component~~ can be viewed as an *internal* water and/or chemical balance that must meet the following ~~conditions~~mass balance ~~conditions~~equations:

Water volume in – water volume out = change in water volume storage

Chemical mass in – chemical mass out = change in chemical mass storage

These relationships must hold true for each ~~internal~~ component and for the entire system ~~as a whole~~. A typical review conducts an independent calculation to determine whether or not the model is preserving mass balance on individual facilities.

This review focuses on assessing model accuracy in:

- Tracking mass balance (water and chemicals),
- Predicting reaction rates (primarily those related to pollutant ~~dissolutiondissolution~~release) relative to benchmark rates for analogous conditions, and
- Propagating uncertainty from model parameters ~~through~~ to estimate uncertainty in water quality predictions.

Comment [MO9]: Most of the detail in the model inputs are actually laid out in the data packages, work plans only contain the values.

Comment [MO10]: Who will be checking for these computational and conceptualization errors?

Comment [ZW11]: This sentence does not follow from the previous and is slightly ambiguous. It seems to be implying from the previous sentence that programming of equations by Barr could lead to errors in conceptualization.?

Comment [ZW12]: This section contradicts the model review process that is more clearly illustrated in Figure 1. For example, the bullets at the end of this section do not include verification of input parameters. Most of this section could be removed with certain aspects incorporated into the 'Modeling and Model Outcome Review Process' section.

Comment [ZW13]: The previous document included reference to the National Research Council's "Models in Environmental Regulatory Decision Making" and formed the basis for the purpose of this document. That section should be included in the next version of this document under the "Background" section.

Comment [ZW14]: A bit extravagant?

Comment [JBF15]: I disagree in that one cannot review the underlying code that governs how the model works. On the other hand, because the model provides only a basic framework for simulating systems, the governing relationships/equations are necessarily input to the model by the modeler, so the real check is on the modeler rather than on the function of the model. For the latter, the web site provides information to address model function.

Comment [MO16]: MDNR is not suggesting doing one or the other. Checks to independent "target cases" and checks on the inputs used in the model should both be included in this model evaluation plan.

Comment [ZW17]: This is not necessarily true.

Comment [ZW18]: What are the facilities?

Comment [ZW19]: Cannot find where this is addressed in the document. Furthermore, isn't propagating uncertainty through the model a main function of the GoldSim software? Does this function need to be checked?

3.0 ~~Model Evaluation Work PlanPlan~~Modeling and Model Outcome Review Process

The Model Evaluation Work Plan includes two distinct phases that are part of the overall model review process, ~~as conceptualized~~ illustrated below in Figure 1. ~~Approval of this work plan (referred to as the QA/QC document in Figure 1) is a pre-requisite for the Co-Leads to authorize PolyMet to initiate modeling.~~ As part of Phase I, ERM will ~~also~~ conduct a review of model inputs concurrent with the initiation of model execution to provide assurance to the Co-Leads that the approved guidance from the IAP ~~Process~~ process has been properly incorporated into the models. Phase II focuses on the model outputs and specifically addresses hydraulic flow and solute migration. These are clearly related components--pollutants ~~migrate almost entirely as solutes in migrating waterwater~~are transported via flow, but they are addressed separately in this plan because they are managed very differently in the GoldSim model. The ~~GoldSim model~~final modeling ~~output~~ review will be conducted by the Co-Lead agencies and/or their consultants using a separate GoldSim license. .

Comment [ZW20]: These are far from distinct. The two phases are not presented in Figure 1.

Comment [ZW21]: They are? GoldSim uses a solute transport code. Does this code only account for solutes?

Comment [MO22]: Referring to the GoldSim viewer software?

Comment [ZW23]: What type of license? Will ERM receive the model in a form that can be modified or just run?

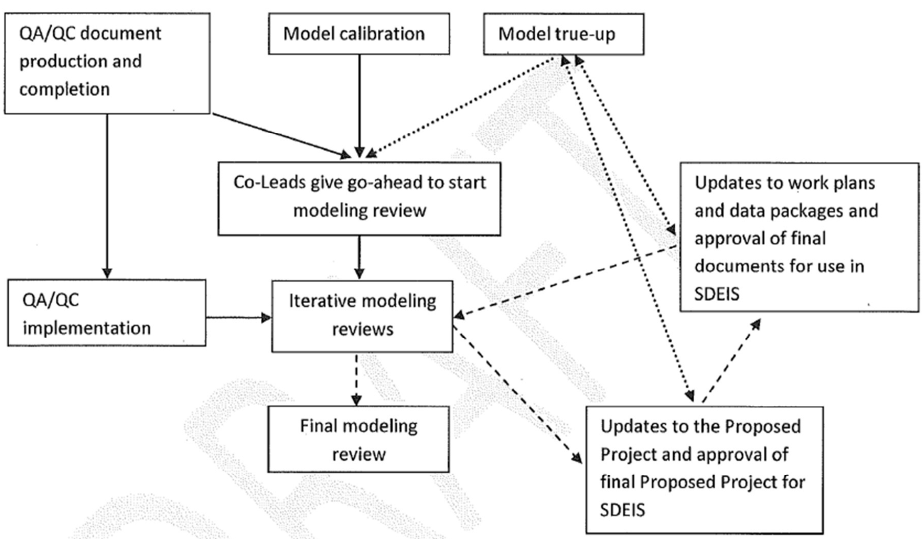

Figure 1. NorthMet EIS Modeling and Model Outcome Review Process
Source: MnDNR, 15 December 2011 (Draft)

Comment [ZW24]: Is this evaluation workplan format is accepted Figure 1 needs to show what boxes are Phase I and II.

3.1 Phase I – Model Input Review

Phase I focuses on model design and inputs and should occur before or at least concurrently with model execution by PolyMet/Barr. ERM will review the inputs to the GoldSim models to ensure

Comment [ZW25]: It is critical that the model design is accurately reflecting the processes agreed upon. For instance 1) there is a link between pH and concentration cap for some solutes, 2) storage of mass occurs once concentration caps are exceeded and this stored mass can be released during periods of increased infiltration, 3) and other checks ensuring the conceptual models (from the various data packages) are being accurately implemented in the DSM.

the~~y reflect the agreed upon guidance~~ values approved by the Co-Leads~~.~~ are accurately incorporated into the model. ~~This~~ The inputs specifically include~~s confirming~~ that ~~the~~ :probabilistic ~~input~~ distributions ~~and the~~, deterministic values, and links between GoldSim elements. ~~established during the IAP Process, as amended by subsequent discussions between PolyMet and the Co-Leads, are accurately incorporated into GoldSim.~~ This work will be led by Fred Marinelli, a subcontractor to ERM and a GoldSim specialist. This work should begin immediately upon approval by the Co-~~Leads~~Lead agencies of this Evaluation Plane~~E~~valuation ~~Plan~~plan.

> **Comment [ZW26]:** It is essential that the links between the elements are correct and accurately reflect interactions among the hydro-geochemical processes.

> **Comment [MO27]:** This work should also include checking the links/relationships between input parameters as well.

3.2 Phase II – Model Output Review

Phase II focuses on ~~model~~checking the model is operating correctly. ~~out puts and will, to some extent,~~Pase II will occur ~~as part of~~~~of~~in conjunction with Barr's iterative modeling, but will primarily focus on ~~confirming~~ determining if the GoldSim model is accurately perfoming calculations.~~computations to again~~ Confirmation of model accuracy will provide the Co-~~Leads~~Lead agencies~~, as well as all~~ and ~~readers of the SDEIS,~~ ~~the~~ with a greater level of assurance that ~~the confidence that~~ the GoldSim model is functioning as proposed in the workplans/data packages~~ed~~~~functioned~~~~functioned~~ ~~properly~~. ERM will evaluate the key model outputs, which include the ~~models~~models'~~models~~ hydraulic and water quality components. ~~We~~ The following describes~~describe~~~~describe~~ ~~below~~ the types of tests and diagnostics ~~that~~ ERM will perform as part of this review.

> **Comment [ML28]:** When and who will check to see if the correct formulas are in the model?

3.2.1 Hydraulic ~~Model~~ Component Evaluation

The evaluation procedures for model hydraulic ~~model~~ components are based on the ~~use of~~on~~of~~ability of GoldSim~~'s ability~~ to export tabulated summaries of model parameters and select results at specified points connecting model ~~cells~~ elements (i.e., between mine facilities) and at selected points in time. ERM will conduct the following three confirmatory tests.

> **Comment [ZW29]:** What are the mine facilities?

1. Confirmation of Values for Temporally-constant Parameters

A standard practice in model review is to "echo" parameter values to demonstrate that the model is using the parameters as entered. This process is somewhat more complicated in the probabilistic model, where many parameters are expressed as random values over specified ranges, but remains a practical test procedure.

> **Comment [MO30]:** Consider word change.

~~Those~~ The water-related inputs (both deterministic and probabilistic) that are established at the beginning of ~~the~~ a simulation and do not change between time steps will be compiled into one Excel spreadsheet. ~~These tabulated results containing the parameter symbol description, units, and, at each new realization, its value.~~ Deterministic parameters remain at constant values~~. But~~ whereas uncertain ~~parameters~~parameter values are reported with their random probability value (between zero and 1)~~ and the associated parameter value taken from the cumulative probability~~ distribution ~~relationship~~. ~~Results from these~~~~t~~These tabulated values of model ~~parameter~~parameters will be assessed for consistency with the ~~assumed~~ actual distributions set as input to the ~~model~~~~model~~DSM.

> **Comment [ZW31]:** This is not a complete sentence and is expendable.

2. Confirmation of Values for Temporally-changing Parameters

This process will check the values used in the model for uncertain parameters that change randomly at each time step. For each model time step, GoldSim will write to a spreadsheet the values for all of the water-related inputs, one line for each time step and columns will list the inputs used during that time step. Deterministic parameters should be represented as a single constant value over time. Parameters that are uncertain over time will be ~~represented by a~~ used to develop a probability distribution that can be compared against the probability distribution assumed in the model input.

3. Confirmation of Hydraulic Mass Balance for Each Mine Facility

The ability to extract information from GoldSim at select time points and at select junctions between facilities will be used to check whether water mass balance is preserved in the model. In practice, water balance can be assessed by having GoldSim write a separate Excel table to record inflows, outflows, and change in storage for each facility at user-selected time steps. Hydraulic mass balance will be calculated for major facilities on the Mine Site (Table 1) and Plant Site (Table 2) at select points in time that cover the simulation period.

Comment [JBF32]: The monte carlo simulation works like this: (1) before a simulation/run is completed, the model selects uncertain parameter values from all cdfs, (2) the uncertain parameter values are set to the values selected randomly from the cdfs, (3) the model simulation/run is completed using the single value chosen for each uncertain parameter. That is, the value of an "uncertain" parameter is "fixed" for a given simulation, but is changed for the next simulation. That is why for a monte carlo analysis the model is run 500 to 1000 times. Only a few model parameters (e.g., precipitation or evaporation) do changes with time-step within a given model run/simulation, but the majority of model parameters, deterministic or uncertain, are fixed for a given model simulation/run.

Comment [JBF33]: This spreadsheet will be quite large as there will be x variables (deterministic and uncertain) by 1000 times (or however many times the model is run)

Comment [ML34]: Is there a way for the model to write the formulas used to the spreadsheet as well?

Comment [ZW35]: What are the mine facilities?

Comment [ZW36]: Again what are the facilities? Are these the 'elements' in the GoldSim model?

Comment [ZW37]: ?

Comment [ZW38]: ?

Comment [JBF39]: Have these been determined? If so reference to where that has been laid out would be helpful.

Table 1. Mine Site Component Water Balances

Component Name	Features Inside the Water Balance Component (refer to Figures A, B, and C in Mine Site Workplan)
Haul Road	Haul Road Pond, Liner, Ground
RTH	RTH Pond, Liner, Ground
LOSP	LOSP, Liner, Ground
Cat 4	Cat 4, Liner, Ground
Cat 2/3	Cat 2/3, Liner, Ground
Cat 1	Cat 1, StW, Cover, GW Containment, Ground (to Partridge R), Ground (to East Pit), Ground (to West Pit)
EQ	EQ Ponds, Liner, Ground
WWTP	WWTP
CPS	CPS Pond, CPS
OSLA	OSLA, StW Mgt, Ground
West Pit	West Pit, Ground
East Pit	East Pit, Ground

Comment [ML40]: Partridge River SW model

Table 2. Plant Site Component Water Balances

Component Name	Features Inside the Water-Balance Component (refer to Figures A, B, and C in Plant Site Workplan [PolyMet 2011b])
HRF	HRF, Liner
Hydromet	Hydrometallurgical Plant~~Plan~~
LTVSMC 2W	LTVSMC Tailings (2W)
2E	Cell 2E Pond
1E	Cell 1E Pond
NM Tails	NorthMet Tailings
Ben	Beneficiation Plant
Beach	NorthMet Beach
LTVSMC E	LTVSMC Tailings (1E / 2E)
Wells	Interception Wells
Embankments	Embankments, Barrier
Seep	Surface Seep SD-026
Toe	Toe of FTB
Buttress	Buttress
GW	Groundwater Transport
River	Embarrass River SW model, Tributaries
5N Pit	Area 5N Pit Overflow, SD-033
FTB WWTP	FTB WWTP

3.2.2 ~~Geochemical~~ Model~~Model~~Water Quality Component Evaluation

Specific components proposed for review of ~~pollutant~~ dissolution~~dissolution~~release rates and ~~migration~~ transport include ~~select tests~~ testing the accuracy of model calculations ~~of calculations accuracy~~ (e.g. mass balance tests comparing solute lost from a source to the mass received down stream) and benchmark~~ing~~ tests of pollution release rates (e.g., sulfate should leach from waste rock ~~facilities~~ at a rate ~~that is~~ related ~~related~~equal to the measured oxidation-rate tests on NorthMet mine rock). Where possible, this evaluation attempts to reproduce major ~~finding~~findings of ~~a~~ the DSM model with ~~a~~ simple ~~calculation~~calculations~~, eliminating at least partially the common complaint that the models~~ are ~~have been rendered opaque by their complexity~~. .

The water quality model evaluation will focus ~~in the review of solute transport is~~ on ~~those~~ ~~components~~pollutants~~components~~ ~~components~~ solutes that are believed to pose the greatest risk to ~~water quality~~ harm the environment. ~~For pollutants, theset~~These are the solutes with surface and groundwater standards that are ~~know~~known~~know~~ to leach from NorthMet Project waste rock and tailings. ~~A~~The Co-Lead agencies and their consultants will select~~A final list of~~ at least 3 representative ~~analytes~~ solutes to use in evaluating model implementation of pollutant behavior. ~~will be selected by the Co-Lead Agencies and their consultants.~~ ~~For facilities, t~~The~~the, the~~ The most important facilitiessites to monitor are those that will be subjected~~subjectsubject~~ to long-term weathering including: the Cat 1 waste rock pile, ~~facility and~~ tailings basin, ~~both of which will oxidize and weather into perpetuity;~~ and the West Pit Lake~~,~~., ~~which will be exposed to the atmosphere for several decades before being flooded by the lake.~~ ~~For chemical effects, the concentratione~~Concentration caps (i.e., maximum concentrations of solutes expected from leachate) ~~in~~ for the Cat 1 waste rock pile ~~have large uncertainty and can have a large effect onon~~could potentially degrade water quality~~ impacts;~~. Therefore, ~~these~~ the concentration caps are included for ~~explicit~~ evaluation in this plan. ~~And for transport pathways, the groundwater between waste rock or tailings and surface water are a major conduit for pollutants, and the solute transport component in this~~the model~~this~~~~this is targeted for independent evaluation.~~ Solute transport from waste rock and tailing basins into groundwater and surface waters is a fundamental environmental concern and is directly addressed in this evaluation plan.

We describe below ten ~~confirmatory~~ tests that will be performed to evaluate if the DSM is correctly simulating impacts to water quality. Houston Kempton will have the lead for conducting these ~~analysesanalyses~~tests, with support from Fred Marinelli and the rest of the ERM Team. As indicated ~~aboveabove~~in Figure 1, this work would begin as soon as ~~some~~ preliminary model results are available, and will comprehensively be conducted on the final model results.

1. Oxidation Rates and Solute Release from Pit Wall Rock

Select a single model year during infilling of the West Pit Lake and compare the change in total mass of SO_4 (plus at least two~~22~~2 other solutes) in the ~~Pit LakeL~~lake predicted by GoldSim model against the change ~~that should have occurredoccurred~~calculated due to loads from wall rock flooding, wall rock runoff, and ground~~-~~water inflow.

Comment [ZW41]: ?

Comment [JBF42]: Only if the calculated concentration remains below gypsum solubility, otherwise there will be chemical mass retention in the waste rock "stock."

Comment [MO43]: Why wouldn't it since the inputs used in the model are derived from the site specific dissolution test?

Comment [MO44]: Sentence needs to be rewritten – not sure what you are trying to say here.

Comment [ZW45]: This technique uses simple calculations to test certain aspects of the DSM. The DSM remains complex.

Comment [MO46]: How do you know this without a sensitivity analysis?

Comment [MO47]: Why only specific elements?

Comment [ZW48]: ?

Comment [ZW49]: pile?

Comment [MO50]: Not sure what this means?

Comment [ZW51]: Actually they are not uncertain at all. They are maximum observed values.

Comment [MO52]: Sentence needs to be rewritten – what interaction is being targeted for an independent evaluation.

Comment [ZW53]: Groundwater is not a conduit, the medium through which flow occurs is.

Implementation

~~Load~~ Total load of sulfate in the pit lake over a time step is ~~is~~includes:

- 50% of sulfate released by oxidation of all wall rock above the lake during the time step,
- 100% of cumulative sulfate stored in the rock that is inundated over the time step,
- 100 % of sulfate produced by oxidation in the rock that is inundated over the time step.
- Groundwater load (flow rate * time step * sulfate concentration in groundwater)

~~This calculation should be done on the West Pit (the East Pit will be backfilled and water quality managed separately).~~

~~In executing e~~Executing the calculation:

- Set the model to average conditions,
- Select a time duration for mass-balance test (e.g., year 10 to 11 after filling begins)
- Run the model past this time and record load changes (volume & concentration) for sulfate ~~SO_4~~ (plus at least ~~2~~two~~22~~ other solutes)
- Independently calculate what the load of sulfate~~$SO_4$$SO_4$$SO_4$~~ (plus at least ~~2~~two~~22~~ other solutes) that should have accumulated~~loadedloadedloaded~~ over the time step, based on wall rock loading and groundwater inflow.

The accuracy of the ~~lake~~ model is determined by comparing the ~~calculated change inin~~total load of sulfate~~$SO_4$$SO_4$~~ SO_4 (and other test solutes) ~~in the West Pit Lake~~ between ~~year 10 and 11, and~~ the model prediction ~~of~~and the independant~~of the same.~~ calculation.

Complications to consider:

- The sulfate production rate increases, then decays over time (eq. 9.3 in Waste Characterization Report, and parameters a_0 and a_1), will the exception of~~exceptexcept that no decay is modeled fo~~r Cat 1 or Virginia Fm. wall rock.
- Rates ~~may~~will~~maymay~~ be scaled down for temperature and fragment size —it is not clear how temperature correction is applied in addition to decay equation parameters a_0 and a_1

Parameters (West Pit):

- Area of each rock type above each level in the pit (PolyMet 2011a, Model work plans, Plant Site, Fig 1-4)
- Average sulfur concentration in the wall rock above each level in the pit (Model work plans, Plant Site: Cat 1 in Fig 1-5, Cat 2/3 in Figure 1-6, Ore in Figure 1-7, [the Model Work Plans for the Plant Site are missing information on sulfur content in Cat 4 Duluth Complex rock)
- Pit volume vs. stage (PolyMet 2011a, Fig 1-1)
- Oxidation rate in the reactive wall rock veneer
  - Cat 1: (PolyMet 2011a, Table 1-24)
  - Cat 2/3: (PolyMet 2011a, Table 1-25)
  - Cat 4 Duluth: (PolyMet 2011a,, Table 1-26)
  - Ore: (PolyMet 2011a, Table 1-27)
- Thickness of wall rock reactive veneer (PolyMet 2011a, Table 1-1, parameters "Wall_Depth_DC" = 1 to 3 m, "Wall_Depth_VF" = 2 to 6 m,

Comment [JBF54]: Please specify this time step.

Comment [ZW55]: Why is this only 50%?

Comment [ZW56]: Stated previously.

Comment [MO57]: Please specify what is meant by "average conditions".

Comment [MO58]: Does this mean 10-11 years into closure?

Comment [ZW59]: Need to include how the comparison determines accuracy.

Comment [MO60]: This should be determined prior to checking the model.

Comment [ZW61]: What is the solution to these complications? Without a solution comparisons between independent and model calculations is not useful.

Comment [MO62]: Are these all of the parameters that will be utilized to perform the independent check?

- Density of wall rock in veneer (PolyMet 2011a, Table 1-1, parameters “WR_Sp_gravity” = 2.93 t/m^3)
- Combined scale factor for temp & size (need to see if this is built into a_0 and a_1 parameters)
  - Decay in oxidation over time (PolyMet 2011c, Eq. 9.3-1; PolyMet 2011a, Table 1-1, parameters = “Decay_a_1” and “Decay_a_0”
  - Equations in PolyMet 2011c, Eq 9.3-1:
    - SO_4 [mg/kg-wk] = 10^{((a_1 * log(time[wks])) + a_0}.

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Comment [ZW63]: This should be done prior to finalizing this document.

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2. *Oxidation Rate in Tailings*

During operations, the tailings will oxidize at a rate that is limited by oxygen diffusion, which in turn is related to the moisture content in the tailings and the intrinsic oxidation rate of the tailings under atmospheric conditions. With GoldSim set to average conditions in a deterministic simulation, the moisture content and ~~intrinsic~~ oxidation rate of the tailings (laboratory rate, scaled by temperature) can be compared to a ~~separate~~ different model calibrated to the NorthMet tailings.

Implementation

Set the GoldSim model to ~~conduct~~ simulate a deterministic simulation of tailings oxidation during mine operations—this will produce fixed values for water flux through and water content in the tailings (PolyMet 2011b [Water Modeling Workplan - Plant Site Ver 11]), then:

- Determine total oxidation rate in the tailings beach estimated~~estimateestimate~~ by GoldSim under average conditions,
- ~~Conduct~~ Simulate a parallel estimate of the total oxidation rate in the tailings beach using the same assumptions (~~intrinsic~~ oxidation rate, porosity, and moisture content) using a ~~separate~~ different model (the Pyrox model was used in the previous 2009 DEIS as a benchmark for comparing the oxidation rate predicted in the NorthMet tailings—see parameters in Table 1-1, "Saturation-Diffusion Inputs", and Table 1-16 for solute release rates in coarse tailings).

Result i~~s~~ comparison of oxidation rates, reported as sulfate production, in GoldSim to the rate estimated by ~~Pyrox~~ a different model..

3. *Solute Transport in Groundwater*

The accuracy of the groundwater transport component in GoldSim will ~~evaluate~~be evaluated by the testing proposed in Barr Engineering's quality assurance plan for the model (PolyMet 2011c, Section 2.4.1 Test Case – Groundwater Transport). The ~~Barr comparison~~ performed by Barr Engineeringquality assurance plan ~~will include development~~includes a comparison between a MODFLOW/MT3DMS simulation~~development of~~ and a deterministic configuration in GoldSim for groundwater flow from the Cat 2/3 stockpile. This evaluation plan will review this comparison to determine whether the results are adequate. If the Co-Lead Agencies determine that a separate and independent evaluation of the groundwater transport model is warranted, they may conduct this using a separate analytical or numerical model that reproduces conditions used in the GoldSim model..

4. *Comparison to Field Scale Analog: Amax Stockpile*

PolyMet's model QAPP includes a benchmark comparison of measured solute release rates from Duluth Complex mine waste under field conditions to solute release rates estimated by a GoldSim model of the same material (PolyMet 2011c, Section 2.4.6 [Model Corroboration – Geochemistry Model of the AMAX Piles]). The AMAX test piles are a ~~collection~~series~~collectioncollection~~ of 1,000-ton waste rock piles that were placed on lined pads

Comment [ZW64]: Specifically, oxidation rate will be limited by oxygen diffusion through an altered layer on the sulfides in an unsaturated environment.

Comment [ZW65]: The meaning of intrinsic oxidation is not clear.

Comment [ZW66]: This sentence must be reworded. It is stating that the oxidation rate is limited by oxygen diffusion which is related to 'intrinsic oxidation', which is circular.

Comment [JBF67]: This is an example of misunderstanding. In effect, each run/simulation of the model is deterministic in that ALL model parameters, except those seasonally dependent and those that decay with time, are set to a fixed value for the duration of a given run/simulation. The probability analysis only derives from 1000s of runs/simulations.

Comment [ZW68]: How do we know that the 'separate model' is correct?

Comment [MO69]: Does ERM have experience using the PYROX model?

Comment [ZW70]: How does comparing two different model outputs prove anything about the validity of the simulation?

Comment [MO71]: Why is sulfate the only parameter being evaluated for the tailings basin model?

Comment [ZW72]: This is not a complete sentence. How much variation between the results is acceptable?

Comment [ZW73]: Is this how the sentence was intended to be written.

Comment [ZW74]: By what criteria will adequacy be determined? Is it adequate to use models by Barr to make an independent evaluation of the DSM?

Comment [MO75]: Not clear what this section is proposing. Please be specific.

Comment [ZW76]: Because GoldSim is proprietary the contaminant transport module should be validated with a publicly available code such as MODFLOW. The DNR has hired consultants to evaluate the GoldSim model. This reads as an unwillingness to conduct such a test.

Comment [MO77]: This exercise was used to determine first principles for scaling f ... [1]

Comment [MO78]: Please define and cite reference.

Comment [ZW79]: Is this the same type of modeling that was previously done in an attempt to validate Polymet's consultant ... [2]

and monitored between 1978 and 1993. The AMAX piles were analyzed to determine sulfur content and particle-size distribution, and splits were subjected to laboratory kinetic testing. This comparison will be reviewed for reliability and applicability as a benchmark test for NorthMet model.

> **Comment [MO80]:** Laboratory data used in Barr's analysis were not splits from the AMAX test piles, it was DCWR humidity cell data from the Babbitt and Dunka Road deposits.

> **Comment [ZW81]:** Again, by what criteria will the QAPP proposed test be deemed reliable?

5. *Waste Rock (Cat 1) Mass Balance*

Sulfate~~TheTheThe~~ A mass balance check ~~on~~ of ~~SO_4~~ (plus at least two~~222~~ other solutes) ~~that is~~ leached out of the Cat 1 waste rock stockpile can be ~~checked~~ calculated by tracking the cumulative mass of each of these solutes leached from the pile over a 200-year model simulation period. The cumulative mass leached out of the ~~facility~~ waste rock pile plus the remaining mass should equal the total mass initially present~~ in the facility~~., ~~or, if~~ If the GoldSim model indicates that some ~~pollutant~~ solutes remain~~s~~ in the waste rock pile after 200 years, then cumulative ~~lost~~ leached mass released~~inin in outflow can be compared to~~ will equal initial total mass ~~less~~ plus the mass remaining in the rock at year 200. This will need to be ~~conducted~~ simulated using a deterministic configuration of the GoldSim model for the Cat 1 stockpile.

> **Comment [MO82]:** Is this the length of each GoldSim realization?

> **Comment [ZW83]:** ?

> **Comment [ZW84]:** ?

> **Comment [ZW85]:** This sentence is not necessary. Delete?

Implementation

- Set Cat 1 waste rock ~~facility~~ parameters to average initial composition (concentrations of sulf~~ide~~ate as a function of %S~~sulfide S~~ and other selected test solutes, and water percolation rate),
- Calculate mass of each solute~~ that should be~~ in the Cat 1 waste rock pile ~~facility~~,
- Record flow and concentration in model discharge from Cat ~~1~~1waste rock pile facility for a 200 year simulation,
- Calculate cumulative sulfate~~$SO_4SO_4SO_4$~~ (plus other selected test solutes) released in flow ~~form~~ from the Cat ~~1~~1waste rock facility,

> **Comment [ZW86]:** ?

> **Comment [MO87]:** Meaning using the average sulfur content of the Cat 1 waste rock (0.06%S)?

> **Comment [ZW88]:** ?

> **Comment [ZW89]:** GoldSim element?

> **Comment [ZW90]:** GoldSim element?

Check mass balance for sulfate~~$SO_4SO_4SO_4$~~ (plus other selected test solutes):

Model mass remaining at ~~yr~~year 200 = (initial mass) – (cumulative ~~load lost~~released~~lost~~mass lost~~, based on flow & concentration~~)

6. *Waste Rock (Cat 2/3, Cat 4 (Duluth Complex and Virginia Formations) Mass Balance*

~~The~~ A mass balance ~~on~~ sulfate~~SO_4SO_4~~check of SO_4 (plus other selected test solutes) ~~that is~~ leached out of the Cat 2/3, Cat 4 (Duluth~~hyDulutyDuluty~~ Duluth Complex) and Cat 4 (Virginia Formation) can be ~~evaluated~~ calculated by tracking cumulative solute release over two discreet ~~singlesingle~~one-year periods: 1) ~~one~~ before onset of acidic conditions, and 2) ~~one~~ after~~.~~ acidic conditions. Over each ~~1~~ one year period, the calculated mass lost from each ~~facility~~waste rock typefacility, ~~as~~ determined by flow and concentration ~~in~~ of the effluent, should equal the loss of mass ~~lost from each facility as~~ recorded in the GoldSim ~~internal~~ model internal mass balance. This check will need to be ~~conducted~~ simulated using a deterministic configuration of the GoldSim model for the rock stockpiles.

> **Comment [ZW91]:** ?

> **Comment [ZW92]:** ?

Implementation

- Set flow rate through the waste rock ~~facilities~~ high enough that concentrations of all solutes are below their ~~solubility~~concentration~~solubility~~ caps (i.e., ~~solubility~~concentration

> **Comment [ZW93]:** ?

~~solubility~~ concentration caps (i.e., ~~solubility~~ concentration caps should not have any effect),

- Set *non-acid concentration~~solubilitysolubilitysolubility~~ concentration caps* to their deterministic median value (PolyMet 2011a, Table 1-31)
- Set *acidic concentration~~solubilitysolubilitysolubility~~ concentration caps* to their deterministic, median values (PolyMet 2011a, Table 1-32, and Table 1-33)
- Record flow and concentrations (sulfate~~$SO_4$$SO_4$$SO_4$~~ plus other selected test solutes) out of each of these three~~33~~ facilities3 waste rock piles~~facilities~~ for the:
  - 1st year (Time 0 to 12 months, before onset of acid in all but Cat 4 VA formation), and
  - 10th year (i.e., after all materials have become acidic).

Check mass balances:

Mass balance on sulfate~~$SO_4$$SO_4$$SO_4$~~:

- Mass of sulfate~~$SO_4$$SO_4$$SO_4$~~ leached over *1st year* (based on flow * concentration) = (*non-acidic oxidation rate* [PolyMet 2011a, Tables 1-25 to 1-28])* (mass of rock)* 1yr
- Mass of sulfate~~$SO_4$$SO_4$$SO_4$~~ leached over *10th year* (based on flow * concentration) = (*acidic oxidation rate*) * (mass of rock)* 1 yr.

Mass balance on other selected test solutes:

- Mass of metal leached over *1st year* (based on model flow * concentration) = (*non-acidic oxidation rate* [PolyMet 2011a, Tables 1-25 to 1-28])) * (mass of rock) * (metal/sulfur (drill core aqua regia)* SO_4 release ratio) * 1yr
- Mass of metal leached over *10th year* (based on model flow * concentration)= (*acidic oxidation rate*) * (metal/ sulfur (drill core aqua regia)* SO_4 release ratio) * (mass of rock) * 1 yr

7. Tailings Mass Balance

~~The~~ A mass balance ~~on~~ sulfate~~$SO_4$$SO_4$~~check of SO_4 (plus other selected test solutes) ~~that is~~ leached out of the tailings over a ~~1~~ one year period can be ~~estimated~~ calculated by multiplying solute concentrations by flow ~~in~~ for the total seepage from the NorthMet tailings. Components ~~in~~ of this flow include discharge to groundwater, discharge to seeps, and discharge to the tailings pond. The mass leached from the tailings over a ~~1~~ one year period should equal the loss in mass of these solutes from the tailings.

Implementation

- Select a one year period during construction of the tailings ~~facility~~basin~~facility~~ (e.g., year 10, the mid point),
- Set the GoldSim model to average conditions for a deterministic simulation,
- Record model flow and model concentrations of sulfate~~$SO_4$$SO_4$$SO_4$~~ (plus other selected test solutes) in discharge from the NorthMet tailings to groundwater, seeps, and the tailings.
- Compare total solutes lost in seepage over the year to mass lost in the GoldSim internal mass-balance tracking

Comment [ZW94]: Does high flow rate result in low concentration? A high flow rate will also result in low pH. How is the correct flow rate determined?

Comment [ZW95]: ?

Comment [MO96]: Release rates used in the model are not all related to the Me/S ratio. This calculation would be constituent specific.

Comment [ZW97]: ?

Comment [ZW98]: What is an acceptable comparison? What exactly are these mass balance tests checking? Is it simply the ability of GoldSim to track mass balance? Mass balance tracking is a hallmark of the GoldSim DSM.

8. Concentration Caps in Waste Rock and Tailings

Concentration caps for the NorthMet project are ~~empirical~~empirically derived maximum ~~allowed~~ values ~~for~~ of solute concentrations ~~in various~~ for mine waste drainage. ~~They are not strictly a component of mass balance, but are more closely related to mass balance than benchmarks.~~ If the GoldSim model is configured so that water flow is very low, then concentrations of all solutes will be at their concentration caps. Comparison of model concentration in effluent from waste rock and tailings~~tailing~~~~tailing~~ against the model ~~solubility~~ concentration caps will test whether or not these ~~concentration caps~~ are implemented correctly. Testing should cover the periods before and after the onset of acidic conditions ~~in~~ for the Cat 2/3~~,~~and Cat 4 waste rock piles ~~,~~ and ore (e.g., before ~4 years, then after ~8 years) to evaluate the implementation of different caps under these two conditions.

Implementation

There are separate ~~solubility~~ concentration caps for the different rock materials (listed in PolyMet 2011a, Water Modeling Workplan – Mine Site Ver 3):

- Cat 1 waste rock and the NorthMet tailings (these are not expected to ever become acidic; see PolyMet 2011a, Table 1-30);
- Cat 2/3, Cat 4, and Ore ~~solubility limits~~concentration caps~~limits~~caps (see PolyMet 2011a, Table 1-31 for non-acidic conditions, PolyMet 2011a, Table 1-32 for acidic conditions in Duluth complex rock, and PolyMet 2011a, Table 1-33 for ~~A~~acidic~~Acidic~~~~Acidic~~ conditions in Virginia Formation rock).
- The West Pit Lake, which will be exposed to the atmosphere for several decades before being flooded by the lake.

The transition from nonacidic to acidic conditions is accompanied by increased release rates and resultant elevated solute concentrations in waste rock drainage. The ~~duration of~~ rock exposure time ~~of rock~~ before ~~it~~drainage~~it~~ becomes acidic~~, causing solute concentrations to jump to a higher threshold,~~ for each rock type is:

- Cat 1 rock and tailings: Infinite
- Cat 2/3 rock: 6.81 years (range 5.33 to 7.99)
- Cat 4 (Duluth ~~c~~Complex~~complex~~~~complex~~): 5.41 years (range 4.97 to 6.81)
- Cat 4 (Virginia ~~f~~Formation~~formation~~~~formation~~): 0 years

Procedure (for tailings, Cat 1, Cat 2/3, and Cat 4 rock):

1. Set ~~solubility~~ concentration caps to deterministic, average values.
2. Reduce meteoric water flow so that all solutes are limited by their ~~solubility limits~~concentration caps~~limits~~caps,
3. Monitor model concentrations of all solutes in discharge from tailings and the ~~3~~three~~3~~~~3~~ waste ~~-~~rock stockpilestypes over a 10 ~~-~~year ~~time~~ period (i.e. beyond when Cat 2/3 and Cat 4 become acidic).

Comment [ZW99]: What is a low water flow rate? Is the 'water flow' specifically referring to a low infiltration rate? Because release rates are variable and if flow rate controls concentration wouldn't the low flow rate selected limit the possible values for the lowest release rates?

Comment [ZW100]: From the text it is not obvious how correct implementation is determined.

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Comment [MO101]: These should be the same concentration caps proposed for the waste rock stockpiles.

Comment [ZW102]: What about pH? pH is the control for many of the concentration caps.

Comment [ZW103]: What is meteoric water flow? Groundwater, surface water, and infiltration?

Comment [ZW104]: Monitor concentrations for what? Monitor where?

9. ~~*Solubility*~~ *Concentration caps in tailings: Uncertainty in SO_4 and other test solutes*

A dramatic reduction in the water flow through the tailings ~~enough~~ would increase oxidation rates and ~~increase~~ solute concentrations in the pore water to ~~the point~~ where~~thatthatthat all solutes are at~~ their concentration caps (concentration caps listed in PolyMet 2011b, Water Modeling Workplan - Plant Site Ver 11 AUG2011, Table 1-16). By setting GoldSim so that water flow into the tailings impoundment is very low, and ~~then~~ fixing all parameters except one concentration cap to deterministic average values (i.e., using GoldSim "sensitivity mode"), the concentrations of a single random variable in seepage from the tailings should have a distribution that matches the uncertainty distribution assumed for the concentration cap for that variable.

Implementation

- Set all parameters in GoldSim tailings model to deterministic average values except ~~for~~ the ~~solubility~~ concentration caps for sulfate~~$SO_4$$SO_4$~~$SO_4$, which remain as random variable~~s~~ (as defined in PolyMet 2011b, Table 1-16).
- Reduce flow rate through the tailings basin so that concentrations of all solutes are limited by their concentration caps.
- Compare the distribution in concentrations of sulfate~~$SO_4$$SO_4$$SO_4$~~ (plus other selected test solutes) in tailings basin seepage to the distributions assumed as input (PolyMet 2011b, Table 1-16) to determine whether uncertainty in concentration caps is propagated accurately through the model.
- Repeat this for the ~~additional 2 or more~~ selected test solutes, in separate "sensitivity mode" GoldSim model runs.

10. *Dissolution Rates in Cat 2/3 Rock: Uncertainty for sulfate~~$SO_4$$SO_4$$SO_4$~~ and other solutes*

The SO_4 release rate is a controlling factor for the release rates of many other elements. ~~The dissolution rates~~ of sulfate~~$SO_4$$SO_4$~~$SO_4$ ~~(and other selected test solutes) in effluent from the Cat 2/3 stockpile are related~~ (i.e., ~~many metals dissolve in proportion~~ metal concentrations are proportional to SO_4 concentration; PolyMet 2011a, Table 1-25 in Water Modeling Workplan - Mine Site Ver 3 complete). By setting GoldSim so that water flow into the Cat 2/3 pile is very high, none of the solutes will be limited by concentration caps, and the probability distributions for solute concentrations in stockpile effluent should be similar to the distributions assumed for dissolution rates.

Implementation

- Set all parameters in GoldSim model simulation of the Cat 2/3 stockpile to deterministic average values except for the dissolution rate of sulfate~~$SO_4$$SO_4$$SO_4$~~ (see values in PolyMet 2011a Table 1-25).
- Increase flow rate through the Cat 2/3 stockpile so that *none of the* solutes are limited by their concentration caps.
- For ~~the last month in the~~ first~~1st1st1st year of modeling (i.e., non-acidic conditions),)~~a selected time interval, compare the distribution ~~in~~ of predicted ~~concentrations of~~ sulfate~~$SO_4$$SO_4$~~ SO_4 concentration(plus other selected test solutes that are linked to SO_4

Comment [ZW105]: Lower flow rate also means higher pH. Because concentration caps are a function of pH and low pH will usually result in higher concentration caps this test is limited in applicability.

Comment [MO106]: What is this function? Sounds like something that might be helpful for many of these geochemistry checks on the model.

Comment [ZW107]: It also depends on how pH is varying. Is there a control on pH?

Comment [ZW108]: This will not work because the SO_4 concentration cap is dependent on elements that are fixed such as Ca, Mg, Na. So this technique will only work for concentration caps that are independently derived.

Comment [ZW109]: It is not clear how this comparison proves correct application of input concentration caps.

Comment [MO110]: Related to what?

Comment [ZW111]: This statement is not clear. It appears to be stating concentration distributions will be similar to dissolution rate distributions.

Comment [ZW112]: Why such a specific evaluation time?

dissolution rates~~) in Cat 2/3 stockpile seepage toto~~and the input distributions ~~assumed in the input~~ for these parameters (PolyMet 2011a, Table 1-25) to determine whether or not uncertainty in predicted ~~stockpile seepageseepage~~concentration distributions is the same as the distribution assumed for the parameters.

Comment [ZW113]: It is not clear what this test is checking.

3.2.3 Model Evaluation Documentation

ERM will coordinate with PolyMet and the Co-Lead agencies to correct any input or computational errors uncovered. ERM will ~~produce~~ submit to the MN DNR a summary report documenting the findings resulting from the Model Evaluation ~~Process~~Work Plan~~Process for the record~~.

4.0 References

CEQ, 1978. Regulations for Implementing NEPA, US Council on Environment Quality, Part 1508 (Terminology). http://ceq.hss.doe.gv/nepa/regs/ceq/toc_ceq.htm

Comment [MO114]: This reference is not cited in the text.

Field Code Changed

NRC, 2007. Models in Environmental Regulatory Decision Making. United States National Research Council. http://www.nap.edu/catalog/11972.html

Comment [MO115]: This reference is not cited in the text.

Field Code Changed

PolyMet Mining (2011a). NorthMet Mine Site Water Modeling Work Plan. September 26, 2011.

PolyMet Mining (2011b). NorthMet Plant Site Water Modeling Work Plan August 11, 2011.

PolyMet Mining (2011c). Mine Site Water Quality Model Quality Assurance Project Plan. November 7, 2011.

Page 10: [1] Comment [MO77] **Mike Olson** **1/3/2012 10:19:00 AM**

This exercise was used to determine first principles for scaling from laboratory to field rates – I think it is being used out of context in this application.

Page 10: [2] Comment [ZW79] **Zach Wenz** **1/3/2012 4:20:00 PM**

Is this the same type of modeling that was previously done in an attempt to validate Polymet's consultants "first principles" scaling factor approach? If it is we know that model is significantly flawed.