Model Evaluation Plans: NorthMet Project Water Quality

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Introduction

The NorthMet Project SDEIS is using computational models to estimate the potential for pollutants that leach from mine waste to degrade the quality of surface or groundwater. These predictive models are based on established conceptual models of mine waste weathering, surface and groundwater flow, and the fate and transport of pollutants in the environment.

The generic term for the type of models proposed for the NorthMet project water quality predictions is "dynamic systems models (DSM). These are computational tools that track the movement of material through various compartments. These specific code used for the NorthMet project is GoldSim, a proprietary but publically available DSM. Two models are being developed for the NorthMet 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, and offsite groundwater migration. The second will cover 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 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 extensive site-specific measurements of pollutant concentrations in the waste and the rate at which these pollutants leach from these materials. In the period since the models were first applied for the 2009 NorthMet DEIS, they have undergone extensive revision in an "Impact Assessment Planning" (IAP) process—a collaborative effort in which the project co-lead agencies (MN DNR, MN PCA, and USFS), and technical experts from participating agencies (EPA) and tribes, met repeatedly to refinement the water quality models. An important component in the IAP process was selecting ranges for model parameters that would contribute to prediction uncertainty.

The NorthMet water quality models now incorporate the range of transport effects that the IAP team identified as important, and uncertainty in model parameters spans the range agreed upon by the 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 solute transport—are presented in the technical support documents for the SDEIS. 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 automatically mass balance tracking, unit conversions, and Monte Carlo tools for propagating uncertainty. But 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 errors in conceptualization, which can affect all predictive models, the configuration process for the NorthMet Mine could have introduced computational errors caused incorrect logic, transcription mistakes, or other errors in the computer code. This memo presents a framework for evaluating whether the NorthMet project water quality models accurately implement the assumptions and fate and transport calculations agreed upon by the co-lead agencies.

Policy Guidance for Evaluating Environmental Models

This model review plan relies on policy guidance to identify a specific set of criteria that, when met, demonstrate that the technical analysis performed to estimate water quality effects from the NorthMet project are reliable enough to support the requirements of EIS reporting and water quality permitting.

The general requirements for adequacy are in the National Environmental Policy Act (NEPA, the regulations that require environmental impacts statements; CEQ, 1978). An EIS is required to identify "any adverse environmental effects which cannot be avoided should the proposal be implemented." The "effects" are defined specifically to include "direct effects, which are caused by the action and occur at the same time and place [and] indirect effects, which are caused by the action and are later in time or farther removed in distance, but are reasonably foreseeable." Specific to the NorthMet Project, potential effects include short- and long-term degradation of water quality caused by solutes leaching from mine waste.

Where such quantitative predictions are part of the EIS, NEPA guidance explicitly requires the EIS preparer to evaluate the "Methodology and scientific accuracy" of the analysis:

> Agencies shall insure the professional integrity, including scientific integrity, of the discussions and analyses in environmental impact statements. They shall identify any methodologies used and shall make explicit reference by footnote to the scientific and other sources rely upon for conclusions in the statement (CEQ, 1978).

But NEPA was promulgated in 1970, before the broad application of computational models in environmental studies. The standards for environmental assessments have since increased as prediction technology has advanced. This original statute provides little specific guidance on how to demonstrate scientific integrity in current modeling projects.

In response, the quantitative assessment of model reliability used here follows the specific guidance provided by the U.S. National Research Council in their report "Models in Environmental Regulatory Decision Making" (NRC 2007). The following excerpts from this

NRC report address specifically the key topics of concern identified during the initial review of the NorthMet modeling studies.

On model evaluation:
"…where the committee describes the process of model evaluation, it adopts the perspective…that a model is a 'tool' designed to fulfill a task—providing scientific and technical support in the regulatory decision-making process—not a 'truth-generating machine'."

On use of proprietary models:
"The committee recommends that EPA adopt a preference for nonproprietary software for environmental modeling… only adopt proprietary models when a clear and well documented case has been made that the advantages of using such models outweigh the costs in lower credibility and transparency that accompanies reliance on proprietary models. Furthermore, proprietary models should be subject to rigorous quality requirements and to peer review that is equivalent to peer review for public models."

On communicating uncertainties:
"…Effective decision making will require providing policy makers with more than a single probability distribution for a model result (and certainly more than just a single number, such as the expected net benefit, with no indication of uncertainty)".

"…performing uncertainty analysis for environmental regulatory activities requires extensive discussion between analysts and decision makers."

"…in practice, it will be necessary to make strategic choices about which sources of uncertainty justify [probabilistic] treatment and which sources are better handled through less formal means, such as consideration of how model outputs change as an input varies through a range of plausible values."

The specific components in this Model Evaluation Plan reflect guidance for environmental modeling presented in the NRC 2007 report, and the specific characteristics of the GoldSim model that has been developed to estimate water quality effects from the NorthMet project.

Background: Rationale for Designing Model Evaluation Plans

The GoldSim model is able to conduct, among other things, water flow and solute-migration at mines. It is a proprietary code, and thus somewhat inconsistent with the recommendations in the 2007 NRC guidance. However, GoldSim appears to have largely circumvented this concern by allowing open execution and sensitivity testing of any GoldSim models using the GoldSim web page. Further, it does present significant advantages for this project, including internal mass balance tracking, cross-checking for consistency in units, and Monte Carlo simulation to estimate prediction uncertainty. As a result, the co-lead agencies have not expressed concern over selection of this platform for the NorthMet SDEIS.

This evaluation framework proposed herein is for a "high-level" review, in which results are evaluated in a number of targeted test cases where results are known. This approach is in

contrast to a more detailed review of computer code, which is generally impractical to conduct for complicated models, and may be less reliable method for evaluating overall model accuracy. In this high-level review, the model is run with a set of input data and calculations associated with certain internal components are checked independently with hand or spreadsheet calculations.

Considering the mass balance 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:

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 for each internal component and for the system as a whole. A typical review conducts an independent calculation to determine whether the model is preserving mass balance on individual facilities.

The framework for the model evaluation plan is drawn from the list of criteria in the National Research Council's guidance on environmental modeling (NRC 2007):

- Adequacy of conceptual models,
- Accuracy of mass-balance accounting,
- "Benchmark" checks on rates (e.g., chemical reactions, calibration to measured field conditions or analog sites, etc.),
- Corroboration of model results with observations,
- Peer review, and
- Assessment of prediction uncertainty.

The conceptual models were refined and approved as part of the IAP process, and are described in the Mine Site and Plant Site model Work Plans (PolyMet, 2011a and 2011b). As a result, no additional review of the conceptual models is included in this plan. Similarly, the peer review requirement has been met by this review of conceptual models and associated modification of parameter values that was conducted by the technical members of the co-lead agencies. Model results are being corroborated by PolyMet as part of the internal quality control (PolyMet, 2011c). Corroboration tests include comparison of predicted vs. observed surface water quality under baseline conditions, and predicted pollutant load rates from well-studies analogous waste rock facilities (the AMAX test piles, which are composed of Duluth Complex rock similar NorthMet Project waste). The final components in the peer review process is the independent evaluation of model results proposed herein, and the upcoming review of the model results by co-lead agencies. Finally, the uncertainty assessment has been rigorously incorporated through the Monte Carlo capabilities of the GoldSim code, again reflecting parameter ranges selected with input from technical peer reviewers during the IAP process.

That leaves the focus of this review primarily on assessing the model accuracy in:

- Tracking mass balance (water and chemicals),
- Predicting reaction rates (primarily pollutant dissolution) relative to benchmark rates for analogous conditions, and

- Propagating uncertainty from model parameters through to estimate uncertainty in water quality predictions.

Taken together, these model-review components from the NRC guidance address most concerns related to the NEPA requirement for the "EIS preparer to evaluate the computations and describe these methods."

Model Evaluation Work Plan

This Evaluation Plan addresses separately the components related to hydraulic flow solute migration. These are clearly related components--pollutants migrate almost entirely as solutes in migrating water. But they are addressed separately in this plan because they are managed very differently in the GoldSim model. Water balance is a more standard component of DSM models, and model parameters and mass balance can be checked often through comparison against parameter values and mass balance extracted from GoldSim. In contrast, the chemical balance has more constraints (changes in dissolution rates, maximum allowable concentrations, etc.). The chemical components are more often checked by designing model test cases that will generate known results.

Hydraulic Model Evaluation

The evaluation procedures for hydraulic model components are based use of GoldSim's ability to export tabulated summaries of model parameters and select results at specified points connecting model cells (i.e., between mine facilities) and at selected points in time.

Confirmation of values for temporally-constant parameters in model execution

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.

The GoldSim models will set to writes parameter values used in a Monte Carlo simulation to an Excel spreadsheets. Those water-related inputs (both deterministic and uncertain) that are established at the beginning of the 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 uncertain parameters are reported with their random probability value (between zero and 1) and the associated parameter value taken from the cumulative probability relationship. Results from these tabulated values of model parameter will be assessed for consistency with the assumed distributions set as input to the model.

Confirmation of values for temporally changing parameters in model execution

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 probability distribution that can be compared against the probability distribution assumed in the model input.

Confirmation of hydraulic mass balance on 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.

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

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 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

Geochemical Model Evaluation

Specific components proposed for review of pollutant dissolution and migration include select tests of calculations accuracy (e.g. mass balance tests comparing solute lost from a source to the mass received down stream) and benchmarking tests of pollution release rates (e.g., sulfate should leach from waste rock facilities at a rate that is related to the measured oxidation-rate tests

on NorthMet mine rock). Where possible, this evaluation attempts to reproduce major finding of a model with a simple calculation, eliminating at least partially the common complaint that the models have been rendered opaque by their complexity.

The focus in the review of solute transport is on those components that are believed to pose the greatest risk to water quality. For pollutants, these are the solutes with surface and groundwater standards that are know to leach from NorthMet Project waste rock and tailings: sulfate (the direct product of mine waste oxidation), nickel, copper, and arsenic. For facilities, the most important are those that will be subject to long-term weathering: the Cat1 waste rock 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 concentration caps (i.e., maximum concentrations of solutes expected from leachate) in the Cat1 rock have large uncertainty and can have a large effect on water quality impacts; these 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 is targeted for independent evaluation.

Benchmark Comparisons in Geochemical Model

The benchmarks compare rates of chemical reactions predicted by the NorthMet models against rates observed in independent but analogous situations.

Oxidation rates and solute release from pit wall rock

Concept

Select a single model year during infilling of the West Pit Lake and compare the change in total mass of SO4, As, and Ni in the Pit Lake predicted by GoldSim model against the change that should have occurred due to loads from wall rock flooding, wall rock runoff, and ground water inflow.

Implementation

Load of sulfate in the pit lake over a time step is:

- 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 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 SO4, As, and Ni load changes (volume & concentration)
- Independently calculate what the load of SO4, As, and Ni that should have loaded 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 in load of SO4, As, and Ni in the West Pit Lake between year 10 and 11, and the model prediction of the same.

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), except that no decay is modeled for Cat 1 or Virginia Fm. wall rock.
- Rates may 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: Cat1 in Fig 1-5, Cat2/3 in Figure 1-6, Ore in Figure 1-7, [the Model Work Plans for the Plant Site are missing information on sulfur content in Cat4 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)
    - Cat4 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,
- 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_a1" and "Decay_a0"
    - Equations in PolyMet 2011c, Eq 9.3-1:
        - SO4[mg/kg-wk] = 10^{((a_1 * log(time[wks])) + a_0}

Oxidation rate in tailings

Concept

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 model calibrated to the NorthMet tailings.

Implementation

Set the GoldSim model to conduct a deterministic simulation of tailings 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 estimate by GoldSim under average conditions,
- Conduct a parallel estimate of total oxidation rate in the tailings beach using the same assumptions (intrinsic oxidation rate, porosity, and moisture content) using a separate 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 is comparison of oxidation rates, reported as sulfate production, in GoldSim to the rate estimated by Pyrox model.

Solute transport in groundwater

The accuracy of the groundwater transport component in GoldSim will evaluate 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 will include development of a deterministic configuration in GoldSim for groundwater flow from the Cat2/3 stockpile. This evaluation plan will review this comparison to determine whether the results are adequate.

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 of 1,000-ton waste rock that were placed on lined pads 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.

Mass Balance Evaluations in Geochemical Model

Waste Rock (Cat1) Mass Balance

Concept

The mass balance on sulfate, As & Ni that is leached out of the Cat1 waste rock stockpile can be checked 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 should equal the total mass initially present in the facility, or, if the GoldSim model indicates that some pollutant remains in the waste rock pile after 200 years, then cumulative lost mass in outflow can be compared to initial total mass less the mass remaining in the rock at year 200. This will need to be conducted using a deterministic configuration of the GoldSim model for the Cat1 stockpile.

Implementation

- Set Cat1 rock facility to average initial composition (sulfide S, Ni, As, water percolation rate),
- Calculate mass of each solute that should be in the Cat1 facility,
- Record flow and concentration in model discharge from Cat1 facility for 200 year simulation,
- Calculate cumulative SO4, Ni, and As released in flow form the Cat1 facility,

Check mass balance for SO4, As, and Ni:

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

Waste Rock (Cat2/3, Cat4(Duluth Complex), Cat4(Virginia Formation) Mass Balance

Concept

The mass balance on sulfate, As & Ni that is leached out of the Cat2/3, Cat4 (Duluty Complex) and Cat4 (Virginia Formation) can be evaluated by tracking cumulative solute release over two discreet single-year periods: one before onset of acidic conditions, and one after. Over each 1-year period, the mass lost from each facility, as determined by flow and concentration in effluent, should equal the mass lost from each facility as recorded in the GoldSim internal model mass balance. This will need to be conducted using a deterministic configuration of the GoldSim model for the rock stockpiles.

Implementation

Set flow rate through waste rock facilities high enough that concentrations of all solutes are below their solubility caps (i.e., solubility caps should not have any effect),
Set *non-acid solubility caps* to their deterministic median value (PolyMet 2011a, Table 1-31)
Set *acidic solubility caps* to their deterministic, median values (PolyMet 2011a, Table 1-32, and Table 1-33)
Record flow and concentration (SO4, As, Ni) out of each of these 3 facilities for:

- 1st year (Time 0 to 12 months, before onset of acid in all but Cat4 VA formation), and
- 10th year (i.e., after all materials have become acidic).

Check mass balances:

<u>Mass balance on SO4:</u>
Mass of SO4 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 SO4 leached over *10th year* (based on flow * concentration) =
(*acidic oxidation rate*) * (mass of rock)* 1 yr.

<u>Mass balance on As and Ni:</u>
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/SO4 release ratio) * 1yr
Mass of metal leached over *10th year* (based on model flow * concentration)=

(*acidic oxidation rate*) * (metal/SO4 release ratio) * (mass of rock) * 1 yr

Tailings Mass Balance

Concept

The mass balance on sulfate, As & Ni that is leached out of the tailings over a 1-year period can be estimated by multiplying solute concentrations by flow in the total seepage from the NorthMet tailings. Components in this flow include discharge to groundwater, discharge to seeps, and discharge to the tailings pond. The mass leached from the tailings over a 1-year period should equal the loss in mass of these solutes from the tailings.

Implementation

- Select a year during construction of the tailings 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, As, and Ni 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

Concentration caps in waste rock and tailings

"Concentration caps" are empirical maximum-allowed values for solute concentrations in various mine waste. They are not strictly a component of mass balance, but are more closely related to mass balance than benchmarks.

Concept

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 tailing against the model solubility caps will test whether these concentration caps are implemented correctly. Testing should cover the periods before *and after* the onset of acidic conditions in Cat2/3, Cat4, 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 caps for the different materials (listed in PolyMet 2011a, Water Modeling Workplan – Mine Site Ver 3):

- Cat1 waste rock and the NorthMet tailings (these are not expected to ever become acidic; see PolyMet 2011a, Table 1-30);
- Cat2/3, Cat4, and Ore solubility limits (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 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 duration of exposure of rock before it becomes acidic, causing solute concentrations to jump to a higher threshold, is:

- Cat1 rock and tailings: Infinite
- Cat2/3 rock: 6.81 years (range 5.33 to 7.99)
- Cat4 (Duluth complex): 5.41 years (range 4.97 to 6.81)
- Cat4 (Virginia formation): 0 years

Procedure (for tailings, Cat 1, Cat2/3, and Cat 4 rock):

1. Set solubility caps to deterministic, average values.
2. Reduce meteoric water flow so that all solutes are limited by their solubility limits,
3. Monitor model concentrations of all solutes in discharge from tailings and the 3 waste-rock over 10-year time (i.e. beyond when Cat2/3 and Cat4 become acidic).

Uncertainty Propagation in Geochemical Model

A simple method to test the accuracy of the Monte Carlo uncertainty propagation algorithm is to select a parameter that is related linearly to a model result, then conduct a simulation with all parameters except this one set to deterministic values and observe whether the distribution in the result is the same as the distribution in the one random parameter.

Solubility caps in tailings: Uncertainty in SO4, As, and Ni

Concept

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 that 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 fixing all parameters except a concentration cap to deterministic average values, the concentrations of random variable in seepage from the tailings should have a distribution that matches the uncertainty distribution assumed for the random variable.

Implementation

- Set all parameters in GoldSim tailings model to deterministic average values except for the solubility caps for SO4, As, and Ni, which remain as random variables (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 SO4, As, and Ni 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.

Dissolution Rates in Cat2/3 Rock: Uncertainty in SO4, As, and Ni

Concept

The dissolution rates SO4, As, and Ni in effluent from the Cat2/3 stockpile are related (i.e., As and Ni dissolve in proportion to SO4; PolyMet 2011a, Table 1-25 in Water Modeling Workplan - Mine Site Ver 3 complete). By setting GoldSim so that water flow into the Cat2/3 pile is very high, none of the solutes will be limited by concentration caps, and the probability distributions for their concentrations in stockpile effluent should be similar to the distributions assumed for dissolution rates.

Implementation

- Set all parameters in GoldSim model simulation of the Cat2/3 stockpile to deterministic average values except for the dissolution rates (PolyMet 2011a Table 1-25).
- Increase flow rate through the Cat2/3 stockpile so that *none of the* solutes are limited by their concentration caps.
- For the last month in the 1st year of modeling (i.e., non-acidic conditions), compare the distribution in predicted concentrations of SO4, As, and Ni in Cat2/3 stockpile seepage to the distributions assumed in the input for these parameters (PolyMet 2011a, Table 1-25) to determine whether uncertainty in predicted stockpile seepage is the same as the distribution assumed for the parameters.

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