Documentation Report

NorthMet Project GoldSim Mine Site Model
Version 5.0
Project I.D.: 12P777

Poly Met Mining, Inc.
St. Paul, Minnesota

June 2013
NorthMet Project GoldSim Mine Site Model

Version 5.0

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Prepared for

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NorthMet Project GoldSim Mine Site Model

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NorthMet Project GoldSim Mine Site Model

Executive Summary

This document describes in detail Version 5.0 of the GoldSim model developed for the Mine Site at Poly Met Mining, Inc.'s (PolyMet) proposed NorthMet Mine. All inputs, calculations, and outputs are presented as they are applied in the model, and as described in the Water Modeling Data Package Volume 1 – Mine Site.

The GoldSim model described in this document simulates the transfer and storage of water and constituent mass at the mine site on a month-by-month basis. A number of submodels (or “component models”) are used to calculate the different quantities needed to estimate the movement of water and constituent mass through and from the mine site.

A climate model calculates the amount of precipitation and evaporation during each month. Separate component models for the Category 1, Category 2/3 and Category 4 waste rock stockpiles estimate the amount of water and constituent mass loading from each stockpile to other modeled areas. Water flows and mass loads are also determined for the ore surge pile (OSP), overburden storage and laydown area (OSLA), rail transfer hopper and haul roads. Modeled outflows from these areas are determined in three separate submodels and the outflows from each are directed to other component models.

Water and dissolved mass movement from the East and Central Pits is modeled in another submodel, which also accounts for the backfilling of waste rock into the pits after mining operations in each pit are complete. A submodel of the West Pit similarly calculates the water and mass stored within and flowing from the west pit. However, unlike the East and Central Pits, the West Pit will not be backfilled with waste rock; it will be filled exclusively with water.

The waste water treatment facility (WWTF) submodel simulates water treatment during active mining operations, during the reclamation phase, and over the long-term (after the west pit has filled).

Groundwater flow from the mine site is simulated by eight separate flow path submodels: three through the bedrock, and five through the surficial aquifer. Two of the bedrock flow paths originate from the West Pit, and the other originates from the East Pit. The surficial aquifer flow paths originate from the West Pit, OSLA, WWTF, OSP, and the East Pit. All eight flow path models simulate water flow and mass loading from the flow path to the Partridge River, which is modeled using a series of nine river reaches. In addition to water and constituent mass derived from the mine site, the component models account for water and constituent mass from runoff and natural groundwater inflows.

Constituent mass is released from the various different areas and types of exposed rock based on many factors. A summary of the methods used to calculate constituent mass release from exposed rock in the different component models is given in the final section of this document. Descriptions of the calculations used to determine the maximum dissolved concentrations (“concentration caps”) and surface water quality standards—against which model results in the Partridge River are compared—are also given for each constituent in the final section.
In compiling this document, the authors reviewed each GoldSim element and documented, in report format, the specific calculations that are made within the GoldSim model. This review of equations and calculation logic, performed by individuals other than those who developed the models, did not uncover any modeling errors, providing a greater level of confidence in the model formulations.
1 Introduction

Poly Met Mining Inc. has developed a detailed plan to begin mining at a new location near Hoyt Lakes, MN (the “NorthMet” mine). The impacts of the mine on local water resources are predicted by modeling while accounting for the uncertainty in many future environmental factors (e.g. infiltration of rainfall into waste rock stockpiles and the subsequent mass leaching). As a result of this type of uncertainty, the GoldSim modeling software has been used to develop a probabilistic model of the mine site in order to predict a range of potential effects of the mine on surface water and groundwater resources in the area. The range of model results is used to assess the likelihood of certain outcomes (e.g. compliance with surface water quality standards) being realized during and after mining operations at the site.

The structure of the GoldSim model and the calculations used within the model to represent each mine site feature are described in detail in this document. The primary goal of this document is to describe how the GoldSim model works, and to provide model reviewers with a reference for model review. An understanding of how the model is constructed will be a critical part of interpreting and assessing model results. The conceptual models which form the basis for the hydrologic and geochemical components of the computational GoldSim model may be found in the Water Modeling Data Package Volume 1 – Mine Site, and the Waste Characterization Data Package developed by Poly Met.

In compiling this document, the authors reviewed each GoldSim element and documented, in report format, the specific calculations that are made within the GoldSim model. This review of equations and calculation logic, performed by individuals other than those who developed the models, did not uncover any modeling errors, providing a greater level of confidence in the model formulations.
2 Model Setup

2.1 Simulation Structure

The Mine Site model is comprised of several component models that simulate the storage and flow of water and constituent mass during mining operations, the reclamation phase, and afterward (“long-term”). Specifically, the component models are used to simulate water flow and mass transport in each of the stockpile areas, the mine pits, the waste water treatment facilities (WWTFS), groundwater flow paths, and the receiving water body (the Partridge River). A climate model is used to generate precipitation and evaporation inputs to the other component models. The mass transport calculations in the component models include calculations of constituent concentrations in water that can be compared to water-quality standards. The water balance and mass transport equations comprising each component model require input values for their independent variables. Many of these independent variables are explicitly defined as model inputs (all of which are discussed in the ensuing sections of this document). Input variables are either deterministic (assumed to be known with certainty) or probabilistic (assumed to be uncertain). A probabilistic input variable is sampled via Monte Carlo analysis to produce unique and deterministic instances, or realizations, of the uncertain variable.

2.2 Simulation Settings

2.2.1 Simulation Time and Time Stepping

Each simulation is executed for 200 years using time-steps of one month (30.4375 days each). The total number of time steps in each simulation is therefore 2400.

2.2.2 Deterministic Simulations

A deterministic (single-realization) simulation can be made with GoldSim by setting each probabilistic input to a deterministic value. By default, probabilistic input variables are set to their median (50th percentile, or \( P_{50} \)) values in a deterministic simulation. Inputs that are set up to be resampled periodically during the simulation do not vary in a deterministic simulation.

2.2.3 Monte Carlo Simulations

In the Monte Carlo simulation mode, 500 realizations are simulated. Each realization uses a different set of values for probabilistic inputs, randomly selected (“sampled”) from their input distributions. Probabilistic inputs that are set up to be resampled periodically during the simulation take on newly sampled values at the assigned frequency and therefore vary in time.

2.2.4 Constituents (“Species”) Simulated

Mass storage, load, and concentration is simulated for the following twenty-seven constituents (chemical species): silver (Ag), aluminum (Al), alkalinity, arsenic (As), boron (B), barium (Ba), beryllium (Be), calcium (Ca), cadmium (Cd), chloride (Cl), cobalt (Co), chromium (Cr), copper (Cu), fluoride (F), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), sulfate (SO\(_4\)), thallium (Tl), vanadium (V) and zinc (Zn).
3 Climate Model

3.1 Purpose

The climate model is used to simulate variable precipitation and evaporation. The model calculates monthly precipitation and open-water evaporation fluxes (dimensions of length per time [L/T]) along with a flag to indicate if the precipitation is snow or rain.

3.2 Input

The following input variables are defined for the climate model:

1. Annual_Precip_Cuberoot [L/T]^{1/3} – Cube-root of annual precipitation amount
   - Probabilistic input resampled each year
   - Normal distribution (mean = 3.05 (in/yr)^{1/3}; standard deviation = 0.16 (in/yr)^{1/3})
2. Monthly_Precip_Factors [-] – Percentage of annual precipitation falling in each month
   - Deterministic input
   - Values given in Table 1-11 of Attachment B to the Water Modeling Data Package Volume 1 – Mine Site (“WMDP-MS-Attachment B”)
3. Annual_Evap [L/T] – Annual evaporation rate
   - Probabilistic input resampled each year
   - Normal distribution (mean = 20.8 in/yr; standard deviation = 1.33 in/yr)
4. Monthly_Evap_Factors [-] – Percentage of annual evaporation occurring in each month
   - Deterministic input
   - Values given in Table 1-11 of WMDP-MS-Attachment B
5. Snowmelt [-] – Month during which snowmelt occurs
   - Deterministic input; equal to 4 (April)
6. Freezeup [-] – Month when “freezeup” occurs
   - Deterministic input; equal to 11 (November)

3.3 Calculations

The cube-root of annual precipitation (“Annual_Precip_Cuberoot”) is used to calculate annual precipitation as follows:

\[
\text{Annual Precipitation [in/yr]} = (\text{Annual_Precip_Cuberoot})^3 \quad (3-1)
\]

Monthly precipitation rates are subsequently calculated from this annual precipitation rate using the percentages of annual precipitation in each month, “Monthly_Precip_Factors” (which sum to 100%) and Equation 3-2:

\[
\text{Monthly Precipitation [L/T]} = \text{Annual Precipitation} \times \text{Monthly_Precip_Factors} \quad (3-2)
\]

Annual evaporation rates (“Annual_Evap”) are sampled directly from a distribution. Monthly evaporation rates are then calculated in the same way as monthly precipitation, using the analogous list of monthly percentages (“Monthly_Evap_Factors”) and the formula:
Monthly Evaporation \[[\text{L/T}]\] = Annual\_Evap \times Monthly\_Evap\_Factors \hspace{1cm} (3-3)

The variables Snowmelt and Freezeup are used to define the months during which precipitation falls as snow (November–March) and as rain (April–October).

### 3.4 Output

The climate model calculates the following fluxes and used by other component models:
- Monthly precipitation
- Monthly evaporation

The model also determines the physical state of precipitation occurring during each month.
4 **Category 1 Waste Rock Stockpile Model**

4.1 **Purpose**

This model is used to simulate water flow and mass transport through the Category 1 Waste Rock Stockpile. The model calculates water flows and associated constituent mass loads (for all twenty-seven constituents) that are routed to other component models, including the models for the West Pit and the WWTF.

4.2 **Input**

4.2.1 **Inputs from Other Models**

- Monthly Precipitation [L/T], calculated in Equation 3-2
- West Pit water level, determined in Section 11
- Operating status (active or inactive) of the WWTF used during mining operations, determined in Section 12
- Operating status (active or inactive) of the WWTF used during the Reclamation phase (RWWTF), determined in Section 12
- West Pit water level, determined in Section 11
- Operating status (active or inactive) of the long-term waste water treatment facility (LTWWTF), determined in Section 12

4.2.2 **Water Balance Inputs**

1. **Bare_RO [-]** – Fraction of precipitation that runs off of a bare (uncapped) stockpile
   - Deterministic input; equal to zero
2. **Bare_ET [-]** – Fraction of precipitation that evaporates from a bare (uncapped) stockpile
   - Probabilistic input sampled at start of each realization
   - Normal distribution (mean = 0.524; standard deviation = 0.020)
3. **Cat1SP_Bare_Geomem [L^2]** – Area of the bare portion of the stockpile
   - Time-varying deterministic input, interpolated from data points
   - Values at specific times given in Table 1-5 of WMDP-MS-Attachment B
4. **Cat1SP_Geomem_Perc [-]** – Fraction of precipitation that percolates through the geomembrane cap
   - Probabilistic input sampled at start of each realization
   - Log-normal distribution (mean = 0.00527; standard deviation = 0.00636)
5. **Reclaim_ET [-]** – Fraction of precipitation that evapotranspires from reclaimed (capped) waste rock
   - Probabilistic input sampled at start of each realization
   - Normal distribution (mean = 0.704; standard deviation = 0.023)
6. **Closure_Year [T]** – Time after mining begins when operations cease (and closure begins)
   - Deterministic input (20 years)
7. **Cat1SP_RO_EP [L^2]** – Stockpile area contributing runoff to the East Pit
   - Deterministic input (0 acres)
8. **Cat1SP_RO_WP [L^2]** – Stockpile area contributing runoff to the West Pit
   - Deterministic input (279 acres)
9. **Cat1SP_Reclaim_Geomem** [$L^2$] – Area of the reclaimed portion of the stockpile
   - Time-varying deterministic input, interpolated from data points
   - Values given in Table 1-5 of WMDP-MS-Attachment B

10. **Cat1_Contain_Leak** [-] – Fraction of Category 1 Waste Rock Stockpile seepage water that bypasses the containment (collection drain) system (underflow)
    - Deterministic input (0.07)

11. **Cat1SP_Contain_EP** [$L^2$] – Area with contained seepage directed to the East Pit
    - Time-varying deterministic input, interpolated from data points
    - Values given in Table 1-5 of WMDP-MS-Attachment B

12. **Cat1SP_Contain_WP_Extend** [$L^2$] – Area with contained seepage directed to the West Pit
    - Time-varying deterministic input, interpolated from data points
    - Values given in Table 1-5 of WMDP-MS-Attachment B

### 4.2.3 Mass Transport Inputs

1. **Cat1SP_Mass** [M] – Mass of Category 1 waste rock present in the stockpile
   - Time-varying deterministic input, interpolated from data points
   - Values given in Table 1-5 of WMDP-MS-Attachment B

2. **Cat1_content** [M/M] – Category 1 waste rock content
   - Deterministic input, by constituent
   - Values given in Table 1-29 of WMDP-MS-Attachment B

3. **SO4_S_Regression** [M/M/T] – Sulfate release factor used to calculate sulfate release from percent sulfur content in rock (mass of sulfate released per mass of rock per time interval, per percent sulfur in rock)
   - Probabilistic input sampled at start of each realization
   - Normal distribution (mean = 13.92 mg/kg/week/%; standard deviation = 0.581 mg/kg/week/%)

4. **Cat1_Sulfur** [-] – Mass-weighted average sulfur content of Category 1 rock
   - Deterministic input (0.063%)

5. **Cat1_Release_Indep** [M/M/T] – Unscaled constituent release rates (independent of sulfate)
   - For further explanation, see Section 15

6. **Cat1_Ratio_SO4** [M/M] – Constituent release ratios (dependent upon sulfate)
   - For further explanation, see Section 15

7. **Scale_Factor_CDF011** [-] – Scaling factor for Category 1 rock release rates
   - Probabilistic input resampled at start of each year
   - Beta distribution (mean = 0.128; standard deviation = 0.085; minimum = 0.019; maximum = 0.687)

8. **All_Release_CI** [M/M] – Instantaneous chloride mass release from newly-exposed waste rock
   - Probabilistic input sampled at start of each realization
   - Beta distribution (mean = 9.78 mg/kg; standard deviation = 11.67; minimum = 1.38 mg/kg; maximum = 73.04 mg/kg)

9. **Water_Depth** [L] – Average depth of water at the bottom of the stockpile
   - Deterministic input (0.1 inch)
4.3 Calculations

4.3.1 Water Balance Calculations

The flows of water into and out of the waste rock stockpile are calculated via water balance equations outlined below.

For the bare portion of the stockpile, runoff, evapotranspiration (ET) and infiltration fluxes are calculated by Equations 4-1a, 4-1b and 4-1c:

\[
\text{Bare Area Runoff} \ [L/T] = \text{Monthly Precipitation} \ [L/T] \times \text{Bare\_RO} \quad (4-1a)
\]
\[
\text{Bare Area ET} \ [L/T] = \text{Monthly Precipitation} \ [L/T] \times \text{Bare\_ET} \quad (4-1b)
\]
\[
\text{Bare Area Infiltration Flux} \ [L/T] = \text{Monthly Precipitation} \ [L/T] \times (1 - \text{Bare\_RO} - \text{Bare\_ET}) \quad (4-1c)
\]

The total volumetric flow of water infiltrating through the bare portion of the stockpile is then calculated by Equation 4-2:

\[
\text{Bare Area Infiltration} \ [L^3/T] = \text{Bare Area Infiltration Flux} \ [L/T] \times \text{Cat1SP\_Bare\_Geomem} \quad (4-2)
\]

For the reclaimed portion of the stockpile, runoff, ET and infiltration fluxes are calculated by Equations 4-3a, 4-3b and 4-3c:

\[
\text{Reclaimed Area Runoff} \ [L/T] = \text{Monthly Precipitation} \ [L/T] \times (1 - \text{Cat1SP\_Geomem\_Perc} - \text{Reclaim\_ET}) \quad (4-3a)
\]
\[
\text{Reclaimed Area ET} \ [L/T] = \text{Monthly Precipitation} \ [L/T] \times \text{Reclaim\_ET} \quad (4-3b)
\]
\[
\text{Reclaimed Area Infiltration Flux} \ [L/T] = \text{Monthly Precipitation} \ [L/T] \times \text{Cat1SP\_Geomem\_Perc} \quad (4-3c)
\]

After mining operations are complete (as prescribed by the “Closure\_Year” input variable), if the West Pit is not overflowing and the long-term waste water treatment facility (LTWWTF) is not active, then all of the runoff from the reclaimed portion of the stockpile is potentially directed to the pits, or:

\[
\text{Reclaimed Area Runoff to Pits} \ [L/T] = \text{Reclaimed Area Runoff} \quad (4-4)
\]

The flow of water directed to the East and West Pits when these conditions are met are a function of the contributing area to each pit:

\[
\text{Reclaimed Area Runoff to East Pit} \ [L^3/T] = \text{Reclaimed Area Runoff to Pits} \ [L/T] \times \text{Cat1SP\_RO\_EP} \quad (4-5a)
\]
Reclaimed Area Runoff to West Pit \([L^3/T]\) = 
Reclaimed Area Runoff to Pits \([L/T]\) * Cat1SP_RO_WP \hspace{1cm} (4-5b)

The flow of water infiltrating the reclaimed portion of the stockpile is calculated using the infiltration flux (Equation 4-3c) and the current area of the reclaimed portion of the stockpile:

\[
\text{Reclaimed Area Infiltration} \ [L^3/T] = \text{Reclaimed Area Infiltration Flux} \ [L/T] * \text{Cat1SP_Reclaim_Geomem} \hspace{1cm} (4-6)
\]

The total infiltration flow through the stockpile is the sum of the quantities calculated in Equations 4-2 and 4-6:

\[
\text{Total Infiltration} \ [L^3/T] = \text{Bare Area Infiltration} \ [L^3/T] + \text{Reclaimed Area Infiltration} \ [L^3/T] \hspace{1cm} (4-7)
\]

All of this infiltration either leaks (flows under) from the collection-drain containment system, or is retained by the containment system and routed elsewhere:

\[
\text{Containment System Leakage} \ [L^3/T] = \text{Total Infiltration} \ [L^3/T] * \text{Cat1_Contain_Leak} \hspace{1cm} (4-8a)
\]

\[
\text{Retained Containment System Water} \ [L^3/T] = \text{Total Infiltration} \ [L^3/T] * (1 - \text{Cat1_Contain_Leak}) \hspace{1cm} (4-8b)
\]

When a WWTF (during operations, reclamation or long-term) is operating, all of the retained containment system seepage is sent to the WWTF. Otherwise, the contained seepage goes to the East Pit and/or West Pit:

\[
\text{Retained Containment System Water to the East Pit} \ [L^3/T] = \frac{\text{Cat1SP_Contain_EP}}{(\text{Cat1SP_Contain_EP} + \text{Cat1SP_Contain_WP_Extend})} * \text{Retained Containment System Water} \ [L^3/T] \hspace{1cm} (4-9a)
\]

\[
\text{Retained Containment System Water to the West Pit} \ [L^3/T] = \frac{\text{Cat1SP_Contain_WP_Extend}}{(\text{Cat1SP_Contain_EP} + \text{Cat1SP_Contain_WP_Extend})} * \text{Retained Containment System Water} \ [L^3/T] \hspace{1cm} (4-9b)
\]

4.3.2 Mass Transport Calculations

The mass of each constituent contained within the bare portion of the stockpile is calculated in the “Cat1SP_InRock_Bare” cell pathway element and is based upon the total stockpile rock mass present and the composition of the waste rock:

\[
\text{Bare Area Stockpile Constituent Mass} \ [M] = \text{Cat1SP_Mass} * \text{Cat1_content} \hspace{1cm} (4-10)
\]

Mass is removed from the “Cat1SP_InRock_Bare” element in two ways: through release (exposure) to infiltrating water and by transfer to the reclaimed portion of the stockpile as
geomembrane installation progresses. The transfer rate from the bare portion to the reclaimed portion (“Cat1SP_InRock_reclaim”) is a function of the rate of reclamation:

\[
\text{Transfer Rate from Bare to Reclaimed Stockpile} \ [1/T] = \frac{\text{d}l/dt}{\text{Cat1SP_Reclaim_Geomem}/\text{Cat1SP_Bare_Geomem}}
\]  

(4-11)

In Equation 4-11, \(\text{d}l/dt\) (Cat1SP_Reclaim_Geomem) is the rate of change of the reclaimed area [L²/T]. The constituent load transferred from bare rock to reclaimed rock is the product of the transfer rate and the constituent mass in the bare rock.

As with the bare portion of the stockpile, mass is also removed from the reclaimed rock portion by means of release (exposure) to infiltrating water. The release rate calculations vary by constituent. In general, laboratory (unscaled) release rates are either given or are calculated, and a scaling factor is applied to calculate field-scale release rates.

The rate of sulfate release from the Category 1 rock per mass of waste rock present is calculated as:

\[
\text{Release Rate (SO}_4, \text{ Unscaled)} [\text{M/M/T}] = \text{SO}_4 \_\text{S\_Regression} \times \text{Cat1\_Sulfur}
\]  

(4-12)

Sulfate-dependent release rates are calculated for a subset of the constituents using applicable ratios (see Section 15):

\[
\text{Release Rates (SO}_4\text{-Dependent, Unscaled)} [\text{M/M/T}] = \frac{\text{Cat1\_Ratio\_SO}_4 \times \text{Release Rate (SO}_4, \text{ Unscaled)} [\text{M/M/T}]}{\text{Cat1\_Ratio\_SO}_4}
\]  

(4-13)

Unscaled, sulfate-independent release rates (“Cat1_Release_Indep”) are calculated for a different subset of the modeled constituents (see Section 15). Three constituents—Co, Fe and Ni—have both sulfate-dependent and sulfate-independent release rates, and the release rate for each of these constituents used in the model is the sum of these two unscaled rates.

The unscaled release rates are then scaled using the lab-to-field scaling factor:

\[
\text{Release Rates (Scaled)} [\text{M/M/T}] = \frac{\text{Release Rates (Unscaled)} [\text{M/M/T}]}{\text{Scale\_Factor\_CDF011}}
\]  

(4-14)

Chloride release is conceptualized differently from other constituents. Chloride release is assumed to occur instantaneously from the bare portion of the stockpile immediately upon rock placement. No additional chloride is released from the capped portion of the stockpile. The bare fraction of the stockpile is first calculated (“Cat1SP_Bare_fract”):

\[
\text{Cat1SP\_Bare\_fract} [\text{-}] = \frac{\text{Cat1SP\_Bare\_Geomem}}{\text{Cat1SP\_Bare\_Geomem + Cat1SP\_Reclaim\_Geomem}}
\]  

(4-15)
Then the release rate for chloride is calculated by Equation 4-16:

\[
\text{Release Rate (Cl, Scaled)} \, [\text{M/M/T}] = \frac{\text{All_Release_Cl}* \text{Scale_Factor_CDF011} * (d/dt \, (\text{Cat1SP_Mass}))}{(\text{Cat1SP_Mass} \, (t-1) \times \text{Cat1SP_Bare_frat} \, (t-1))}
\] (4-16)

In Equation 4-16, \( d/dt \, (\text{Cat1SP_Mass}) \) is the rate of change of mass contained within the stockpile, \( \text{Cat1SP_Mass} \, (t-1) \) is the rock mass in the previous time step of the simulation, and \( \text{Cat1SP_Bare_frat} \, (t-1) \) is the previous time-step value for \( \text{Cat1SP_Bare_frat} \).

After release rates are calculated, they are used to calculate the fractional release rates (mass of constituent exposed to infiltration water per mass of constituent present, per time period) from the bare and reclaimed portions of the waste rock stockpile. Field-scale release rates specific to the bare portion of the stockpile are calculated using Equation 4-17:

\[
\text{Bare Area Release Rates} \, [\text{1/T}] = \text{Release Rates (Scaled)} \, [\text{M/M/T}] \times \frac{\text{Cat1SP_Mass} \, (t-1) \times \text{Cat1SP_Bare_frat} \, (t-1)}{\text{Cat1SP_InRock_Bare} \, (t-1)}
\] (4-17)

In Equation 4-17, \( \text{Cat1SP_InRock_Bare} \, (t-1) \) represents the masses of constituents bound in the bare portion of the stockpile during the previous time-step. The constituent load from the bare rock to the bare infiltration water is the product of the fractional release rate and the constituent mass in the bare rock.

Similarly, fractional release rates from the reclaimed portion of the stockpile are calculated using Equation 4-18, then multiplied by the constituent mass in reclaimed rock to calculate constituent load from the reclaimed rock to reclaimed infiltration water:

\[
\text{Reclaimed Area Release Rates} \, [\text{1/T}] = \text{Release Rates (Scaled)} \, [\text{M/M/T}] \times \frac{\text{Cat1SP_Mass} \, (t-1) \times (1 - \text{Cat1SP_Bare_frat} \, (t-1))}{\text{Cat1SP_InRock_reclain} \, (t-1)}
\] (4-18)

GoldSim cell elements are used to apply concentration caps (solubility limits) and calculate constituent loads associated with water infiltrating through the stockpile. Constituent mass that is released from the rock in the bare portion of the stockpile is transferred to the cell representing water infiltration through the bare stockpile. The volume of water in this cell is calculated by Equation 4-19:

\[
\text{Volume of Infiltration Water at Base of Bare Stockpile} \, [\text{L}^3] = \text{Water_Depth} \times \text{Cat1SP_Bare_Geomem}
\] (4-19)

Concentration caps are applied based on the infiltration-water concentrations calculated for the cell in the prior time step, using the inputs and methodologies discussed in Section 15.

Similarly, a cell representing water infiltration through the reclaimed portion of the stockpile is used, with water volume calculated by Equation 4-20:

\[
\text{Volume of Infiltration Water at Base of Reclaimed Stockpile} \, [\text{L}^3] = \text{Water_Depth} \times \text{Cat1SP_Reclain_Geomem}
\] (4-20)
Again, concentration caps are applied (see Section 15) based on the prior-time-step water chemistry of this cell.

A transfer of constituent mass from the bare infiltration-water cell to the reclaimed infiltration-water cell is simulated using the fractional rate calculated in Equation 4-11.

Infiltration outflows from the bare and reclaimed infiltration-water cells are taken from Equations 4-2 and 4-6. The infiltration-water cell elements apply the concentration caps to determine the infiltration constituent concentrations in water (for bare and reclaimed portions) as well as the precipitated mass of constituents. Loads are determined as the product of the continuously-variable mixing cell concentration and infiltration flow.

The constituent loads from the bare and reclaimed portions of the stockpile are summed to obtain the total load in infiltration through the stockpile. As described in the discussion of water-balance calculations, a portion of the load is collected in the collection-drain containment system and a portion bypasses the containment system and goes directly to the West Pit. The collected containment-system load is directed to different other models as described in the discussion of water-balance calculations.

### 4.4 Output

The Category 1 Waste Rock Stockpile Model ultimately calculates the following flows along with their associated constituent concentrations and loads:

- Infiltration collected in the containment system and directed to the WWTF
- Infiltration collected in the containment system and directed to the East Pit
- Infiltration collected in the containment system and directed to the West Pit
- Infiltration bypassing the containment system and going to the West Pit

The Category 1 Waste Rock Stockpile Model also calculates the following runoff flows:

- Runoff directed to the West Pit
- Runoff directed to the East Pit
5 Category 2 and Category 3 Waste Rock Stockpile Model

5.1 Purpose
This model is used to simulate water flow and mass transport through the Category 2/3 Waste Rock Stockpile. The model calculates water flows and associated constituent mass loads (for all constituents) that are routed to other component models, including the models of the WWTF used during mining operations and the East Pit and Category 2/3 surficial groundwater flow path.

5.2 Input
5.2.1 Inputs from Other Models
- Monthly Precipitation [L/T], calculated in Equation 3-2

5.2.2 Water Balance Inputs
1. Cat23SP_Bare [L²] – Bare area portion of stockpile
   - Time-varying deterministic input
   - Values given in Table 1-6 of WMDP-MS-Attachment B
2. Liner_Leak_23 [-] – Fraction of water from the top of the stockpile liner that leaks
   - Probabilistic input sampled at start of each realization
   - Log-normal distribution (mean = 0.000302; standard deviation = 0.000274)
3. Cat23SP_Initial_Vol [L³] – Initial volume of saturated overburden material
   - Deterministic input (203,000 cubic yards)
4. SatOB_BulkDens [M/L³] – Bulk density of the saturated overburden
   - Deterministic input (1.472 tonm/yard³)
5. Cat23SP_SatOB [L³] – Volume of saturated overburden in the stockpile
   - Time-varying deterministic input
   - Values given in Table 1-6 of WMDP-MS-Attachment B

5.2.3 Mass Transport Inputs
1. Acid_Onset_Time_23 [T] – Time until acidic conditions first occur in stockpile
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 5.33 yr; mode= 6.81 yr; maximum = 7.79 yr)
2. Cat23SP_Mass [M] – Mass of Category 2/3 waste rock present in stockpile
   - Time-varying deterministic input
   - Values given in Table 1-6 of WMDP-MS-Attachment B
3. Cat23_content [M/M] – Category 2/3 waste rock content
   - Deterministic input
   - Values given in Table 1-29 of WMDP-MS-Attachment B
   - For further explanation, see Section 15
5. Cat23_Release_Indep_acidic [M/M/T] – Acidic, sulfate-independent release rates
   - For further explanation, see Section 15
6. **Cat23_Ratio_SO4 [M/M]** – Nonacidic, sulfate-dependent release ratios
   - For further explanation, see Section 15

7. **Cat23SP_Sulfur [-]** – Mass-weighted average sulfur content of stockpile
   - Deterministic input (0.21%)

8. **Size_Factor [-]** – Scaling factor to adjust release rates for field-scale waste rock
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 0.08; mode = 0.14; maximum = 0.35)

9. **Acid_Factor_DC [-]** – Increase in sulfate release when Duluth Complex rock becomes acidic
   - Probabilistic input sampled at start of each realization
   - Beta distribution (mean = 8.20; standard deviation = 7.48; minimum = 1.01; maximum = 32.36)
   - Correlated to “Decay_a1” (East Pit and Central Pit Model input); correlation value of -0.831

10. **Contact_Factor [-]** – Fraction of waste rock contacted by water
    - Probabilistic input sampled at start of each realization
    - Triangular distribution (minimum = 0.1; mode = 0.5; maximum = 0.9)

### 5.3 Calculations

#### 5.3.1 Water Balance Calculations

Runoff, evapotranspiration and the infiltration flux for the Category 2/3 stockpile are calculated in the same way as for the bare portion of the Category 1 stockpile (see Equations 4-1a, 4-1b, and 4-1c). The volumetric infiltration rate (“Cat23SP_Bare_Infilt”) is subsequently calculated using the infiltration flux, stockpile area (“Cat23SP_Bare”) and Equation 4-2. Direct infiltration of precipitation is the only inflow into the Category 2/3 stockpile. The two outflows from the stockpile are liner leakage (“Cat23SP_Outflow.Liner_leak”, which enters the East Pit-Category 2/3 surficial groundwater flow path) and contained seepage (“Cat23SP_Outflow.To_WWTF”, which is pumped to the WWTF used during mining operations). These outflows are calculated using Equations 4-8a and 4-8b, respectively, with the Category 2/3 stockpile liner leakage fraction (“Liner_Leak_23”) substituted for “Cat1_Contain_Leak”. The contained seepage is pumped to the WWTF West Pond, and liner leakage enters the East Pit and Category 2/3 surficial groundwater flow path model.

#### 5.3.2 Stockpile Mass Calculations

The Category 2/3 waste rock is assumed to not generate acid immediately after being added to the stockpile. Oxidation is assumed to cause the waste rock to begin generating acid an uncertain amount of time (defined by “Acid_Onset_Time_23”) after waste rock is placed in the stockpile.

Nonacidic-generating waste rock mass at the start of the simulation is equal to the initial saturated overburden mass, which is calculated using the predefined initial volume and bulk density of the overburden material:

\[
\text{Initial Overburden Mass [M]} = \text{Cat23SP_Initial_Vol} \times \text{SatOB_BulkDens} \quad (5-1)
\]
The total stockpile mass varies with time and is calculated as the sum of the masses of Category 2/3 waste rock and saturated overburden in the stockpile:

\[
\text{Total Stockpile Mass} \ [M] = \text{Cat23SP\_Mass} + (\text{Cat23SP\_SatOB \times SatOB\_BulkDens}) \quad (5-2)
\]

The rate of change of total mass in the stockpile—and addition to the nonacidic rock mass element (“Cat23SP\_Mass\_nonacid”)—is calculated similarly:

\[
\text{Rate of Change to Total Stockpile Mass} \ [M/T] = \frac{d}{dt} (\text{Cat23SP\_Mass}) + \frac{d}{dt} (\text{Cat23SP\_SatOB} \times \text{SatOB\_BulkDens}) \quad (5-3a)
\]

A similar fractional transfer rate is calculated based on this mass transfer rate:

\[
\text{Fractional Rate of Change to Total Stockpile Mass} \ [1/T] = \frac{\text{Rate of Change to Total Stockpile Mass} \ [M/T]}{\text{Total Stockpile Mass} \ [M]} \quad (5-3b)
\]

Rock mass is removed from the nonacidic rock in two ways: conversion to acid-generating rock (which is accounted for separately in the “Cat23SP\_Mass\_acid” element), and movement to the East Pit during pit backfilling. The amount of mass converted from nonacidic to acidic rock is calculated as a function of the amount of the stockpile remaining after the acid-generation time lag (“Acid\_Onset\_Time\_23”) has been applied:

\[
\text{Mass Transfer Rate from Nonacidic- to Acidic-Generating Rock} \ [M/T] = \text{Rate of Change to Total Stockpile Mass} \ (\text{Time-lagged}) \ [M/T] \times (1 – \text{Cat23SP\_Trans\_frac}) \quad (5-4)
\]

The “Cat23SP\_Trans\_frac” term in Equation 5-4 is equal to the fraction of the full stockpile that has been transferred to the East Pit after pit backfilling begins (i.e. the current total stockpile mass divided by the maximum value).

The rate of mass transfer from the nonacidic-generating portion of the stockpile to the East Pit is calculated as a fraction of the total rate of change (from Equation 5-3a) and the fraction of the stockpile that is not acidic (“Cat23SP\_Nonacid\_frac”, which equals Cat23SP\_Mass\_nonacid / Total Stockpile Mass):

\[
\text{Mass Transfer Rate from Nonacidic Rock to East Pit} \ [M/T] = \text{Rate of Change to Total Stockpile Mass} \ [M/T] \times \text{Cat23SP\_Nonacid\_frac} \quad (5-5)
\]

Acidic mass is only created by oxidation of nonacidic stockpile mass (Equation 5-4). The only means of acidic mass removal from the stockpile is the transfer of mass to the East Pit:

\[
\text{Mass Transfer Rate from Acidic Rock to East Pit} \ [M/T] = \text{Rate of Change to Total Stockpile Mass} \ [M/T] \times (1 – \text{Cat23SP\_Nonacid\_frac}) \quad (5-6)
\]

Thus, the mass of Category 2/3 waste rock in the nonacidic portion of the stockpile is calculated using the time-step size of one month and Equation 5-7:
Nonacidic Mass \([M]\) = Initial Overburden Mass \([M]\) + 
(Rate of Change to Total Stockpile Mass \([M/T]\) – 
Mass Transfer Rate from Nonacidic- to Acidic-Generating Rock \([M/T]\) – 
Mass Transfer Rate from Nonacidic Rock to East Pit \([M/T]\)) \times 1 month, \hspace{1cm} (5-7)

Similarly, the amount of mass in the acidic portion of the stockpile is calculated as:

Acidic Mass \([M]\) = 
(Mass Transfer Rate from Nonacidic- to Acidic-Generating Rock \([M/T]\) – 
Mass Transfer Rate from Acidic Rock to East Pit \([M/T]\)) \times 1 month, \hspace{1cm} (5-8)

5.3.3 Mass Transport Calculations
Stockpile infiltration dissolves constituent mass from the Category 2/3 waste rock. The water containing this dissolved mass then either percolates to the stockpile liner—where it can leak to the East Pit and Category 2/3 stockpile model or be retained and sent to the WWTF—or is retained within the waste rock pore spaces and is transferred to the East Pit during pit backfilling.

The calculations used to determine release rates from the Category 2/3 stockpile differ from those for the Category 1 waste rock stockpile because dissolution rates of the Category 2/3 waste rock will depend upon whether or not the rock generates acid. The sulfate release rate is calculated using Equation 4-12 (with the Category 2/3 sulfur content, Cat23SP_Sulfur, substituted for “Cat1_Sulfur”) and the resulting quantity is identified as “Cat23SP_SO4”. Unscaled, sulfate-dependent release rates are calculated for the Category 2/3 stockpile using this quantity in the same manner as for the bare portion of the Category 1 waste rock stockpile:

\[
\text{Nonacidic Release Rates (SO}_4\text{-Dependent, Unscaled)} \hspace{0.5cm} [M/M/T] = \frac{\text{Cat23_Ratio_SO4} \times \text{Cat23SP_SO4}}{[M/M/T]} \hspace{1cm} (5-9)
\]

Nonacidic, sulfate-independent release rates for the remaining species other than chloride (“Cat23_Release_Indep_nonacid”) are determined as indicated in Section 15.

Chloride is assumed to be released only from the freshly-mined, nonacidic rock portion of the Category 2/3 stockpile, and chloride release rates are calculated differently from those for the Category 1 waste rock stockpile. A size factor (“Size_Factor”) is included for the Category 2/3 waste rock in place of the Category 1 waste rock stockpile scaling factor, and the following equation is used to both calculate and scale the release rate:

\[
\text{Nonacidic Release Rate (Cl, Scaled)} \hspace{0.5cm} [M/M/T] = \frac{\text{Rate of Change to Total Stockpile Mass} \times \text{All_Release_Cl} \times \text{Size_Factor}}{\text{Cat23SP_Mass_nonacid}} (t-1) \hspace{1cm} (5-10)
\]

In Equation 5-10, “Cat23SP_Mass_nonacid (t-1)” is the nonacidic waste rock mass from the previous time-step.

Acidity is accounted for in the sulfate-dependent release rates from the acidic portion of the stockpile by the addition of an acid factor to Equation 5-9:
Acidic Release Rates (SO$_4$-Dependent, Unscaled) [M/M/T] =
Cat23_Ratio_SO4 * Cat23SP_SO4 [M/M/T] * Acid_Factor_DC \hspace{100pt} (5-11)

Sulfate-independent release rates from the acidic portion of the stockpile
(“Cat23_Release_Indep_acidic”) are also determined differently from those for the nonacidic rock
(see Section 15).

The final Category 2/3 waste rock release rates for all constituents other than chloride are scaled
using the size factor:

Nonacidic Release Rates (Scaled) [M/M/T] =
Nonacidic Release Rates (Unscaled) [M/M/T] * Size_Factor \hspace{100pt} (5-12)

Acidic Release Rates (Scaled) [M/M/T] =
Acidic Release Rates (Unscaled) [M/M/T] * Size_Factor \hspace{100pt} (5-13)

While rock mass is still present in the stockpile, the fractional mass release rates from the
nonacidic portion—or, the fraction of the total mass of each constituent present that is released
during a particular time-step—is calculated as follows:

Mass Released from Nonacidic Rock (All Constituents) [1/T] =
Nonacidic Release Rates (Scaled) * Cat23SP_Mass_nonacid (t-1) / Cat23SP_InRock_nacid (t-1) \hspace{100pt} (5-14)

In Equation 5-14, “Cat23SP_InRock_nacid (t-1)” is the mass of each constituent bound in the
nonacidic waste rock during the previous time-step.

A contact factor is then applied to this fractional release rate to partition the released constituent
mass (calculated by Equation 5-14) into mass that is available for transport out of the stockpile:

Mass Released from Nonacidic Rock (All Constituents, Available for Transport) [1/T] =
Mass Released from Nonacidic Rock (All Constituents) * Contact_Factor \hspace{100pt} (5-15)

and mass that is unavailable for transport:

Mass Released from Nonacidic Rock (All Constituents, Unavailable for Transport) [1/T] =
Mass Released from Nonacidic Rock (All Constituents) * (1 – Contact_Factor) \hspace{100pt} (5-16)

The constituent loading rates to the cells representing mass available and unavailable for
transport are the products of these two fractional rates and the constituent mass in the nonacidic
waste rock. The mass available for transport is removed from the nonacidic rock
(“Cat23SP_InRock_nacid” element) and added to the nonacidic water at the bottom of the
stockpile (“Cat23SP_Water_nacid”).

Constituent mass is also transferred from the nonacidic portions of the stockpile (i.e. released and
unreleased constituent mass) to the acidic portion. The rate at which this transfer occurs is equal
to the product of the constituent mass present in the nonacidic rock, and a fractional rate that is calculated using the lagged, mass-based transfer rate (from Equation 5-4) and the nonacidic rock mass present (from Equation 5-7):

\[
\text{Mass Transfer Rate from Nonacidic- to Acidic-Generating Rock (All Constituents)} \ [1/T] = \frac{\text{Mass Transfer Rate from Nonacidic- to Acidic-Generating Rock} \ [M/T]}{\text{Nonacidic Mass} \ [M]}
\] (5-17)

The fourth (and final) constituent mass outflow from the nonacidic rock is the backfill of Category 2/3 waste rock to the East Pit. The fractional transfer rate for this mass removal from the stockpile is calculated based on the transfer rate of rock to the East Pit (Equation 5-5) and the total stockpile mass (Equation 5-2):

\[
\text{Mass Transfer Rate from Nonacidic Rock to East Pit Backfill (All Constituents)} \ [1/T] = \frac{\text{Mass Transfer Rate from Nonacidic Rock to East Pit} \ [M/T]}{\text{Total Stockpile Mass} \ [M]}
\] (5-18)

An analogous set of formulas to Equations 5-15, 5-16 and 5-18 are used to determine constituent mass movement from the acidic portion of the waste rock stockpile (“Cat23SP_InRock_acid”) to acidic water at the bottom of the stockpile (“Cat23SP_Water_acid”), the sequestered or “non-contacted” mass element, and the East Pit backfill:

\[
\text{Mass Released from Acidic Rock (All Constituents, Available for Transport)} \ [1/T] = \frac{\text{Mass Released from Acidic Rock (All Constituents)} \times \text{Contact Factor}}{\text{Total Stockpile Mass} \ [M]}
\] (5-19)

\[
\text{Mass Released from Acidic Rock (All Constituents, Unavailable for Transport)} \ [1/T] = \frac{\text{Mass Released from Acidic Rock (All Constituents)} \times (1 - \text{Contact Factor})}{\text{Total Stockpile Mass} \ [M]}
\] (5-20)

\[
\text{Mass Transfer Rate from Acidic Rock to East Pit Backfill (All Constituents)} \ [1/T] = \frac{\text{Mass Transfer Rate from Acidic Rock to East Pit} \ [M/T]}{\text{Total Stockpile Mass} \ [M]}
\] (5-21)

The conceptualization of the fate of Category 2/3 stockpile seepage is similar to that of the Category 1 waste rock stockpile. Infiltrating water moves through the nonacidic (“Cat23SP_Water_nacid”) and acidic (“Cat23SP_Water_acid”) portions of the stockpile, where the nonacidic and acidic concentration caps are applied separately (see Section 15). Water from both portions of the stockpile then mixes at the bottom of the stockpile (“Cat23SP_Water_mixed”).

The volume of nonacidic water in the stockpile is:

\[
\text{Volume of Nonacidic Water in the Stockpile} \ [L^3] = \frac{\text{Water Depth} \times \text{Cat23SP_Bare} \times \text{Nonacidic Mass} \ [M]}{\text{Total Stockpile Mass} \ [M]}
\] (5-22)

The nonacidic-derived constituent mass is then transferred to the bottom of the stockpile (“Cat23SP_Water_mixed”) based on the constituent concentrations in the nonacidic water and the following volumetric flow rate:
Nonacidic Water to Bottom of Stockpile \([L^3/T]\) = \(\text{Cat23SP\_Bare\_Infilt} \ [L^3/T] \times \) 
Nonacidic Mass \([M]\) / Total Stockpile Mass \([M]\) \hspace{1cm} (5-23)

Constituent mass is transferred from the nonacidic water to water in the acidic rock ("Cat23SP\_Water\_acid") at a fractional rate of:

Nonacidic Water to Acidic Water \([1/T]\) = 
Mass Transfer Rate from Nonacidic- to Acidic-Generating Rock \([M/T]\) / 
Nonacidic Mass \([M]\) \hspace{1cm} (5-24)

Mass transfer to water in the East Pit backfill occurs at the fractional rate calculated by Equation 5-25:

Nonacidic Water to East Pit Backfill \([1/T]\) = 
Mass Transfer Rate from Nonacidic Rock to East Pit \([M/T]\) / 
Total Stockpile Mass \([M]\) \hspace{1cm} (5-25)

Constituent mass added to water in the acidic rock originates from two sources: acidic rock and nonacidic water. The mass loading rates from these sources are the products of the fractional rates calculated by Equations 5-19 and 5-24 and the constituent masses in the acidic rock ("Cat23SP\_InRock\_acid") and nonacidic water ("Cat23SP\_Water\_nacid"), respectively. The two mass loadings leaving the acidic water ("Cat23SP\_Water\_acid") are due to percolation to the bottom of the stockpile and removal of the stockpile during East Pit backfilling. The loading rate to the mixed water at the bottom of the stockpile is calculated by multiplying the acidic water concentrations by the volumetric flow rate calculated by Equation 5-26:

Acidic Water to Bottom of Stockpile \([L^3/T]\) = \(\text{Cat23SP\_Bare\_Infilt} \ [L^3/T] \times \) 
(1 – Nonacidic Mass \([M]\) / Total Stockpile Mass \([M]\)) \hspace{1cm} (5-26)

The rate of constituent mass transfer from acidic water in the stockpile to the East Pit backfill water occurs at the following fractional rate:

Acidic Water to East Pit Backfill \([1/T]\) = 
Mass Transfer Rate from Acidic Rock to East Pit \([M/T]\) / 
Total Stockpile Mass \([M]\) \hspace{1cm} (5-27)

The volume of mixed nonacidic and acidic water at the base of the stockpile is calculated by multiplying the total stockpile area by the predefined water depth, or:

Volume of Water at Bottom of Stockpile \([L^3]\) = 
Water\_Depth \times \text{Cat23SP\_Bare} \hspace{1cm} (5-28)

The inflows to this volume are calculated by multiplying the volumetric rates calculated by Equations 5-23 and 5-26 by the continuously-variable nonacidic and acidic mixing cell concentrations, respectively. Mass leaves the mixed water at the bottom of the stockpile by direct transfer to the East Pit porewater, drainage to the stockpile containment system (which is pumped to the WWTF), and leakage from the stockpile containment system to the East Pit and
Category 2/3 surficial groundwater flow path (discussed in Section 13). The fractional rate used to transfer constituent mass to the East Pit porewater is:

\[
\text{Water from Bottom of Stockpile to East Pit Backfill} \ [1/T] = \\
\text{Rate of Change to Total Stockpile Mass} \ [M/T] \div \text{Total Stockpile Mass} \ [M] 
\] (5-29)

The mass loading rate from the mixed stockpile water to the WWTF, by way of the stockpile containment system, is the product of the continuously-variable constituent concentrations in the mixed water at the bottom of the stockpile and the volumetric rate calculated using Equation 4-8b (as described above):

\[
\text{Water from Bottom of Stockpile to WWTF West Pond} \ [L^3/T] = \\
\text{Cat23SP\_Outflow\_To\_WWTF} \ [L^3/T] 
\] (5-30)

For each of the 13 cells in the second section of the East Pit and Category 2/3 surficial aquifer flow path model, the constituent mass loading rate from the mixed stockpile water is the product of the continuously-varying mixed water concentrations and the volumetric liner leakage rate to each cell:

\[
\text{Discharge to Each Flow Path Cell (Section 2)} \ [L^3/T] = \\
\text{Cat23SP\_Outflow\_Liner\_leak} \ [L^3/T] / 13 \text{ cells} 
\] (5-31)

5.4 Output

The Category 2/3 Waste Rock Stockpile Model ultimately calculates the following flows and their associated constituent concentrations and loads:

- Infiltration collected in the liner/containment system and directed to the WWTF
- Leakage from the stockpile liner to the East Pit and Category 2/3 surficial aquifer flow path
- Constituent mass transferred from the mass bound in the waste rock, released unavailable mass, and the water in the stockpile to East Pit-Central Pit porewater during pit backfilling
6 Category 4 Waste Rock Stockpile Model

6.1 Purpose
This model is used to simulate water flow and mass transport through the Category 4 Waste Rock Stockpile. The model calculates water flows and associated constituent mass loads (for all constituents) that are routed to other component models, including the models of the WWTF used during mining operations and the East Pit and Category 4 surficial groundwater flow path.

6.2 Input
6.2.1 Inputs from Other Models
- Monthly Precipitation [L/T], calculated in Equation 3-2

6.2.2 Water Balance Inputs
1. \text{Cat4SP\_Bare} [L^2] – Bare area portion of stockpile
   - Time-varying deterministic input
   - Values given in Table 1-7 of WMDP-MS-Attachment B
2. \text{Cat4SP\_SatOB} [L^3] – Volume of saturated overburden material
   - Time-varying deterministic input
   - Values given in Table 1-7 of WMDP-MS-Attachment B
3. \text{Liner\_Leak\_4\_OSP} [M/L^3] – Fraction of water from the top of the liner that leaks
   - Probabilistic input sampled at start of each realization
   - Log-normal distribution (mean = 0.000081; standard deviation = 0.000073)

6.2.3 Mass Transport Inputs
1. \text{Cat4SP\_MassDC} [M] – Duluth Complex rock mass present in stockpile
   - Time-varying deterministic input
   - Values given in Table 1-7 of WMDP-MS-Attachment B
2. \text{Cat4DC\_content} [M/M] – Category 4 Duluth Complex waste rock content
   - Deterministic input
   - Values given in Table 1-29 of WMDP-MS-Attachment B
3. \text{Cat4SP\_MassVF} [M] – Virginia Formation rock mass present in stockpile
   - Time-varying deterministic input
   - Values given in Table 1-7 of WMDP-MS-Attachment B
4. \text{Cat4VF\_content} [M/M] – Category 4 Virginia Formation waste rock content
   - Deterministic input
   - Values given in Table 1-29 of WMDP-MS-Attachment B
5. \text{Cat4VF\_Release\_Indep} [M/M/T] – Sulfate-independent release rates (Virginia Formation)
   - For further explanation, see Section 15
6. \text{Cat4VF\_Ratio\_SO4} [M/M] – Sulfate-dependent release ratios (Virginia Formation)
   - For further explanation, see Section 15
7. \text{Cat4VF\_Release\_SO4} [M/M/T] – Sulfate release rate (independent of sulfur content)
   - Probabilistic input sampled at start of each realization
• Triangular distribution (minimum = 44.4 mg/kg/week; mode = 57.6 mg/kg/week; maximum = 57.6 mg/kg/week)

8. **Cat4DC_Release_Indep** [M/M/T] – Sulfate-independent release rates (Duluth Complex)
   • For further explanation, see Section 15

9. **Cat4DC_Ratio_SO4** [M/M] – Sulfate-dependent release ratios (Duluth Complex)
   • For further explanation, see Section 15

10. **Cat4DC_Release_SO4** [M/M/T] – Sulfate release rate (independent of sulfur content)
    • Probabilistic input sampled at start of each realization
    • Beta distribution (mean = 12.7 mg/kg/week; standard deviation = 8.37 mg/kg/week; minimum = 3.74 mg/kg/week; maximum = 55.0 mg/kg/week)

### 6.3 Calculations

#### 6.3.1 Water Balance Calculations

Runoff, evapotranspiration and the infiltration flux for the Category 4 stockpile are calculated in the same manner as for the bare portions of the Category 1 and 2/3 stockpiles (see Equations 4-1a through 4-1c). The volumetric infiltration rate ("Cat4SP_Bare_Infilt") is subsequently calculated using the infiltration flux, stockpile area ("Cat4SP_Bare"), and Equation 4-2. Infiltration of precipitation is the only inflow into the Category 4 stockpile. The two outflows from the stockpile are liner leakage ("Cat4SP_Outflow.Liner_leak") and contained seepage ("Cat4SP_Outflow.To_WWTF"). These outflows are calculated using Equations 4-8a and 4-8b, respectively, with the Category 4 stockpile liner leakage fraction ("Liner_Leak_4_OSP") substituted for “Cat1_Contain_Leak”.

#### 6.3.2 Stockpile Mass Calculations

The entire Category 4 waste rock stockpile is assumed to generate acid immediately after being added to the stockpile. The VF mass in the stockpile is calculated as the sum of the actual mass of VF rock and the saturated overburden mass (i.e. saturated overburden is treated identically to VF rock):

\[
\text{Total VF Mass in Stockpile \[M\]} = \text{Cat4SP_MassVF} + (\text{Cat4SP_SatOB} \times \text{SatOB_BulkDens}) \quad (6-1)
\]

The total waste rock mass in the stockpile varies with time and is defined as the sum of the VF rock mass and Duluth Complex (DC) rock mass ("Cat4SP_MassDC"):

\[
\text{Total Mass in Stockpile \[M\]} = \text{Total VF Mass in Stockpile \[M\]} + \text{Cat4SP_MassDC} \quad (6-2)
\]

The rate of change of total mass in the VF and DC portions of the stockpile are calculated by Equations 6-3 and 6-4:

\[
\text{Rate of Change to VF Mass in Stockpile \[M/T\]} = \frac{d}{dt}(\text{Cat4SP_MassVF}) + \frac{d}{dt}(\text{Cat23SP_SatOB}) \times \text{SatOB_BulkDens} \quad (6-3)
\]
Rate of Change to DC Mass in Stockpile \([M/T] = \frac{d}{dt} (Cat4SP\_MassDC)\) \hspace{1cm} (6-4)

The total rate of mass change in the stockpile is therefore:

\[
\text{Rate of Change to Total Stockpile Mass} [M/T] = \\
\text{Rate of Change to VF Mass in Stockpile} [M/T] + \\
\text{Rate of Change to DC Mass in Stockpile} [M/T]
\] \hspace{1cm} (6-5a)

and the fractional transfer rate of mass into or out of the stockpile is:

\[
\text{Rate of Change to Total Stockpile Mass} \left[\frac{1}{T}\right] = \\
\text{Rate of Change to Total Stockpile Mass} [M/T] / \\
\text{Total Mass in Stockpile} [M]
\] \hspace{1cm} (6-5b)

6.3.3 Mass Transport Calculations

Constituent mass is dissolved by infiltrating water and flows passively from the stockpile to the containment system, where it either leaks to the East Pit or is retained and pumped to the WWTF. During East Pit backfilling, constituent mass is also transferred to the East Pit backfill water.

The calculations used to determine release rates from the Category 4 stockpile differ from those for the Category 1 and 2/3 stockpiles, in part because the Category 4 material is derived from two distinctly different rock formations (VF and DC).

The VF sulfate-dependent release rates are calculated similarly to those for the Category 1 and 2/3 rock types:

\[
\text{VF Release Rates (SO}_4^-\text{-Dependent, Unscaled)} [M/M/T] = \\
\text{Cat4VF\_Ratio}_SO4 \text{* Cat4VF\_Release}_SO4
\] \hspace{1cm} (6-6)

Sulfate-dependent release rates from DC rock are calculated using Equation 6-6 with the addition of a term to account for acidity:

\[
\text{DC Release Rates (SO}_4^-\text{-Dependent, Unscaled)} [M/M/T] = \\
\text{Cat4DC\_Ratio}_SO4 \text{* Cat4DC\_Release}_SO4 \text{* Acid\_Factor\_DC}
\] \hspace{1cm} (6-7)

 Unscaled, sulfate-independent release rates from both VF (“Cat4VF\_Release\_Indep”) and DC (“Cat4DC\_Release\_Indep”) rock are also either given directly as model inputs, or are calculated for the appropriate constituents (see Section 15).

The final Category 4 waste rock release rates for constituents other than chloride are then scaled using the size factor:

\[
\text{VF Release Rates (Scaled)} [M/M/T] = \\
\text{VF Release Rates (Unscaled)} [M/M/T] \text{* Size\_Factor}
\] \hspace{1cm} (6-8)
DC Release Rates (Scaled) [M/M/T] =
DC Release Rates (Unscaled) [M/M/T] * Size_Factor

\( \text{VF Release Rate (Cl, Scaled) [M/M/T]} = \frac{\text{Rate of Change to VF Mass in Stockpile [M/T]} \times \text{All_Release_Cl} \times \text{Size_Factor}}{\text{Total VF Mass in Stockpile (t-1) [M]}} \) \quad (6-10)

\( \text{DC Release Rate (Cl, Scaled) [M/M/T]} = \frac{\text{Rate of Change to DC Mass in Stockpile [M/T]} \times \text{All_Release_Cl} \times \text{Size_Factor}}{\text{Total DC Mass in Stockpile (t-1) [M]}} \) \quad (6-11)

The “Total VF Mass in Stockpile (t-1)” and “Total DC Mass in Stockpile (t-1)” terms in Equations 6-10 and 6-11 are, respectively, the VF and DC masses in the stockpile during the previous time-step.

As with the Category 1 and 2/3 stockpiles, chloride is assumed to be released as soon as waste rock is added to the stockpile. The size factor is also used to scale the Category 4 waste rock release rates, and the following equations are used to both calculate and scale these rates for the VF and DC rock:

While Virginia Formation mass is still present in the stockpile, the fractional constituent release rates from the VF portion—that is, the fraction of the total mass of each constituent present that is released during a particular time-step—is calculated as follows:

\( \text{Mass Released from VF Rock (All Constituents) [1/T]} = \frac{\text{Total VF Mass in Stockpile (t-1) [M]} / \text{Cat4SP_InRock_VF (t-1) [M]}}{\text{VF Release Rates (All Constituents, Scaled) [M/M/T]}} \) \quad (6-12)

The term “Cat4SP_InRock_VF (t-1)” used in Equation 6-12 is the mass of each constituent bound in the VF waste rock during the previous time-step, and is equal to the product of the total VF mass in the stockpile (calculated by Equation 6-1) and the VF rock content for each constituent (“Cat4VF_content”).

A contact factor is applied to this fractional release rate to divide the mass released from the stockpile between mass considered available for transport out of the stockpile:

\( \text{Mass Released from VF Rock (All Constituents, Available for Transport) [1/T]} = \frac{\text{Mass Released from VF Rock (All Constituents) [1/T]} \times \text{Contact_Factor}}{\text{Contact_Factor}} \) \quad (6-13)

and mass considered unavailable for transport:

\( \text{Mass Released from VF Rock (All Constituents, Unavailable for Transport) [1/T]} = \frac{\text{Mass Released from VF Rock (All Constituents) [1/T]} \times (1 - \text{Contact_Factor})}{\text{Contact_Factor}} \) \quad (6-14)

The above mass available for transport is moved from the VF rock element (Cat4SP_InRock_VF) to the element representing water in the VF rock (Cat4SP_Water_VF), where the Virginia
Formation concentration caps are applied (see Section 15). The mass unavailable for transport is transferred from the VF rock to the non-contacted VF rock element (Cat4SP_nonContact_VF).

The third and final constituent mass outflow from the VF rock occurs due to the backfill of Category 4 waste rock into the East Pit. This mass is transferred—from both released and unreleased mass elements—at a fractional rate, which is calculated based upon the mass-based transfer rate of rock to the East Pit (Equation 6-5a) and the total stockpile mass (Equation 6-2):

\[
\text{VF Mass Transfer Rate from Stockpile to East Pit Backfill (All Constituents)} \left[ \frac{1}{T} \right] = \frac{\text{Rate of Change to Total Stockpile Mass}}{\text{Total Mass in Stockpile}} \left[ \frac{M}{T} \right] \quad (6-15)
\]

An analogous set of formulas to Equations 6-12 to 6-15 are used to determine fractional transfer rates from DC rock, and constituent mass movement from the DC rock portion of the stockpile (“Cat4SP_InRock_DC”) to (1) DC mass in water available for transport (“Cat4SP_Water_DC”), (2) the sequestered or “non-contacted” mass (“Cat4SP_nonContact_DC”), and (3) the East Pit backfill (“Cat4Bkf_DC_InRock”):

\[
\text{Mass Released from DC Rock (All Constituents)} \left[ \frac{1}{T} \right] = \text{DC Release Rates (Scaled)} \times \frac{\text{Cat4SP_MassDC (t-1)}}{\text{Cat4SP_InRock_DC (t-1)}} \left[ \frac{M}{T} \right] \quad (6-16)
\]

\[
\text{Mass Released from DC Rock (All Constituents, Available for Transport)} \left[ \frac{1}{T} \right] = \text{Mass Released from DC Rock (All Constituents)} \left[ \frac{1}{T} \right] \times \text{Contact_Factor} \quad (6-17)
\]

\[
\text{DC Mass Transfer Rate from Stockpile to East Pit Backfill (All Constituents)} \left[ \frac{1}{T} \right] = \frac{\text{Rate of Change to Total Stockpile Mass}}{\text{Total Mass in Stockpile}} \left[ \frac{M}{T} \right] \quad (6-19)
\]

In Equation 6-16, “Cat4SP_MassDC (t-1)” and “Cat4SP_InRock_DC (t-1)” are, respectively, the total DC waste rock mass and the mass of each constituent bound in the DC waste rock during the previous time-step. The Duluth Complex concentration caps are applied to water in the DC rock (“Cat4SP_Water_DC” element).

The conceptualization of the fate of Category 4 stockpile seepage is similar to that of the Category 2/3 stockpile. Rainfall infiltrates into the stockpile and is represented by two water elements: “Cat4SP_Water_DC” and “Cat4SP_Water_VF”. This infiltration then flows to the base of the stockpile separately where it mixes (in the “Cat4SP_Water_mixed” element), and then flows to the containment system. The volumes of water in the DC and VF portions of the stockpile are calculated by Equations 6-20 and 6-21:

\[
\text{Volume of DC Water in the Stockpile} \left[ \frac{L^3}{T} \right] = \text{Water_Depth} \times \text{Cat4SP_Bare} \times \frac{\text{Maximum DC Mass During Operations}}{\text{Maximum Total Stockpile Mass During Operations}} \left[ \frac{M}{T} \right] \quad (6-20)
\]
Volume of VF Water in the Stockpile \([L^3] = \text{Water\_Depth} \cdot \text{Cat4SP\_Bare} \cdot [1 - (\text{Maximum DC Mass During Operations} / \text{Maximum Total Stockpile Mass During Operations})] \) \hspace{1cm} (6-21)

The DC-derived constituent mass is then transferred to the East Pit backfill water element (“Cat4Bkf\_DC\_Water”) at the fractional rate defined by Equation 6-19. Mass loading rate from water in the DC rock to the mixed water at the bottom of the stockpile (“Cat4SP\_Water\_Mixed”) is the product of the continuously-varying constituent concentrations in DC rock water and the volumetric flow rate of this water to the bottom of the stockpile:

\[
\text{DC Water to the Bottom of the Stockpile} \ [L^3/T] = \frac{\text{Cat4SP\_Bare\_Infilt} \cdot \text{Maximum DC Mass During Operations}}{\text{Maximum Total Stockpile Mass During Operations}} \] \hspace{1cm} (6-22)

The VF-derived constituent mass is transferred to the East Pit backfill water (“Cat4Bkf\_VF\_Water”) during backfilling at the rate defined by Equation 6-15, and to the water at the bottom of the stockpile (“Cat4SP\_Water\_Mixed”) at a volumetric rate equal to:

\[
\text{VF Water to the Bottom of the Stockpile} \ [L^3/T] = \frac{\text{Cat4SP\_Bare\_Infilt} \cdot \text{Maximum DC Mass During Operations}}{\text{Maximum Total Stockpile Mass During Operations}} \] \hspace{1cm} (6-23)

The volume of mixed VF and DC water at the bottom of the stockpile is calculated using the stockpile area and the predefined water depth:

\[
\text{Amount of Water at Bottom of Stockpile} \ [L^3] = \text{Water\_Depth} \cdot \text{Cat4SP\_Bare} \] \hspace{1cm} (6-24)

The two inflows to this mixed volume of water are calculated as the product of the volumetric flow rates given by Equations 6-22 and 6-23 and the continuously-varying constituent concentrations in DC and VF water. Constituent mass removed from the bottom of the stockpile either flows passively or is sent to three areas: the East Pit backfill, the WWTF’s West Pond, and the East Pit sump. The fractional loading rate to the East Pit backfill water is determined by Equation 6-25:

\[
\text{Water from Bottom of Stockpile to East Pit backfill} \ [1/T] = \frac{\text{Rate of Change to Total Stockpile Mass} \cdot \text{Total Mass in Stockpile}}{\text{Maximum DC Mass During Operations}} \] \hspace{1cm} (6-25)

Stockpile seepage retained by the containment system is pumped to the West Pond of the WWTF for treatment. This mass loading rate is calculated as the product of the continuously-variable mixed water constituent concentrations and the volumetric flow rate determined by Equation 4-8b (with the substitution for the liner leakage fraction indicated above), or:

\[
\text{Water from Bottom of Stockpile to WWTF West Pond} \ [L^3/T] = \frac{\text{Cat4SP\_Outflow\_To\_WWTF}}{\text{Maximum DC Mass During Operations}} \] \hspace{1cm} (6-26)
Leakage from the stockpile liner flows to the East Pit sump. The constituent loading that accompanies this flow is the product of the continuously-variable mixed water concentration and the volumetric flow rate calculated by Equation 4-8a (with the appropriate liner leakage fraction substitution):

\[
\text{Water from Bottom of Stockpile to East Pit Sump Water} \ [L^3/T] = \frac{\text{Cat4SP_Outflow.Liner_leak}}{6.4}
\]

(6-27)

### 6.4 Output

The Category 4 Waste Rock Stockpile Model ultimately calculates the following flows and their associated constituent concentrations and loads:

- Infiltration collected in the containment system and directed to the WWTF
- Infiltration bypassing the containment system flowing to the East Pit sump
- Transfer of the mass bound in the waste rock, released unavailable mass, and the water contained within Duluth Complex rock to the East Pit backfill water
- Transfer of the mass bound in the waste rock, released unavailable mass, and the water contained within Virginia Formation rock to the East Pit backfill water
7 Ore Surge Pile (OSP) Model

7.1 Purpose
This model is used to simulate water flow and mass transport through the Ore Surge Pile. The model calculates water flows and associated constituent mass loads (for all constituents) that are routed to other component models, including the model of the WWTF used during mining operations and the Ore Surge Pile surficial groundwater flow path.

7.2 Input

7.2.1 Inputs from Other Models
- Monthly Precipitation [L/T], calculated in Equation 3-2

7.2.2 Water Balance Inputs
1. OSP_Bare [L²] – Area occupied by the ore surge pile (OSP)
   - Time-varying deterministic input
   - Values given in Table 1-8 of WMDP-MS-Attachment B

7.2.3 Ore Mass Inputs
1. Acid_Onset_Time_4DC [T] – Time until acidic conditions first occur in the Duluth Complex material in the pile
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 4.97 years; mode= 5.41 years; maximum = 6.81 years)
2. OSP_Mass [M] – Mass of waste rock present in the OSP
   - Time-varying deterministic input
   - Values given in Table 1-8 of WMDP-MS-Attachment B

7.2.4 Mass Transport Inputs
1. OSP_Sulfur [-] – Average sulfur content of ore
   - Deterministic input (0.608%)
2. Ore_Release_Indep [M/M/T] – Ore release rates independent of sulfate
   - For further explanation, see Section 15
3. Ore_Ratio_SO4 [M/M] – Ore release ratios for sulfate-dependent release rate calculations
   - For further explanation, see Section 15

7.3 Calculations

7.3.1 Water Balance Calculations
Runoff, evapotranspiration and infiltration fluxes for the OSP are calculated in the same ways as for the bare portion of the Category 1 waste rock stockpile (see Equations 4-1a, 4-1b, and 4-1c). The volumetric infiltration rate (“OSP_Bare_Infilt”) is subsequently calculated using Equation 4-2, the infiltration flux, and the stockpile area (“OSP_Bare”). Direct infiltration of precipitation is the only inflow of water to the OSP. The two outflows from the stockpile are liner leakage
(“OSP_Outflow.Liner_leak”) and contained seepage (“OSP_Outflow.To_WWTF”). These outflows are calculated using Equations 4-8a and 4-8b, respectively, with the OSP liner leakage fraction (“Liner_Leak_4_OSP”) substituted for “Cat1_Contain_Leak”. Contained seepage is pumped to the West Pond of the WWTF and liner leakage enters the OSP surficial groundwater flow path (see Section 13).

7.3.2 Ore Mass Calculations

The Duluth Complex (DC) portion of the OSP is assumed to not generate acid immediately after being added to the stockpile. Instead, oxidation is assumed to cause the waste rock to begin generating acid an uncertain amount of time (defined by “Acid_Onset_Time_4DC”) after mining begins.

The rate at which ore mass is added to the nonacidic portion of the OSP (“OSP_Mass_nonacid” element) during mining operations is equal to the rate of change of the specified total OSP mass:

\[
\text{Rate of Change of Ore Mass} \ [M/T] = \frac{d}{dt}(OSP_{\text{Mass}})
\]

(7-1)

Thus, all ore mass added to the pile is initially not acid-generating. Ore is removed from the “OSP_Mass_nonacid” element in two ways: conversion to acid-generating material (which is accounted for in the “OSP_Mass_acid” element), and transfer to the Plant Site for processing. The amount of mass converted from nonacidic- to acid-generating is calculated as a function of the amount of the pile remaining after the time lag has been applied. When the quantity calculated by Equation 7-1 is negative, no mass is transferred from nonacidic to acidic ore, and when it is positive the mass transfer is calculated as:

\[
\text{Mass Transfer Rate from Nonacidic- to Acid-Generating Ore} \ [M/T] = \frac{\text{Rate of Change of Ore Mass}}{(Time-lagged)} \ [M/T] \times (1 - OSP_{\text{Trans_frac}})
\]

(7-2)

In Equation 7-2, “OSP_Trans_frac” is the fraction of the OSP mass that has been transferred to the Plant Site for processing (i.e. the current value of “OSP_Mass” divided by the maximum value) and is calculated internally by the model.

The rate of mass transfer from the nonacidic-generating portion of the OSP to the Plant Site is calculated as a fraction of the total rate of change:

\[
\text{Mass Transfer Rate from Nonacidic Ore to Plant Site} [M/T] = \frac{\text{Rate of Change of Ore Mass}}{M/T} \times OSP_{\text{Nonacid_frac}},
\]

(7-3)

The “OSP_Nonacid_frac” term in Equation 7-3 is the time-varying, unitless fraction of the pile that is not acidic as calculated by the model (or, \(OSP_{\text{Mass_nonacid}} [M] / OSP_{\text{Mass}} [M]\)).

Acidic mass is only created by the oxidation of nonacidic ore (Equation 7-2), and the only means of acidic mass removal is the transfer of ore to the Plant Site for processing:

\[
\text{Mass Transfer Rate from Acidic Ore to Plant Site} [M/T] = \frac{\text{Rate of Change of Ore Mass}}{M/T} \times (1 - OSP_{\text{Nonacid_frac}})
\]

(7-4)
7.3.3 Mass Transport Calculations

Constituent mass from the OSP originates from ore in the pile and either flows to the OSP surficial groundwater flow path (Section 13) or is pumped to the WWTF’s West Pond. The calculations used to determine constituent release rates from the OSP are similar to those for the Category 2/3 stockpile because dissolution of ore in the OSP is also expected to generate acid. The sulfate release rate ($OSP_{SO4}$) is calculated using Equation 4-12 (with the ore sulfur content, $OSP_{Sulfur}$, substituted for “Cat1_Sulfur”). Unscaled, sulfate-dependent release rates are subsequently calculated for the OSP in the same manner as for the Category 2/3 stockpile and the bare portion of the Category 1 waste rock stockpile:

$$Nonacidic\ Release\ Rates\ (SO_4\text{-Dependent,\ Unscaled})\ [M/M/T] = \frac{Ore\_Ratio\_{SO4} [M/M] \times OSP\_SO4 [M/M/T]}{OSP\_Mass\_nonacid(t-1) [M]}$$

(7-5)

The constituents with release rates that vary with sulfate release ($OSP_{SO4}$) are identified in Section 15. Similar unscaled release rates (“Ore\_Release\_Indep”) are calculated for the sulfate-independent constituents (see Section 15).

Chloride release rates are calculated similarly to those for the Category 2/3 stockpile, and the following equation is used to calculate and scale the release rate to field-scale:

$$Nonacidic\ Release\ Rate\ (Cl,\ Scaled)\ [M/M/T] = \frac{Rate\ of\ Change\ of\ Ore\ Mass\ [M/T] \times All\_Release\_Cl\ [M/M] \times Size\_Factor}{OSP\_Mass\_nonacid\ (t-1) [M]}$$

(7-6)

The nonacidic ore rock mass from the previous time-step (“OSP\_Mass\_nonacid\ (t-1)”) is used to make this calculation.

Acidity is accounted for in the sulfate-dependent release rates from the acidic portion of the pile by the addition of an acid factor ($Acid\_Factor\_DC$) to Equation 7-5:

$$Acidic\ Release\ Rates\ (SO_4\text{-Dependent,\ Unscaled})\ [M/M/T] = \frac{Ore\_Ratio\_{SO4} \times OSP\_SO4 \times Acid\_Factor\_DC}{OSP\_Mass\_nonacid\ (t-1) [M]}$$

(7-7)

The sulfate-independent release rates from acidic ore are identical to those for the nonacidic ore. The final ore release rates are scaled using the size factor and Equations 5-12 and 5-13 for nonacidic and acidic ore, respectively.

While mass is still present in the OSP the fractional mass release rates from the nonacidic portion of the pile are calculated as follows:

$$Mass\ Released\ from\ Nonacidic\ Ore\ (All\ Constituents)\ [1/T] = \frac{Nonacidic\ Release\ Rates\ (All\ Constituents,\ Scaled)\ [M/M/T]}{OSP\_Mass\_nonacid\ (t-1) [M]}$$

(7-8)

The “OSP\_InRock\_nacid\ (t-1)” term in Equation 7-8 is the mass of each constituent bound in the nonacidic waste rock during the previous time-step.
A contact factor is applied to this fractional release rate to separate constituent mass released from the stockpile into mass considered available for transport:

\[
\text{Mass Released from Nonacidic Ore (All Constituents, Available for Transport)} \ [1/T] = \text{Mass Released from Nonacidic Ore (All Constituents)} \ [1/T] \ast \text{Contact\_Factor} \tag{7-9}
\]

and that which is unavailable for transport:

\[
\text{Mass Released from Nonacidic Ore (All Constituents, Unavailable for Transport)} \ [1/T] = \text{Mass Released from Nonacidic Ore (All Constituents)} \ [1/T] \ast (1 - \text{Contact\_Factor}) \tag{7-10}
\]

The above mass available for transport is moved from the nonacidic ore rock ("OSP\_InRock\_nacid") to water in the nonacidic ore ("OSP\_Water\_nacid"). the unavailable mass is transferred to the "OSP\_nonContact\_nacid” element. The rates of mass movement between these model elements are equal to the fractional rates calculated by Equations 7-9 and 7-10 and the constituent mass present in the nonacidic ore.

Constituent mass is also transferred directly from the nonacidic portion of the pile to the acidic portion at a fractional rate calculated using the mass-based transfer rate (from Equation 7-2) and the nonacidic rock mass:

\[
\text{Mass Transfer Rate from Nonacidic- to Acidic-Generating Ore (All Constituents)} \ [1/T] = \text{Mass Transfer Rate from Nonacidic- to Acidic-Generating Ore} \ [M/T] / \text{OSP\_Mass\_nonacid} \ [M] \tag{7-11}
\]

The fourth and final constituent mass outflow from the nonacidic rock element ("OSP\_InRock\_nacid") accounts for the transfer of ore from the nonacidic portion of the OSP to the Plant Site for processing. The fractional rate of mass transfer is based upon the mass-based transfer rate to the Plant Site (Equation 7-3) and the total mass present in the pile:

\[
\text{Mass Transfer Rate from Nonacidic Ore to Plant Site (All Constituents)} \ [1/T] = \text{Mass Transfer Rate from Nonacidic Ore to Plant Site} \ [M/T] / \text{OSP\_Mass} \tag{7-12}
\]

An analogous set of formulas to Equations 7-9, 7-10 and 7-12 are used to determine constituent mass movement from the acidic ore in the OSP ("OSP\_InRock\_acid") to the dissolved mass available for transport ("OSP\_Water\_acid”), the sequestered or “non-contacted” mass ("OSP\_nonContact\_acid”), and the Plant Site ("Sink\_Load\_Removed"):  

\[
\text{Mass Released from Acidic Ore (All Constituents, Available for Transport)} \ [1/T] = \text{Mass Released from Acidic Ore (All Constituents)} \ [1/T] \ast \text{Contact\_Factor} \tag{7-13}
\]

\[
\text{Mass Released from Acidic Ore (All Constituents, Unavailable for Transport)} \ [1/T] = \text{Mass Released from Acidic Ore (All Constituents)} \ [1/T] \ast (1 - \text{Contact\_Factor}) \tag{7-14}
\]
Mass Transfer Rate from Acidic Ore to Plant Site (All Constituents) \([1/\text{T}] = \frac{\text{Mass Transfer Rate from Acidic Ore to Plant Site} \ [\text{M/\text{T}}]}{\text{OSP Mass}} \)  

(7-15)

The conceptualization of the fate of mass loading leaving the OSP is similar to that of the other rock stockpiles: infiltrating water from the two portions of the pile (represented by the “OSP_Water_nacid” and “OSP_Water_acid” elements) percolates to the base of the stockpile and mixes (which takes place in the “OSP_Water_mixed” element). This mixed water either leaks into the surficial aquifer or is captured by the stockpile liner system and pumped to the WWTF. The volume of nonacidic water in the stockpile is a function of the fraction of the OSP that is nonacidic:

\[
\text{Volume of Nonacidic Water in the OSP} \ [\text{L}^3] = \text{Water Depth} \times \text{OSP Bare} \times \frac{\text{OSP Mass nonacid} \ [\text{M}]}{\text{OSP Mass}} 
\]

(7-16)

The constituent mass loading from nonacidic water (“OSP_Water_nacid”) to the mixed water at the bottom of the pile (“OSP_Water_mixed”) is the product of the continuously-varying, nonacidic water concentrations and the volumetric flow rate given by Equation 7-17:

\[
\text{Nonacidic Water to Bottom of the OSP} \ [\text{L}^3/\text{T}] = \text{OSP Bare Inflit} \ [\text{L}^3/\text{T}] \times \frac{\text{OSP Mass nonacid}}{\text{OSP Mass}} 
\]

(7-17)

The fractional loading rate from water in the nonacidic rock to acidic rock water (“OSP_Water_acid”) occurs at a fractional rate of:

\[
\text{Nonacidic Water to Acidic Water} \ [1/\text{T}] = \frac{\text{Mass Transfer Rate from Nonacidic- to Acid-Generating Ore} \ [\text{M/\text{T}}]}{\text{OSP Mass nonacid} \ [\text{M}]} 
\]

(7-18)

A similar fractional transfer rate is to the Plant Site (“Sink_Load_Removed”) at a rate of:

\[
\text{Nonacidic Water to Plant Site} \ [1/\text{T}] = \frac{\text{Mass Transfer Rate from Nonacidic Ore to Plant Site} \ [\text{M/\text{T}}]}{\text{OSP Mass}} 
\]

(7-19)

The volume of acidic water at the bottom of the stockpile is a function of the fraction of the OSP that is acidic, and is calculated using Equation 7-16 with “OSP Mass nonacid” replaced by the mass of acid-generating ore (OSP Mass_acid).

The two inflow rates to water in the acidic ore (“OSP_Water_acid”) are calculated by Equation 7-13 and Equation 7-18. The two outflows from this element are to the mixed water at the bottom of the stockpile and to the Plant Site. The mass loading rate to water at the the bottom of the stockpile is the product of the continuously-varying constituent concentrations in the acidic water and the volumetric flow rate of acidic water to the bottom of the stockpile, which is:

\[
\text{Acidic Water to Water at the Bottom of the OSP} \ [\text{L}^3/\text{T}] = \text{OSP Bare Inflit} \times (1 - (\text{OSP Mass nonacid} / \text{OSP Mass})) 
\]

(7-20)
The fractional loading rate of constituent mass to the Plant Site is calculated by Equation 7-21:

\[
\text{Acidic Water to Plant Site \([1/T]\)} = \frac{\text{Mass Transfer Rate from Acidic Ore to Plant Site \([M/T]\)}}{\text{OSP\_Mass}} \tag{7-21}
\]

The volume of the element representing the mixture of acidic and nonacidic water at the bottom of the stockpile (“OSP\_Water\_mixed”) is calculated by multiplying the OSP-covered area by the water depth:

\[
\text{Total Water Volume at Bottom of OSP \([L^3]\)} = \text{Water\_Depth} \times \text{OSP\_Bare} \tag{7-22}
\]

The inflow rates to “OSP\_Water\_mixed” are calculated by Equations 7-17 and 7-20. The outflow from this element is sent to the WWTF’s West Pond (Section 12), the Plant Site, and the OSP surficial aquifer flow path (Section 13). Mass loadings to the WWTF West Pond are the products of the continuously-variable concentrations in the mixed water at the bottom of the stockpile (OSP\_Water\_mixed) and the volumetric flow rate to the WWTF (OSP\_Outflow.To_WWTF). The mass outflow rate to the Plant Site is the product of the constituent mass present in the mixed water and the fractional outflow rate, which is:

\[
\text{Water from Bottom of the OSP to Plant Site \([1/T]\)} = \frac{\text{Rate of Change of Ore Mass \([M/T]\)}}{\text{OSP\_Mass}} \tag{7-23}
\]

The outflow from the “OSP\_Water\_mixed” element to each of the nine cells in section 1 of the OSP surficial aquifer flow path model is:

\[
\text{Discharge to Each Flow Path Cell (Section 1) \([L^3/T]\)} = \frac{\text{OSP\_Outflow.Liner\_leak \([L^3/T]\)}}{9 \text{ cells}} \tag{7-24}
\]

### 7.4 Output

The Ore Surge Pile Model ultimately calculates the following flows along with their associated concentrations and loadings:

- Ore surge pile seepage captured by the liner system and directed to the WWTF used during mining operations
- Leakage from the liner system to the OSP surficial aquifer flow path
8 Overburden Storage and Laydown Area (OSLA) Model

8.1 Purpose
This model is used to simulate water flow and mass transport through the overburden and storage laydown area (OSLA). The model calculates water flows and the associated constituent mass loads (for all constituents) that are routed to the WWTF during mining operations and the OSLA surficial groundwater flow path.

8.2 Input

8.2.1 Inputs from Other Models
- Monthly Precipitation [L/T], calculated in Equation 3-2

8.2.2 Water Balance Inputs
1. Reclaim_RO [-] – Runoff fraction
   - Probabilistic input sampled at start of each realization
   - Normal distribution (mean = 0.082; standard deviation = 0.0027)
2. Peat_Bare [L^2] – Area of peat in the OSLA
   - Deterministic input (22.4 acres)
3. UnsatOB_Bare [L^2] – Area of unsaturated overburden in the OSLA
   - Deterministic input (22.4 acres)

8.2.3 Mass Transport Inputs
1. OB_Unsat_rand [M/L^3] – Seepage concentrations from unsaturated overburden storage
   - Probabilistic input sampled at start of each realization
   - Uniform distributions defined by minima and maxima in Table 1-23 of WMDP-MS-Attachment B
2. OB_Peat_rand [M/L^3] – Seepage concentrations from peat storage areas
   - Probabilistic input sampled at start of each realization
   - Uniform distributions defined by minima and maxima in Table 1-23 of WMDP-MS-Attachment B

8.3 Calculations

8.3.1 Water Balance Calculations
The fractions of monthly precipitation falling on the bare portion of the stockpile that become the runoff, evapotranspiration and infiltration fluxes are calculated by Equations 8-1a, 8-1b and 8-1c:

\[
\text{Runoff} [L/T] = \text{Monthly Precipitation} [L/T] \times \text{Reclaim}_\text{RO} \quad (8-1a)
\]

\[
\text{Evaporation} [L/T] = \text{Monthly Precipitation} [L/T] \times \text{Reclaim}_\text{ET} \quad (8-1b)
\]

\[
\text{Infiltration Flux} [L/T] = \text{Monthly Precipitation} [L/T] \times (1 - \text{Reclaim}_\text{RO} - \text{Reclaim}_\text{ET}) \quad (8-1c)
\]
The volumetric runoff rates from the peat and unsaturated overburden (OB) portions of the OSLA are calculated as follows:

\[
\text{Peat Runoff } [L^3/T] = \text{Runoff } [L/T] \times \text{Peat\_Bare} \quad (8-2a)
\]

\[
\text{Unsaturated OB Runoff } [L^3/T] = \text{Runoff } [L/T] \times \text{UnsatOB\_Bare} \quad (8-2b)
\]

Total runoff from the OSLA is then the sum of these individual runoff components:

\[
\text{Total Runoff } [L^3/T] = \text{Peat Runoff } [L^3/T] + \text{Unsaturated OB Runoff } [L^3/T] \quad (8-2c)
\]

The volumetric infiltration rates into the peat and unsaturated OB portions of the OSLA are calculated similarly:

\[
\text{Infiltration to Peat } [L^3/T] = \text{Infiltration } [L/T] \times \text{Peat\_Bare} \quad (8-3a)
\]

\[
\text{Infiltration to Unsaturated OB } [L^3/T] = \text{Infiltration } [L/T] \times \text{UnsatOB\_Bare} \quad (8-3b)
\]

The total volumetric infiltration rate into the OSLA is the sum of these flows:

\[
\text{Total Infiltration } [L^3/T] = \text{Infiltration to Peat } [L^3/T] + \text{Infiltration to Unsaturated OB } [L^3/T] \quad (8-3c)
\]

### 8.3.2 Mass Transport Calculations

Mass fluxes from the OSLA occur as a result of infiltration and runoff from peat and saturated overburden areas. All of the resulting constituent mass loading enters either the OSLA surficial aquifer flow path (infiltration) the Central Pumping Station pond (runoff).

Water in contact with the unsaturated OB is represented by the “OSLA\_Unsat\_Water” element, which has a constant volume during mining operations equal to:

\[
\text{Water Contacting Unsaturated OB } [L^3] = \text{Water\_Depth} \times \text{UnsatOB\_Bare} \quad (8-4a)
\]

The water contacting peat (represented by the “OSLA\_Peat\_Water” element) has a constant volume calculated by Equation 8-4b:

\[
\text{Water Contacting Peat } [L^3] = \text{Water\_Depth} \times \text{Peat\_Bare} \quad (8-4b)
\]

The mass loading rate for each constituent to the “OSLA\_Unsat\_Water” element is the product of the constant unsaturated OB seepage concentration (“OB\_Unsat\_rand”) and the sum of the infiltration into and runoff from the unsaturated overburden:

\[
\text{Constituent Mass Loading to Unsaturated OB } [M/T] = \text{OB\_Unsat\_rand} \times \left( \text{Infiltration to Unsaturated OB } [L^3/T] + \text{Unsaturated OB Runoff } [L^3/T] \right) \quad (8-5)
\]
The constituent mass loading rates to the “OSLA_Peat_Water” element are calculated similarly:

\[
\text{Constituent Mass Loading to Peat} \ [\text{M}/\text{T}] = \text{OB_Peat_rand} \times (\text{Infiltration to Peat} \ [\text{L}^3/\text{T}] + \text{Peat Runoff} \ [\text{L}^3/\text{T}]) 
\]  

(8-6)

The constituent loads from peat and unsaturated OB runoff are, respectively, transferred from the “OSLA_Peat_Water” and “OSLA_Unsat_Water” elements to the Central Pumping Station pond (“CPS_Pond_Water”) at the rates calculated by Equations 8-2a and 8-2b. Constituent masses from peat and unsaturated OB infiltration are also transferred from the “OSLA_Peat_Water” and “OSLA_Unsat_Water” elements to the “OSLA_Mixed_Water” element. The loading rates associated with these mass flows are the products of the volumetric flow rates calculated in Equations 8-3a and 8-3b and the constituent concentrations in the respective areas.

The fate of all infiltrating water (i.e. outflow from “OSLA_Mixed_Water”) and the constituent mass contained within it is the first section of the OSLA surficial aquifer flow path model (see Section 13). The sum of all OSLA infiltration (calculated by Equation 8-3c) is divided evenly between the 14 cells that represent this section of the OSLA surficial aquifer flow path:

\[
\text{Discharge to Each Flow Path Cell (Section 1)} \ [\text{L}^3/\text{T}] = \frac{\text{Total Infiltration} \ [\text{L}^3/\text{T}]}{14 \text{ cells}} 
\]

(8-7)

The constituent mass loading from the mixed water in the OSLA is therefore the product of this volumetric flow rate and the continuously-varying mixed water concentration calculated by GoldSim.

### 8.4 Output

The Overburden Storage and Laydown Area Model ultimately calculates the following flows and the associated concentrations and loadings:

- Infiltration through peat and unsaturated overburden to the OSLA surficial flow path
- Runoff from peat and unsaturated overburden to the WWTF Central Pumping Station Pond
9 Rail Transfer Hopper and Haul Road Model

9.1 Purpose
This model is used to simulate water flow and mass transport from the rail transfer hopper (RTH) and haul road (HR) areas. The model calculates water flows and the associated constituent mass loads (for all constituents) that are routed to the WWTF used during mining operations.

9.2 Input
9.2.1 Inputs from Other Models
- Monthly Precipitation [L/T], calculated in Equation 3-2

9.2.2 Water Balance Inputs
1. \textit{RTH\_Trib\_Area\_Ops} [L^2] – Rail transfer hopper contributing area during operations
   - Deterministic input (1.65 acres)
2. \textit{HR\_Trib\_Area\_Ops} [L^2] – Haul road contributing area during operations
   - Deterministic input (72.4 acres)
3. \textit{Wall\_RO} [-] – Runoff fraction from pit walls
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.4; maximum = 0.6)

9.2.3 Rock and Ore Mass Inputs
1. \textit{RTH\_Ore\_Depth} [L] – Depth of spilled fine ore material on the RTH
   - Deterministic input (1 foot)
2. \textit{WR\_Sp\_Gravity} [-] – Waste rock specific gravity
   - Deterministic input (2.93)
   - Deterministic input (999.87 kg/m^3)
4. \textit{HR\_Cat1\_Depth} [L] – Depth of crushed Category 1 rock on the haul roads
   - Deterministic input (1 foot)

9.2.4 Mass Transport Inputs
1. \textit{Activation\_Energy} [M-L^2/T^2-mol] – Activation energy of pyrrhotite (for use in the Arrhenius equation)
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 47 kJ/mol; maximum = 63 kJ/mol)
   - Deterministic input (8.314472 J/mol-K)
3. \textit{Lab\_Temp} [degrees] – Laboratory temperature
   - Deterministic input (20°C)
4. \textit{Field\_Temp} [degrees] – Average annual site air temperature, assumed to be the same temperature as the ore
   - Probabilistic input resampled each year
• Normal distribution (mean = 2.004°C; standard deviation = 1.388°C)

9.3 Calculations

9.3.1 Water Balance Calculations

Rainfall onto the RTH and HR areas either evapotranspires or becomes runoff. The runoff will be collected in ponds and sent to the WWTF for treatment. The partitioning of rainfall into runoff and evapotranspiration for the RTH and HR areas differs slightly from other stockpile areas because there is no infiltration. First, the total volumetric precipitation rates are calculated from the global precipitation rate:

RTH Precipitation \( [L^3/T] = \) Monthly Precipitation \( [L/T] * RTH\_Trib\_Area\_Ops \) \hspace{1cm} (9-1a)

HR Precipitation \( [L^3/T] = \) Monthly Precipitation \( [L/T] * RTH\_Trib\_Area\_Ops \) \hspace{1cm} (9-1b)

These two volumetric rates are divided into runoff and evapotranspiration components for the RTH:

RTH Runoff \( [L^3/T] = RTH\_Precipitation [L^3/T] * Wall\_RO \) \hspace{1cm} (9-2a)

RTH Evapotranspiration \( [L^3/T] = RTH\_Precipitation [L^3/T] * (1 – Wall\_RO) \) \hspace{1cm} (9-2b)

and for the haul roads:

HR Runoff \( [L^3/T] = HR\_Precipitation [L^3/T] * Wall\_RO \) \hspace{1cm} (9-3a)

HR Evapotranspiration \( [L^3/T] = HR\_Precipitation [L^3/T] * (1 – Wall\_RO) \) \hspace{1cm} (9-3b)

9.3.2 Rock and Ore Mass Balance Calculations

Fine ore may be spilled during the process of transferring it to the hopper. The amount of spilled ore at the RTH (“RTH\_Ore\_Mass”) is calculated as:

Spilled Ore Mass \( [M] = RTH\_Ore\_Depth * RTH\_Trib\_Area\_Ops * WR\_Sp\_Gravity * WatDens \) \hspace{1cm} (9-4)

Category 1 waste rock will be crushed and used as a top dressing for the haul road surface. The mass of rock used for this purpose is calculated similarly to the spilled ore mass:

HR Waste Rock Mass \( [M] = HR\_Cat1\_Depth * HR\_Trib\_Area\_Ops * WR\_Sp\_Gravity * WatDens \) \hspace{1cm} (9-5)
9.3.3 Mass Transport Calculations

Constituent mass leaving the RTH and HR areas occurs entirely as a result of runoff. All of the runoff-derived constituent mass is ultimately sent to the WWTF used during operations for treatment.

The calculations used to determine release rates from ore at the RTH are similar to those for the ore in the OSP. The unscaled ore releases rates are calculated by Equation 7-5. The notable difference is that a temperature factor is used to scale the ore release rates:

\[
\text{RTH Release Rates (Scaled) [M/M/T]} = \frac{\text{Release Rates (Unscaled) [M/M/T] * Temp\_Factor}}{} \tag{9-6a}
\]

The temperature factor in Equation 9-6a is calculated as:

\[
\text{Temp\_Factor} = \exp\left[\frac{\text{Activation\_Energy}}{R} \left(\frac{1}{\text{Lab\_Temp}} - \frac{1}{\text{Field\_Temp}}\right)\right] \tag{9-6b}
\]

Haul road release rates are calculated similarly to those for the RTH, but the mass derived from the haul roads is assumed to have the properties of Category 1 waste rock. The unscaled sulfate release rates are calculated using Equation 4-12. The total release rates for the other constituents are calculated as described in Section 4, and these rates are then scaled using Equation 9-6a.

The volume of water in the RTH spilled ore element (“RTH\_Ore\_Water”) is calculated as:

\[
\text{Volume of Water in Spilled Ore [L^3]} = \text{Water\_Depth} \times \text{RTH\_Trib\_Area\_Ops} \tag{9-7}
\]

Constituent mass from the spilled ore is added to the ore water (“RTH\_Ore\_Water”) at the rate defined in Equation 9-8:

\[
\text{Constituent Mass Released to Ore Water [M/T]} = \frac{\text{RTH Release Rates (Scaled) [M/M/T] \times Spilled Ore Mass [M]}}{} \tag{9-8}
\]

Constituent concentrations in the ore water are calculated based upon these constituent mass release rates and the volume of water in the spilled ore (Equation 9-7). Water in the spilled ore is transferred to the WWTF’s East Pond at the rate defined in Equation 9-2a, and constituent mass fluxes from the spilled ore to the WWTF are calculated by multiplying this volumetric flow rate by the continuously-variable ore water concentrations. Constituent mass within water in the spilled ore may be precipitated based on the nonacidic concentration caps (Section 15), and any mass precipitated is removed from the model.

The volume of water in the haul road’s top dressing (“HR\_Cat1\_Water”) is calculated as:

\[
\text{Volume of Water in Top Dressing [L^3]} = \text{Water\_Depth} \times \text{HR\_Trib\_Area\_Ops} \tag{9-9}
\]
The constituent mass loading rates to this volume of water from the Category 1 rock used as top dressing are given by Equation 9-10:

\[
\text{Mass Released to Water in Top Dressing} \ [\text{M/T}] = \\
\text{HR Release Rates (Scaled)} \ [\text{M/M/T}] * \text{HR Waste Rock Mass} \ [\text{M}]
\] (9-10)

The fate of all water in the haul road top dressing is the East Pond of the WWTF. The rate of mass transfer between these two areas is the product of the volumetric flow rate determined by Equation 9-3a, and the continuously-varying constituent concentrations in the haul road water (“HR_Cat1_Water”).

9.4 Output

The Rail Transfer Hopper and Haul Road Model ultimately calculates the following flows and their corresponding constituent concentrations and loads:

- Runoff from spilled ore at the rail transfer hopper to the WWTF East Pond
- Runoff from the haul road’s top dressing to the WWTF East Pond
10 East Pit and Central Pit Model

10.1 Purpose
This model is used to simulate water flow and mass transport within and from the East Pit and Central Pit. The model calculates water flows and associated constituent mass loads (for all constituents) that are routed to other component models, including the models for the West Pit, the WWTF, and groundwater flow paths.

10.2 Input

10.2.1 Inputs from Other Models
- Monthly Precipitation [L/T], calculated in Equation (3-2).
- The simulated precipitation and evaporation from the Climate Model is used in the East Pit & Central Pit Model, along with the flag indicating whether the precipitation is snow or rain.
- The Category 1 Waste Rock Stockpile Model simulates the flow and load associated with infiltration collected in the Category 1 Waste Rock Stockpile containment system and directed to the East Pit. The Category 1 Waste Rock Stockpile Model also calculates the runoff flow directed from that stockpile to the East Pit.
- The Category 2/3 and Category 4 Waste Rock Stockpile Models calculate the amount of constituent mass transferred from each stockpile to the East Pit and Central Pit during backfilling.
- The WWTF model determines the amount of water and constituent mass loading (from the WWTFs used during operations and the Reclamation phase) to the East Pit and Central Pit.

10.2.2 Waste Rock Backfill Inputs
1. CP_Mine_Start [T] – Time that mining in the Central Pit begins
   - Deterministic input (10.75 years)
2. CP_Mine_End [T] – Year that mining in the Central Pit is complete
   - Deterministic input (15.25 years)
3. EPCP_Max_Mass [M] – Maximum tonnage of backfill rock in the combined East Pit
   - Deterministic input (140,191,500 ton)
4. SatOB_Porosity [-] – Porosity of the saturated overburden backfill
   - Deterministic input (0.2)
5. EPCP_Max_OBVol [L^3] – Maximum volume of backfilled saturated overburden in the combined East Pit
   - Deterministic input (4,498,100 yd^3)
6. WR_Swell [-] – Swelling of the rock
   - Deterministic input (0.3)

10.2.3 Water Balance Inputs
1. EP_Elev_to_Volume
   - Deterministic lookup table which determines the volume of the East Pit shell as a function of elevation (Figure 1-1 of WMDP-MS-Attachment B)
2. **EP_Elev_to_PlanArea**
   - Deterministic lookup table which determines the area of the water surface in the East Pit based on the water level elevation (Figure 1-2 of WMDP-MS-Attachment B)

3. **CP_Elev_to_PlanArea**
   - Deterministic lookup table which determines the area of the water surface in the Central Pit based on the water level elevation (Figure 1-2 of WMDP-MS-Attachment B)

4. **EP_Volume_to_Elev**
   - Deterministic lookup table which determines the elevation of the water surface in the East Pit based on the pit water volume (Figure 1-1 of WMDP-MS-Attachment B)

5. **CP_Volume_to_Elev**
   - Deterministic lookup table which determines the elevation of the water surface in the Central Pit based on the pit water volume (Figure 1-1 of WMDP-MS-Attachment B)

6. **EP_Footprint_Area \([L^2]\) – Area contributing runoff during operations**
   - Deterministic input (154.7 acres)

7. **CP_Footprint_Area \([L^2]\) – Area contributing runoff during operations**
   - Deterministic input (51.9 acres)

8. **EPCP_RO_Area \([L^2]\) – Natural areas contributing runoff to East Pit after mining operations cease**
   - Deterministic inputs (83 acres when West Pit is not full and the long-term WWTF is not operational; 83 acres otherwise)

9. **RO_fraction \([-\] – Runoff fraction**
   - Probabilistic input resampled each year, and variable by season
   - Winter: Normal distribution (mean = 0.63; standard deviation = 0.275)
   - Summer: Normal distribution (mean = 0.30; standard deviation = 0.092)

    - Time-varying deterministic input, interpolated from data points
    - Values given in Table 1-22a of WMDP-MS-Attachment B

11. **Pit_GW_Uncertainty_unshift [-] – Groundwater inflow uncertainty multiplier**
    - Probabilistic input sampled at start of each realization
    - Log-normal distribution (mean = 0.30; standard deviation = 0.31)

12. **Pit_GW_Uncertainty_shift [-] – Upward shift for the groundwater inflow uncertainty multiplier**
    - Deterministic input (0.7)

13. **CP_GW_Inflow_Ops \([L^3/T]\) – Groundwater inflow to the Central Pit during operations**
    - Time-varying deterministic input, interpolated from data points
    - Values given in Table 1-22a of WMDP-MS-Attachment B

    - Deterministic lookup table which determines the groundwater inflow rate to the East Pit during closure based on the pit water volume (Table 1-22b of WMDP-MS-Attachment B)
15. CP_GW_Inflow [L³/T]
   • Deterministic lookup table which determines the groundwater inflow rate to the Central Pit during closure based on the pit water volume (Table 1-22b of WMDP-MS-Attachment B)

16. EPCat23_K [L/T] – Hydraulic conductivity of the East Pit and Category 2/3 stockpile surficial aquifer flow path
   • Probabilistic input sampled at start of each realization
   • Triangular distribution (minimum = 0.82 m/d; mode = 1.94 m/d; maximum = 5.49 m/d)

17. EPCat23_w [L] – Width of the East Pit and Category 2/3 stockpile surficial aquifer
   • Deterministic input (1440 m)

18. EPCat23_b [L] – Thickness of the East Pit and Category 2/3 stockpile surficial aquifer
   • Deterministic input (5 m)

19. l_close_EP23surf [-] – Average gradient of the East Pit and Category 2/3 stockpile surficial flow path after the pit is full
   • Probabilistic input sampled at start of each realization
   • Uniform distribution (minimum = 0.00599; maximum = 0.00646)

20. CP_to_WP [L³/T] – Flow through bedrock from Central Pit porewater to West Pit
   • Deterministic input (0.1 gallons per minute)

21. EPCP_GW_OutElev [L] – Minimum elevation of the surficial aquifer base (top of bedrock) at the East Pit
   • Deterministic input (1577 feet)

22. EPCP_Outlet_Elev [L] – Elevation of the wetland outlet structure (spillway)
   • Deterministic input (1592 feet)

23. EPCP_Sump_Volume [L³] – Volume of the pit sump
   • Deterministic input (10,000 cubic feet)

24. C_W [-] – Weir coefficient for wetland spillway
   • Deterministic input (0.611)

25. b [L] – Wetland spillway width
   • Deterministic input (20 feet)

26. g [L/T²] – Gravitational acceleration constant
   • Deterministic input (9.80665 m/s²)

27. EPCP_Total_Mass [M] – Mass of backfill in the East Pit by rock category (not including overburden)
   • Time-varying deterministic input
   • Values given in Table 1-10b of WMDP-MS-Attachment B

28. EPCP_Total_OBVol [L³] – Volume of saturated overburden used to backfill the East Pit
   • Time-varying deterministic input, interpolated from data points
   • Values given in Table 1-10b of WMDP-MS-Attachment B

10.2.4 Mass Transport Inputs
1. EP_GW_Surf_Ops [-] – Fraction of inflow to the pit during operations that comes from the surficial aquifer
   • Time-varying deterministic input, interpolated from data points
• Values given in Table 1-22a of WMDP-MS-Attachment B

2. CP_GW_Surf_Ops [-] – Fraction of inflow to the pit during operations that comes from the surficial aquifer
   • Time-varying deterministic input, interpolated from data points
   • Values given in Table 1-22a of WMDP-MS-Attachment B

3. Cat1SP_RO_EP [-] – Area with runoff directed to the East Pit during pit flooding
   • Deterministic input (0 acres)

4. EPCP_Elev_to_WallArea
   • Deterministic lookup table which determines total exposed wall area in the East Pit-Central Pit as a function of elevation (Figure 1-4 of WMDP-MS-Attachment B)

5. EPCP_Elev_to_SetBackArea
   • Deterministic lookup table which determines the area of the pit rim set back above the final pit shell as a function of elevation (Figure 1-4 of WMDP-MS-Attachment B)

6. EPCP_Elev_to_WallFrac_1
   • Deterministic lookup table which determines the fraction of the pit wall consisting of Category 1 rock as a function of elevation (Figure 1-3a of WMDP-MS-Attachment B)

7. EPCP_Elev_to_WallFrac_23
   • Deterministic lookup table which determines the fraction of the pit wall consisting of Category 2/3 rock as a function of elevation (Figure 1-3a of WMDP-MS-Attachment B)

8. EPCP_Elev_to_WallFrac_4DC
   • Deterministic lookup table which determines the fraction of the pit wall consisting of Category 4 Duluth Complex rock as a function of elevation (Figure 1-3a of WMDP-MS-Attachment B)

9. EPCP_Elev_to_WallFrac_4VF
   • Deterministic lookup table which determines the fraction of the pit wall consisting of Category 4 Virginia Formation rock as a function of elevation (Figure 1-3a of WMDP-MS-Attachment B)

10. EPCP_Elev_to_WallFrac_Ore
    • Deterministic lookup table which determines the fraction of the pit wall consisting of ore rock as a function of elevation (Figure 1-3a of WMDP-MS-Attachment B)

11. Decay_a0 [-] – Parameter to define shape of decay of sulfate release
    • Probabilistic input sampled at start of each realization
    • Uniform distribution (minimum = 1.6; maximum = 3.48)
    • Correlated to “Decay_a1” (below); correlation value of -0.989

12. Decay_a1 [-] – Parameter to define shape of decay of sulfate release
    • Probabilistic input sampled at start of each realization
    • Uniform distribution (minimum = -1.088; maximum = -0.087)

    • Deterministic input (3983.666 ton/acre-foot)

14. Wall_Depth_DC [L] – Average depth of oxidizing Duluth Complex wall rock
    • Probabilistic input sampled at start of each realization
    • Triangular distribution (minimum = 1 m; mode = 2 m; maximum = 3 m)
15. **Wall_Depth_VF [L]** – Average depth of oxidizing Virginia Formation wall rock
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 2 m; mode= 4 m; maximum = 6 m)
16. **SetBack_Depth_Fraction [-]** – Fraction of oxidizing bedrock in the pit rim set back
   - Deterministic input (0.1)
17. **EP_Elev_to_Sulfur_1 [%]**
   - Deterministic lookup table containing the average sulfur content of Category 1 wall rock as a function of elevation (Figure 1-5 of WMDP-MS-Attachment B)
18. **EP_Elev_to_Sulfur_23 [%]**
   - Deterministic lookup table containing the average sulfur content of Category 2/3 wall rock as a function of elevation (Figure 1-6 of WMDP-MS-Attachment B)
19. **EP_Elev_to_Sulfur_Ore [%]**
   - Deterministic lookup table containing the average sulfur content of ore wall rock as a function of elevation (Figure 1-7 of WMDP-MS-Attachment B)
20. **EP_Spill_Elev [L]** – Elevation at the pit rim low point
    - Deterministic input (1594 feet)
21. **Size_Factor_walls [-]** – Scaling factor to adjust wall rock release rates to field scale
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.05; maximum = 0.15)
22. **South_Face_EP [-]** – South-facing portion of pit wall that is subject to solar heating
    - Deterministic input (0.5)
23. **Wall_Temp_Solar [degrees]** – Average temperature increase for portion of pit wall that has solar heating
    - Deterministic input (1.5°C)
24. **Field_Temp_Mean [-]** – Average annual temperature
    - Probabilistic input resampled each year
    - Normal distribution (mean = 2.004°C; standard deviation = 0.2534°C)
    - Time-varying deterministic input
    - Values given in Table 1-9 of WMDP-MS-Attachment B
26. **WP_BlastOre_Mass [M]** – Blasted ore in the West Pit awaiting removal
    - Time-varying deterministic input
    - Values given in Table 1-9 of WMDP-MS-Attachment B
27. **EPCP_Direct_Mass [M]** – Mass of Category 1, 2/3, and 4 (Virginia Formation and Duluth Complex) waste rock transferred directly from the West Pit to the East Pit
    - Time-varying deterministic input, interpolated from data points
    - Values given in Table 1-10 of WMDP-MS-Attachment B
28. **Ore_Processing_Rate [M/T]** – Rate of ore production and transfer to Plant Site
    - Deterministic input (30,860 ton/day)

### 10.3 Calculations

The East and Central Pits are created by the gradual removal of waste rock and ore during mining operations. Groundwater inflow to each pit varies during operations based on pit depth. For wall rock mass balance calculations, however, the East Pit and Central Pit are assumed to be mined out.
(fully open) at the beginning of mining operations. Water levels during operations are maintained at the bottom of the pits through pumping from sumps. The sumps get inflows and loads from various sources including wall-rock runoff, ore processing within the pits, and runoff from upland areas.

As mining progresses, the two pits are backfilled with waste rock and overburden. Backfilling of the East Pit begins 10.5 years after mining operations begin. Mining of the Central Pit then begins at 10.75 years (specified by the “CP_Mine_Start” input) and continues until 15.25 years (“CP_Mine_End”). Backfilling of the Central Pit then begins and, once the backfill elevations in the East and Central Pits are equal, the combined East Pit-Central Pit (EPCP) is backfilled until the time of mine closure (20 years).

During backfilling, inflows of water fill the pore space from the bottom up, and eventually a wetland forms atop the backfilled, combined East and Central Pit. The wetland discharges into the West Pit via a designed spillway, and groundwater can flow from the backfill porewater to the West Pit and to groundwater flow paths.

### 10.3.1 Waste Rock Backfill Calculations

The mass of waste rock (“EPCP_Total_Mass”) and volume of overburden material (“EPCP_Total_OBVol”) used to backfill the East and Central Pits through time are defined by the Mine Plan. The total amount of backfilled waste rock present in the East and Central Pits through time is calculated on a volumetric basis as a function of the backfill bulk density:

\[
\text{Total}_{\text{Bkf}}\text{Vol} \left[ \text{L}^3 \right] = \left( \frac{\text{EPCP}_{\text{Total}}\text{Mass}}{\text{Bkf}_{\text{BulkDens}}} \right) + \text{EPCP}_{\text{Total}}\text{OBVol} \tag{10-1a}
\]

The backfill bulk density (“Bkf_BulkDens”) is calculated as a function of the waste rock specific gravity (introduced in Section 9) and rock swelling:

\[
\text{Bkf}_{\text{BulkDens}} \left[ \text{M/L}^3 \right] = \text{WR}_{\text{Sp Gravity}} \times \text{WatDens} / (1 + \text{WR}_{\text{Swell}}) \tag{10-1b}
\]

Once backfilling begins, all of the backfilled rock is initially placed in the East Pit. Then, after mining of the Central Pit ceases, backfilling of the East Pit stops temporarily and all of the backfill is placed in the Central Pit until the top elevations of the East and Central pits are equal. (The top elevations of the backfill in the pits are calculated using the volume-to-elevation lookup tables “EP_Volume_to_Elev” and “CP_Volume_to_Elev”). Thereafter, the combined East Pit-Central Pit is filled with the remaining backfill.

The porosity of the backfilled material directly influences the total volume of water that each of the three pit areas can hold as well as the rate of water level rise as water fills each area. The backfill porosity is calculated as the volume-weighted average of the porosities of the saturated overburden material and waste rock used as backfill:

\[
\text{Backfill Porosity \ [-]} = \frac{(\text{Waste Rock Porosity \ [-]} \times \text{EPCP}_{\text{Max Mass}} \left[ \text{M} \right] / \text{Bkf}_{\text{BulkDens}} \left[ \text{M/L}^3 \right] + \text{SatOB Porosity \ [-]} \times \text{EPCP}_{\text{Max OBVol}} \left[ \text{L}^3 \right])}{(\text{EPCP}_{\text{Max Mass}} \left[ \text{M} \right] / \text{Bkf}_{\text{BulkDens}} \left[ \text{M/L}^3 \right] + \text{EPCP}_{\text{Max OBVol}} \left[ \text{L}^3 \right])} \tag{10-2a}
\]
The waste rock porosity in the above equation is defined as:

\[
\text{Waste Rock Porosity} = 1 - (1 + \text{WR}_\text{Swell})^1
\]

(10-2b)

10.3.2 Water Balance Calculations

Reservoir Elements

Several Goldsim reservoir elements are used to track the water volumes and flows into and out of the East Pit and Central Pit sumps during operation and volumes and flows into and out of the backfill pore space and wetland during and after flooding.

One reservoir element is used to simulate the East Pit sump (during operations) and porewater within the East Pit below the minimum top of bedrock elevation (EPCP\_GW\_OutElev). This porewater is called “lower” porewater and has a prescribed minimum value of zero and maximum volume equal to the product of the backfill porosity and the pit volume below the top of bedrock elevation (determined using this elevation and the “EP\_Elev\_to\_Volume” lookup table).

A similar reservoir simulates the Central Pit sump and lower porewater, which has a maximum volume equal to the product of the backfill porosity and the pit volume below the top of bedrock elevation (determined using the “CP\_Elev\_to\_Volume” lookup table). The minimum value for this reservoir is also zero.

A third reservoir element simulates “upper” porewater in backfill of the combined East and Central Pit (EPCP) above the top of bedrock elevation. When the two lower porewater reservoirs become full, the overflow from those reservoirs becomes inflow to the upper porewater reservoir.

Finally, a fourth reservoir element simulates the open-water wetland atop backfill in the combined East and Central Pit. This reservoir element receives overflow from the upper porewater reservoir element.

In general (except as noted below), inflows and outflows to the individual pits are applied to the uppermost active reservoir associated with the pit, as follows:

- Before the water level in the pits reaches the surficial aquifer, flows are applied to the East Pit and Central Pit lower porewater reservoirs (which represent the sumps during mining and the porewater in the backfill below the surficial aquifer).
- All flows go to the combined EPCP upper porewater reservoir between the times when the pit water levels reach the surficial aquifer and when the pit backfill has completely flooded.
- Once the backfill has completely filled with water, flows enter the overlying EPCP wetland reservoir.

The water flows entering the East and Central Pits include:

- Direct precipitation onto open water or backfill
- Runoff from
  - i.  pit wall rock
  - ii.  natural areas of the watershed upland of the pits
iii. a portion of the Category 1 Waste Rock Stockpile (calculated in the Category 1 Waste Rock Stockpile model), if any

- Category 1 waste rock stockpile seepage collected in the containment system of that stockpile and routed to the East/Central Pit (calculated in the Category 1 Waste Rock Stockpile model), if any
- Groundwater inflow to the pits
- Flow pumped into the pit backfill from the WWTF for reflooding during backfilling
- Treated flow returned to the pit from the WWTF during post-flooding porewater treatment.

Outflows from the pits include:

- Evaporation from open water or backfill
- Groundwater outflow from pit porewater
- Flow pumped from the sumps or from porewater to the WWTF to maintain water levels
- Flow pumped from porewater during post-flooding porewater treatment
- Surface-water discharge from the EPCP wetland to the West Pit
- Potential uncontrolled overflow from the EPCP wetland to the Partridge River

Calculations for these inflows and outflows are discussed below.

**Precipitation**

Direct precipitation onto open water in the pits is calculated as:

\[
\text{East Pit Direct Precipitation} \left[ \frac{L^3}{T} \right] = \text{Monthly Precipitation} \left[ \frac{L}{T} \right] \times \text{EP_Water_Area} \left[ L^2 \right] \\
\text{Central Pit Direct Precipitation} \left[ \frac{L^3}{T} \right] = \text{Monthly Precipitation} \left[ \frac{L}{T} \right] \times \text{CP_Water_Area} \left[ L^2 \right]
\]  

(10-3)

(10-4)

In Equations 10-3 and 10-4, the water areas are determined using the current calculated pit water levels and the elevation-to-area lookup tables “EP_Elev_to_PlanArea” and “CP_Elev_to_PlanArea”. The pit water levels are themselves determined as a function of the current pit (reservoir) water volumes and the volume-to-elevation lookup tables “EP_Volume_to_Elev” and “CP_Volume_to_Elev”.

A snowpack model is used to accumulate surface water flows during the winter months (as defined by months of snow in the Climate Model). During winter, all surface flow to the pits (precipitation, wall runoff, stockpile runoff, and runoff from natural areas) is accumulated as snowpack volume rather than added to the pit-reservoir water budgets.

The entire accumulated winter snowpack then melts during the month of April for addition to the appropriate pit reservoir water budgets (and the snowpack volume is reset to zero):

\[
\text{Snowmelt} \left[ \frac{L^3}{T} \right] = \frac{\text{Accumulated Snowpack Volume} \left[ L^3 \right]}{1 \text{ month}}
\]  

(10-5)
Evaporation

After backfilling begins and while the pit water levels are below the top of the backfill, evaporation is calculated as the evapotranspiration from a bare rock stockpile:

East Pit Evaporation \[ \frac{L^3}{T} = \]
East Pit Direct Precipitation \[ \frac{L^3}{T} \] * Bare_ET \hspace{1cm} (10-6)

Central Pit Evaporation \[ \frac{L^3}{T} = \]
Central Pit Direct Precipitation \[ \frac{L^3}{T} \] * Bare_ET \hspace{1cm} (10-7)

At all other times the volumetric evaporation rates are:

East Pit Evaporation \[ \frac{L^3}{T} = \]
Monthly Evaporation \[ \frac{L}{T} \] * EP_Water_Area \[ L^2 \] \hspace{1cm} (10-8)

Central Pit Evaporation \[ \frac{L^3}{T} = \]
Monthly Evaporation \[ \frac{L}{T} \] * CP_Water_Area \[ L^2 \] \hspace{1cm} (10-9)

Runoff

Runoff from the East Pit and Central Pit walls is determined separately:

East Pit Wall Runoff \[ \frac{L^3}{T} = \]
Monthly Precipitation \[ \frac{L}{T} \] * EP_Wall_RO_Area \[ L^2 \] * Wall_RO \hspace{1cm} (10-10)

Central Pit Wall Runoff \[ \frac{L^3}{T} = \]
Monthly Precipitation \[ \frac{L}{T} \] * CP_Wall_RO_Area \[ L^2 \] * Wall_RO \hspace{1cm} (10-11)

In Equations 10-5 and 10-10, the wall areas are calculated by subtracting the open-water areas from the full footprints of the pit: \( \text{EP}_{\text{Wall}}_{\text{RO}}_{\text{Area}} = \text{EP}_{\text{Footprint}}_{\text{Area}} – \text{EP}_{\text{Water}}_{\text{Area}} \) and \( \text{CP}_{\text{Wall}}_{\text{RO}}_{\text{Area}} = \text{CP}_{\text{Footprint}}_{\text{Area}} – \text{CP}_{\text{Water}}_{\text{Area}} \).

During mining, runoff from natural, upland areas does not get routed to the pits. After mining operations cease (which happens at time equal to “Closure_Year”), runoff from natural upland areas to the backfilled East/Central Pit is calculated as:

Runoff from Natural Areas \[ \frac{L^3}{T} = \]
Monthly Precipitation \[ \frac{L}{T} \] * EPCP_RO_Area \[ L^2 \] * RO_fraction \hspace{1cm} (10-12)

This runoff flow is always directed to the EPCP Wetland reservoir because runoff from these areas is only allowed to enter the pits after wetland creation.

Runoff from the Category 1 Waste Rock Stockpile that is directed to the East/Central Pit is calculated in the Category 1 Waste Rock Stockpile Model. This runoff flow is also directed to the EPCP wetland reservoir.
During winter months, runoff is added to the precipitation snowpack, and released in April.

Category 1 Waste Rock Stockpile Seepage

The portion of the Category 1 Waste Rock Stockpile Seepage (if any) that is collected in the containment system and routed to the East Pit is calculated by the Category 1 Waste Rock Stockpile Model. As with other East Pit flows, this flow is directed to the East Pit sump/lower-porewater reservoir, the EPCP upper porewater reservoir, or the EPCP wetland reservoir, depending on the pit water level.

Groundwater Inflow

Natural groundwater inflows to the East and Central Pits are calculated differently depending on whether or not the water level in the pits is known or is uncertain. During mining, the inflows to the East and Central Pits are:

\[
\text{Natural Groundwater Inflow (East Pit)} \left[ \frac{L^3}{T} \right] = \text{Groundwater Flow Uncertainty Coefficient} \times \text{EP\_GW\_Inflow\_Ops} \tag{10-13a}
\]

\[
\text{Natural Groundwater Inflow (Central Pit)} \left[ \frac{L^3}{T} \right] = \text{Groundwater Flow Uncertainty Coefficient} \times \text{CP\_GW\_Inflow\_Ops} \tag{10-13b}
\]

In Equations 10-13a and 10-13b, the groundwater flow uncertainty coefficient is the sum of two pre-defined input variables:

\[
\text{Groundwater Flow Uncertainty Coefficient} = \text{Pit\_GW\_Uncertainty\_shift} + \text{Pit\_GW\_Uncertainty\_unshift} \tag{10-13c}
\]

After mining in each pit has ceased, groundwater inflows to the pits are:

\[
\text{Natural Groundwater Inflow (East Pit)} \left[ \frac{L^3}{T} \right] = \text{Groundwater Flow Uncertainty Coefficient} \times \text{EP\_GW\_Inflow} \tag{10-14a}
\]

\[
\text{Natural Groundwater Inflow (Central Pit)} \left[ \frac{L^3}{T} \right] = \text{Groundwater Flow Uncertainty Coefficient} \times \text{CP\_GW\_Inflow} \tag{10-14b}
\]

In Equations 10-14a and 10-14b, EP\_GW\_Inflow and CP\_GW\_Inflow are functions of the water levels in the pits (interpolated from lookup tables).

Groundwater Outflow

Groundwater outflows can occur from the East Pit lower porewater, the Central Pit lower porewater, and the EPCP upper porewater.

Groundwater outflow from the East Pit lower porewater is to the upstream end of the East Pit bedrock groundwater flow path. This outflow occurs after the pit water elevation reaches the
surficial aquifer base elevation (top of bedrock) and only if porewater is not being pumped to the WWTF. The amount of outflow is calculated in the East Pit Bedrock Flow Path Model (Section 13).

Outflow from the Central Pit lower porewater to the West Pit is zero prior to the pit water level reaching the surficial aquifer base elevation (top of bedrock). It is also zero if porewater is being pumped to the WWTF or if the WWTF is in long-term closure operation (i.e. the West Pit is full). Otherwise the flow from the Central Pit to the West Pit is defined as:

\[
\text{Central Pit Bedrock Groundwater Outflow} \ [L^3/T] = \text{CP_to_WP} \ [L^3/T] \times \text{Groundwater Flow Uncertainty Coefficient} \quad (10-15)
\]

Groundwater outflow from the East/Central Pit upper porewater to the upstream end of the Surficial Aquifer East Pit and Category 2/3 flow path can also occur when the water level in the pits reaches the aquifer base elevation. The flow is calculated by the East Pit and Category 2/3 Flow Path Model (Section 13).

**Dewatering during Operations**

During mining, water is pumped from the sumps as needed to maintain dewatered conditions in the pits. The dewatering flow for each pit is equal to the net inflow to the sump in that pit (net of precipitation, evaporation, runoff, stockpile seepage, groundwater inflow, and groundwater outflow), unless that inflow exceeds the pumping capacity as defined in the WWTF Model (Pump_Limit_EP).

Once backfilling of the East Pit begins, some net inflow is desired to flood the backfill. The desired water level in the pit is calculated as:

\[
\text{Desired Pit Water Level (at end of time step)} \ [L] = \text{Backfill Elevation (at end of time step)} - \text{EP_Bkf_MARGIN} \quad (10-16)
\]

However, the desired East Pit water level cannot be greater than the Central Pit sump level as long as the Central Pit is being mined.

The total volume of the East Pit below the desired water level elevation is then determined (using the EP_Elev_to_Volume lookup table) and this volume is multiplied by the backfill porosity to determine the desired porewater volume in the East Pit backfill.

The dewatering outflow desired for the East Pit lower porewater reservoir in order to obtain the desired level in 1 month is then calculated:

\[
\text{Desired Dewatering Flow} \ [L^3/T] = \frac{\text{Net Inflow from Other Sources/Sinks} - (\text{Desired Porewater Volume} - \text{Current Porewater Volume})}{1 \text{ month}} \quad (10-17)
\]

Again, the actual dewatering flow may be limited by the pump capacity at the WWTF.
If the calculated desired dewatering quantity is negative, the flow represents a desired flooding inflow demand from the WWTF as discussed below.

Flooding Inflow from the WWTF

Water may be pumped from the WWTF into the East and Central Pits to accelerate backfill flooding. The East Pit & Central Pit Model calculates the desired inflows (water demands) to bring the water level in the pits up to the desired level. The WWTF Model then calculates the actual inflows to be supplied when the desired inflows exceed the net of other inflows and outflows that are active during backfilling (i.e. precipitation, evaporation, runoff, stockpile seepage, groundwater inflow, and groundwater outflow).

The desired flooding inflows during a time step are calculated based on the desired porewater volumes for the EP and CP backfill which are in turn based on the elevations of backfill in the pits at the end of the time step, as follows:

The Central Pit desired water level is first determined:
- Prior to completion of central pit mining, the desired water level is the minimum (sump) water level.
- Up until the backfilling is complete, the desired water level is calculated using Equation 10-16
- Once the backfilling is complete the desired water level for flooding is the maximum backfill elevation.

Similarly, the East Pit desired water level is calculated:
- Prior to the onset of backfilling in the East Pit, the desired water level is the minimum (sump) water level.
- Up until the backfilling is complete, the desired water level is calculated by Equation 10-16 except that it can be no greater than the desired water level in the Central Pit.
- Once the backfilling is complete the desired water level for flooding is the maximum backfill elevation.

The total volumes of each pit below the desired water level elevations are then determined (using the CP_Elev_to_Volume and EP_Elev_to_Volume lookup tables) and these volumes are multiplied by the backfill porosity to determine the desired porewater volumes in each pit.

The flooding flow desired for the East Pit lower porewater reservoir in order to obtain the desired level in 1 month is then calculated:

\[
\text{Desired Flooding Inflow} \ [\, L^3/T\,] = \frac{(\text{Desired Porewater Volume} - \text{Current Porewater Volume})}{1 \text{ month}} \quad (10-18)
\]

The same equation is used to calculate the desired Central Pit flooding flow.

If the desired flooding inflow is greater than the net inflow from other sources and sinks, then the desired flow demand from the WWTF is calculated as:
Desired Flooding Flow from WWTF \([L^3/T] =\)

\[
\text{Desired Flooding Inflow} - \text{Net Inflow from Other Sources/Sinks}\tag{10-19}
\]

The actual porewater flooding flows from the WWTF are limited by the water available at the WWTF and are calculated using Equation 12-5b.

Once the backfill is completed, the desired flow to fill the wetland (to the outlet elevation) in one month is calculated. This desired flow becomes another demand for the WWTF Model, limited by the combined pump capacities of the East Pit and Central Pit, less any desired flow to completely flood the backfill. The actual flooding flow to the wetland is calculated in the WWTF Model.

**Porewater Treatment Flows**

After the backfill is reflooded, and during the reclamation phase of the project, porewater is pumped to the RWWTF for treatment. A portion of the treated flow is then returned to the backfilled and flooded pit. The total allowable porewater withdrawal for treatment is determined in the WWTF Model. This allowable total outflow to the WWTF is apportioned to the three porewater reservoirs based on the relative porewater-volume of each.

The total allowable return flow of treated water from the WWTF is also determined in the WWTF Model. The desired return flows to each porewater reservoir are apportioned based on the relative porewater volume. These become demands for water; the actual return flows to each reservoir are determined in the WWTF Model.

**Wetland Discharge and Overflow**

The EPCP wetland discharges into the West Pit after its water level reaches the spillway elevation (\(\text{EPCP\_Outlet\_Elev}\)). Potential discharge is calculated using the sharp-crested weir equation:

\[
\text{Potential Wetland Discharge to West Pit} \ [L^3/T] = (2/3) * C_W * b * \left[ 2 * g * (\text{East Pit Water Level Elevation} - \text{EPCP\_Outlet\_Elev}) \right]^{0.5} \tag{10-20a}
\]

(Note that \(g\) represents the acceleration constant in Equation 10-20a.)

The discharge is limited to the flow that would reduce the wetland water level to the spillway elevation in one time step, thereby reducing flows to zero:

\[
\text{Maximum Wetland Discharge to West Pit} \ [L^3/T] = \text{Net Wetland Inflow} + \frac{(\text{EPCP Wetland Volume} - \text{Wetland Volume at Spillway})}{1 \text{ month}} \tag{10-20b}
\]

If the weir discharge is insufficient to keep the wetland volume at or below its maximum value (based on the spill elevation, “\(\text{EPCP\_Spill\_Elev}\)”), then there is an additional uncontrolled overflow from the wetland that is directed to the Partridge River upstream of SW003.

**Flows between Reservoirs**
As porewater reservoirs are filled to their maximum volumes, overflows from the reservoirs are directed as follows:

- Overflow from both lower porewater reservoirs are inflows to the EPCP upper porewater reservoir.
- Overflow from the EPCP upper porewater reservoir is inflow to the wetland reservoir.

Additionally, after the backfilled material is completely flooded, downward seepage from the overlying wetland replenishes any natural outflows from the three underlying areas to keep these reservoirs full. These seepage rates are calculated by Equations 10-21a, 10-21b and 10-21c:

\[
\text{Wetland Seepage to Upper EPCP Porewater} \ [\text{L}^3/\text{T}] = \\
\text{One-Month Flow Required to Completely Fill EPCP Porewater or} \\
\text{Total Natural Outflow from EPCP Porewater} \text{ (whichever is greater)} \quad (10-21a)
\]

In this equation, the “One-Month Flow” term is the difference between the total EPCP porewater capacity and the current EPCP volume divided by one month, and the “Total Natural Outflow” term is the sum of groundwater and evaporation outflows apportioned to the EPCP upper porewater reservoir.

Similarly,

\[
\text{Wetland Seepage to Lower East Pit Porewater} \ [\text{L}^3/\text{T}] = \\
\text{One-Month Flow Required to Completely Fill East Pit Lower Porewater or} \\
\text{Total Natural Outflow from East Pit Lower Porewater} \text{ (whichever is greater)} \quad (10-21b)
\]

and

\[
\text{Wetland Seepage to Lower Central Pit Porewater} \ [\text{L}^3/\text{T}] = \\
\text{One-Month Flow Required to Completely Fill Central Pit Lower Porewater or} \\
\text{Total Natural Outflow from Central Pit Lower Porewater} \text{ (whichever is greater)} \quad (10-21c)
\]

10.3.3 Mass Transport Calculations

Several GoldSim cell elements are used to determine constituent movement into and out of the East and Central Pits. One cell represents the sump, which is located in either the East or Central Pit (whichever is actively being mined). Another cell represents the combined East and Central Pit porewater below the minimum top of bedrock elevation (“lower porewater”). A third cell is used to represent the porewater above the bedrock elevation (“upper porewater”) in addition to water in the overlying wetland.

Various constituent loads to the East Pit, Central Pit, and combined East/Central Pit are calculated during the simulation. The mass input loads are:

- Background-concentration loading from groundwater inflow
- Background-concentration loading from upland and stockpile runoff (in closure)
- Loading from infiltration through blast ore temporarily stored in the pits
- Loading from runoff contact with exposed wall rock and setback areas
• Loading due to flooding wall rock and setback areas with released (exposed) constituent mass
• Loading in the sump water at the time backfill begins in each pit
• Loading in the porewater contained in the Category 4 and Category 2/3 rock that is moved from the stockpiles into the pits as backfill (calculated in the Category 4 and Category 2/3 Stockpile Models)
• Loading from infiltration through unsaturated backfill
• Loading due to flooding backfill with released (exposed) constituent mass
• Loading in the Category 1 contained seepage that is directed to the East Pit (calculated by the Category 1 Waste Rock Stockpile Model), if any
• Loading in leakage from the Category 4 Stockpile (calculated in the Category 4 Stockpile Model)
• Loading in treated water pumped into the pits from the WWTF during flooding and during porewater treatment in reclamation.

Outgoing mass loads from the East and Central Pit Model include:
• Loading in pumped flows that go the WWTF during dewatering (eastern equalization basin)
• Loading in precipitate that is removed from the sumps during operation
• Loading in discharge from the East Pit lower porewater to the East Pit bedrock flow path
• Loading in discharge from the Central Pit lower porewater to the West Pit via groundwater
• Loading in discharge from the East/Central Pit upper porewater to the East Pit and category 2/3 surficial aquifer flow path
• Loading in pumped flows that go the WWTF during reclamation for porewater treatment
• Loading in the discharge from the wetland to the West Pit
• Loading to the Partridge River upstream of SW003 if and when there is uncontrolled overflow of the wetland

Loads from walls and setbacks (due to runoff contact and flooding) are calculated separately for the five different rock types in the model:
• Category 1 rock,
• Category 2/3 rock,
• Category 4 Duluth Complex rock,
• Category 4 Virginia Formation rock, and
• ore.

Likewise, loads due to backfill infiltration and flooding are calculated separately for the four rock types used in backfill (same as above excluding ore).
**Background Loading**

Groundwater flows into the East and Central Pits at the rates determined earlier in this Section. This inflow originates from both the bedrock and the surficial aquifer and the fraction of groundwater entering the pits from each of these aquifers—and thus the mass loading to the pits—varies with time, and with the pit water level. Prior to the end of Central Pit mining (as defined by “CP_Mine_End”) the fraction of groundwater inflow that originates in the surficial aquifer for the East and Central Pits are specified in the “EP_GW_Surf_Ops” and “CP_GW_Surf_Ops” inputs. The remaining fraction of influent groundwater to each pit comes from the bedrock aquifer. The loading to the pits from each aquifer is the product of inflow rate from the aquifer and either the bedrock or surficial groundwater concentrations. These concentrations are uncertain and identical to those calculated in the flow path model (Equations 13-3 and 13-13b). Constituent mass loading rates to the pits from natural bedrock and surficial groundwater inflows are the product of these concentrations and the corresponding volumetric inflow rates from each aquifer. Mass loadings from these natural groundwater inflows during mining transfer constituent mass to the pit sumps.

After Central Pit mining ends, the fraction of inflows to the East and Central Pits from the surficial aquifer are as a function of the pit water levels using a surficial percentage lookup table (Table 1-22b of the WMDP-MS-Attachment B). The subsequent calculations for mass loading from each aquifer to the pits are the same as those used during active mining identified above. However, the destination of the mass loading differs. Until the combined pit water level reaches the minimum bedrock elevation all of this mass loading goes to the lower EPCP porewater mixing cell. Once the water level has reached this surficial aquifer, the natural loading then is added to the upper EPCP porewater mixing cell.

Additional background loading to the combined East Pit-Central Pit during closure comes from runoff from natural areas and the Category 1 waste rock stockpile. The natural runoff concentrations are the same as those used by the Partidge River model; the concentration for each constituent is uncertain and is defined by a log-normal distribution with the mean and standard deviation in Table 1-13 of the WMDP-MS-Attachment B. The runoff rate to the East Pit from natural areas and the Category 1 Waste Rock Stockpile are calculated by Equations 10-12 and 4-5a. Mass loading from this runoff to the upper EPCP porewater during closure is the product of the runoff concentrations and the combined runoff rate from the stockpile and natural areas.

**Category 1 High Wall Rock**

The high wall is the portion of the wall rock that is above the pit rim low point elevation and therefore never becomes flooded. The area of the exposed Category 1 high-wall rock is determined by the total area of the high wall and the fraction of the high-wall rock that is Category 1 rock:

\[
\text{Exposed Area of Category 1 Rock (High Wall)} \ [L^2] = \\
\text{EPCP}_{-}\text{Elev}_{-}\text{to}_{-}\text{WallArea} \text{ (above pit rim low point elevation)} \times \\
\text{EPCP}_{-}\text{Elev}_{-}\text{to}_{-}\text{WallFrac}_{-}1 \text{ (above pit rim low point elevation)} \tag{10-22}
\]
The mass of exposed Category 1 rock in the high wall rock is then calculated as:

\[
\text{Exposed Category 1 Rock Mass (High Wall)} [M] = \text{Wall Depth DC} [L] \times \text{WR Density} [M/L^3] \times \text{Exposed Area of Category 1 Rock (High Wall)}
\]

(10-23)

The initial mass of each constituent in the high wall rock is defined by the constituent content in the rock:

\[
\text{Initial Constituent Mass in Category 1 Rock (High Wall)} [M] = \text{Exposed Category 1 Rock Mass (High Wall)} \times \text{Cat1 content}
\]

(10-24)

Category 1 release rates (see Section 15) and scaling factors define the availability of constituent mass available for transport. Pit oxidation and the subsequent release of constituent mass are assumed to begin at the start of mining operations. Unscaled release rates for the exposed high wall rock are calculated in the same manner as for Category 1 waste rock using the percentage of sulfur in Category 1 rock above the pit rim low point (determined using the “EP_Elev_to_Sulfur_1” lookup table and the low point of the pit rim, “EP_Spill_Elev”) in place of the Category 1 Waste Rock Stockpile sulfur percentage (“Cat1_Sulfur”). These release rates are then scaled using a scaling factor that accounts for the effects of temperature and size:

\[
\text{Category 1 Release Rates (High Wall, Scaled)} [M/M/T] = \text{Category 1 Release Rates (High Wall, Unscaled)} \times \text{EP Wall Scale}
\]

(10-25)

where

\[
\text{EP Wall Scale} [-] = \text{Size Factor walls} \times \left( \text{Temp Factor} \times (1 - \text{South Face EP}) + \text{Temp Factor North Walls} \times \text{South Face EP} \right)
\]

(10-26a)

and

\[
\text{Temp Factor North Walls} = \exp\left[\frac{\text{Activation Energy}}{R} \times (1/\text{Lab Temp} - (1/(\text{Field Temp} + \text{Wall Temp Solar})))\right]
\]

(10-26b)

The exposed high-wall rock mass is then used to calculate the fraction of mass released from the high wall Category 1 rock:

\[
\text{Fractional Category 1 Rock Release Rates (High Wall)} [1/T] = \text{Category 1 Release Rates (High Wall, Scaled)} \times \frac{\text{Exposed Category 1 Rock Mass (High Wall)} (t-1)}{\text{Constituent Mass in Category 1 Rock (High Wall)} (t-1)}
\]

(10-27)
Mass transfer from the high wall rock into water contacting the high wall rock is further adjusted by the water contact factor:

\[ \text{Mass from Category 1 High Wall Rock to High Wall Water} \ [1/T] = \]
\[ \text{Fractional Category 1 Rock Release Rates (High Wall)} [1/T] \times \text{Contact Factor} \]

(10-28)

The remainder of the constituent mass released, but not contacted by water, remains in place and does not become a load to the pits because the high wall rock is never flooded.

A GoldSim cell element is used to apply concentration caps in the contact water of the Category 1 high-wall rock. Section 15 discusses the application of concentration caps. The water volume in the cell is assumed to be:

\[ \text{Water Volume in Category 1 High Wall Rock} [L^3] = \]
\[ \text{Water Depth} \times \text{Exposed Area of Category 1 Rock (High Wall)} \]

(10-29)

The flow of water on and through the Category 1 wall rock cell is the sum of wall runoff from and groundwater inflow through the high wall and high set back area, multiplied by the fraction of the wall rock that is Category 1 and part of the high wall.

Other High Wall Rock

Similar calculations to those in Equations 10-22 through 10-29 are made for the remaining high wall materials: ore, Category 2/3, Category 4 Virginia Formation, and Category 4 Duluth Complex rock. There are two notable differences in the other models:

1. For the Category 4 Virginia Formation, “Wall_Depth_VF” is substituted for “Wall_Depth_DC” in Equation 10-23, and
2. Acidification is taken into consideration for all non-Category 1 rock.

The temperature-corrected onset time of acidic conditions in wall rock (“Acid_Time_TempCorr”) is determined as follows:

\[ \text{Acid_Time_TempCorr} [T] = \frac{\text{Acid_Onset_Time_23} [T]}{\exp[\text{Activation_Energy} / R 	imes ((1/\text{Lab_Temp} – (1/\text{Field_Temp_Mean}))]} \]

(10-30)

Prior to this time after mining operations begin (i.e., when \( t < \text{Acid_Time_TempCorr} \)) constituents are released from Category 2/3 wall rock at the sulfate-independent release rates defined in Section 15 ("Cat23_Release_Indep_nonacid"). After the onset of acidic conditions, constituent mass is released at the acidic sulfate-independent release rates ("Cat23_Release_Indep_acid").

The sulfate-dependent release rates for Category 2/3 high wall rock also vary with the amount of time that the rock above the spill elevation has been exposed:

\[ \text{Category 2/3 High Wall Nonacidic Release Rates (SO}_4^-\text{-Dependent, Unscaled)} = \]
\[ \text{Cat23_Ratio_SO4} \times \text{EPCat23_HiWall_SO4_decayed} \]

(10-31)
The “EPCat23_HiWall_SO4_decayed” term in Equation 10-31 is the decaying sulfate release rate for rock above the spill elevation, and is defined as a function of the time needed for Category 2/3 rock to become acidic (“Acid_Onset_Time_23”). Before this amount of time has elapsed:

\[
\text{EPCat23\_HiWall\_SO4\_decayed} = \text{SO4\_S\_Regression} \times \text{EPCat23\_HiWall\_Sulfur} \quad (10-32a)
\]

After “Acid_Onset_Time_23” has elapsed:

\[
\log(\text{EPCat23\_HiWall\_SO4\_decayed}) = (\text{Decay_a1} \times \log (t – \text{Acid\_Time\_TempCorr}) + \text{Decay_a0}) \quad (10-32b)
\]

The time value (“t”) in this equation has units of [weeks], and the resulting value of “EPCat23\_HiWall\_SO4\_decayed” has the units of [mg/kg/week].

The unscaled release rates for the ore walls and the Duluth Complex Category 4 rock are also calculated by Equations 10-30 through 10-32b—using the appropriate, material-specific parameters—and scaled by Equations 10-25. Equations 10-27 through 10-28b are subsequently used to calculate the mass fluxes of constituents released from all rock types to water in the high wall rock and to non-contacted material. Equation 10-29 is also used to calculate the volume of the wall water elements, and flow rate out of the wall water elements is calculated in the same manner as for the high wall rock.

**High Set Back Area**

Similar calculations to those for the high wall rock (made by Equations 10-22 to 10-32b) are made for the high set back area. Notable details regarding these calculations are:

- Equation 10-23 has an additional term (“SetBack_Depth_Fraction”) by which the rest of the equation is multiplied.
- High set back area release rates are the same as those for high wall rock.
- The contact flow for each rock type in the high set back area includes runoff and surficial aquifer inflow.

**Other Wall Rock**

The lower portion of the pit walls are subject to inundation during pit filling. Therefore the exposed area (calculated by Equation 10-22) varies as a function of water level. For example:

\[
\text{Exposed Area of Category 1 Rock (Low Wall)} \ [L^2] = \text{EPCP\_Elev\_to\_WallArea (at current water level)} \times \text{EPCP\_Elev\_to\_WallFrac\_1 (at current water level)} - \text{Exposed Area of Category 1 Rock (High Wall)} \quad (10-33)
\]

The low wall areas are then used to calculate the exposed low wall masses (Equation 10-23, with “Wall_Depth_VF” used for Category 4 Virginia Formation wall rock), which are themselves used to define the constituent wall rock masses (Equation 10-24). Unscaled release rates for the Category 1 (low) wall rock are then calculated using Equations 4-12 and 4-13 with the percentage
of sulfur in wall rock above the current water level (determined using the “EP_Elev_to_Sulfur_1” lookup table) substituted for the Category 1 Waste Rock Stockpile sulfur percentage (“Cat1_Sulfur”). The other unscaled release rates are calculated by Equations 10-31 through 10-2b, and all the release rates are scaled using Equation 10-25. Fractional release rates are calculated by a modified version of Equation 10-27:

\[
\text{Category 1 Rock Release Rates (Low Wall) } [1/T] = \frac{\text{Category 1 Release Rates (Low Wall, Scaled) * Exposed Category 1 Rock Mass (Low Wall) } (t-1)}{\text{Constituent Mass in Category 1 Rock (Low Wall) } (t-1)}
\]  

(10-34)

Just as was the case with the high wall rock, low wall rock constituents can be transferred to water in the wall rock by Equations 10-28. The remaining fraction of mass released (i.e. the “1 – Contact Factor” fraction) calculated for each constituent is released to the mass considered unavailable for transport (non-contacted). The actual mass transfer rates from the low wall rock to wall rock water and non-contacted cells are the product of these fractional mass transfer rates and the constituent mass present in the low wall rock. The volume of water in the wall rock is then determined by Equation 10-29, and it should be noted that, because the exposed wall area decreases with time during backfilling, so also does the wall rock water volume.

Flooding of the pits after backfilling gradually submerges the previously exposed low walls, and water contained within the areas being submerged is considered. Mass is transferred from water in the exposed wall rock to either the lower and upper EPCP porewater. When the water level in the pit is below the surficial aquifer the submerged wall water goes to the lower EPCP porewater, and after the water level reaches the surficial aquifer it goes to the upper EPCP porewater. The rate of this mass transfer for Category 1 rock is:

\[
\text{Mass Transfer from Water in the (Low) Wall to EPCP Porewater } [1/T] = - \frac{ddt}{dt} \frac{(\text{Exposed Low Wall Category 1 Rock Mass})}{(\text{Exposed Low Wall Category 1 Rock Mass} )}
\]  

(10-35)

The released constituent mass in the wall rock that was previously considered unavailable for transport (“non-contacted”) is also added to the backfill porewater as wall rock becomes submerged. This transfer of constituent mass also occurs at the fractional rate calculated by Equation 10-35, and the corresponding mass flow rate is the product of this fractional rate and the remaining non-contacted constituent mass in the wall rock.

During pit flooding the unreleased constituent mass remaining in the wall rock is transferred to a cell element (“Sink_EPCP_Pore_SubAq”) where it is permanently sequestered. The rate of mass transfer from each type of wall rock to this cell also occurs at the fractional rate defined above (Equation 10-35).

\textit{Other Set Back Area}

The set back areas are also subject to inundation during pit filling. Similar calculations to those for the wall rock (described in the previous subsection) are made for the set back areas. Exceptions to this are:
Exposed Area of Category 1 Rock (Set Back Area) [L^2] =
(EPCP_Elev_to_SetBackArea (at current water level) *
EPCP_Elev_to_WallFrac_1 (at current water level)) –
Exposed Area of Category 1 Rock (High Set Back Area) (10-36)

- As with the high set back area, when Equation 10-23 is applied to the set back area it
  includes the “SetBack_Depth_Fraction” term by which the rest of the equation is
  multiplied.
- The flow over each rock type in the set back area is equal to the sum of the second and
  third terms in Equation 10-10 (i.e. runoff and surficial aquifer flow).

_Blast Ore Model_

Scaled, nonacidic blast ore release rates for chloride are calculated by Equation 10-37a:

\[
\text{Blast Ore Release Rate (Cl, Scaled)} \ [\text{M/M/T}] = \text{All_Release_Cl} \times \text{Size_Factor} \times \\
\text{Ore_Processing_Rate} \times \text{EPBlastOre_Store_Frac} / \text{EP_BlastOre_Mass} \tag{10-37a}
\]

where

\[
\text{EPBlastOre_Store_Frac} = \\
\text{EP_BlastOre_Mass} / (\text{EP_BlastOre_Mass} + \text{WP_BlastOre_Mass}) \tag{10-37b}
\]

Unscaled, nonacidic blast ore release rates are calculated for the other constituents by Equation
7-5, and these rates are scaled by Equation 5-12. Constituent release from the blast ore
(“EPBlastOre_Release”) is calculated as:

\[
\text{Constituent Release from Blast Ore} [\text{M}] = \text{EP_BlastOre_Mass} \times \\
\text{Nonacidic Blast Ore Release Rates (All Constituents, Scaled)} \tag{10-38a}
\]

This cumulative release is used to calculate the cumulative input to the blast ore water:

\[
\text{Constituent Input to Blast Ore Water} [\text{M}] = \\
\text{Constituent Release from Blast Ore} \times \text{Contact_Factor} \tag{10-38b}
\]

The remaining fraction of mass released (i.e. “1 − Contact_Factor”) is considered unavailable for
transport. The volume of water in the blast ore is

\[
\text{Volume of Water in Blast Ore} [\text{L}^3] = 0.5 \times \text{Water_Depth} \times \text{OSP_Bare} \tag{10-39}
\]

and the infiltration rate through the blast ore is

\[
\text{Infiltration into Blast Ore} [\text{L}^3/T] = \text{Monthly Precipitation} [\text{L}/T] \times \\
(1 − \text{Bare_RO − Bare_ET}) \times (0.5 \times \text{OSP_Bare}) \tag{10-40}
\]

This infiltration rate is also the flow rate from the blast ore water to the operational sump.
Category 1 Waste Rock Backfill Model

The amount of waste rock mass exposed to air is needed to determine waste rock dissolution rates. The mass of Category 1 waste rock exposed to air is initially zero, and the rate of change to this mass is the difference between the input rate of new rock (due to backfilling) and the rate of backfill flooding:

\[
\begin{align*}
\text{Category 1 Rock Exposed to Air (Rate of Change)} &\ [M/T] = \\
\frac{d}{dt} \left( \text{EPCP\_Direct\_Mass}[\text{Category 1}] \right) - \\
\text{Category 1 Rock Exposed to Air} &\ [M] \times \text{Fractional Rate of Backfill Flooding} \ [1/T]
\end{align*}
\]

(10-41)

where the fractional rate of backfill flooding is zero when (1) the water level is above the top of the backfill, (2) the rate of backfill flooding during the previous month is zero, or (3) the volume of backfilled rock is zero. When none of these conditions are met:

\[
\text{Fractional Rate of Backfill Flooding} \ [1/T] = \frac{d}{dt}(\text{EPCP\_Bkf\_Flood\_Vol} (t-1)) / (\text{Total\_Bkf\_Vol} - \text{EPCP\_Bkf\_Flood\_Vol})
\]

(10-42)

where “EPCP\_Bkf\_Flood\_Vol (t-1)” is the cumulative flooded volume of waste rock in the East Pit and Central Pit (EP\_Bkf\_Flood\_Vol + CP\_Bkf\_Flood\_Vol) below the current water level, and these rock volumes are determined separately using the pit water level and the lookup tables “EP\_Elev\_to\_Volume” and “CP\_Elev\_to\_Volume”.

Similar to the wall rock and set back areas, the unreleased constituent mass in the backfill rock is also transferred to the “Sink\_EPCP\_Pore\_Sub\_Aq” cell element, where it remains permanently. The rate of mass transfer from each type of backfill rock to this cell occurs at the fractional rate of backfill flooding (Equation 10-42).

The mass exposed to air is then used to calculate the fraction of rock exposed to air that is Category 1 waste rock:

\[
\text{Fraction of Waste Rock Exposed to Air (Category 1 Rock)} = \\
\frac{\text{Category 1 Rock Exposed to Air} [M]}{(\text{Category 1 Rock Exposed to Air} [M] + \\
\text{Category 2/3 Rock Exposed to Air} [M] + \\
\text{Category 4 Duluth Complex Rock Exposed to Air} [M] + \\
\text{Category 4 Virginia Formation Rock Exposed to Air} [M])}
\]

(10-43)

The volume of water in the exposed Category 1 backfill is:

\[
\text{Volume of Water in Exposed Category 1 Rock} [L^3] = \\
\text{EP\_Elev\_to\_PlanArea (at current water level)} \times \text{Water\_Depth} \times \\
\text{Fraction of Waste Rock Exposed to Air (Category 1 Rock)}
\]

(10-44)

 Unscaled Category 1 release rates from the exposed backfill for all constituents other than chloride are calculated by Equations 4-12 and 4-13 and are scaled as follows:
Category 1 Backfill Release Rates (non-Cl, Scaled) [M/M/T] = \text{Temp\_Factor} \times \text{Size\_Factor} \times \text{Category 1 Backfill Release Rates (non-Cl, Unscaled)} \quad (10-45)

The chloride release rate is:

\[
\text{Category 1 Backfill Release Rates (Cl, Scaled) [M/M/T]} = \frac{\text{All\_Release\_Cl} \times \text{Size\_Factor} \times \frac{d}{dt} (EPCP\_Direct\_Mass[\text{Category 1}])}{\text{Category 1 Rock Exposed to Air} (t-1)}
\] \quad (10-46)

Fractional mass release rates from the backfilled Category 1 rock for all constituents are then:

\[
\text{Fractional Mass Release Rates (All Constituents)} = \frac{\text{Category 1 Backfill Release Rates (All Constituents, Scaled)} \times \text{Category 1 Rock Exposed to Air} (t-1)}{\text{Backfilled Category 1 Rock Mass} (t-1)}
\] \quad (10-47)

This fractional rate is used to calculate the fractional transfer rates from Category 1 backfill to water in Category 1 backfill (Equation 5-15) and non-contacted Category 1 backfill (Equation 5-16). The fractional rate of mass transfer to the submerged waste rock—which is a constituent sink—is the same as the rate of backfill flooding (calculated by Equation 10-42).

Water in the Category 1 backfill can be transferred to either the upper or lower East Pit-Central Pit porewater by one of two mechanisms: by infiltration or by being directly incorporated as a result of the rising pit water level. These transfer rates are zero before and after pit flooding, but during the flooding of the pit backfill these rates are:

\[
\text{Water Flow from Category 1 Backfill to EPCP Porewater} \left[ \frac{L^3}{T} \right] = \left( \text{East Pit Precipitation} + \text{Central Pit Precipitation} - \text{East Pit Evaporation} - \text{Central Pit Evaporation} \right) \times \frac{\text{Fraction of Waste Rock Exposed to Air (Category 1 Rock)}}{(t-1)}
\] \quad (10-48a)

\[
\text{Direct Transfer from Category 1 Backfill to EPCP Porewater} \left[ \frac{1}{T} \right] = \frac{\text{Fractional Rate of Backfill Flooding}}{(t-1)}
\] \quad (10-48b)

Both of these quantities go to the lower EPCP porewater prior to the water level in the backfill reaching the surficial aquifer. After that milestone is reached, all of the Category 1 backfill water transferred to EPCP porewater goes to the upper EPCP porewater.

Other Waste Rock Backfill Models

The general procedure for calculating mass fluxes for the remaining backfill rock types is the same as that outlined above (Equations 10-41 through 10-48b, with substitutions for all rock type-specific values). Notable differences are:

- The calculation for the amount of Category 2/3, 4 (Virginia Formation) and 4 (Duluth Complex) rock exposed to air is different than for Category 1 rock, because mass of these rock types is transferred from the temporary Category 2/3 and Category 4 Waste Rock...
Stockpiles. For example, the rate of change to the exposed Category 2/3 rock mass (which is initially zero) is:

\[
\frac{d}{dt} \text{(EPCP_Direct_Mass[Category 2/3])} + \\
\text{Rate of Change to Category 2/3 Stockpile Mass [M/T]} - \\
\text{Category 2/3 Rock Exposed to Air [M]} \times \\
\text{Fractional Rate of Backfill Flooding [1/T]}
\]  

(10-49)

where the rate of change to the stockpile mass is calculated by Equation 5-3a.

- The unscaled, non-chloride release rates from the exposed rock are calculated by Equations 5-9 and 5-10 (Category 2/3), Equation 6-6 (Category 4 Virginia Formation), and Equation 6-7 (Category 4 Duluth Complex). These rates are then scaled by Equation 5-12. The scaled chloride release rates are still calculated by Equation 10-46.

- Influxes to the backfill water for all non-Category 1 rock types also includes acidic and nonacidic porewater from the Category 2/3 and 4 stockpiles. These quantities are calculated on a fractional basis by Equations 5-18 and 5-21 (Category 2/3) and Equations 6-15 and 6-19 (one set of calculations each for the two Category 4 groups).

**Calculation of Concentration and Outflowing Loads**

All of the East Pit and Central Pit inflows are directed to the EPCP sump during mining operations. There inflows include runoff from and groundwater flow through the various rock types from all rock types present in the walls (i.e. Category 1, 2/3, 4 VF, 4 DC, and ore). Water from the blasted ore in the pit and the Category 4 stockpile liner system are also directed to the sump until mining ceases in the Central Pit. The constituent mass loading rates from all of these sources are the products of the volumetric inflow rate and dissolved concentrations in each mass source area.

The three outflows from the operational sump which are used for contaminant transport calculations are: (1) pumping to the WWTF East Pond during operations, (2) precipitate mass removal from the model during operations, and (3) transfer to the lower EPCP porewater after Central Pit mining ends.

The pumping rate from the operational sump to the WWTF prior to the start of pit backfilling is defined by the desired dewatering flow rates calculated by the WWTF model and the WWTF pumping limitations (“Pump Limit _EP” and “Pump Limit _CP”). Any precipitated constituent mass is removed from the model altogether until Central Pit mining ends, at which point all constituent mass is transferred to the combined EPCP lower porewater.

The volume of the EPCP lower porewater through time is the sum of the East Pit and Central Pit lower porewater volumes. Some of the mass inflows to the EPCP lower porewater after backfilling begins are the same as those to the pit sumps during pit mining, including mass flows from water in the various wall rock types and areas. In addition to the mass added by means of actual water flows, mass previously released from the low wall and set back area rock that was
considered unavailable for transport is gradually incorporated into the lower EPCP porewater as the pit water level rises. These direct additions of constituent mass to the lower porewater occur at the fractional submergence rates described earlier in this section.

Similarly, constituent mass released from the waste rock stockpiles that was not available for transport out of the stockpiles is added to the constituent mass in the lower EPCP porewater as the waste rock is moved to the pits. Mass dissolved within the residual water in the backfilled material is also added to the lower porewater as the pit water level rises, and the rate of mass transfer from these two stockpile sources is based on the fractional transfer rates described above.

Additions of mass to the lower porewater also originate from the WWTF’s Central Pumping Station during the Reclamation phase (Section 12). The lower porewater also receives mass loadings by way of seepage from the overlying upper porewater after the lower porewater is full and the upper porewater is either filling or completely full with water. As in all previous cases where constituent mass transfer is due to an actual flow of water, the mass loading from the overlying upper porewater to the lower porewater is the product of the continuously-variable upper porewater concentrations and the volumetric seepage rate (denoted earlier in this section).

East Pit-Central Pit lower porewater is pumped to the WWTF’s East Pond during mining operations, to the Reclamation WWTF after the EPCP wetland is full, and passively flow to the East Pit bedrock flow path and to the West Pit. The constituent mass loading rates to these other areas within the model are the product of the volumetric outflow rates and the continuously-variable concentrations in the lower EPCP porewater.

Water in the upper EPCP porewater and EPCP wetland is modeled as part of the same GoldSim element, and the volume of this element is the sum of the volumes of these two areas. Many of the mass inflows to this area originate from the same areas as the lower porewater inflows noted above. The notable difference is that mass loadings from these areas (indicated below) are added to the lower porewater until it is completely filled, and are added to the upper porewater thereafter. These similarly-calculated mass inflows originate from all the rock types and areas in the pit walls, water within the backfilled waste rock, and the constituent mass previously released from waste rock backfill that was considered unavailable for transport.

The remaining mass inflows to the upper porewater and wetland are derived from the one-time overflow of lower porewater into the upper porewater (calculated automatically by GoldSim), and from the CPS during porewater treatment (see Section 12). The mass loading rates from these areas to the upper EPCP porewater/wetland are each the product of the volumetric flow rate and the continuously-variable constituent concentrations in the source water.

Outgoing mass flows from the EPCP wetland and upper porewater include seepage to the lower porewater (described above), overflow to the West Pit (also described above), surficial groundwater flow to the East Pit and Category 2/3 stockpile flow path (Section 13), and pumping to the WWTFs used during operations and the Reclamation phase (Section 12). The mass loading rates to each of these areas is the product of the flow rate and the continuously-variable concentrations in the combined wetland and upper porewater area.
10.4 **Output**

The East Pit and Central Pit Models calculate the following flows along with their associated constituent concentration and loads:

- Water flow and constituent mass loading to the East Pit bedrock aquifer
- Water flow and constituent mass loading to the East Pit-Category 2/3 surficial aquifer
- Water flow and constituent mass loading to the West Pit (via bedrock groundwater flow and wetland spillway discharge)
- Water flow and constituent mass loading to the WWTF used during mining operations
- Water flow and constituent mass loading to the Reclamation WWTF
- Water flow and constituent mass loading to the Partridge River upstream of SW003 if the wetland overflows

The models also calculate the following quantities:

- Precipitate mass removed from the sumps during mining
- Water concentrations in the sumps during mining, in the lower porewater of the backfill, and in the upper porewater of the backfill and wetland
11 West Pit Model

11.1 Purpose

This model is used to simulate water flow and mass transport within and from the West Pit. The model calculates water flows and associated constituent mass loads (for all constituents) that are routed to other component models, including models for the WWTFs and groundwater flow paths.

11.2 Input

11.2.1 Inputs from Other Models

- Monthly precipitation [L/T], calculated in Equation 3-2
- Flow and load associated with infiltration that both bypassed and was collected in the Category 1 waste rock stockpile containment system, determined in Section 4
- Operating status (active or inactive) of the long-term waste water treatment facility (LTWWTF) and the WWTF used during mining operations, both determined in Section 12
- Flow and load associated with overflow from the EPCP wetland, determined in Section 10
- East Pit-Central Pit water level, determined in Section 10
- Flow and load associated with groundwater inflow originating in the Central Pit, determined in Section 10
- Flow and load associated with pumped water from the WWTFs CPS during West Pit filling, determined in Section 12

11.2.2 Water Balance Inputs

1. **WP_Elev_to_PlanArea**
   - Deterministic relationship which determines the area of the water surface in the West Pit based on the water level elevation (Figure 1-2 of WMDP-MS-Attachment B)

2. **WP_Volume_to_Elev**
   - Deterministic relationship which determines the elevation of the water surface in the West Pit based on the pit water volume (Figure 1-1 of WMDP-MS-Attachment B)

3. **WP_Footprint_Area** [L^2] – Area contributing runoff during operations
   - Time-varying deterministic input
   - Values given in Table 1-9b of WMDP-MS-Attachment B

4. **WP_RO_Area** [L^2] – Natural areas contributing runoff to the West Pit after mining operations cease
   - Deterministic inputs (291 acres when West Pit is not full and the long-term WWTF is not operational; 0 acres otherwise)

5. **WP_GW_Inflow_Ops** [L^3/T] – Groundwater inflow to the West Pit during operations
   - Time-varying deterministic input
   - Values given in Table 1-22a of WMDP-MS-Attachment B

6. **WP_GW_Inflow** [L^3/T] – Groundwater inflow to the West Pit during closure
   - Time-varying deterministic input
   - Values given in Table 1-22b of WMDP-MS-Attachment B
7. **TB_Stop_Elev** [L] – West Pit water elevation that marks a cessation of water transfer from the Tailings Basin on the Plant Site
   - Deterministic input (1550 feet)
8. **TB_Stop_Vol** [L$^3$] – Maximum permissible volume of water transferred to the West Pit from the Tailings Basin on the Plant Site; after this volume has been transferred, flow to the West Pit from the Tailings Basin ceases
   - Deterministic input (60,000 acre-feet)
9. **Pump_Limit_WP** [L$^3$/T] – Maximum pumping rate between the WWTF and West Pit
   - Deterministic input (5000 gallons per minute)
10. **WP_Sump_Volume** [L$^3$] – Volume of the sump, which is assumed to always be full
    - Deterministic input (10,000 ft$^3$)
11. **LongTerm_Pump_WP** [L$^3$/T] – Maximum total rate of treatment and discharge from the West Pit
    - Deterministic input (600 gallons per minute)
12. **WP_Spill_Elev** [L] – Elevation at the low point of the West Pit rim
    - Deterministic input (1579 feet)
13. **WP_Outlet_Elev** [L] – Elevation at which discharge via the LTWWTF begins
    - Deterministic input (1573 feet)

### 11.2.3 Mass Transport Inputs

1. **WP_Elev_to_WallArea**
   - Deterministic relationship which determines total exposed wall area in the West Pit as a function of elevation (Figure 1-4 of WMDP-MS-Attachment B)
2. **WP_Elev_to_SetBackArea**
   - Deterministic relationship which determines the area of the pit rim set back above the final pit shell as a function of elevation (Figure 1-4 of WMDP-MS-Attachment B)
3. **WP_Elev_to_WallFrac_1**
   - Deterministic relationship which determines the fraction of the pit wall consisting of Category 1 rock as a function of elevation (Figure 1-3b of WMDP-MS-Attachment B)
4. **WP_Elev_to_WallFrac_23**
   - Deterministic relationship which determines the fraction of the pit wall consisting of Category 2/3 rock as a function of elevation (Figure 1-3b of WMDP-MS-Attachment B)
5. **WP_Elev_to_WallFrac_4DC**
   - Deterministic relationship which determines the fraction of the pit wall consisting of Category 4 Duluth Complex rock as a function of elevation (Figure 1-3b of WMDP-MS-Attachment B)
6. **WP_Elev_to_WallFrac_Ore**
   - Deterministic relationship which determines the fraction of the pit wall consisting of ore rock as a function of elevation (Figure 1-3b of WMDP-MS-Attachment B)
7. **WP_Elev_to_Sulfur_1 [-]**
   - Deterministic relationship containing the average sulfur content of Category 1 wall rock as a function of elevation (Figure 1-5 of WMDP-MS-Attachment B)

8. **WP_Elev_to_Sulfur_23 [-]**
   - Deterministic relationship containing the average sulfur content of Category 2/3 wall rock as a function of elevation (Figure 1-6 of WMDP-MS-Attachment B)

9. **WP_Elev_to_Sulfur_Ore [-]**
   - Deterministic relationship containing the average sulfur content of ore wall rock as a function of elevation (Figure 1-7 of WMDP-MS-Attachment B)

10. **South_Face_WP [-]** – South-facing portion of pit wall that is subject to solar heating
    - Deterministic input (0.5)

11. **WP_BlastOre_Mass [M]** – Inventory of blasted ore in pit awaiting removal
    - Time-varying deterministic input
    - Values given in Table 1-9 of WMDP-MS-Attachment B

### 11.3 Calculations

#### 11.3.1 Water Balance Calculations

**Natural Inflows**

Natural inflows to the West Pit include direct precipitation, runoff from the pit walls and from natural areas, and Category 1 Waste Rock Stockpile runoff. Direct precipitation onto the West Pit is calculated using Equation 10-3 and the open water area (“**WP_Water_Area**”, which is determined using the relationships “**WP_Elev_to_PlanArea**” and “**WP_Volume_to_Elev**”). Runoff from the pit walls is calculated by Equation 10-5 and “**WP_Wall_RO_Area**”

where **WP_Wall_RO_Area [L^2]** = **WP_Footprint_Area [L^2]** – **WP_Water_Area [L^2]**.

Runoff from natural areas is calculated by Equation 10-11 (substituting “**WP_RO_Area**” for “**EPCP_RO_Area**”). Runoff from the Category 1 Waste Rock Stockpile is calculated by Equation 4-5b, as long as the West Pit is not overflowing and the LTWWTF is inactive. If these two conditions are not met, the stockpile runoff is directed elsewhere.

The state of these four natural inflows is determined by the climate model. During winter, all precipitation falling directly on areas which drain to the West Pit is assumed to be snowfall and accumulates during winter months:

\[
\text{West Pit Snowpack Accumulation Rate [L}^3/\text{T}] = \text{West Pit Direct Precipitation [L}^3/\text{T}] + \text{West Pit Wall Runoff [L}^3/\text{T}] + \text{Natural Area Runoff [L}^3/\text{T}] + \text{Category 1 Waste Rock Stockpile Runoff to West Pit [L}^3/\text{T}] \tag{11-1}
\]

The entire snowpack melts during the month defined by the climate model and flows into the West Pit.
Groundwater inflows to the West Pit are defined by Equation 10-13a during operations, with the

time-series of deterministic groundwater inflows to the West Pit (“WP_GW_Inflow_Ops”) substituted for “EP_GW_Inflow_Ops.” After mining operations cease, groundwater flow into the

West Pit is calculated by Equation 10-14a (using “WP_GW_Inflow” instead of “EP_GW_Inflow”).

The same groundwater flow uncertainty multipliers used for the East Pit (“Pit_GW_Uncertainty_shift” and “Pit_GW_Uncertainty_unshift”) are used for the West Pit. When the EPCP wetland overflows, the overflow rate to the West Pit is automatically determined by Equation 10-20a or 10-20b. Bedrock groundwater flow from the Central Pit to the West Pit is calculated by Equation 10-15. Total seepage from the Category 1 waste rock stockpile to the West Pit is the sum of the containment system leakage and diverted retained containment system water, as calculated by Equations 4-8a and 4-9b, respectively.

Other Inflows

There are two inflows to the West Pit other than the natural inflows identified above: pumping from the WWTF’s CPS during West Pit filling (determined as described in the “Central Pumping Station” sub-section of Section 12) and inflow from the Plant Site’s Tailings Basin. This latter flow is zero both during mining operations and after either the West Pit water elevation reaches 1550 feet (TB_Stop_Elev) or 60,000 acre-feet (TB_Stop_Vol) of water has been transferred from the Tailings Basin to the West Pit. After mining operations cease and before either of these conditions is met, the rate of transfer from the Plant Site to the West Pit is defined by a truncated normal distribution and the time-series of means and standard deviations given in Table 1-35 of the WMDP-MS-Attachment B.

Natural Outflows

The two types of natural outflows from the West Pit are open water evaporation and groundwater flow to the Partridge River. Open water evaporation is calculated using Equation 10-8 and the West Pit open water area (WP_Water_Area). Groundwater outflow is the sum of outflows to the surficial aquifer (which terminates in the reach upstream of SW-004a), and the outflows to the two bedrock groundwater flow paths (terminating in the reaches upstream of SW-004 and SW-004a), as calculated in Section 13.

Outflow to Waste Water Treatment Facilities (WWTFs)

In addition to the natural outflows from the West Pit described above, there is one additional outflow from the West Pit: pumping to either the WWTF used during operations or the LTWWTF. This pumping rate (“WP_Actual_Dewater”) is the smaller of two quantities: the maximum allowed pumping rate between the WWTFs and the West Pit (“Pump_Limit_WP”), and the pumping rate needed to manage the pit water level during operations (“WP_Desired_Dewater”). A detailed series of conditions are used to determine this desired rate at which West Pit water is pumped to the WWTFs, and they are outlined below. When none of these three conditions are met, the desired pumping rate is zero.
1. During mining operations, the dewatering rate is the rate needed to remove concurrent inflows:

$$ WP_{Desired\_Dewater} \left[ \frac{L^3}{T} \right] = \Sigma (\text{Natural Inflows}) \left[ \frac{L^3}{T} \right] - \Sigma (\text{Natural Outflows}) \left[ \frac{L^3}{T} \right] + \frac{(\text{West Pit Volume} \left[ L^3 \right] - \text{WP\_Sump\_Volume})}{1 \text{ month}} $$

The pit volume in Equation 11-2 is determined using Equation 11-4c.

2. After mining operations end, but while the WWTF used during operations is still operational (i.e. while the EPCP wetland is not yet full), the desired dewatering rate is the greater of two quantities: zero, and the difference between the total natural inflows and outflows (i.e. the first two terms in Equation 11-2).

3. When the LTWWTF is operational West Pit water is treated and the desired pumping rate becomes the rate at which water is pumped to the LTWWTF for treatment. This rate of treatment, however, depends on (1) whether the Reclamation WWTF is also operational, and (2) West Pit water levels:

- If the LTWWTF and Reclamation WWTF are running simultaneously, the rate of treatment at the LTWWTF is equal to 600 gpm (“LongTerm\_Pump\_WP”).
- If the Reclamation WWTF is not operational and the West Pit water level elevation is less than 2 feet below the lowest point of the pit rim (“WP\_Spill\_Elev”) the desired pumping rate is:

$$ WP_{Desired\_Dewater} \left[ \frac{L^3}{T} \right] = \text{LongTerm\_Pump\_WP} - \frac{\text{Retained Category 1 Waste Rock Stockpile Containment System Water to the LTWWTF} \left[ \frac{L^3}{T} \right]}{11-3a} $$

The retained containment system water term in Equation 11-3a is defined by Equation 4-8b.

- If the Reclamation WWTF is not operational and the West Pit water level is below the desired long-term water elevation (“WP\_Outlet\_Elev”):

$$ WP_{Desired\_Dewater} \left[ \frac{L^3}{T} \right] = 0.25 * \text{LongTerm\_Pump\_WP} - \frac{\text{Retained Category 1 Waste Rock Stockpile Containment System Water to the LTWWTF} \left[ \frac{L^3}{T} \right]}{11-3b} $$

- If none of these three conditions are met when the LTWWTF is operational, the rate of West Pit water treatment is:

$$ WP_{Desired\_Dewater} \left[ \frac{L^3}{T} \right] = 0.5 * \text{LongTerm\_Pump\_WP} - \frac{\text{Retained Category 1 Waste Rock Stockpile Containment System Water to the LTWWTF} \left[ \frac{L^3}{T} \right]}{11-3c} $$
West Pit Water Volume

The total inflow rate to the West Pit based on the aforementioned inflows is therefore:

\[
\text{Total West Pit Inflow} \ [L^3/T] = \\
\text{West Pit Direct Precipitation (If Not Winter)} \ [L^3/T] + \\
\text{West Pit Wall Runoff (If Not Winter)} \ [L^3/T] + \\
\text{Natural Area Runoff (If Not Winter)} \ [L^3/T] + \\
\text{Category 1 Waste Rock Stockpile Runoff to West Pit (If Not Winter)} \ [L^3/T] + \\
\text{Snowmelt (If Appropriate Month)} \ [L^3/T] + \\
\text{EPCP Wetland Overflow} \ [L^3/T] + \\
\text{Central Pit Bedrock Groundwater Outflow} \ [L^3/T] + \\
\text{Containment System Leakage (Category 1 Stockpile)} \ [L^3/T] + \\
\text{Retained Containment System Water to the West Pit (Category 1 Stockpile)} \ [L^3/T] + \\
\text{Natural Groundwater Inflow (West Pit)} \ [L^3/T] + \\
\text{Snowmelt (If Appropriate Month)} \ [L^3/T] + \\
\text{WWTF Discharge to West Pit} \ [L^3/T] + \\
\text{Flow from Tailings Basin to West Pit} \ [L^3/T] 
\]

(11-4a)

Similarly, the total West Pit outflow rate is:

\[
\text{Total West Pit Outflow} \ [L^3/T] = \\
\text{West Pit Evaporation} \ [L^3/T] + \\
\text{West Pit Bedrock Groundwater Outflow to SW-004} \ [L^3/T] + \\
\text{West Pit Bedrock Groundwater Outflow to SW-004a} \ [L^3/T] + \\
\text{West Pit Surficial Groundwater Outflow to SW-004a} \ [L^3/T] + \\
\text{Pumping to WWTF} \ [L^3/T].
\]

(11-4b)

The West Pit volume is therefore:

\[
\text{West Pit Volume} \ [L^3] = \text{West Pit Volume} \ (t-1) \ [L^3] + \\
(\text{Total West Pit Inflow} \ [L^3/T] – \text{Total West Pit Outflow} \ [L^3/T]) \times 1 \text{ month}
\]

(11-4c)

11.3.2 Mass Transport Calculations

Constituent mass loads to the West Pit are the product of the inflows identified in Equation 11-4a and their associated continuously-variable constituent concentrations. Likewise, mass loads from the West Pit to the WWTFs and groundwater flow paths are the product of the outflows identified in Equation 11-4b and their associated continuously-variable constituent concentrations. Mass loads into the West Pit can originate from other Mine and Plant Site locations (Category 1 waste rock stockpile and Tailings Basin, respectively). In addition to the mass loads associated with this diverted water, mass loads into the West Pit result from the exposure of naturally inflowing water (overflow, runoff, groundwater) and in-pit water to the exposed pit walls and blast ore. The manner in which the exposed pit walls and blast ore contribute mass to the water in the West Pit is described below. This discussion and derivation of West Pit wall rock-based mass loads relies upon a number of the calculations presented in Section 10.
Wall Rock Models

The amount of constituent mass originating from the exposed pit walls varies as a function of pit water levels, and differs by rock type; mass released from Category 1, Category 2/3, Category 4 Duluth Complex, and ore wall rock are calculated separately. Note that, unlike the East and Central Pits, there is no Category 4 Virginia Formation in the West Pit.

As with the East and Central Pits, each type of exposed rock in the West Pit is subdivided into four areas – (low) wall, high wall, set back, and high set back areas – and constituent mass released from each area is calculated independently. The source mass loads from the high wall and high set back areas of the four rock types in the West Pit are calculated as described in Section 10. Source mass loads from (low) wall rock areas of the West Pit are calculated as indicated in Section 11. However, during West Pit flooding, (low) wall rock mass is transferred to West Pit water; thus Equation 10-35 calculates Mass Transfer from Water in the (Low) Wall to West Pit Water, when applied to the West Pit. The set back areas of the West Pit are calculated in the same manner as those for the East Pit. In all of these calculations, West Pit-specific inputs (i.e. WP_Elev_to_WallArea, WP_Elev_to_SetBackArea, WP_Elev_to_WallFrac_1, WP_Elev_to_WallFrac_23, WP_Elev_to_WallFrac_4DC, WP_Elev_to_WallFrac_Ore, WP_Elev_to_Sulfur_1, WP_Elev_to_Sulfur_23, WP_Elev_to_Sulfur_Ore, and South_Face_WP) are employed.

The unreleased constituent mass in the set back area and wall rock is gradually transferred to a cell element (“Sink_WPInRock_SubAq”) during pit flooding where it remains permanently. Mass transfer from each type of wall rock to this element occurs at fractional rates calculated identically to the analogous East Pit and Central Pit rates (Equation 10-35).

Equations 11-5a and 11-5b are used to calculate surficial groundwater flow through the West Pit’s set back and (low) wall areas, and are applicable for all four rock types in the West Pit:

Surficial Aquifer Groundwater Flow through Set Back Area \((\text{per rock type})\) \(\frac{[\text{L}^3/\text{T}]}{=\text{Fraction of Wall Rock Consisting of the Rock Type} \times \text{Natural Groundwater Inflow (West Pit)} \times \text{WP GW Fraction from Surficial Aquifer}}\times \frac{(\text{Exposed Area of the Rock Type (Set Back Area)} \times \text{Exposed Area of the Rock Type (High Set Back Area)} \times (1) \times (11-5a))}{\text{Exposed Area of the Rock Type (Set Back Area)} + \text{Exposed Area of the Rock Type (High Set Back Area)}}\)

Bedrock Groundwater Flow through Low Wall \((\text{per rock type})\) \(\frac{[\text{L}^3/\text{T}]}{=\text{Fraction of Wall Rock Consisting of the Rock Type} \times \text{Natural Groundwater Inflow (West Pit)} \times \text{(1 – WP GW Fraction from Surficial Aquifer)} \times \text{Exposed Area of the Rock Type (Low Wall)} + \text{Exposed Area of the Rock Type (High Wall)}}\)

\(\frac{[\text{L}^3/\text{T}]}{11-5b)}\)
As was the case for the East and Central Pits, the fraction of West Pit groundwater inflow derived from the surficial aquifer in these two equations varies with the pit water level and is determined using the water levels and percentages given in Table 1-22b of the WMDP-MS-Attachment B. The fractions of wall rock consisting of each rock type are determined using the pit water level and the rock-specific elevation-to-rock fraction relationships (WP_Elev_to_WallFrac_1, WP_Elev_to_WallFrac_23, WP_Elev_to_WallFrac_4DC, and WP_Elev_to_WallFrac_Ore). These four relationships are then used—along with the West Pit elevation-to-rock area relationships (WP_Elev_to_WallArea and WP_Elev_to_SetBackArea)—to determine the exposed rock area terms in Equations 11-5a and 11-5b in the same manner as for the analogous East Pit rock area terms (described in Section 10).

**Blast Ore Model**

The chloride release rates for blasted ore in the West Pit are calculated by Equation 10-37, with the ore mass in the West Pit (“WP_BlastOre_Mass”) substituted for the East Pit ore mass (“EP_BlastOre_Mass”) and the fraction of the total ore mass in the East Pit (“EPBlastOre_Store_Frac”) replaced by the analogous amount in the West Pit (“WPBlastOre_Store_Frac”)

where WPBlastOre_Store_Frac = WP_BlastOre_Mass / (EP_BlastOre_Mass + WP_BlastOre_Mass).

The nonacidic release rates for the remaining constituents are calculated as described in Section 7 and scaled by Equation 5-12.

Equations 10-38a and 10-38b, respectively, are used to calculate the cumulative mass of all constituents released from the West Pit blast ore and the portion of this mass that is available for transport and is input to the blast ore water. The volume of water in the West Pit blast ore is calculated using Equation 10-39. Infiltration into the blast ore is calculated by Equation 10-40. As in the case of the East Pit, the infiltration flow rate is equal to the rate of flow from the blast ore to the operational sump in the West Pit.

**Constituent Mass Derived from Plant Site (Tailings Basin)**

The concentration of water pumped to the West Pit from the Plant Site’s Tailings Basin is modeled as an uncertain quantity. The concentration is defined through time by a truncated normal distribution and the mean concentrations and standard deviations given in Tables 1-36 and 1-37, respectively, of the WMDP-MS-Attachment B.

**West Pit Water**

As previously mentioned, mass loads to and from the West Pit are the product of water fluxes and their associated continuously-variable constituent concentrations. The fluxes that gain constituent mass from the exposed pit walls (all rock types) and contribute mass to the West Pit water are calculated similarly to the analogous fluxes in the East Pit. These fluxes originate from:
- high wall water
- high set back area water
- (low) wall water
- (low) wall non-contacted material
- set back area water
- set back area non-contacted material

The remaining inflows to the West Pit, which are not dependent upon rock type, are:

From blast ore – Equation 10-40
From Plant Site (Tailings Basin) – Tables 1-36 and 1-37 (WMDP-MS-Attachment B)
From CPS pond – Described in “Central Pumping Station” section of Section 12
From Category 1 waste rock stockpile containment system – Equation 4-9b
From water at the bottom of the Category 1 waste rock stockpile (leakage) – Equation 4-8a
From EPCP lower porewater (via bedrock groundwater flow) – Equation 10-15
From EPCP wetland – Equation 10-20a or 10-20b (lesser of the two quantities)

The outflows from the West Pit are:

To WWTF’s East Pond (during operations) or LTWWTF (when operational) – Smaller of the quantities “WP_Desired_Dewater” (defined by Equations 11-2 through 11-3c and associated criteria), and “Pump_Limit_WP”
To West Pit surficial groundwater flow path to SW-004a – Equation 13-21
To West Pit bedrock groundwater flow path to SW-004 – Equation 13-6
To West Pit bedrock groundwater flow path to SW-004a – Equation 13-6
Mass removed by precipitation (during operations only) – 100% of remaining mass

11.4 Output

The West Pit Model ultimately calculates the following flows along with their associated constituent concentrations and loads:
- Outflow to two West Pit bedrock groundwater flow paths
- Outflow to the West Pit surficial aquifer flow path
- Outflow to the WWTF (during mining operations)
- Outflow to the LTWWTF
12 Waste Water Treatment Facility (WWTF) Models

12.1 Purpose

This model is used to simulate water flow and mass transport within and from the three waste water treatment facilities (WWTFs): 1) that which is used during mining, 2) the Reclamation WWTF (RWWTF), and 3) the long-term WWTF (LTWWTF). The model calculates water flows and associated constituent mass loads (for all constituents) that are routed to other component models, including models for the surficial aquifer, the East and Central pits, and the Partridge River.

12.2 Input

12.2.1 Inputs from Other Models

- East Pit water level, determined in Section 10
- East Pit lower porewater concentration, determined in Section 10
- Flow and load associated with pumping from the East Pit to the WWTFs, determined in Section 10
- Desired inflow rates and cumulative natural inflow rates to the East and Central pits, determined in Section 10
- West Pit water level, determined in Section 11
- Flow and load associated with pumping from the West Pit to the WWTFs, determined in Section 11
- Flow and load associated with rail transfer hopper and haul road runoff, calculated in Section 9
- Flow and load associated with runoff from the overburden storage and laydown area, calculated in Section 8
- Flow and load associated with infiltration collected in the Category 1 waste rock stockpile containment system and directed to the WWTFs, calculated in Section 4
- Flow and load associated with infiltration collected in the Category 2/3 waste rock stockpile containment system and directed to the WWTFs, calculated in Section 5
- Flow and load associated with infiltration collected in the Category 4 waste rock stockpile containment system and directed to the WWTFs, calculated in Section 6
- Flow and load associated with infiltration collected in the ore surge pile containment system and directed to the WWTFs, calculated in Section 7

12.2.2 Water Balance Inputs

1. **EastPond_Area** [L^2] – Liner area of the East Pond (WWTF used during operations)
   - Deterministic input (2.4 acres)
2. **Pond_Leakage** [L^3/L^2/T] – Leakage rate from the lined WWTF and CPS ponds
   - Deterministic input (5.0 gallons/acre/day)
3. **WestPond_Area** [L^2] – Liner area of the West Pond (WWTF used during operations)
   - Deterministic input (4.9 acres)
4. **Concentrate_toWWTF_Flow** [L^3/T] – Flow of concentrate returned from the Plant Site to the chemical precipitation plant
• Probabilistic input sampled every time-step
• Normal distribution (time-varying mean and standard deviation values given in Table 1-38 of WMDP-MS-Attachment B)

5. **EP_Return_Deficit** [L^3/T] – Amount of treated porewater not returned to the East Pit in order to maintain an inward groundwater gradient
   • Deterministic input (100 gallons per minute)

6. **Sludge_Water_Out** [L^3/T] – Rate of water loss from the WWTF due to sludge removal
   • Deterministic input (5.0 gallons/minute)

   • Deterministic input (2400 gallons/minute)

8. **Retentate_Reclam** [-] – Portion of inflows to the Reclamation WWTF that is treated further by chemical precipitation
   • Deterministic input (20%)

9. **CPS_Pond_Area** [L^2] – Liner area of the CPS pond
   • Deterministic input (1.3 acres)

10. **Pump_Limit_EP** [L^3/T] – Maximum pumping rate between the WWTF and East Pit
    • Deterministic input (5000 gallons per minute)

11. **Pump_Limit_CP** [L^3/T] – Maximum pumping rate between the WWTF and Central Pit
    • Deterministic input (5000 gallons per minute)

12. **EPCP_Elev_to_Volume** [L^3] – Lookup table for volume of the combined EPCP as a function of elevation
    • Deterministic lookup table which determines the elevation of the water surface in the East Pit-Central Pit based on the pit water volume (Figure 1-1 of WMDP-MS-Attachment B)

13. **Retentate_LongTerm** [-] – Portion of inflows to the LTWWTF’s reverse osmosis line lost by evaporation or removal from site
    • Deterministic input (5%)

12.2.3 **Mass Transport Inputs**

1. **Concentrate_toWWTF_Conc** [M/L^3] – Concentration of Plant Site WWTP concentrate being pumped to the chemical precipitation plant
   • Probabilistic, constituent-specific inputs resampled each month
   • Normal distribution (mean and standard deviations values defined in Tables 1-39 and 1-40 of WMDP-MS-Attachment B)

12.3 **Calculations**

12.3.1 **Water Balance Calculations**

**WWTF Used During Mining Operations**

The WWTF used during mining operations will consist of an East Pond, a West Pond, the actual WWTF itself, and a Central Pumping Station (CPS). This facility will remain in operation until the EPCP wetland is full (i.e. the East Pit water level reaches the outlet elevation).
Mine Site water designated for treatment is sent to one of the ponds prior to treatment. The inflows to the East Pond are: water pumped from the East Pit and Central Pit (as described in Section 10), the West Pit (as described in Section 11), rail transfer hopper runoff (calculated by Equation 9-2a), haul road runoff (Equation 9-3a), and retained Category 1 waste rock stockpile seepage (Equation 4-8b). Flow out of the East Pond occurs either as pumped flow to the WWTF or as leakage through the pond’s bottom. Leakage from the East Pond occurs when the pond is not frozen (i.e. April through October) and is calculated as:

\[ \text{East Pond Leakage} \left[ \frac{L}{T} \right] = \text{Pond Leakage} * \text{EastPond Area} \]  

The remaining water in the East Pond is pumped to the WWTF and treated.

Inflows to the West Pond are drainage from the liner systems of the Category 2/3 stockpile, the Category 4 stockpile, and the ore surge pile (as described in Sections 5, 6 and 7, respectively). Leakage from the West Pond is calculated by Equation 12-1, with “WestPond Area” substituted for “EastPond Area”. The remaining water in the West Pond is treated.

The total inflow rate to the Mine Site WWTF is the sum of the inflows to the two ponds, minus pond leakage, plus the rate of WWTP concentrate pumping from the Plant Site. The flow rate from the Plant Site WWTP (“Concentrate_toWWTF_Flow”) is a probabilistic input (see Section 10) defined by a truncated normal distribution and the mean and standard deviation given in Table 1-38 of the WMDP-MS-Attachment B.

The outflow rate from this WWTF to the Central Pumping Station pond is determined by Equation 12-2:

\[ \text{WWTF Outflow} \left[ \frac{L}{T} \right] = \text{WWTF Inflow} \left[ \frac{L}{T} \right] - \text{Sludge Water Out} \]  

Reclamation WWTF

The Reclamation WWTF (RWWTF) begins to treat water when the EPCP wetland is full (i.e. it becomes active immediately following termination of water treatment at the WWTF used during operations). The inflows to the RWWTF are Plant Site WWTP concentrate (“Concentrate_toWWTF_Flow”), Category 1 waste rock stockpile seepage (Equation 4-8b), and water pumped from the East Pit and Central Pit porewater (Equations 12-3a through 12-3c).

\[ \text{East Pit Lower Porewater Pumped to Reclamation WWTF} \left[ \frac{L}{T} \right] = \frac{\text{Total East Pit Porewater Treatment Rate} * \left( \text{East Pit Lower Porewater Volume} / \left( \text{East Pit Lower Porewater Volume} + \text{Central Pit Lower Porewater Volume} + \text{East Pit-Central Pit Upper Porewater Volume} \right) \right)}{\left( \text{East Pit Lower Porewater Volume} + \text{Central Pit Lower Porewater Volume} + \text{East Pit-Central Pit Upper Porewater Volume} \right)} \]  

\[ \text{Central Pit Lower Porewater Pumped to Reclamation WWTF} \left[ \frac{L}{T} \right] = \frac{\text{Total East Pit Porewater Treatment Rate} * \left( \text{Central Pit Lower Porewater Volume} / \left( \text{East Pit Lower Porewater Volume} + \text{Central Pit Lower Porewater Volume} + \text{East Pit-Central Pit Upper Porewater Volume} \right) \right)}{\left( \text{East Pit Lower Porewater Volume} + \text{Central Pit Lower Porewater Volume} + \text{East Pit-Central Pit Upper Porewater Volume} \right)} \]
East Pit-Central Pit Upper Porewater Pumped to Reclamation WWTF \([L^3/T]\) = 
Total East Pit Porewater Treatment Rate \(*\)
\((\text{East Pit-Central Pit Upper Porewater Volume} / \text{(East Pit Lower Porewater Volume + Central Pit Lower Porewater Volume + East Pit-Central Pit Upper Porewater Volume)})\) \(12-3c\)

The time-varying porewater volumes in Equations 12-3a through 12-3c are determined based on the inflows and outflows to the reservoirs representing the three porewater entities. The total pumping rate from the East and Central pit porewater to the RWWTF (also used by Equations 12-3a through 12-3c) is defined by the model variable \(\text{EP}_\text{Treat}_\text{Allow}\) and is calculated as:

\[
\text{Total East Pit Porewater Treatment Rate} [L^3/T] = 
\frac{[(\text{Reclam}_\text{Pump}_\text{Total} + (\text{Sludge}_\text{Water}_\text{Out} / (1 – \text{Retentate}_\text{Reclam}))) / (1 + \text{Retentate}_\text{Reclam} / (1 – \text{Retentate}_\text{Reclam}))] – \text{Retained Containment System Water (Category 1 Waste Rock Stockpile)} [L^3/T] – \text{Concentrate}_\text{toWWTF}_\text{Flow}}
\]  
\(12-4\)

As in the case of the WWTF outflow rate, the outflow rate for the RWWTF is the difference between the RWWTF inflow rate and the rate of water loss due to sludge removal; it is calculated in a manner analogous to Equation 12-2.

**Central Pumping Station**

The inflows to the Central Pumping Station (CPS) are the outflows from the WWTF used during operations (Equation 12-2), the Reclamation WWTF (Equation 12-2), and runoff from the peat and unsaturated overburden areas of the OSLA (Equation 8-2c).

There is assumed to be a one time-step (i.e. one month) lag between all inflows to and outflows from the CPS. The outflows are:

- CPS pond leakage (calculated by Equation 12-1 using “CPS_Pond_Area”)
- Pumping to East Pit and Central Pit lower porewater

These quantities are calculated as indicated in Section 10 once the EPCP wetland is full (i.e. the “Reclamation” phase has begun). If the EPCP water level is between the base of the surficial aquifer and the outlet elevation (i.e. the wetland is not yet entirely full), no water is pumped to the two lower porewater areas. If the EPCP water level is below the base of the surficial aquifer and the desired inflow rate to the East Pit lower porewater (Equation 12-5a) is more than the total natural inflows (i.e. total natural inflows minus total natural outflows), then the pumping rate from the CPS to the East Pit lower porewater is defined by Equation 12-5b:

\[
\text{Desired Inflow Rate (East Pit Lower Porewater)} [L^3/T] = 
\frac{(\text{EP}_\text{Pore}_\text{Vol}_\text{Desire} [L^3] – \text{East Pit Lower Porewater Volume} [L^3])}{1 \text{ month}}
\]  
\(12-5a\)
WWTF Pumping to East Pit Lower Porewater $[L^3/T] =$
\[
\text{Desired Inflow Rate (East Pit Lower Porewater } [L^3/T]) - \\
\text{[Total Natural East Pit Inflows (lower porewater only) } [L^3/T] - \\
\text{Total Natural East Pit Outflows (lower porewater only) } [L^3/T]\]
\] (12-5b)

The “EP_Pore_Vol_Desire” term in Equation 12-5a is the desired East Pit pore volume, which is the product of the backfill porosity and the desired water level (introduced in Section 10).

Equations 12-5a and 12-5b are also used to calculate an analogous quantity for the Central Pit when the same conditions are met. If none of the aforementioned sets of conditions for pumping to the lower porewater areas are met, no water is pumped to either lower porewater area.

- Pumping to the EPCP upper porewater.

This pumping rate is calculated as indicated in Section 10 after the EPCP wetland is full. If the EPCP backfill has filled completely but the EPCP wetland is not yet full, no water is pumped to the upper EPCP porewater. If EPCP backfilling is complete but the backfilled material is not yet fully saturated, the pumping rate is defined by Equation 12-6a:

\[
\text{WWTF Pumping to EPCP Upper Porewater } [L^3/T] = \\
\left[\left(\text{Maximum EPCP Upper Porewater Volume } [L^3] - \\
\text{EPCP Upper Porewater Volume } [L^3]\right) / 1 \text{ month}\right]
\] (12-6a)

The maximum upper porewater volume is the product of the backfill porosity (defined in Section 10) and the difference between the lookup table-based pit volumes (“EPCP_Elev_to_Volume”) at the top and bottom elevations of the upper porewater area (i.e. the top of the backfill and the bottom of the upper porewater, “EPCP_GW_OutElev”).

If the EPCP backfilling is not yet completed, the pumping rate for the CPS to the EPCP upper porewater is conditional upon the desired inflow rate to the East Pit upper porewater. The calculation of this desired flow rate is defined by Equation 12-6b:

\[
\text{Desired Inflow Rate (EPCP Upper Porewater) } [L^3/T] = \\
\text{East Pit Lower Porewater Volume } [L^3] + \right. \\
\left. \text{Central Pit Lower Porewater Volume } [L^3] + \\
\text{EPCP Upper Porewater Volume } [L^3] \right) / 1 \text{ month}
\] (12-6b)

The desired Central Pit pore volume, \text{CP_Pore_Vol_Desire}, was introduced in Section 10.

If the desired inflow rate to the East Pit upper porewater is more than the natural net inflow to the pit, then the pumping rate from the CPS to the East Pit upper porewater, calculated by Equation 12-6c, must compensate for this inflow deficiency:
WWTF Pumping to EPCP Upper Porewater \([L^3/T] = \)

Desired Inflow Rate (EPCP Upper Porewater) \([L^3/T] – \)

(Total Natural East Pit and Central Pit Inflows (upper porewater only) \([L^3/T] – \)

Total Natural East Pit and Central Pit Outflows (upper porewater only) \([L^3/T] ) \)

\( (12-6c) \)

If none of the above conditions for pumping to the EPCP upper porewater are met, no such pumping occurs.

- Pumping to the EPCP wetland (which varies with the state of EPCP backfilling and flooding).

After EPCP backfilling is complete, but before the backfill is fully saturated (flooded), the pumping rate to the wetland is the smaller of these two rates, defined by Equations 12-7a and 12-7b:

\[
\left( \frac{\text{Maximum EPCP Wetland Volume} - \text{EPCP Wetland Volume}}{1 \text{ month}} \right) - \left( \frac{\text{Total Natural East Pit Inflows} + \text{Total Natural Central Pit Inflows}}{\text{Total Natural East Pit Outflows} + \text{Total Natural Central Pit Outflows} + \text{Total Wetland Seepage to Porewater}} \right) \]

\( (12-7a) \)

\[
\text{Pump\_Limit\_EP} + \text{Pump\_Limit\_CP} - \left( \frac{\text{Maximum EPCP Upper Porewater Volume} - \text{EPCP Upper Porewater Volume}}{1 \text{ month}} \right) \]

\( (12-7b) \)

The two “Total Natural Outflow” terms in Equation 12-7a are the sums of the natural outflows from the East and Central pits described in Section 10. The maximum wetland volume is calculated similarly to the maximum upper porewater volume (described above) using the pit volumes at the top and bottom of the wetland (i.e. the elevations of the spillway and the top of the backfill).

Once the backfill is fully saturated (but prior to the wetland filling completely), the pumping rate to the wetland is defined to be the smaller of two rates:

i. the Desired Inflow Rate (East Pit wetland), calculated by Equations 12-7a and 12-7b, or

ii. the sum of the maximum pumping rates between the WWTF and the East and Central Pits (\(\text{Pump\_Limit\_EP} + \text{Pump\_Limit\_CP} \)) \([L^3/T] \).

Once the EPCP wetland is full (i.e. during “Reclamation”) there is no pumping from the CPS to the wetland in the model. Note that in reality the pumped return water from the RWWTF will be added to the surface of the pit and will percolate downward.

After all of the above CPS outflows have been allocated, if there is any additional WWTF effluent remaining it is all sent to either the Plant Site (before mining operations end) or the West Pit (after mining ends).
Long-Term WWTF

The long-term WWTF (LTWWTF) begins treating water when the West Pit water level reaches the desired long-term elevation ("WP_Outlet_Elev"). If the RWWTF is still operational when the LTWWTF begins treatment, the LTWWTF will only treat West Pit water at the rate defined in Section 11 ("WP_Actual_Dewater"). After the RWWTF goes offline, the LTWWTF will additionally treat the retained Category 1 waste rock stockpile seepage (Equation 4-8b). A portion of the inflow to the LTWWTF is either lost or is transported off-site; this simulated loss exits the model at a flow rate given by Equation 12-8a. The remainder of inflow to the LTWWTF is treated and discharged to the Partridge River at a rate given by Equation 12-8b.

\[
\begin{align*}
\text{LTWWTF Discharge Removed from Model [L}^3/\text{T]} &= \text{Total Inflow to LTWWTF [L}^3/\text{T}] \times \text{Retentate}_\text{LongTerm} \\
\text{LTWWTF Discharge to Partridge River (SW-004a) [L}^3/\text{T]} &= \text{Total Inflow to LTWWTF [L}^3/\text{T}] \times (1 - \text{Retentate}_\text{LongTerm})
\end{align*}
\] (12-8a)

12.3.2 Mass Transport Calculations

WWTF Used During Mining Operations

The WWTF used during mining operations and both the East and West ponds are all assumed to have constant volumes of 1000 m\(^3\), each. The constituent mass inflows to the elements representing these three areas are calculated by multiplying the constituent concentrations by the water balance inflows described earlier in this Section. Mass loading from the Plant Site WWTP concentrate is the product of the uncertain flow rates (\text{Concentrate\_toWWTF\_Flow}) and concentrations (\text{Concentrate\_toWWTF\_Conc}) of this inflow. The dewatered sludge removed from the WWTF is removed entirely from the model.

Reclamation WWTF

The element representing the mixture of water entering the RWWTF also has a fixed volume of 1000 m\(^3\). Mass loading from the Plant Site WWTP is estimated in the same manner as for the WWTF used during operations. Water and the associated constituent mass are routed through a 1 m\(^3\) element ("WWTF\_Reclam\_Water") where the treatment targets given in Table 1-34 of the WMDP-MS-Attachment B are applied as solubility limits. Constituent mass in excess of these limits is removed by either chemical precipitation or removal of WWTF sludge. Discharge from this 1 m\(^3\) element goes to the CPS pond element at the rate determined by Equation 12-2.

Central Pumping Station

The CPS pond element has a volume of 1 m\(^3\), and the inflows to it are the same as those defined in the water balance calculations (described above). The concentrations in treated water for all constituents other than calcium and magnesium are limited by the operations target concentrations defined in Table 1-34 of the WMDP-MS-Attachment B. WWTF effluent concentrations of calcium and magnesium are calculated as:
\[ \text{WWTF Effluent Concentration (Ca)} \ [\text{M/L}^3] = \frac{\text{Current WWTF Concentration (Ca)} \ [\text{M/L}^3] \times \text{Hardness Target Concentration}}{\text{Influent Hardness}} \]  \tag{12-9a}

\[ \text{WWTF Effluent Concentration (Mg)} \ [\text{M/L}^3] = \frac{\text{Current WWTF Concentration (Mg)} \ [\text{M/L}^3] \times \text{Hardness Target Concentration}}{\text{Influent Hardness}} \]  \tag{12-9b}

where

\[ \text{Influent Hardness} = 2.5 \times [\text{Ca}_{\text{influent}}] + 4.1 \times [\text{Mg}_{\text{influent}}]. \]

The leakage from the East, West and CPS ponds is combined into a single element (with a prescribed volume of 1000 m$^3$) and is divided evenly amongst the first 15 cells that comprise the WWTF surficial aquifer flow path model (see Section 13). Mass precipitated in the CPS pond is completely removed from the model. Constituent mass exiting the CPS as outflow described in the water balance above, exit the CPS at fluxes calculated by multiplying the CPS outflow rates defined in the water balance by the constituent concentrations of this outflowing water.

**Long-Term WWTF**

The element used to represent the mixture of water entering the LTWWTF has a constant volume of 100 m$^3$. As is the case with the RWWTF, inflows to the LTWWTF are then routed through a 1 m$^3$ element (“WWTF_LongTerm_Water”) to which the long-term treatment targets (Table 1-34, WMDP-MS-Attachment B) are applied as solubility limits. Mass exits the LTWWTF element as chemical precipitate (which leaves the model) or as concentrate in the outflowing water whose rate is defined by either Equation 12-8a or Equation 12-8b, depending upon the manner of outflow.

**12.4 Output**

The WWTF models ultimately calculate the following flows along with their associated constituent concentration and loads:

- Leakage from the East, West, and CPS ponds to the surficial aquifer flow paths
- Outflow pumped from the CPS to the East and Central Pits porewaters
- Outflow pumped from the CPS to the East and Central Pits wetlands
- Outflow pumped from the CPS to either the Plant Site or the West Pit
- LTWWTF water transported from the Site or lost to evaporation
- Outflow pumped from the LTWWTF into the Partridge River
13 Flow Path Models

13.1 Purpose

This model is used to simulate water flow and mass transport through the bedrock and surficial aquifer from the sources at the Mine Site to the discharge points along the Partridge River. The model calculates water flows and associated constituent mass loads (for all constituents) that are routed to the Partridge River Model.

13.2 Input

13.2.1 Inputs from Other Models

- Flow and load associated with leakage from the East Pit into the bedrock and surficial aquifer, calculated in Section 10
- East Pit water level, determined in Section 10
- Treatment status (actively being treated or not) of East Pit and Central Pit water, determined in Section 12
- Flow and load associated with leakage from the West Pit into the bedrock and surficial aquifer, calculated in Section 11
- West Pit water level, determined in Section 11
- Flow and load associated with leakage from the Category 2/3 Waste Rock Stockpile into the surficial aquifer, calculated in Section 5
- Flow and load associated with leakage from the Ore Surge Pile into the surficial aquifer, calculated in Section 7
- Flow and load associated with leakage from the WWTF ponds into the surficial aquifer, calculated in Section 12
- Flow and load associated with infiltration through overburden and peat at the OSLA, calculated in Section 9

13.2.2 Water Balance and Mass Transport Inputs

1. **EP_Bed_w** [L] – Width of the East Pit bedrock aquifer
   - Deterministic input (1735 m)
   - Deterministic input (100 m)
3. **Bedrock_Porosity** [-] – Porosity of bedrock flow paths
   - Deterministic input (0.05)
4. **Bed_alpha** [ln(M/L^3)] – Bedrock groundwater concentration parameter
   - Probabilistic, constituent-specific inputs sampled at start of each realization
   - Normal distribution with mean (“Log Mean α”) and standard deviation values (“Log Mean α Std. Error”) given in Table 1-12 of WMDP-MS-Attachment B
5. **Bed_Beta** [ln(M/L^3)] – Bedrock groundwater concentration parameter
   - Deterministic, constituent-specific inputs
   - Values given in Table 1-12 of WMDP-MS-Attachment B (“Log Std. Dev. B”)
   - Probabilistic input sampled at start of each realization
7. \( I_{close\_EPBed} \) [-] – Average gradient of the East Pit bedrock flow path after the pit is full
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.00805; maximum = 0.00859)

8. \( WP\_Bed4\_w \) [L] – Width of the West Pit bedrock aquifer flow path to SW-004
   - Deterministic input (535 m)

9. \( WP\_Bed4\_b \) [L] – Thickness of the West Pit bedrock aquifer flow path to SW-004
   - Deterministic input (100 m)

10. \( WP\_Bed4\_Clos\_Grad \) [L/L] – Average gradient of the West Pit bedrock flow path to SW-004 after the pit is full
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 0.00907; maximum = 0.00973)

11. \( WP\_Bed4\_K \) [L/T] – Hydraulic conductivity of the West Pit bedrock flow path to SW-004
    - Probabilistic input sampled at start of each realization
    - Triangular distribution (minimum = 4.7x10^{-6} m/d; mode = 1.5x10^{-5} m/d; maximum = 4.7x10^{-5} m/d)

12. \( WP\_Bed4\_a\_w \) [L] – Width of the West Pit bedrock aquifer flow path to SW-004a
    - Deterministic input (810 m)

13. \( WP\_Bed4\_a\_b \) [L] – Thickness of the West Pit bedrock aquifer flow path to SW-004a
    - Deterministic input (100 m)

14. \( WP\_Bed4\_a\_Clos\_Grad \) [L/L] – Average gradient of the West Pit bedrock flow path to SW-004a after the pit is full
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 0.00907; maximum = 0.00973)

15. \( WP\_Bed4\_a\_K \) [L/T] – Hydraulic conductivity of the West Pit bedrock flow path to SW-004a
    - Probabilistic input sampled at start of each realization
    - Triangular distribution (minimum = 4.7x10^{-6} m/d; mode = 1.5x10^{-5} m/d; maximum = 4.7x10^{-5} m/d)

16. \( Surficial\_Porosity \) [-] – Porosity of surficial aquifer
    - Deterministic input (0.3)

17. \( I\_ops\_EP23surf \) [-] – Hydraulic gradient of East Pit-Category 2/3 stockpile surficial aquifer flow path during mining operations (uncertain input defined by minimum and maximum)
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 0.00387; maximum = 0.00434)

18. \( I\_close\_EP23surf \) [-] – Hydraulic gradient of East Pit-Category 2/3 stockpile surficial aquifer flow path during closure (uncertain input defined by minimum and maximum)
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 0.00599; maximum = 0.00646)

19. \( K\_EP23surf \) [L/T] – Hydraulic conductivity of the East Pit-Category 2/3 stockpile surficial aquifer
    - Probabilistic input sampled at start of each realization
    - Triangular distribution (minimum = 0.82 m/d; mode = 1.94 m/d; maximum = 4.7x10^{-5} m/d)
maximum = 5.49 m/d)
20. **EPCat23_w** [L] – Width of the East Pit-Category 2/3 stockpile surficial aquifer flow path
   - Deterministic input (1440 m)
21. **EPCat23_b** [L] – Thickness of the East Pit-Category 2/3 stockpile surficial aquifer flow path
   - Deterministic input (5 m)
22. **Recharge_min** [L/T] – Minimum allowed recharge rate to surficial aquifer
   - Deterministic input (0.36 inches/year)
23. **Mean_Bare_Infilt** [L/T] – Infiltration for mean stockpile conditions (precipitation, evapotranspiration, and runoff)
   - Deterministic input (13.50537 inches/year)
24. **Recharge_max** [L/T] – Maximum allowed recharge rate to surficial aquifer
   - Deterministic input (1.8 inches/year)
25. **Surf_alpha** [ln(M/L^3)] – Surficial groundwater concentration parameter
   - Probabilistic, constituent-specific inputs sampled at start of each realization
   - Normal distribution with mean (“Log Mean α”) and standard deviation values (“Log Mean α Std. Error”) given in Table 1-12 of WMDP-MS-Attachment B
26. **Surf_Beta** [ln(M/L^3)] – Surficial groundwater concentration parameter
   - Deterministic, constituent-specific inputs
   - Values given in Table 1-12 of WMDP-MS-Attachment B (“Log Std. Dev. B”)
27. **Surficial_Density** [M/L^3] – Bulk density of the surficial flow paths
   - Deterministic input (1500 kg/m^3)
28. **Kd_As** [L^3/M] – Arsenic sorption coefficient
   - Deterministic input (25 L/kg)
29. **Kd_Cu** [L^3/M] – Copper sorption coefficient
   - Deterministic input (22 L/kg)
30. **Kd_Ni** [L^3/M] – Nickel sorption coefficient
   - Deterministic input (16 L/kg)
31. **Kd_Sb** [L^3/M] – Antimony sorption coefficient
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 1.3 L/kg; mode= 1.6 L/kg; maximum = 6.1 L/kg)
32. **OSP_b** [L] – Thickness of the ore surge pile surficial aquifer flow path
   - Deterministic input (5 m)
33. **OSP_w** [L] – Width of the ore surge pile surficial aquifer flow path
   - Deterministic input (430 m)
34. **I_ops_OSPsurf** [-] – Hydraulic gradient of ore surge pile surficial aquifer flow path during mining operations
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.00954; maximum = 0.0102)
35. **OSP_K** [L/T] – Hydraulic conductivity of the ore surge pile surficial flow path
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 0.23 m/d; mode= 0.5 m/d; maximum = 1.25)
36. **WWTF_b** [L] – Thickness of the WWTF surficial aquifer flow path
   - Deterministic input (5 m)
37. **WWTF_w** [L] – Width of the WWTF surficial aquifer flow path
   - Deterministic input (240 m)
38. **l_ops_WWTFsurf** [-] – Hydraulic gradient of the WWTF surficial aquifer flow path during mining operations
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.00821; maximum = 0.00879)
39. **WWTF_K** [L/T] – Hydraulic conductivity of the WWTF surficial flow path
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 0.39 m/d; mode= 0.83 m/d; maximum = 2.07)
40. **OSLA_b** [L] – Thickness of the overburden storage and laydown area surficial aquifer flow path
   - Deterministic input (5 m)
41. **OSLA_w** [L] – Width of the overburden storage and laydown area surficial aquifer flow path
   - Deterministic input (550 m)
42. **OSLA_K** [L/T] – Hydraulic conductivity of the OSLA surficial flow path
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 2.07 m/d; mode= 3.58 m/d; maximum = 6.22)
43. **l_ops_OSLAsurf** [-] – Hydraulic gradient of the OSLA surficial aquifer flow path during mining operations
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.00856; maximum = 0.00919)
44. **Mean_Reclaim_Infilt** [L/T] – Infiltration for mean stockpile conditions (precipitation, evapotranspiration, and runoff)
   - Deterministic input (6.071742 inches/year)
45. **K_WPsurf** [L/T] – Randomly generated hydraulic conductivity of West Pit surficial aquifer flow path
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 0.39 m/d; mode= 1.31 m/d; maximum = 4.73 m/d)
46. **WP_b** [L] – Thickness of the West Pit surficial aquifer flow path
   - Deterministic input (5 m)
47. **WP_w** [L] – Width of the West Pit surficial aquifer flow path
   - Deterministic input (665 m)
48. **l_ops_WPsurf** [-] – Hydraulic gradient of the West Pit surficial aquifer flow path during closure
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.00399; maximum = 0.00465)
49. **l_close_WPsurf** [-] – Hydraulic gradient of the West Pit surficial aquifer flow path during closure
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.00897; maximum = 0.00963)
13.3 Calculations

13.3.1 Water Balance and Mass Transport Calculations

East Pit Bedrock Flow Path Model

Bedrock groundwater flows from the East Pit to the Partridge River when two conditions are met: (1) the water level in the East Pit backfill has reached the surficial aquifer, and (2) East Pit and Central Pit are not being pumped for treatment. The East Pit bedrock flow path consists of 65 flow path cells which are divided into two sequential flow path “sections” of the aquifer. Flow path section 1 consists of 50 cells and represents the area between the East Pit and the lone groundwater evaluation point. A groundwater evaluation point marks the intersection of a flow path and perimeter around the site beyond which groundwater emanating from the site is required to meet water quality standards imposed for the constituents released from the site. Flow path section 2 contains the 15 remaining cells and represents the area between the groundwater evaluation point and the reach of the Partridge River upstream of the “SW-004” surface water evaluation point. The volumes of the cells in each section are calculated as:

\[
\text{Cell Volume (Per EP Bedrock Flow Path Cell, Section 1)} \ [L^3] = \text{EP\_Bed\_w} \times \text{EP\_Bed\_b} \\
\times \text{Distance between East Pit and Evaluation Point} \ [L] \div 50 \text{ cells} \quad (13-1a)
\]

\[
\text{Cell Volume (Per EP Bedrock Flow Path Cell, Section 2)} \ [L^3] = \text{EP\_Bed\_w} \times \\
\text{EP\_Bed\_b} \times \text{Distance between Evaluation Point and Partridge River} \ [L] \div 15 \text{ cells} \quad (13-1b)
\]

The distance between the East Pit and the evaluation location is 1435 meters, and the evaluation location is 440 meters upgradient of the Partridge River. The volumes calculated by Equations 13-1a and 13-1b include the volumes of both bedrock and bedrock groundwater, which are calculated separately as:

\[
\text{Bedrock Volume (EP Bedrock Flow Path Cell, Section 1)} \ [L^3] = (1 - \text{Bedrock\_Porosity}) \times \\
\text{Cell Volume (Per EP Bedrock Flow Path Cell, Section 1)} \ [L^3] \quad (13-2a)
\]

\[
\text{Bedrock Groundwater Volume (EP Bedrock Flow Path Cell, Section 1)} \ [L^3] = \\
\text{Bedrock\_Porosity} \times \text{Cell Volume (Per EP Bedrock Flow Path Cell, Section 1)} \quad (13-2b)
\]

Calculations identical to these are made for bedrock and bedrock groundwater volumes for flow path section 2.

The initial concentrations for the bedrock flow path cells are calculated from the stochastic input “Bed\_alpha,” defined by a mean and standard error provided in Table 1-12 of the WMDP-MS-Attachment B, and “Bed\_Beta,” a deterministic input whose values are provided in the same table. The calculation of initial bedrock concentrations is provided in Equation 13-3. This is an empirical equation that calculates groundwater concentration in units of \(\mu g/L\) when “Bed\_alpha” and “Bed\_beta” are provided in units of the natural log (\(ln\)) of mg/L:
**Bedrock Groundwater Concentrations** \([\mu g/L] = exp(Bed\_alpha + 0.5 \times Bed\_Beta^2)\) 

(13-3)

The inflow to the first flow path cell from the East Pit is calculated by Equation 13-4.

**East Pit Bedrock Groundwater Outflow** \([L^3/T]\) =

\[-K\_EPbed \times EP\_Bed\_w \times EP\_Bed\_b \times I\_close\_EPbed\]  

(13-4)

There is assumed to be no other source of flow to this flow path, so (1) the inflows to and outflows from all 65 East Pit bedrock flow path cells are equal to the inflow to the first cell, and (2) subsequently, the inflow to SW-004 from this flow path is also equal to the quantity calculated by Equation 13-4.

The mass loading rate from this and all other flow path models is equal to the product of the continuously-variable constituent concentrations in the farthest downgradient flow path cell and the volumetric outflow rate from the cell. For example, the mass loading rates from the East Pit bedrock flow path model to the Partridge River are the products of each constituent concentration in the 65th flow path cell and the volumetric outflow rate calculated by Equation 13-4.

**West Pit Bedrock Flow Path (to SW-004) Model**

Bedrock groundwater flows from the West Pit to the Partridge River when the pit water level elevation has reached 1550 feet. Like the East Pit bedrock flow path, there are also two sections in the bedrock flow path between the West Pit and the Partridge River reach upstream of SW-004, with the groundwater evaluation point at the boundary between sections. Flow path section 1 has 18 cells and section 2 has 41 cells. The volume of the cells in each section are calculated as:

**Cell Volume (Per WP Bedrock Flow Path Cell, Section 1, SW-004)** \([L^3]\) =

\[WP\_Bed4\_w \times WP\_Bed4\_b \times \text{Distance between East Pit and Evaluation Point} \] / 18 cells  

(13-5a)

**Cell Volume (Per WP Bedrock Flow Path Cell, Section 2, SW-004)** \([L^3]\) =

\[WP\_Bed4\_w \times WP\_Bed4\_b \times \text{Distance between Evaluation Point and Partridge River} \] / 41 cells  

(13-5b)

The distance between the West Pit and the evaluation location is 505 meters, and the evaluation location is 1115 meters upgradient of the Partridge River. Equations 13-2a and 13-2b are used to calculate the bedrock and groundwater volume components of these total cell volumes.

Like the East Pit bedrock flow path, the inflow to the farthest upgradient cell in flow path section 1 of the West Pit bedrock flow path is calculated using Darcy’s Law:

**West Pit Bedrock Groundwater Outflow (SW-004)** \([L^3/T]\) =

\[-WP\_Bed4\_K \times WP\_Bed4\_w \times WP\_Bed4\_b \times WP\_Bed4\_Clos\_Grad\]  

(13-6)
As was the case with the East Pit bedrock groundwater flow path, the outflow from the West Pit to this groundwater flow path is equal to the outflow from the flow path to the Partridge River. That is, there are no sources to the flow path other than the West Pit, thus the outflow from the flow path to the Partridge River is also given by Equation 13-6.

West Pit Bedrock Flow Path (to SW-004a) Model

A second West Pit bedrock flow (which also begins when the pit water level reaches 1550 feet), there are also two sections to the bedrock groundwater flow path between the West Pit and the Partridge River reach upstream of SW-004a. The first section has 13 cells, and the second has 43 cells, and the volumes of these cells are:

\[
\text{Cell Volume (Per WP Bedrock Flow Path Cell, Section 1, SW-004a) } [L^3] = \frac{\text{WP\_Bed4a\_w} \times \text{WP\_Bed4a\_b} \times \text{Distance between East Pit and Evaluation Point} [L]}{13 \text{ cells}} \quad (13-7a)
\]

\[
\text{Cell Volume (Per WP Bedrock Flow Path Cell, Section 2, SW-004a) } [L^3] = \frac{\text{WP\_Bed4a\_w} \times \text{WP\_Bed4a\_b} \times \text{Distance between Evaluation Point and Partridge River} [L]}{43 \text{ cells}} \quad (13-7b)
\]

The distance between the West Pit and the evaluation location along this flow path is 340 meters, and the evaluation location is 1160 meters upgradient of the Partridge River.

As before, Equations 13-2a and 13-2b are used to calculate the bedrock and groundwater volume components of these total cell volumes. Equation 13-6 is executed to calculate the flow from the West Pit into the first cell of the first flow path section using the properties of this bedrock flow path (i.e. WP\_Bed4a\_w, WP\_Bed4a\_b, WP\_Bed4a\_Clos\_Grad and WP\_Bed4a\_K), which, as in the case of the flow paths described above, is the flow path outflow rate to the Partridge River.

East Pit & Category 2/3 Stockpile Surficial Aquifer Flow Path Model

After the water level in the East Pit backfill has reached the surficial aquifer, groundwater travels along a flow path from the East Pit and Category 2/3 waste rock stockpile to the Partridge River (upstream of SW-004) through the surficial aquifer. This flow path is divided into three zones: Zone 1 is upgradient of the Category 2/3 stockpile, Zone 2 is underneath the stockpile, and Zone 3 is downgradient of the stockpile (i.e. between the stockpile and the Partridge River). Zones are distinct from flow path sections inasmuch as each zone can have a different recharge rate. The flow path is divided into five flow path sections consisting of (in downstream order) 26, 13, 1, 15 and 26 cells. Section 1 encompasses all of Zone 1 and section 2 includes all of Zone 2. Zone 3 is divided into three flow path sections (Sections 5 through 7) because there are two groundwater evaluation locations within Zone 3. These evaluation points are located at the upstream and downstream ends of flow path Section 6.

The width and thickness of this flow path are 1440 m (“EPCat23\_w”) and 5 m (“EPCat23\_b”), respectively. The lengths of the five flow path sections (in downstream order) are: 775 m, 395 m, 30 m, 140 m, and 780 m. The cell volumes in each of these sections are calculated as:
Cell Volume \( [L^3] \) = \( \text{EPCat23}_w \times \text{EPCat23}_b \times \text{Length of Section} \ [L] \) / Number of Cells in Section \hfill (13-8a)

The portions of this volume consisting of water and rock are calculated using these general equations:

Overburden Volume (Per East Pit-Cat. 2/3 Surficial Flow Path Cell) \( [L^3] \) = 
\( (1 – \text{Surficial Porosity}) \) * 
Cell Volume (Per East Pit-Cat. 2/3 Surficial Flow Path Cell) \ [L] \hfill (13-8b)

Water Volume (Per East Pit-Cat. 2/3 Surficial Flow Path Cell) \( [L^3] \) = 
\( \text{Surficial Porosity} \) * 
Cell Volume (Per East Pit-Cat. 2/3 Surficial Flow Path Cell) \ [L] \hfill (13-8c)

The inflow to the first cell in flow path section 1 (coming from the East Pit) is equal to the total outflow minus the recharge from all three flow path zones, and is calculated by Equation 13-9a.

\[ \text{East Pit-Central Pit Surficial Groundwater Outflow} \ [L^3/T] = -\text{EPCat23}_K \times \text{EPCat23}_w \times \text{EPCat23}_b \times \text{I_close_EP23surf} – \text{Total Recharge from Aquifer Zones 1, 2 and 3} \] \hfill (13-9a)

Unlike the three bedrock groundwater flow paths, surface recharge occurs to each surficial aquifer cell. This surficial recharge rate is constant within each zone; the resulting recharge is an inflow into each cell of the zone. Thus, the outflow from each cell is a sum of the recharge and the outflow from the cell located immediately upgradient:

\[ \text{Outflow from an East Pit-Category 2/3 Stockpile Surficial Aquifer Cell} \ [L^3/T] = \text{Groundwater Inflow to Cell (from upgradient)} + (\text{Length of Aquifer Section} \ [L] \times \text{Zone-Specific Aquifer Recharge Rate} \ [L/T] \times \text{EPCat23}_w \ [L]) / \text{Number of Cells in Aquifer Section} \] \hfill (13-9b)

The recharge rates to Zones 1 and 3 are calculated using this general equation:

\[ \text{Recharge Rate (Zones 1 and 3)} \ [L/T] = -2 \times (\text{Flow Path Hydraulic Conductivity} \ [L/T] \times \text{EPCat23}_b \times \text{EPCat23}_w \times \text{I_ops_EP23surf} + \text{Groundwater Flow into Zone from Upgradient} \ [L^3/T]) / (\text{Length of Zone} \ [L] \times \text{EPCat23}_w) \] \hfill (13-10)

The flow path hydraulic conductivity is an uncertain parameter (sampled once per realization), but which has some special restrictions. Unlike the hydraulic conductivities of the flow paths described above, the sampled hydraulic conductivity value for this flow path (\( \text{EPCat23}_K \)) is checked against calculated minimum and maximum hydraulic conductivities. These calculated hydraulic conductivity bounds depend upon the spatial dimensions of the flow path, as well as surficial recharge variables:

\[ \text{Minimum Hydraulic Conductivity (East Pit-Cat. 2/3)} \ [L/T] = - \left[ \text{Recharge_min} \times ((\text{Total Length of Sections 1, 3, 4, 5} \ [L])^2 + \right] \]
The maximum hydraulic conductivity value is calculated using this same equation, with “Recharge_max” substituted for “Recharge_min”. If the randomly generated hydraulic conductivity value is greater than the maximum value it is changed to the maximum value. Similarly, if the generated value is less than the minimum value it is changed to the minimum value.

While the Category 2/3 stockpile is present, the recharge rate to Zone 2 is the liner leakage rate from the stockpile:

\[
\text{Zone 2 Recharge Rate (while stockpile is present) [L/T]} = \frac{\text{Total Category 2/3 Stockpile Infiltration [L}/T] \times \text{Liner_leak_23}}{\text{EPCat23_w} \times \text{Length of Zone 2 [L]}}
\]  

(13-12)

After the Category 2/3 stockpile has been completely removed, the Zone 2 recharge rate is calculated by Equation 13-10.

Constituent mass loading from stockpile seepage to each of the Zone 2 (i.e. flow path section 2) cells occurs at the rate calculated by Equation 5-31. All constituent mass entering the remaining cells—as well as Zone 2 cells after the stockpile has been removed—comes from recharge (calculated by Equation 13-13a), and either the East Pit (in the case of the first cell in section 1) or the flow path cell immediately upgradient.

\[
\text{Constituent Mass Loading from Natural Area (Per Cell) [M/T]} = \frac{\text{Surficial Groundwater Concentrations (All Constituents) [M/L}^3]}{\text{Zone Recharge Rate [L/T]} \times \text{EPCat23_w} \times \text{Length of Aquifer Section [L]}} \times \frac{\text{Number of Cells in Aquifer Section}}{13-13a}
\]

The surficial groundwater concentrations in Equation 13-13a are calculated similarly to the bedrock groundwater concentrations:

\[
\text{Surficial Groundwater Concentrations [M/L}^3] = \exp(\text{Surf_alpha} + 0.5 \times \text{Surf_Beta}^2)
\]  

(13-13b)

Equation 13-13b defines an empirical relationship that calculates groundwater concentration in units of µg/L when “Bed_alpha” and “Bed_beta” are provided in units of the natural log (ln) of µg/L.

The initial mass of each constituent that is present in each flow path cell is determined by Equation 13-14:
Initial Constituent Mass \([M]\) = \text{Surficial Groundwater Concentration} \([M/L^3]\) * \\
\text{(Cell Water Volume} \([L^3]\) + \\
\text{Rock Volume} \([L^3]\) * \text{Surficial Density} * \text{Sorption Coefficient} \([L/M^3]\)) \hspace{1cm} (13-14)

The sorption coefficients for all constituents other than As, Cu, Ni and Sb are zero. The sorption coefficients for these four constituents are defined by the inputs “\(Kd_{As}\)”, “\(Kd_{Cu}\)”, “\(Kd_{Ni}\)” and “\(Kd_{Sb}\)”, respectively.

The final flow path cell adds flow and solute mass to the Partridge River reach upstream of SW-004 through an intermediate cell ("Mine\_GW\_to\_SW004") which has a volume of 10 m\(^3\). This intermediate cell is a confluence point where multiple flow paths intersect the Partridge River.

Ore Surge Pile (OSP) Surficial Aquifer Flow Path Model

Groundwater flows from the OSP through the surficial aquifer flow path to the Partridge River. This flow path is divided into two zones: Zone 1 is underneath the OSP and Zone 2 extends from the downgradient edge of the OSP to the Partridge River. Zone 1 consists of a single section, and Zone 2 is subdivided into three sections. The four sections are comprised of (in downstream order) 9, 2, 41 and 2 cells. There are two groundwater evaluation locations: at the upstream and downstream ends of section 3.

The width and thickness of this flow path are 430 m ("OSP\_w") and 5 m ("OSP\_b"), the cell volumes are calculated using these values substituted into Equation 13-8a, and the water and rock volumes are calculated with Equations 13-8b and 13-8c. The lengths of the four sections are: 230 m, 40 m, 1085 m, and 60 m.

This flow path model differs from those described previously in that there is no groundwater flow from upgradient entering the first flow path cell; the only inflow to this cell is leakage from the OSP liner system (when the OSP is present during mining operations), or recharge (after the OSP has been completely removed). The rate of liner leakage—and constituent mass loading—to the cells in flow path section 1 during mining operations is calculated by Equation 7-24. The recharge rate to Zone 2 (and to Zone 1 after the OSP has been removed) is calculated by Equation 13-10 using OSP-specific values (i.e. “\(OSP\_b\)”, “\(OSP\_w\)” and “\(I_{ops\_OSPSurf}\)”). The generated hydraulic conductivity value (“\(OSP\_K\)”) is again checked against the minimum and maximum allowable values that are calculated based on flow path dimension and surficial recharge variables. The calculation of these bounding hydraulic conductivity values are defined by a different equation than that which was employed for the East Pit and Category 2/3 waste rock stockpile flow path:

\[
\text{Minimum Hydraulic Conductivity (OSP) [L/T]} = - \frac{\text{Recharge}_{\text{min}} [L/T] \times \left(\frac{\text{Total Length of Sections 2, 3, 4 [L]}}{\text{(Length of Section 1 [L])}^2 + (\text{Liner\_Leak\_4\_OSP} \times \text{Mean\_Bare\_Infiltration})} \right)}{\left(2 \times \text{Length of Section 1 [L]} \times \text{Total Length of Sections 2, 3, 4 [L]} \right) / (2 \times \text{OSP\_b} \times I_{ops\_OSPSurf} \times \text{Total Flow Path Length [L]})} \hspace{1cm} (13-15)
\]
The maximum hydraulic conductivity value is also calculated using this equation by substituting “Recharge_max” for “Recharge_min”. These limits are then imposed on the hydraulic conductivity value used in Equation 13-10.

The outflow rates for the cells in this flow path are calculated with Equation 13-9b using the average recharge rate of the two flow path zones. As with the East Pit and Category 2/3 stockpile flow path, this flow path terminates in the intermediate “Mine_GW_to_SW004” cell prior to entering the Partridge River reach upstream of SW-004.

**WWTF Surficial Aquifer Flow Path Model**

This flow path model is similar to the OSP surficial flow path model. It also consists of two zones and four sections, with Zone 1 coinciding with flow path section 1, and Zone 2 containing sections 2 through 4. The two groundwater quality evaluation points also lie at both ends of section 3. There also are no upgradient groundwater inflows to the first flow path cell; the only inflow to section 1 is leakage from the three WWTF ponds (East, West, and CPS) and recharge from the surrounding areas.

The width and depth of the flow path are 240 m (“WWTF_w”) and 5 m (“WWTF_b”), respectively. The four sections are (in downstream order) 420 m, 60 m, 910 m and 340 m in length, and consist of 15, 2, 33 and 12 cells. The volumes of the cells in each section are calculated by Equation 13-8a, and the portions of these volumes consisting of water and rock are calculated with Equations 13-8b and 13-8c.

The recharge rate for Zone 2 is calculated by Equation 13-10 with flow path-specific values (i.e. “WWTF_b”, “WWTF_w” and “I_ops_WWTFsurf”). The minimum and maximum flow path hydraulic conductivity values are calculated as:

\[
\text{Minimum Hydraulic Conductivity (WWTF)} \ [L/T] = - \left[ \frac{\text{Recharge_min} \times \left(\text{Total Length of Sections 2, 3, 4} \ [L]\right)^2 + \text{Minimum Source Zone Flux} \ [L/T] \times \left(\text{Length of Section 1} \ [L]\right)^2 + 2 \times \text{Length of Section 1} \ [L] \times \text{Total Length of Sections 2, 3, 4} \ [L]\right]}{2 \times \text{WWTF_b} \times \text{I_ops_WWTFsurf} \times \text{Total Flow Path Length} \ [L]} \right) \tag{13-16a}
\]

and

\[
\text{Maximum Hydraulic Conductivity (WWTF)} \ [L/T] = - \left[ \frac{\text{Recharge_max} \times \left(\text{Total Length of Sections 2, 3, 4} \ [L]\right)^2 + \text{Maximum Source Zone Flux} \ [L/T] \times \left(\text{Length of Section 1} \ [L]\right)^2 + 2 \times \text{Length of Section 1} \ [L] \times \text{Total Length of Sections 2, 3, 4} \ [L]\right]}{2 \times \text{WWTF_b} \times \text{I_ops_WWTFsurf} \times \text{Total Flow Path Length} \ [L]} \right) \tag{13-16b}
\]

The minimum and maximum source zone fluxes in Equations 13-16a and 13-16b are:

\[
\text{Minimum Source Zone Flux} \ [L/T] = \left(\frac{\text{Pond Leakage} \times \text{Pond Area} + \text{Recharge_min} \times \text{NonPond Area}}{\text{Length of Section 1} \ [L] \times \text{WWTF_w}}\right) \tag{13-16c}
\]
Maximum Source Zone Flux \([L/T]\) =
\[
(Pond_{Leakage} \times Pond_{Area} + Recharge_{max} \times NonPond_{Area}) / (Length of Section 1 \ [L] \times WWTF\_w)
\]

(13-16d)

The “Pond_{Area}” term in these formulas is the sum of the active WWTF pond areas, and the non-pond is calculated by Equation 13-16e:

\[
NonPond\_Area \ [L^2] = WWTF\_w \times Length of Section 1 \ [L] – Pond\_Area
\]

(13-16e)

While the WWTF ponds are present (i.e. during mining operations and the Reclamation phase), the recharge rate to Zone 1 must account for both the areas that are and are not covered by the three ponds. Therefore, recharge to Zone 1 when the ponds are present is calculated as:

\[
Recharge\ Rate \ (Zone \ 1) \ [L/T] = \left(\frac{\left[(East\ Pond\ Leakage + West\ Pond\ Leakage + CPS\ Pond\ Leakage + Recharge\ Rate \ (Zone\ 2)) \times NonPond\_Area\right]}{WWTF\_w \times Length of Section 1}\right)
\]

(13-17)

After the RWWTF stops treating water, the recharge rate for Zone 1 is calculated by Equation 13-10. Outflow rates from the cells in this flow path are determined using Equation 13-9b with the recharge rates from the two flow path zones. As with the previous surficial flow paths, water and mass from this flow path terminate in the “Mine\_GW\_to\_SW004” cell before entering the Partridge River reach upstream of SW-004.

**Overburden Storage & Laydown Area (OSLA) Surficial Aquifer Flow Path Model**

This flow path consists of four sections which are divided into two zones. Zone 1 and flow path section 1 cover the same area, and Zone 2 includes sections 2, 3, and 4. The sections are 375 m, 5 m, 235 m, and 985 m in length, and consist of 14, 0, 8 and 36 cells. It is worthy of note that flow path section 2 contains no transport cells because its length (5 m) is less than the length of a single OSLA flow path cell (approximately 27.6 m); thus, no transport calculations are made for this flow path section. There are two groundwater quality evaluation points along the flow path: at the upgradient and downgradient ends of section 3. The width (“OSLA\_w”) and depth (“OSLA\_b”) of the flow path are 550 m and 5 m, and the flow path cell volumes (total, rock and water) for each section are calculated using these values in Equations 13-8a, 13-8b and 13-8c.

As with the OSP and WWTF surficial flow paths, no groundwater flow from upgradient enters the first cell of the OSLA surficial flow path. The only inflow to the cells in flow path section 1 is infiltration, which is calculated by Equation 8-3c. When the OSLA is present during mining operations, the recharge rate to Zone 1 (section 1) is:

\[
Zone\ 1\ Recharge\ Rate \ (while\ stockpile\ is\ present) \ [L/T] = \left(\frac{Total\ OSLA\ Infiltration \ [L^3/T]}{(OSLA\_w \times Length of Zone\ 1 \ [L])}\right)
\]

(13-18)

After mining operations cease, the recharge rate to Zone 1 is calculated using Equation 13-10 and no mass loading from OSLA infiltration occurs. The recharge rate to Zone 2 (i.e. flow path sections 3 and 4) is always calculated by Equation 13-10. The minimum and maximum hydraulic conductivity values are again imposed on the generated value (“OSLA\_K”) prior to
using Equation 13-10 to calculate recharge rates. These limiting values are calculated by Equation 13-19 (“Recharge_max” is again substituted for “Recharge_min” to calculate the maximum allowable value).

\[
\text{Minimum Hydraulic Conductivity (OSLA) [L/T]} = - \left[ \text{Recharge_min [L/T]} \times \right. \\
\left( \text{Total Length of Sections 2, 3, 4 [L]} \right)^2 + \\
\text{Mean_Reclaim_Infilt \times ((Length of Section 1 [L])}^2 + \\
2 \times \text{Length of Section 1 [L]} \times \text{Total Length of Sections 2, 3, 4 [L]} \right] + \\
\left( (2 \times \text{OSLA_b} \times \text{I_ops_OSLAsurf} \times \text{Total Flow Path Length [L]}) \right)
\]

(13-19)

Equation 13-9b is used to calculate the outflow rate for each flow path cell.

The mass inflow to each of the 14 cells in flow path section 1 is calculated by Equation 8-7, and mass loading occurs from the recharge added along sections 3 and 4 at the rate determined by Equation 13-13a. The outflow from the farthest downgradient cell also terminates in the intermediate “Mine_GW_to_SW004” cell immediately before entering the Partridge River reach upstream of SW-004.

**West Pit Surficial Aquifer Flow Path**

This flow path consists of three sections within a single zone. The sections are (in downstream order) 175 m, 680 m and 650 m long and consist of 7, 24, and 25 flow path cells. The flow path is 665 m wide (“WP_w”) and 5 m deep (“WP_b”). Groundwater quality evaluation points are located at the upgradient and downgradient ends of section 2.

There is no vertical seepage to the flow path other than natural recharge, so the recharge calculations are simpler than for the surficial flow paths described above. When the West Pit water level has reached the surficial aquifer, the recharge rate to all three flow path sections is:

\[
\text{Recharge Rate (All Zones) [L/T]} = -2 \times \text{Flow Path Hydraulic Conductivity [L/T]} \times \\
\text{WP_b} \times \text{I_ops_WPsurf} / \text{Total Flow Path Length [L]}
\]

(13-20a)

The flow path hydraulic conductivity is the uncertain value generated by the model (“K_WPsurf”) with the upper and lower limits imposed:

\[
\text{Minimum Hydraulic Conductivity (WP Surficial Aquifer) [L/T]} = \\
- \left( \text{Recharge_min \times Total Flow Path Length [L]} \right) / (2 \times \text{WP_b} \times \text{I_close_WPsurf})
\]

(13-20b)

\[
\text{Maximum Hydraulic Conductivity (WP Surficial Aquifer) [L/T]} = \\
- \left( \text{Recharge_max \times Total Flow Path Length [L]} \right) / (2 \times \text{WP_b} \times \text{I_close_WPsurf})
\]

(13-20c)

The inflow from the West Pit to the first flow path cell in section 1 is calculated by Equation 13-21:

\[
\text{Inflow to Flow Path from West Pit [L}^3/\text{T]} = - \text{WP_w} \times 
\]
The two sources of constituent mass loading to this flow path are the West Pit and background recharge added to each flow path cell (Equation 13-13a).

Outflow from each flow path cell is again calculated by Equation 13-9b. The total outflow from this flow path enters an intermediate cell (“Mine_GW_to_SW004a”, which has a defined volume of 10 m$^3$) prior to entering the Partridge River reach upstream of SW-004a.

13.4 Output

The Flow Path Models ultimately calculate the following flows along with their associated constituent concentration and loads to the Partridge River:

- Groundwater flow from the East Pit through the bedrock and the surficial aquifer
- Groundwater flow from the West Pit through the bedrock and the surficial aquifer
- Groundwater flow from the East Pit and Category 2/3 waste rock stockpiles through the surficial aquifer
- Groundwater flow from the Ore Surge Pile through the surficial aquifer
- Groundwater flow from the WWTFs through the surficial aquifer
- Groundwater flow from the OSLA through the surficial aquifer

\[
(I\_close\_WPsurf * \text{Flow Path Hydraulic Conductivity [L/T]} * WP\_b + 0.5 * \text{Recharge Rate (All Zones) [L/T]} * \text{Total Flow Path Length [L]})
\] (13-21)
14 Partridge River Model

14.1 Purpose
The Partridge River model is used to simulate water flow and mass transport into and out of the Partridge River and Colby Lake. The model calculates water flows and the associated constituent mass loads of all constituents from natural areas and in the surface water system. This is the terminal model in the system, and therefore produces no water flows or mass loadings to other models.

14.2 Input

14.2.1 Inputs from Other Models
- Water flow and mass loading from the East Pit-Category 2/3 Stockpile Surficial Aquifer Flow Path Model, determined in Section 13
- Water flow and mass loading from the Ore Surge Pile Surficial Aquifer Flow Path Model, determined in Section 13
- Water flow and mass loading from the OSLA Surficial Aquifer Flow Path Model, determined in Section 13
- Water flow and mass loading from the WWTF Surficial Aquifer Flow Path Model, determined in Section 13
- Water flow and mass loading from the West Pit Bedrock Flow Path Model to the river reach upstream of evaluation point SW-004, determined in Section 13
- Water flow and mass loading from the West Pit Bedrock Flow Path Model to the river reach upstream of evaluation point SW-004a, determined in Section 13
- Water flow and mass loading from the West Pit Surficial Aquifer Flow Path Model, determined in Section 13
- Water flow and mass loading from the East Pit Bedrock Flow Path Model, determined in Section 13
- Water flow and mass loading from the LTWWTF, determined in Section 12
- Natural groundwater concentrations, determined by Equation 13-13b

14.2.2 Water Balance Inputs
1. Flow_PMP \([\text{L}^3/\text{T}]\) – Flow from Peter Mitchell Pit dewatering
   - Deterministic input (1 ft\(^3\)/sec)
2. Inc_Flow_Factor [-] – Factor by which discharge at SW-006 is multiplied to give the incremental inflow between nodes
   - Monthly deterministic inputs, time-varying
   - Values given in Tables 1-20A through 1-20L of WMDP-MS-Attachment B
3. GW_Inc_Baseflow \([\text{L}^3/\text{T}]\) – Baseflow added to evaluation points via natural groundwater
   - Time-varying deterministic input
   - Values given in Table 1-21 of WMDP-MS-Attachment B
4. Segment_Length [L] – Length of river segments upstream of each node
   - Deterministic input
   - Values given in Table 1-17 of WMDP-MS-Attachment B
5. **Segment_Area** \([L^2]\) – Cross sectional area of river segments upstream of each node
   - Deterministic input
   - Values given in Table 1-17 of WMDP-MS-Attachment B
6. **Colby_Volume** \([L^3]\) – Colby Lake storage volume
   - Deterministic input (5300 acre-feet)

### 14.2.3 Mass Transport Inputs

1. **SW_Conc.Partridge** [-] – Initial Partridge River concentrations
   - Deterministic, constituent- and reach-specific inputs
   - Values given in Table 1-14 of WMDP-MS-Attachment B
2. **SW_Conc.RO** [-] – Natural runoff concentrations
   - Probabilistic, constituent-specific inputs
   - Log-normal distribution (mean and standard deviation values given in Table 1-13 of the WMDP-MS-Attachment B)
3. **SW_Conc.PMP** [-] – Northshore discharge concentrations
   - Deterministic, constituent-specific inputs
   - Values given in Table 1-13 of WMDP-MS-Attachment B

### 14.3 Calculations

Two alternate representations of the Partridge River are modeled: one including the Mine Site and all of its impacts on surface water quantity and quality, and another “No Action” model without any such Mine Site effects. The following subsections describe in detail the calculations made to consider the effects of mining. Similar calculations to those indicated below are made in the “No Action” model, except that the water flows and mass loadings originating from the groundwater flow path models and WWTF model are omitted.

#### 14.3.1 Water Balance Calculations

The Partridge River is divided into nine segments which, in downstream order, are upstream of the following surface water monitoring points: SW-001, SW-002, SW-003, SW-004, SW-004a, SW-004b, SW-005, SW-006 and Colby Lake (“CL”).

Streamflow at SW-001 is calculated as the sum of natural surface water and groundwater inflows, and flow derived from dewatering of the Peter Mitchell Pit:

\[
\text{River Discharge (SW-001) [L}^3\text{/T]} = \text{Natural Surface Water Inflow (SW-001) + Flow_PMP + Natural Groundwater Inflow (SW-001)} \tag{14-1a}
\]

For each time-step, the natural surface water and groundwater inflows to the river reach upstream of SW-001 are calculated by Equations 14-1b and 14-1c:

\[
\text{Natural Surface Water Inflow (SW-001) [L}^3\text{/T]} = \text{Streamflow at SW-006 (current month) [L}^3\text{/T]} \ast \text{Inc_Flow_Factor (SW-001, current month) [-] – GW_Inc_Baseflow (SW-001) [L}^3\text{/T]} \ast \text{GW Reduction Factor}} \tag{14-1b}
\]
Natural Groundwater Inflow (SW-001) \([L^3/T]\) =

\[
GW\_Inc\_Baseflow\ (SW-001) \ [L^3/T] \times GW\ \text{Reduction Factor} \ [-] \quad (14-1c)
\]

In Equation 14-1b, the streamflow at SW-006 is defined by the distributions given in Table 1-19 of the WMDP-MS-Attachment B, and the groundwater reduction factor depends on the magnitudes of two quantities:

\[
GW\_Inc\_Baseflow\ (SW-001), \text{ and}
\]

Streamflow at SW-006 \((current\ month)\ \times \text{Inc\_Flow\_Factor}\ (SW-001,\ current\ month)\) \quad (14-2a)

When “GW Inc_Baseflow (SW-001)” is the smaller of these quantities, the groundwater reduction factor is equal to one (i.e. groundwater inflow is not reduced). When the quantity calculated by Equation 14-2a is the smaller of the two quantities, the reduction factor is:

\[
GW\ \text{Reduction Factor} \ [-] = \frac{\text{Streamflow at SW-006} \ (current\ month) \ [L^3/T] \times \text{Inc\_Flow\_Factor} \ (SW-001,\ current\ month) \ [-]}{GW\_Inc\_Baseflow\ (SW-001)} \quad (14-2b)
\]

Discharge values at surface water evaluation points SW-002 and SW-003 are calculated similarly, using the two natural inflow components and river discharge from upstream:

\[
\text{River Discharge} \ (SW-002) \ [L^3/T] = \text{Natural Surface Water Inflow} \ (SW-002) + \text{River Discharge} \ (SW-001) + \text{Natural Groundwater Inflow} \ (SW-002) \quad (14-3)
\]

\[
\text{River Discharge} \ (SW-003) \ [L^3/T] = \text{Natural Surface Water Inflow} \ (SW-003) + \text{River Discharge} \ (SW-002) + \text{Natural Groundwater Inflow} \ (SW-003) \quad (14-4)
\]

River discharge at SW-004 is derived from upstream discharge, the two natural inflows, and groundwater discharge from the Mine Site flow path models (Section 13):

\[
\text{River Discharge} \ (SW-004) \ [L^3/T] = \text{Natural Surface Water Inflow} \ (SW-004) + \text{River Discharge} \ (SW-003) + \text{Natural Groundwater Inflow} \ (SW-004) + \text{Groundwater Flow from Flow Path Models} \ (SW-004) \quad (14-5a)
\]

The total groundwater flow from the six modeled flow paths which terminate in this river reach is calculated by Equation 14-5b:

\[
\text{Groundwater Flow from Flow Path Models} \ (SW-004) \ [L^3/T] = \text{GW Reduction Factor} \times (\text{East Pit-Category 2/3 Surficial Aquifer Flow Path Outflow} + \text{OSP Surficial Aquifer Flow Path Outflow} + \text{OSLA Surficial Aquifer Flow Path Outflow} + \text{WWTF Surficial Aquifer Flow Path Outflow} + \text{West Pit Bedrock Groundwater Outflow} \ (SW-004) + \text{East Pit Bedrock Groundwater Outflow}) \quad (14-5b)
\]
The natural groundwater inflow term in Equation 14-5a is calculated by Equation 14-5c:

\[
\text{Natural Groundwater Inflow } (SW\text{-}004) \ [L^3/T] = \\
GW\_\text{Inc\_Baseflow} (SW\text{-}004) \ast GW\ \text{Reduction Factor} [-] - \\
\text{Groundwater Flow from Flow Path Models } (SW\text{-}004) \ [L^3/T] 
\] (14-5c)

Discharge in the next reach downstream, which is directly above evaluation point SW-004a, is subsequently calculated by Equation 14-6a:

\[
\text{River Discharge } (SW\text{-}004a) \ [L^3/T] = \text{Natural Surface Water Inflow } (SW\text{-}004a) + \\
\text{River Discharge } (SW\text{-}004) \ + \ \text{Natural Groundwater Inflow } (SW\text{-}004a) + \\
\text{LTWWTF Discharge to Partridge River } (SW\text{-}004a) + \\
\text{Groundwater Flow from Flow Path Models } (SW\text{-}004a) 
\] (14-6a)

The natural groundwater inflow to this reach is calculated by Equation 14-5c using the reach-specific value for “GW\_Inc\_Baseflow” and the flow calculated by Equation 14-6b. The total groundwater inflow from the flow path models to this reach is calculated by Equation 14-6b:

\[
\text{Groundwater Flow from Flow Path Models } (SW\text{-}004a) = GW\ \text{Reduction Factor} \ast \\
(\text{West Pit Surficial Aquifer Flow Path Outflow} + \\
\text{West Pit Bedrock Groundwater Outflow } (SW\text{-}004a) ) 
\] (14-6b)

No Mine Site-derived flow enters the river downstream of evaluation point SW-004a. Therefore, discharge at each of the evaluation points farther downstream is calculated as the sum of upstream Partridge River discharge and the natural surface water and groundwater inflows:

\[
\text{River Discharge } (SW\text{-}004b) \ [L^3/T] = \text{Natural Surface Water Inflow } (SW\text{-}004b) + \\
\text{River Discharge } (SW\text{-}004a) \ + \ \text{Natural Groundwater Inflow } (SW\text{-}004b) 
\] (14-7)

\[
\text{River Discharge } (SW\text{-}005) \ [L^3/T] = \text{Natural Surface Water Inflow } (SW\text{-}005) + \\
\text{River Discharge } (SW\text{-}004b) \ + \ \text{Natural Groundwater Inflow } (SW\text{-}005) 
\] (14-8)

\[
\text{River Discharge } (SW\text{-}006) \ [L^3/T] = \text{Natural Surface Water Inflow } (SW\text{-}006) + \\
\text{River Discharge } (SW\text{-}005) \ + \ \text{Natural Groundwater Inflow } (SW\text{-}006) 
\] (14-9)

\[
\text{River Discharge } (\text{Inflow to Colby Lake}) \ [L^3/T] = \\
\text{Natural Surface Water Inflow } (Colby\ \text{Lake}) \ + \ \text{River Discharge } (SW\text{-}006) \ + \\
\text{Natural Groundwater Inflow } (Colby\ \text{Lake}) 
\] (14-10)

The surface water inflow terms in Equations 14-3 through 14-10 are calculated by Equations 14-1b, 14-2a and 14-2b with substitutions for the reach-specific values. The natural groundwater inflow terms for the reaches above SW-002, SW-003, SW-004b, SW-005, SW-006 and Colby Lake are calculated by Equations 14-1c through 14-2b.
14.3.2 Mass Transport Calculations

The volume of the cells used to represent each of the nine river reaches is the product of the length ("Segment_Length") and cross-sectional area ("Segment_Area") of each reach. The initial concentrations in each reach are equal to the values in Table 1-14 of the WMDP-MS-Attachment B ("SW_Conc.Partridge").

Constituent mass loading to the reach upstream of SW-001 for each constituent is the sum of the loadings from the reach’s three water sources:

\[
\text{Mass Loading (SW-001) [M/T]} = \text{Natural Runoff Loading (SW-001) + Peter Mitchell Pit Loading + Natural Groundwater Loading (SW-001)} \quad (14-11)
\]

The mass loading terms in Equation 14-11 are the products of the volumetric flow rates and the concentration of each source:

\[
\text{Peter Mitchell Pit Loading [M/T]} = \text{Flow}_\text{PMP} \times \text{Northshore Discharge Concentrations [M/L}^3\text{]} \quad (14-12)
\]

\[
\text{Natural Runoff Loading (SW-001) [M/T]} = \\
\text{Natural Surface Water Inflow (SW-001) [L}^3\text{/T]} \times \text{Natural Runoff Concentration [M/L}^3\text{]} \quad (14-13)
\]

\[
\text{Natural Groundwater Loading (SW-001) [M/T]} = \\
\text{Natural Groundwater Inflow (SW-001) [L}^3\text{/T]} \times \text{Natural Groundwater Concentration [M/L}^3\text{]} \quad (14-14)
\]

The natural runoff concentration for each constituent in Equation 14-13 is an uncertain input defined by a log-normal distribution and the mean and standard deviation in Table 1-13 of the WMDP-MS-Attachment B ("SW_Conc.RO"). The Northshore discharge concentrations in Equation 14-12 ("SW_Conc.PMP") are certain inputs that can also be found in Table 1-13 of the WMDP-MS-Attachment B. Natural groundwater concentrations for each realization and constituent are determined by Equation 13-13b. Mass loading to the river reach immediately downstream of SW-001 (i.e. the reach above SW-002) is calculated as:

\[
\text{Mass Loading (SW-002) [M/T]} = \text{Natural Runoff Loading (SW-002) + Natural Groundwater Loading (SW-002) + Mass Loading from Upstream (SW-001)} \quad (14-15)
\]

The natural runoff and groundwater loading rates in Equation 14-15 are again calculated using Equations 14-13 and 14-14 with appropriate substitutions for the volumetric inflow rates. The mass loading rate to SW-003 is also calculated by Equation 14-15.

Constituent loading to SW-004 includes mass derived from the river reach upstream, natural inflows, and loading from the six flow path models identified in Equation 14-5b.
Mass Loading (SW-004) [M/T] = Natural Runoff Loading (SW-004) + 
Natural Groundwater Loading (SW-004) + 
Mass Loading from Upstream (SW-003) + 
Loading from Flow Path Models (SW-004)  

\[ \text{(14-16)} \]

The mass loadings from the flow path models to SW-004 are routed through an intermediate cell (“Mine_GW_to_SW004”) cell at the combined volumetric flow rate calculated by Equation 14-5b. The natural runoff and groundwater loading rates are calculated by Equations 14-13 and 14-14, as before.

Constituent loading to SW-004a accounts for the remaining Mine Site-derived flows:

\[ \text{Mass Loading (SW-004a) [M/T]} = \text{Natural Runoff Loading (SW-004a)} + \]
\[ \text{Natural Groundwater Loading (SW-004a) + Mass Loading from Upstream (SW-004) +} \]
\[ \text{Loading from Flow Path Models (SW-004a) + LTWWTF Loading} \]

\[ \text{(14-17)} \]

The first three terms in Equation 14-17 are determined as described above. Mass loading from the flow path models to SW-004a comes from “Mine_GW_to_SW004a” at the total flow rate calculated by Equation 14-6b. Loading from the LTWWTF is the product of the discharge rate to the Partridge River (calculated using Equation 12-8b) and the LTWWTF outflow concentrations calculated by the WWTF model or prescribed as inputs (Table 1-34 of the WMDP-MS-Attachment B).

Loading to the reaches upstream of evaluation points SW-004b, SW-005, SW-006, and the river’s terminus at Colby Lake are calculated by Equation 14-15.

Concentrations in Colby Lake are modeled using a single cell with a fixed volume defined by “Colby_Volume”. The lake cell has a single inflow—river discharge from the Partridge River—and a single outflow, which is also equal to Partridge River discharge.

14.4 Output

The Partridge River Model calculates:

- River discharge and the associated constituent concentrations and loads
- Colby Lake constituent concentrations
15  Release Rate, Concentration Cap and Water Quality Standard Calculations

15.1  Purpose

The purpose of this section is to define how constituent release rates, constituent release ratios, and concentration caps are calculated. Sample equations are provided to illustrate the procedure for calculating release rates, release ratios, concentration caps and water quality standards for all constituents. The criteria and data upon which these calculations depend are referenced in this section.

15.2  Input

15.2.1  Release Rates and Release Ratios Inputs

1.  Cat1_Ratio_Cd_Zn [M/M] – Cadmium-to-zinc release ratio from Category 1 rock
   • Probabilistic input sampled at start of each realization
   • Distribution type and parameters in Table 1-24 of WMDP-MS-Attachment B

2.  Cat1_Ratio_Zn_Mg [M/M] – Zinc-to-magnesium release ratio from Category 1 rock
   • Probabilistic input sampled at start of each realization
   • Distribution type and parameters in Table 1-24 of WMDP-MS-Attachment B

3.  Cat1_Release_Mg [M/M/T] – Sulfate-independent magnesium release rate from Category 1 rock
   • Probabilistic input sampled at start of each realization
   • Distribution type and parameters in Table 1-24 of WMDP-MS-Attachment B

4.  Cat1_Ratio_Al_Ca [M/M] – Aluminum-to-calcium release ratio from Category 1 rock
   • Probabilistic input sampled at start of each realization
   • Distribution type and parameters in Table 1-24 of WMDP-MS-Attachment B

5.  Cat1_Ratio_Al_Na [M/M] – Aluminum-to-sodium release ratio from Category 1 rock
   • Probabilistic input sampled at start of each realization
   • Distribution type and parameters in Table 1-24 of WMDP-MS-Attachment B

6.  Cat1_Ratio_Co_Ni [M/M] – Cobalt-to-nickel release ratio from Category 1 rock
   • Probabilistic input sampled at start of each realization
   • Distribution type and parameters in Table 1-24 of WMDP-MS-Attachment B

7.  Cat1_Ratio_Ni_S [M/M] – Nickel-to-sulfur release ratio from Category 1 rock
   • Probabilistic input sampled at start of each realization
   • Distribution type and parameters in Table 1-24 of WMDP-MS-Attachment B

8.  Cat23_Ratio_Al_Ca [M/M] – Aluminum-to-calcium release ratio from Category 2/3 rock
   • Probabilistic input sampled at start of each realization
   • Distribution type and parameters in Table 1-25 of WMDP-MS-Attachment B

9.  Cat23_Ratio_Ca_SO4 [M/M] – Calcium-to-sulfate release ratio from Category 2/3 rock
   • Probabilistic input sampled at start of each realization
   • Distribution type and parameters in Table 1-25 of WMDP-MS-Attachment B

10. Cat23_Ratio_Al_Na [M/M] – Aluminum-to-sodium release ratio from Category 2/3 rock
    • Probabilistic input sampled at start of each realization
    • Distribution type and parameters in Table 1-25 of WMDP-MS-Attachment B
11. **Cat23_Ratio_Na_SO4** [M/M] – Sodium-to-sulfate release ratio from Category 2/3 rock
   - Probabilistic input sampled at start of each realization
   - Distribution type and parameters in Table 1-25 of WMDP-MS-Attachment B

12. **Cat4DC_Release_SO4** [M/M/T] – Sulfate release rate from Category 4 Duluth Complex rock
   - Probabilistic input sampled at start of each realization
   - Distribution type and parameters in Table 1-27 of WMDP-MS-Attachment B

13. **Cat4VF_Release_SO4** [M/M/T] – Sulfate release rate from Category 4 Virginia Formation rock
   - Probabilistic input sampled at start of each realization
   - Distribution type and parameters in Table 1-27 of WMDP-MS-Attachment B

### 15.2.2 Concentration Cap Inputs

1. **Cat1_cap_Percent** [-] – Percentile for generating Category 1 rock concentration caps from AMAX data
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 95%; maximum = 100%)

2. **Cat1_pH** [-] – pH for generating Category 1 rock concentration caps from AMAX data
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 7.0; maximum = 7.5)

3. **Cat1_Cap_Sb** [M/L$^3$] – Category 1 concentration cap for antimony
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.0083 mg/L; maximum = 0.1 mg/L)

4. **Cat1_Ratio_Se_SO4** [M/M] – Selenium-to-sulfate release ratio for Category 1 rock
   - Probabilistic input sampled at start of each realization
   - Distribution type and parameters can be found in Table 1-24 of WMDP-MS-Attachment B

5. **Cat234_Cap_Percent** [-] – Percentile for generating Ore and Category 2, 3, and 4 rock concentration caps from AMAX data
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 95%; maximum = 100%)

6. **Cat234_pH** [-] – pH for generating Ore Category 2, 3, and 4 rock concentration caps from AMAX data
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 6.0; maximum = 7.5)

7. **Cat234_Cap_Sb** [M/L$^3$] – Nonacidic Category 2/3, 4 Duluth Complex concentration cap for antimony
   - Probabilistic input sampled at start of each realization
   - Uniform distribution (minimum = 0.0083 mg/L; maximum = 0.1 mg/L)

8. **Cat23_Ratio_Cd_Zn** [M/M] – Cadmium-to-zinc release ratio for Category 2/3 rock
   - Probabilistic input sampled at start of each realization
   - Distribution type and parameters can be found in Table 1-25 of WMDP-MS-Attachment B
9. **Cat23_Ratio_Se_SO4 [M/M]** – Selenium-to-sulfate release ratio for Category 2/3 rock
   - Probabilistic input sampled at start of each realization
   - Distribution type and parameters can be found in Table 1-25 of WMDP-MS-Attachment B

15.2.3 **Water Quality Standard Inputs**

1. **A [-]** – Coefficient used to calculate surface water hardness standard
   - Deterministic, constituent-specific input (Table 1-4 of WMDP-MS-Attachment B)
2. **B [-]** – Coefficient used to calculate surface water hardness standard
   - Deterministic, constituent-specific input (Table 1-4 of WMDP-MS-Attachment B)

15.3 **Calculations**

15.3.1 **Release Rates and Release Ratios**

*Category 1 Rock – Sulfate-Independent Release Rates*

Unscaled release rates from Category 1 rock for fifteen constituents—Ag, alkalinity, As, B, Be, Ca, Cr, F, K, Mg, Na, Pb, Sb, Tl and V—are sampled directly from the types of distributions with the mean, mode, standard deviations, minima and/or maxima given in Table 1-24 of the WMDP-MS-Attachment B. Additional sulfate-independent release rates are determined as a function of these release rates. For example, the Cd release rate is calculated from the Zn release rate:

\[
\text{Category 1 Sulfate-Independent Release Rate (Cd, Unscaled) [M/M/T]} = \text{Cat1_Ratio_Cd_Zn} \times \text{Category 1 Sulfate-Independent Release Rate (Zn, Unscaled)}
\]

(15-1a)

Where the sulfate-independent zinc release rate used in Equation 15-1a is calculated by Equation 15-1b:

\[
\text{Category 1 Sulfate-Independent Release Rate (Zn, Unscaled) [M/M/T]} = \text{Cat1_Ratio_Zn_Mg} \times \text{Category 1 Sulfate-Independent Release Rate (Mg, Unscaled)}
\]

(15-1b)

The sulfate-independent magnesium release rate in Equation 15-1b is sampled from the probabilistic input “Cat1_Release_Mg,” as noted above.

Four other constituents—Ba, Co, Fe, and Ni—have sulfate-independent release rates which, like Cd, are dependent upon the release rate of at least one other constituent. All necessary release ratios can be found in Table 1-24 of the WMDP-MS-Attachment B. The final constituent with a sulfate-independent release rate (Al) is calculated uniquely:

\[
\text{Category 1 Sulfate-Independent Release Rate (Al, Unscaled) [M/M/T]} = \text{Cat1_Ratio_Al_Ca} \times \text{Category 1 Sulfate-Independent Release Rate (Ca, Unscaled)} + \text{Cat1_Ratio_Al_Na} \times \text{Category 1 Sulfate-Independent Release Rate (Na, Unscaled)}
\]

(15-2)
where the sulfate-independent calcium and sodium release rates are sampled from their beta distributions (Table 1-24, WMDP-MS-Attachment B).

All of these release rates—Ag, Al, alkalinity, As, B, Ba, Be, Ca, Cd, Co, Cr, F, Fe, K, Mg, Na, Ni, Pb, Sb, Tl, V and Zn—are stored as the “Cat1_Release_Indep” variable referenced in Section 4.

**Category 1 Rock – Sulfate-Dependent Release Ratios**

The sulfate release rate (calculated by Equation 4-12) is used in Equation 4-13 to calculate additional constituent release from Category 1 rock for six constituents—Co, Cu, Fe, Mn, Ni and Se—along with the release ratios for these constituents. The sulfate-dependent Co release ratio is:

\[
\text{Category 1 Sulfate-Dependent Release Ratio (Co-to-SO}_{4} [\text{M/M}] = \frac{\text{Cat1_Ratio_Co}_\text{Ni}}{\text{Category 1 Sulfate-Dependent Release Ratio (Ni-to-SO}_{4})}\]

(15-3a)

The Cu and Fe release ratios are also calculated by Equation 15-3a.

The nickel-to-sulfate release ratio in Equation 15-3a is calculated using the nickel-to-sulfur release ratio and the constant ratio of sulfur to sulfate mass (equal to 0.33378):

\[
\text{Category 1 Sulfate-Dependent Release Ratio (Ni-to-SO}_{4}) [\text{M/M}] = \frac{\text{Cat1_Ratio_Ni}_S}{\text{Ratio of Sulfur to Sulfate Mass [M/M]}}
\]

(15-3b)

The release ratios for Mn and Se are also calculated by Equation 15-3b. All of these release ratios are the sulfate-dependent release ratios ("Cat1_Ratio_SO4"), which are used to calculate overall Category 1 release rates by Equation 4-13.

**Category 2/3 Rock – Sulfate-Independent, Nonacidic Release Rates**

Data defining the probabilistic direct release rates from nonacidic Category 2/3 rock are given for alkalinity, B, Cr, F and Tl (Table 1-25 of the WMDP-MS-Attachment B). These release rates constitute the values used in Sections 5 and 10 (“Cat23_Release_Indep_nonacid”).

**Category 2/3 Rock – Sulfate-Independent, Acidic Release Rates**

Data defining the probabilistic direct release rates from acid-generating Category 2/3 rock are given for B, Cr, F and Tl (Table 1-25 of the WMDP-MS-Attachment B). These release rates constitute the values used in Sections 5 and 10 (“Cat23_Release_Indep_acid”). No alkalinity is released from acid-generating rock.
Category 2/3 Rock – Sulfate-Dependent (Nonacidic) Release Ratios

The sulfate release rate (e.g., “Cat23SP_SO4”) is used by Equation 5-9 to calculate additional constituent release from Category 2/3 rock for twenty constituents—Ag, Al, As, Ba, Be, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sb, Se, V and Zn. Equation 5-9 also employs the release ratios for the constituents. Whereas many of these ratios are sampled from probability distributions or are calculated in a manner similar to Equations 15-3a and 15-3b, the release ratios for Al, Fe and Ni are calculated as the sum of the two release ratios on which each depends. For example:

\[
\text{Category 2/3 Sulfate-Dependent Release Ratio (Al-to-SO}_4\text{)} [M/M] = \\
\text{Category 2/3 Sulfate-Dependent Release Ratio (Al-to-Ca)} [M/M] + \\
\text{Category 2/3 Sulfate-Dependent Release Ratio (Al-to-Na)} [M/M] \tag{15-4a}
\]

The aluminum-to-calcium release ratio in Equation 15-4a is calculated as:

\[
\text{Category 2/3 Sulfate-Dependent Release Ratio (Al-to-Ca)} [M/M] = \\
\text{Cat23_Ratio_Al_Ca} [M/M] \times \text{Cat23_Ratio_Ca_SO}4 [M/M] \tag{15-4b}
\]

and the aluminum-to-sodium release ratio in Equation 15-4a is calculated as:

\[
\text{Category 2/3 Sulfate-Dependent Release Ratio (Al-to-Na)} [M/M] = \\
\text{Cat23_Ratio_Al_Na} [M/M] \times \text{Cat23_Ratio_Na_SO}4 [M/M] \tag{15-4c}
\]

Similar calculations to these are made using the same two intermediate constituents for Fe and Ni (S and Mg) to determine the sulfate release ratio of these constituents. The release ratios for all sulfate-dependent constituents are those referred to as “Cat23_Ratio_SO4” in Equations 5-9, 5-11, and 10-31.

Category 4 Duluth Complex Rock – Sulfate-Independent Release Rates

Data defining the probabilistic direct release rates from nonacidic Category 4 Duluth Complex rock are given for alkalinity, B, Cr, F and Tl (Table 1-26 of the WMDP-MS-Attachment B). After areas consisting of this rock type become acid-generating, the uncertain “acidic conditions” release rates for all constituents other than alkalinity are used (also in Table 1-26 of the WMDP-MS-Attachment B). No alkalinity is generated by weathering of acid-generating rock. These release rates are identified as “Cat4DC_Release_Indep” in Section 6.

Category 4 Duluth Complex Rock – Sulfate-Dependent Release Ratios

The uncertain sulfate release rate (“Cat4DC_Release_SO4”) is used in Equation 6-7 to calculate constituent release from Category 4 Duluth Complex rock for twenty constituents—Ag, Al, As, Ba, Be, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sb, Se, V and Zn. The sulfate release ratios for these constituents are either given directly (Ca, K, Mg, Mn, Na, Se) or are calculated the same way as those for Category 1 and 2/3 rock described above. As for Category 2/3 rock, the release ratios for Al, Fe and Ni are the sum of the two ratios on which each depends (i.e. Ca and Na; S and
Mg; and S and Mg, respectively). Data defining all necessary probabilistic release ratios can be found in Table 1-26 of the WMDP-MS-Attachment B.

**Category 4 Virginia Formation Rock – Sulfate-Independent Release Rates**

Data defining the probabilistic direct release rates from Category 4 Virginia Formation rock are given for alkalinity, B, Cr, F, Mn and Tl (Table 1-28 of the WMDP-MS-Attachment B). Virginia Formation rock is assumed to generate acidic conditions at all times, therefore separate nonacidic and acidic release rates—similar to those for Category 2/3 and Category 4 Duluth Complex rock—are not required. These release rates are those referred to as “Cat4VF_Release_Indep” in Section 6.

**Category 4 Virginia Formation Rock – Sulfate-Dependent Release Ratios**

The uncertain sulfate release rate from Virginia Formation rock (“Cat4VF_Release_SO4”) is used by Equation 6-6 to calculate constituent release for nineteen constituents—Ag, Al, As, Ba, Be, Ca, Cd, Co, Cu, Fe, K, Mg, Na, Ni, Pb, Sb, Se, V and Zn. The sulfate release ratios for these constituents are either sampled directly from distributions (Ca, Fe, K, Mg, Na, Se) or are calculated the same way as those for Category 2/3 and 4 Duluth Complex rock described above. Two notable exceptions are that Fe- and Ni-to-SO4 release ratios for Virginia Formation rock are directly dependent upon only sulfate or sulfur release (i.e. neither is influenced by Mg release). Data defining all necessary probabilistic release ratios to perform these calculations can be found in Table 1-28 of the WMDP-MS-Attachment B. The resulting release ratios are those identified as “Cat4VF_Ratio_SO4” in Section 6.

**Ore Rock – Sulfate-Independent Release Rates**

Data defining the probabilistic direct release rates from ore rock are given for alkalinity, B, Cr, F and Tl (Table 1-27 of the WMDP-MS-Attachment B). These rates are referred to as “Ore_Release_Indep” in Section 7.

**Ore Rock – Sulfate-Dependent Release Ratios**

The sulfate release rate from ore rock (“OSP_SO4”) is used by Equations 7-5 and 7-7 to calculate constituent release for twenty constituents—Ag, Al, As, Ba, Be, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sb, Se, V and Zn. The sulfate release ratios for these constituents are either given directly (Ca, Fe, K, Mg, Na, Se) or are calculated the same way as those for Category 2/3 and 4 Duluth Complex rock described above. The probabilistic release ratios needed to make these calculations can be found in Table 1-27 of the WMDP-MS-Attachment B. The resulting release ratios are those identified as “Ore_Ratio_SO4” in Section 7.

### 15.3.2 Concentration Caps

**Category 1 Concentration Caps**

Category 1 concentration caps for Ag, As, B, Be, Cr, Pb, Tl and V are constant values (Table 1-30, WMDP-MS-Attachment B). Caps for alkalinity, Co, Cu, Fe, K, Mn, Na, Ni and Zn are
calculated using two uncertain inputs: a percentile ("Cat1_cap_Percent") and a pH value ("Cat1_pH"). The sampled pH value is employed to determine the 95th and 100th percentile concentration cap values given the data in Table 1-30 of the WMDP-MS-Attachment B. These bounding percentiles are subsequently used to interpolate the concentration cap that corresponds to the sampled percentile.

The Sb concentration cap ("Cat1_Cap_Sb") is sampled from a uniform distribution. The concentrations caps for Cd and Se are calculated as follows:

\[
\text{Global Concentration Cap (Cd, Category 1)} \ [M/L^3] = \frac{\text{Global Concentration Cap (Zn, Category 1)}}{\text{Cat1_Ratio_Cd_Zn}} \quad (15-5)
\]

\[
\text{Global Concentration Cap (Se, Category 1)} \ [M/L^3] = \frac{\text{Global Concentration Cap (SO}_4, \text{ Category 1)}}{\text{Cat1_Ratio_Se_SO4}} \quad (15-6)
\]

There is no Category 1 concentration cap for chloride, and the caps for the six remaining constituents (Al, Ba, Ca, F, Mg and SO_4) are calculated using the equations at the bottom of Table 1-30 of the WMDP-MS-Attachment B. It is worthy of note that, because the caps for some constituents (e.g. Ba and F) are dependent upon the concentrations of other constituents (SO_4 and Ca), concentration caps are calculated locally for all areas to which the Category 1 concentration caps are applied. These areas are:

- West Pit Category 1 wall water
- West Pit Category 1 high wall water
- West Pit Category 1 set back area water
- West Pit Category 1 high set back area water
- East Pit Category 1 wall water
- East Pit Category 1 high wall water
- East Pit Category 1 set back area water
- East Pit Category 1 high set back area water
- Water at the bottom of the Category 1 waste rock stockpile (bare portion)
- Water at the bottom of the Category 1 waste rock stockpile (reclaimed portion)
- Water contacting the haul road
- Category 1 backfill water
- West Pit water

It is also noteworthy that the Category 1 waste rock stockpile is assumed to have the same pH as all other Category 1 rock.

**Duluth Complex Category 2/3, 4 and Ore Rock Nonacidic Concentration Caps**

The nonacidic concentration caps for Duluth Complex rock are calculated using generally the same guidelines as for their Category 1 counterparts. Chloride again has no concentration cap, and global concentration caps for Ag, As, B, Be, Cr, Pb, Tl and V are constant values (Table 1-31, WMDP-MS-Attachment B). The Sb cap is an uncertain value ("Cat234_Cap_Sb")
with the same distribution as its Category 1 analog (“Cat1_Cap_Sb”). Lookup tables based on AMAX data are again used—along with a percentile value between 95 and 100 (“Cat234_Cap_Percent”) and a pH value between 6.0 and 7.5 (“Cat234_pH”)—to interpolate the concentration caps for alkalinity, Co, Cu, Fe, K, Mn, Na, Ni and Zn. Caps for Al, Ca, Mg, SO₄, Ba and F are calculated using the equations at the bottom of Table 1-31 of the WMDP-MS-Attachment B. Cadmium and selenium caps are calculated based on release ratios as follows:

\[
\text{Nonacidic Global Concentration Cap (Cd, Category 2/3/4) [M/L}^3] = \frac{\text{Nonacidic Global Concentration Cap (Zn, Category 2/3/4)} \times \text{Cat23_Ratio_Cd_Zn}}{15-7}
\]

\[
\text{Nonacidic Global Concentration Cap (Se, Category 2/3/4) [M/L}^3] = \frac{\text{Nonacidic Global Concentration Cap (SO}_4, \text{ Category 2/3/4)} \times \text{Cat23_Ratio_Se_SO4}}{15-8}
\]

The areas within the model where these nonacidic concentration caps are applied are:

- Category 2/3 stockpile (nonacidic water)
- OSP (nonacidic water)
- Rail Transfer Hopper ore water
- East Pit blast ore water
- West Pit blast ore water
- Upper EPCP porewater
- Lower EPCP porewater
- East Pit sump water
- Category 2/3 backfill water
- Category 4 Duluth Complex backfill water
- Category 4 Virginia Formation backfill water

Prior to the beginning of wall acidification, these caps also apply to:

- West Pit Category 4 Duluth Complex wall water
- West Pit Category 4 Duluth Complex high wall water
- West Pit Category 4 Duluth Complex set back area water
- West Pit Category 4 Duluth Complex high set back area water
- West Pit ore wall water
- West Pit ore high wall water
- West Pit ore set back area water
- West Pit ore high set back area water
- West Pit Category 2/3 wall water
- West Pit Category 2/3 high wall water
- West Pit Category 2/3 set back area water
- West Pit Category 2/3 high set back area water
- East Pit Category 2/3 wall water
- East Pit Category 2/3 high wall water
- East Pit Category 2/3 set back area water
- East Pit Category 2/3 high set back area water
- East Pit ore wall water
- East Pit ore high wall water
- East Pit ore set back area water
- East Pit ore high set back area water
- East Pit Category 4 Duluth Complex wall water
- East Pit Category 4 Duluth Complex high wall water
- East Pit Category 4 Duluth Complex set back area water
- East Pit Category 4 Duluth Complex high set back area water
- East Pit Category 2/3 wall water

**Duluth Complex Category 2/3, 4 and Ore Rock Acidic Concentration Caps**

The acidic concentration caps for Duluth Complex rock are determined differently from the nonacidic rock, in as much as acidic concentration caps are sampled from probability distributions. There are a few exceptions. Alkalinity, in addition to chloride, does not have an acidic cap for Category 2/3, 4 and ore rock. Caps for Ba and F are again calculated using the solubility formulas beneath Table 1-32 in the WMDP-MS-Attachment B. Arsenic and selenium caps are constant values equal to 0.1 mg/L. The caps for the remaining constituents are sampled directly from beta distributions with the distribution parameters given in Table 1-32 in the WMDP-MS-Attachment B.

The areas within the model where these concentration caps apply are:

- Category 2/3 stockpile (acidic water)
- OSP (acidic water)
- Category 4 stockpile (Duluth Complex water)

After wall acidification begins, these caps also apply to:

- West Pit Category 4 Duluth Complex wall water
- West Pit Category 4 Duluth Complex high wall water
- West Pit Category 4 Duluth Complex set back area water
- West Pit Category 4 Duluth Complex high set back area water
- West Pit ore wall water
- West Pit ore high wall water
- West Pit ore set back area water
- West Pit ore high set back area water
- West Pit Category 2/3 wall water
- West Pit Category 2/3 high wall water
- West Pit Category 2/3 set back area water
- West Pit Category 2/3 high set back area water
- East Pit Category 2/3 wall water
• East Pit Category 2/3 high wall water
• East Pit Category 2/3 set back area water
• East Pit Category 2/3 high set back area water
• East Pit ore wall water
• East Pit ore high wall water
• East Pit ore set back area water
• East Pit ore high set back area water
• East Pit Category 4 Duluth Complex wall water
• East Pit Category 4 Duluth Complex high wall water
• East Pit Category 4 Duluth Complex set back area water
• East Pit Category 4 Duluth Complex high set back area water

Virginia Formation Category 2/3, 4 and Ore Rock

The Virginia Formation concentration caps are calculated similarly to the acidic Duluth Complex caps. Neither chloride nor alkalinity has a concentration cap, and the fluoride cap is calculated by the solubility equation at the bottom of Table 1-33 in the WMDP-MS-Attachment B. The remaining constituents’ caps are sampled directly from beta distributions with the distribution parameters given in Table 1-33 of the WMDP-MS-Attachment B.

The areas within the model where these caps apply are:

• Category 4 stockpile (Virginia Formation water)
• East Pit Category 4 Virginia Formation wall water
• East Pit Category 4 Virginia Formation high wall water
• East Pit Category 4 Virginia Formation set back area water
• East Pit Category 4 Virginia Formation high set back area water

15.3.3 Water Quality Standard Calculations

The primary and secondary groundwater quality standards are given in Table 1-2 of the WMDP-MS-Attachment B. The surface water quality standards for the Partridge River and Colby Lake are given in Table 1-3 of the WMDP-MS-Attachment B. The hardness-based surface water quality standards for Cd, Cu, Ni, Pb and Zn are calculated as:

\[
\text{Surface Water Quality Standard} \ [\text{mg/L}] = 0.001 \times \exp(A \times \ln(\text{Hardness}) + B) \quad (15-9a)
\]

In Equation 15-9a, the values for “A” and “B” for each of the five constituents are given in Table 1-4 of the WMDP-MS-Attachment B. The hardness values in Equation 15-9a (expressed in [mg/L]) are defined as 90.8 mg/L for the reach immediately upstream of SW-004, 102 mg/L for the reach immediately upstream of SW-004a, and are calculated by Equation 15-9b for the remaining reaches using the calcium and magnesium concentrations:

\[
\text{Hardness} \ [\text{mg/L}] = 2.5 \times \text{Calcium} \ [\text{mg/L}] + 4.1 \times \text{Magnesium} \ [\text{mg/L}] \quad (15-9b)
\]