Documentation Report

NorthMet Project GoldSim Plant Site Model

Version 5.0

Project I.D.: 12P777

Poly Met Mining, Inc.
St. Paul, Minnesota

June 2013

POLYMET MINING

Foth

TETRA TECH

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TETRA TECH

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NorthMet Project GoldSim Plant Site Model

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Executive Summary

This document describes in detail Version 5.0 of the GoldSim model developed for the Plant Site at Poly Met Mining, Inc.'s (PolyMet) proposed NorthMet Project. All inputs, calculations, and outputs are presented as they are applied in the model, and as described in the Water Modeling Data Package Volume 2 – Plant Site.

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

A climate model calculates the amount of precipitation and evaporation during each month. The Beneficiation Plant component model estimates the amount of water, tailings, and constituent mass loading from the ore processing plant to the Flotation Tailings Basin. A separate component model for the Hydrometallurgical Plant calculates leakage from the Hydrometallurgical Residue Facility (HRF) pond.

The dimensions and physical properties of the Flotation Tailings Basin are calculated as it is created by the deposition of tailings, and another submodel estimates the rate of water and dissolved mass movement from Cells 1E and 2E of the basin to their surroundings (i.e. pond overflow, discharge to groundwater, and surface discharge of groundwater seepage). A separate submodel determines the amount of water and dissolved mass leaving Cell 2W. A submodel of the tailings basin toes and flow collection systems calculates the amounts of water and mass derived from the tailings basin that are captured by the flow collection systems. The waste water treatment plant (WWTP) submodel simulates water treatment during active mining operations and afterward. The amount, quality, and fate of treated water that is blended with untreated water captured by the four tailings basin toe collection systems are also calculated.

Surficial groundwater flow from the plant site is simulated by three separate flow path submodels, which originate at the flotation tailings basin and flow to the north, northwest and west. Each flow path model simulates water flow and mass loading from the flow path to the Embarrass River or one of its three tributaries: Mud Lake Creek, Trimble Creek, and Unnamed Creek. The Embarrass River and these tributaries are modeled by a series of river reaches. The surface water system submodel accounts for water and constituent mass from runoff and natural groundwater inflows in addition to water and mass derived from the plant site.

Descriptions of the calculations used to determine the maximum dissolved concentrations ("concentration caps") are also given in the final section of this document.

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. (PolyMet) has developed a detailed plan to begin mining at a new location near Hoyt Lakes, Minnesota (the NorthMet Project). The impacts of ore processing and long-term storage of mine tailings on local water resources can be predicted by models, which can account for uncertainty in many future environmental factors (e.g. infiltration into tailings piles and the resulting mass leaching). As a result of this type of uncertainty, the GoldSim modeling software has been used to develop a probabilistic model of the ore processing (“Plant”) site in order to predict a range of potential effects of ore processing and long-term tailings storage on surface water and groundwater resources in the area. The range of model results is used to assess the likelihood of certain outcomes being realized during and after plant operations at the site.

The structure of the GoldSim model and the calculations used within the model to represent each plant site feature are described 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 2 – Plant Site (WMDP-PS), and the Waste Characterization Data Package developed by PolyMet.

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 Existing Conditions and Proposed Project Models

Two separate models are contained within the NorthMet project GoldSim model of the Plant Site: one represents the current (existing) conditions at the site, and the other represents the site conditions corresponding to those proposed for the site in version 5.0 of the Adaptive Water Management Plan (AWMP). Only the second of these models is described in this document.

2.2 Simulation Structure

The Plant Site model is comprised of several component models that simulate the storage and flow of water and constituent mass during mining operations and afterward. Specifically, the component models are used to simulate water flow, tailings mass transport (when applicable) and dissolved constituent mass transport between the processing plants, Tailings Basin, Tailings Basin collection systems, waste water treatment plant (WWTP), hydrometallurgical residue facility (HRF), groundwater flow paths, and the receiving water bodies (the Embarrass River and three of its tributaries). A climate model is used to generate precipitation 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.

2.3 Simulation Settings

2.3.1 Simulation Time and Time Stepping

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

2.3.2 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 (50^{th} 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.

2.3.3 Monte Carol 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.

2.4 Constituents ("Species") Simulated

Mass storage and flows for the following twenty-seven chemical species are simulated: 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). Hardness is subsequently calculated at surface water evaluation locations as a function of simulated calcium and magnesium concentrations.

3 Climate Model

3.1 Purpose

The climate model is used to simulate variable precipitation and evapotranspiration. The model calculates monthly precipitation and evapotranspiration (ET) fluxes with dimensions of length per time ([L/T]), and determines which of the three seasons (summer, winter or snowmelt) that each time-step falls within.

3.2 Input

The following input variables are defined for the climate model:

- Precip_cuberoot [$(\text{in/yr})^{1/3}$] – Cube-root of annual precipitation amount
  - Probabilistic input resampled each year
  - Normal distribution (mean = 3.03; standard deviation = 0.15)
- Annual_P_Variation [yr/mon] – Fraction of annual precipitation falling in each month
  - Deterministic inputs
  - Values given in Table 1-51 of the Water Modeling Data Package, Volume 2 – Plant Site, Attachment B (WMDP-PS-Attachment B)
- Snowmelt_Start [-] – Month of the year when snow melt starts
  - Deterministic input (April)
- Snowmelt_Stop [-] – Final snow melt month of the year
  - Deterministic input (May)
- Frozen_Period [T] – Duration that the inactive tailings are frozen each year (limits oxygen diffusion)
  - Probabilistic input resampled each year
  - Triangular distribution (minimum = 2.4 months; mode = 3.4 months; maximum = 4.4 months)
- Bare_ET [-] – Fraction of precipitation which evapotranspires from bare waste rock
  - Probabilistic input sampled at start of each realization
  - Normal distribution (mean = 0.524; standard deviation = 0.020)
- Beach_Evap_Frac [-] – Fraction of precipitation that evaporates from the Flotation Tailings beaches
  - Probabilistic input resampled at start of each year
  - Normal distribution (mean = 0.528; standard deviation = 0.046)
- Beach_BNT_Evap_Frac [-] – Fraction of precipitation that evaporates from the bentonite-amended Flotation Tailings beaches
  - Probabilistic input resampled at start of each year
  - Normal distribution (mean = 0.662; standard deviation = 0.073)
- Delta_Evap [L/T] – Evaporation rate from the active delta in the Flotation Tailings beach
  - Probabilistic input resampled at start of each year
  - Normal distribution (mean = 46 in/yr; standard deviation = 0.69 in/yr)
- LTVSMC_Tailings_Evap_frac [-] – Fraction of precipitation that evaporates from the LTVSMC tailings in Cells 1E, 2E, and 2W

    - Probabilistic input resampled at start of each year
    - Normal distribution (mean = 0.449; standard deviation = 0.045)
- Rec_Bank_Evap_Frac [-] – Fraction of precipitation that evaporates from the bentonite-amended dams
    - Probabilistic input resampled at start of each year
    - Normal distribution (mean = 0.662; standard deviation = 0.073)
- Cell2W_Bank_Evap_Frac [-] – Fraction of precipitation which evaporates from the banks of Cell 2W
    - Probabilistic input resampled each year
    - Normal distribution (mean = 0.471; standard deviation = 0.048)
- Cell2E_Bank_Evap_Frac [-] – Fraction of precipitation that evaporates from the banks of Cell 2E
    - Probabilistic input resampled each year
    - Normal distribution (mean = 0.560; standard deviation = 0.057)
- Open_Water_Evap_OPS_Early [L/T] – Annual open water evaporation rate from Cell 1E and 2E ponds during operations (accounts for artificially heated water)
    - Probabilistic input resampled at start of each year
    - Normal distribution (mean = 32.5 in/yr; standard deviation = 0.56 in/yr
- Open_Water_Evap_OPS_Late [L/T] – Annual open water evaporation rate during operations after the Cell 1E and 2E ponds combine (accounts for artificially heated water)
    - Probabilistic input resampled at start of each year
    - Normal distribution (mean = 30.8 in/yr; standard deviation = 0.69 in/yr)
- Open_Water_Evap_CLSR [L/T] – Evaporation rate from open water after operations (accounts for normal water temperature)
    - Probabilistic input resampled at start of each year
    - Normal distribution (mean = 17.1 in/yr; standard deviation = 2.16 in/yr)
- Annual_E_Variation [yr/mon] – Fraction of annual evaporation occurring in each month
    - Deterministic inputs
    - Values given in Table 1-51 of the WMDP-PS-Attachment B

3.3 Calculations

The uncertain variable "Precip_cuberoot" is used to calculate annual precipitation:

Annual Precipitation [in/yr] = (Precip_cuberoot)^3 **(3-1)**

Monthly precipitation rates are calculated from the annual precipitation rate using the portions of annual precipitation in each month ("Annual_P_Variation"):

Monthly Precipitation [in/mon] =
Annual Precipitation [in/yr] * Annual_P_Variation [yr/mon] **(3-2)**

Three seasons are defined in the model: snowmelt, summer and winter. January, February and March are always considered part of winter. Snowmelt then begins in April (as defined by "Snowmelt_Start") and continues through the end of May ("Snowmelt_Stop"). Summer begins the following month and lasts through the month prior to the start of winter. The first winter month is determined based on the number of months that water at the site is frozen, which is an uncertain input ("Frozen_Period"). The sampled value of the frozen period is rounded to the nearest whole month, and if the rounded value is four then December is the first winter month. Otherwise, winter begins in January and the period from June through December is considered to be summer.

Evapotranspiration is calculated differently for many of the modeled areas. The following uncertain inputs are used to calculate the fraction of precipitation that evapotranspires from different modeled areas:

- From North and South buttress waste rock: Bare_ET
- From Flotation Tailings beaches (before bentonite amendment): Beach_Evap_Frac
- From Flotation Tailings beaches (after bentonite amendment): Beach_BNT_Evap_Frac
- From active delta: Delta_Evap
- From LTVSMC tailings: LTVSMC_Tailings_Evap_frac
- From the banks of bentonite-amended dams: Rec_Bank_Evap_Frac
- From the Cell 2W embankment: Cell2W_Bank_Evap_Frac
- From the Cell 2E embankment: Cell2E_Bank_Evap_Frac
- From the Cell 1E and 2E ponds during operations: Open_Water_Evap_OPS_Early
- From the Cell 1E/2E pond during operations: Open_Water_Evap_OPS_Late
- From the Cell 1E/2E pond after operations: Open_Water_Evap_CLSR

These time- and/or location-specific evapotranspiration fractions are used to locally calculate evaporation rates using the following general equation:

Monthly Evaporation [in/mon] =
Annual Precipitation [in/yr] * *ET Fraction* * Annual_E_Variation [yr/mon] **(3-3)**

3.4 Output

The Climate Model calculates the following fluxes and variables used by other component models:

- Monthly precipitation
- Timing and duration of the three climatic seasons: summer, winter, and snowmelt

The Climate Model also defines the fraction of precipitation which evapotranspires.

4 Flotation Tailings Basin Properties

4.1 Purpose

The purpose of the calculations defined in this section is to determine the physical dimensions, hydraulic properties, and tailings masses of the various physical features of the Flotation Tailings Basin. These values are subsequently used in one or more of the component models described later in this document to determine water flows and constituent mass loadings.

4.2 Input

4.2.1 Inputs from Other Models

- Fraction of plant discharge sent to the tailings basin beaches, determined in Section 5
- FTB pond volume [L^3], determined in Section 6

4.2.2 Pond Inputs

1. Design_Depth [L] – Designed optimum depth of the FTB pond
    - Deterministic input (8 feet)
2. Pond_Bottom_Area [L^2] – Designed area of the bottom of the FTB pond
    - Time-varying deterministic input
    - Values given in Table 1-30 of the WMDP-PS-Attachment B
3. Pond_Top_Area [L^2] – Designed area of the FTB pond water surface
    - Time-varying deterministic input
    - Values given in Table 1-30 of the WMDP-PS-Attachment B
4. Crest_Area [L^2] – Area of the basin crest that receives rainfall
    - Time-varying deterministic input
    - Values given in Table 1-24 of the WMDP-PS-Attachment B
5. Pond_Slope [-] – Slope of the tailings under the FTB pond water surface
    - Deterministic input (3%)

4.2.3 Beach Inputs

1. Beach_Width [L] – Width of the tailings beaches from dam to pond edge
    - Deterministic input (625 feet)
2. Beach_Slope [-] – Slope of the tailings beaches from dam to pond edge
    - Deterministic input (1%)
3. N_Beach_Area [L^2] – Designed beach area along the North dam
    - Time-varying deterministic input
    - Values given in Table 1-24 of the WMDP-PS-Attachment B
4. E_Beach_Area_IMP [L^2] – Area of the East beach
    - Time-varying deterministic input
    - Values given in Table 1-24 of the WMDP-PS-Attachment B
5. S_Beach_Area_IMP [L^2] – Area of the South beach
    - Time-varying deterministic input
    - Values given in Table 1-24 of the WMDP-PS-Attachment B

6. C_Beach_Area_IMP [L^2] – Area of the Closure beaches
    - Time-varying deterministic input
    - Values given in Table 1-24 of the WMDP-PS-Attachment B
7. Delta_Angle [degrees] – The angle at which spigotted water and tailings will spread as they flow down the tailings beaches
    - Deterministic input (75 degrees)
8. Delta_Flow_Frac [-] – Percent of the delta receiving active flow
    - Deterministic input (30%)
9. Beach_Porosity [-] – Porosity of tailings in the beaches
    - Probabilistic input resampled each year prior to closure
    - Triangular distribution (minimum = 0.3668; mode = 0.4012; maximum = 0.4685)
10. Perc_Fines_Retained [-] – Percent of tailings in the beaches from the fine fraction (by mass)
    - Probabilistic input resampled each year prior to closure
    - Normal distribution (mean = 35%; standard deviation = 3.04%)
11. Ksat_Coeff_mm [-] – Coefficient to determine the saturated hydraulic conductivity of the tailings prior to bentonite amendment
    - Deterministic input (2.793)
12. Ksat_Coeff_bm [-] – Coefficient to determine the saturated hydraulic conductivity of the tailings prior to bentonite amendment
    - Deterministic input (2.4585)
13. Ksat_Coeff_mb [-] – Coefficient to determine the saturated hydraulic conductivity of the tailings prior to bentonite amendment
    - Deterministic input (-3.6293)
14. Ksat_Coeff_bb [-] – Coefficient to determine the saturated hydraulic conductivity of the tailings prior to bentonite amendment
    - Deterministic input (-3.1175)
15. BNT_Ksat [L/T] – Saturated hydraulic conductivity of bentonite-amended tailings
    - Deterministic input (5.56×10^{-6} cm/s)
16. ResMoist_Coeff_mm [-] – Coefficient to determine the residual moisture content of the NorthMet tailings
    - Deterministic input (-0.2417)
17. ResMoist_Coeff_bm [-] – Coefficient to determine the residual moisture content of the NorthMet tailings
    - Deterministic input (0.0543)
18. ResMoist_Coeff_mb [-] – Coefficient to determine the residual moisture content of the NorthMet tailings
    - Deterministic input (0.1173)
19. ResMoist_Coeff_bb [-] – Coefficient to determine the residual moisture content of the NorthMet tailings
    - Deterministic input (-0.0155)
20. AirSuct_Coeff_mm [-] – Coefficient to determine the Van Genuchten air suction parameter for the NorthMet tailings
    - Deterministic input (0.002036)

21. AirSuct_Coeff_bm [-] – Coefficient to determine the Van Genuchten air suction parameter for the NorthMet tailings
    - Deterministic input (0.008121)
22. AirSuct_Coeff_mb [-] – Coefficient to determine the Van Genuchten air suction parameter for the NorthMet tailings
    - Deterministic input (-0.15927)
23. AirSuct_Coeff_bb [-] – Coefficient to determine the Van Genuchten air suction parameter for the NorthMet tailings
    - Deterministic input (0.010728)
24. VGBeta_Coeff_mm [-] – Coefficient to determine the Van Genuchten beta parameter for the NorthMet tailings
    - Deterministic input (-31.3442)
25. VGBeta_Coeff_bm [-] – Coefficient to determine the Van Genuchten beta parameter for the NorthMet tailings
    - Deterministic input (8.6015)
26. VGBeta_Coeff_mb [-] – Coefficient to determine the Van Genuchten beta parameter for the NorthMet tailings
    - Deterministic input (14.6871)
27. VGBeta_Coeff_bb [-] – Coefficient to determine the Van Genuchten beta parameter for the NorthMet tailings
    - Deterministic input (-1.4748)

4.2.4 Tailings Inputs

1. Solids_Discharge.Beneficiation [M/T] – Flow rate of solids from the concentrator plant to the FTB
    - Deterministic input (1.235 x 10^7 tonm/yr)
2. Plant_Uptime [-] – Annual average percent of time the plant is running
    - Deterministic input (91.26%)
3. Perc_Coarse_Feed [-] – Percent of tailings feed in the coarse fraction (by mass)
    - Probabilistic input resampled each year
    - Normal distribution (mean = 38%; standard deviation = 1.82%)
4. NM_SG [-] – Specific gravity of NorthMet tailings (both coarse and fine fractions)
    - Deterministic input (3.0)
5. Pond_Porosity [-] – Porosity of tailings under the Flotation Tailings Basin pond
    - Probabilistic input resampled each year prior to closure
    - Triangular distribution (minimum = 0.4049; mode = 0.5602; maximum = 0.5696)

4.3 Calculations

4.3.1 Pond and Beach Dimension Calculations

The design volume of the flotation tailings basin (FTB) pond is calculated for each time-step by Equation 4-1:

Pond Design Volume $[L^3]$ =
Design_Depth [L] * 0.5 * (Pond_Bottom_Area $[L^2]$ + Pond_Top_Area $[L^2]$) **(4-1)**

The design volume at the next time-step is used to determine the pumping rate from the FTB pond to the Beneficiation Plant (Section 5). This pumping rate is calculated differently during different time periods. Prior to closure (which occurs 20 years after operations begin):

Pond Design Volume (t+1) $[L^3]$ = **Pond Design Volume** +
[*dt* * Design_Depth * 0.5 * (*d/dt* (Pond_Bottom_Area) + *d/dt* (Pond_Top_Area))]
(4-2a)

The "*dt*" term in Equation 4-2a is the time-step size (i.e. one month).

Between 20 and 30 years after operations begin:

Pond Design Volume (t+1) $[L^3]$ = **Pond Design Volume** +
[*dt* * Design_Depth * 0.5 * (*d/dt*(Pond_Bottom_Area) + *d/dt*(Pond_Top_Area))] –
(89.611 acre-ft/yr * (*Current Time* + *dt* – 20 years)) **(4-2b)**

Between 30 and 40 years:

Pond Design Volume (t+1) $[L^3]$ = **Pond Design Volume** +
[*dt* * Design_Depth * 0.5 * (*d/dt*(Pond_Bottom_Area) + *d/dt*(Pond_Top_Area))] –
(89.611 acre-ft/yr * (40 years – *Current Time* + *dt*)) **(4-2c)**

After *t*=40 years the pond design volume is again calculated by Equation 4-2a.

The actual depth of water in the FTB pond is calculated based on the water volume present in either the Cell 2E pond (prior to combining with the Cell 1E pond) or in the combined 1E/2E pond. If the water volume is greater than the design volume (calculated by Equation 4-1), then:

Pond Depth [L] =
[(2 * (**Pond Volume** $[L^3]$ – C2) / m2) + $(b2/m2)^2]^{0.5}$ – b2/m2 **(4-3a)**

The previously undefined terms in this equation are defined as:
C2 $[L^3]$ = (0.5 * (m1 – m2) * Design_Depth^2) + (b1 – b2) * Design_Depth
m1 [L] = (Pond_Top_Area – Pond_Bottom_Area) / Design_Depth
m2 [L] = (Crest_Area – Pond_Top_Area) / (Beach_Width * Beach_Slope)
b1 $[L^2]$ = Pond_Bottom_Area
b2 $[L^2]$ = Pond_Top_Area – m2 * Design_Depth

If the water volume is less than or equal to the design volume:

Pond Depth [L] =
[(2 * **Pond Volume** / m1) + $(b1/m1)^2]^{0.5}$ – b1/m1 **(4-3b)**

The surface area of the FTB pond depends on the calculated depth of the FTB pond. If the pond depth is greater than "Design_Depth":

Pond Surface Area [L^2] = m2 * **Pond Depth** + b2 **(4-4a)**

Alternatively, if the pond depth is less than or equal to the design depth:

Pond Surface Area [L^2] = m1 * **Pond Depth** + b1 **(4-4b)**

When the pond depth is greater than the design depth, the length of the tailings beaches that is covered by pond water in excess of the design volume ("Less_Beach_Length") is determined based on the beach slope:

Less_Beach_Length [L] = (**Pond Depth** – Design_Depth) / Beach_Slope **(4-5a)**

When the pond depth is less than the design depth, this length is negative and is calculated based on the steeper pond slope:

Less_Beach_Length [L] = (**Pond Depth** – Design_Depth) / Pond_Slope **(4-5b)**

The exposed areas of the four tailings beaches—North, East, South and Closure—are calculated by Equations 4-6a through 4-6d:

Exposed North Beach Area [L^2] =
N_Beach_Area * (1 – (Less_Beach_Length / Beach_Width)) **(4-6a)**

Exposed East Beach Area [L^2] =
E_Beach_Area * (1 – (Less_Beach_Length / Beach_Width)) **(4-6b)**

Exposed South Beach Area [L^2] =
S_Beach_Area * (1 – (Less_Beach_Length / Beach_Width)) **(4-6c)**

Exposed Closure Beach Area [L^2] =
C_Beach_Area * (1 – (Less_Beach_Length / Beach_Width)) **(4-6d)**

The "E_Beach_Area", "S_Beach_Area" and "C_Beach_Area" terms in Equations 4-6a through 4-6d are all equal to zero before the Cell 1E and 2E ponds combine, and are equal to the inputs "E_Beach_Area_IMP", "C_Beach_Area_IMP" and "S_Beach_Area_IMP" after the ponds combine.

The ratio of pond area to beach area is used to calculate the fraction of Beneficiation Plant discharge that is directed to the beaches (Section 5). This value is defined as 1.90 at the start of each simulation, and thereafter it is calculated by the model based on the pond and beach areas:

Ratio of Pond Area to Beach Area [-] = **Pond Surface Area** /
(**Exposed North Beach Area** + **Exposed East Beach Area** +
Exposed South Beach Area + **Exposed Closure Beach Area**) **(4-7)**

The wetted area of the active beach—which is used to determine the infiltration rate of Plant discharge into the tailings beaches—is calculated as:

Active Beach Area [L^2] =
(Beach_Width)^2 * *tan*(0.5 * Delta_Angle) * Delta_Flow_Frac **(4-8)**

4.3.2 Hydraulic Property Calculations

Infiltration and runoff from the flotation tailings beaches are dependent upon the hydraulic conductivity of the tailings. Prior to the addition of a bentonite layer to the tailings, the saturated hydraulic conductivity of the beaches is:

K_{sat} (Beaches) [cm/s] = 10^[(Ksat_Coeff_mm * Beach_Porosity * Perc_Fines_Retained) +
(Ksat_Coeff_bm * Beach_Porosity) +
(Ksat_Coeff_mb * Perc_Fines_Retained) + Ksat_Coeff_bb] **(4-9)**

After bentonite amendment, the beach saturated hydraulic conductivity is equal to "BNT_Ksat".

The residual moisture content of the NorthMet tailings beaches ("TLNGS_ResMoist") is calculated using an equation similar to the exponential term in Equation 4-9:

TLNGS_ResMoist [-] = (ResMoist_Coeff_mm * Beach_Porosity * Perc_Fines_Retained) +
(ResMoist_Coeff_bm * Beach_Porosity) +
(ResMoist_Coeff_mb * Perc_Fines_Retained) + ResMoist_Coeff_bb **(4-10)**

The Van Genuchten air suction parameter for the NorthMet tailings is calculated using Equation 4-10 with the following coefficients substituted for those above: "AirSuct_Coeff_mm", "AirSuct_Coeff_bm", "AirSuct_Coeff_mb" and "AirSuct_Coeff_bb". The resulting air suction parameter ("TLNGS_AirSuct") has the dimension [cm^{-1}]. The Van Genuchten beta parameter ("TLNGS_VGBeta") is also calculated in this manner by using different coefficients ("VGBeta_Coeff_mm", "VGBeta_Coeff_bm", "VGBeta_Coeff_mb" and "VGBeta_Coeff_bb").

4.3.3 Tailings Delivery Calculations

The average flow rate of solids from the plant to the FTB is the product of the plant's actual solid discharge rate when the plant is operating and the fraction of the time which the plant is actually in operation:

Total Flow Rate of Tailings to FTB [M/T] =
Solids_Discharge.Beneficiation * Plant_Uptime **(4-11)**

The rates of fine and coarse tailings discharge to the pond are then calculated based on the percent of tailings delivered which are coarse ("Perc_Coarse_Feed"):

Fine Tailings Delivery to Pond [M/T] = **Total Flow Rate of Tailings to FTB** *
(1 – Perc_Coarse_Feed * (1 + **Fraction of Plant Discharge to Beaches** *
(Perc_Fines_Retained / (1 – Perc_Fines_Retained)))) **(4-12a)**

Coarse Tailings Delivery to Pond [M/T] = **Total Flow Rate of Tailings to FTB** * (1 – **Fraction of Plant Discharge to Beaches**) * Perc_Coarse_Feed **(4-12b)**

The fraction of plant discharge to the beaches in the above equations is calculated by Equation 5-7, and “Perc_Coarse_Feed” and “Perc_Fines_Retained” are uncertain inputs defined by normal distributions.

The total rate of change to the volume of tailings present beneath the FTB pond is then:

Rate of Change in Tailings Volume [L^3/T] = (**Fine Tailings Delivery to Pond** + **Coarse Tailings Delivery to Pond**) / (NM_SG * ρ_{water} * (1 – Pond_Porosity)) **(4-13)**

4.4 Output

The following quantities calculated in this section are used in various component models:

- Flotation tailings basin pond design volume
- Pond and tailings beach surface areas
- Ratio of pond area to beach area
- NorthMet tailings infiltration capacity (tailings saturated hydraulic conductivity)
- Tailings residual moisture content
- Rate of change in tailings volume under the flotation tailings basin pond

5 Beneficiation Plant and Hydrometallurgical Plant Models

5.1 Purpose

The plant models are used to simulate water flow and mass transport from the Beneficiation Plant, the Hydrometallurgical Plant, and the Hydrometallurgical Residue Facility (HRF). The models calculate water flows and associated constituent mass loads for all constituents that are routed to other component models, including models for the Flotation Tailings Basin and Waste Water Treatment Plant (WWTP).

5.2 Input

5.2.1 Inputs from Other Models

- Monthly precipitation [L/T], determined in Section 3
- Ratio of pond area to beach area [-], determined in Section 4
- FTB pond design volume [L^3], determined in Section 4
- Active beach area [L^2], determined in Section 4
- FTB pond volume [L^3], determined in Section 6
- Direct precipitation [L^3/T] on FTB ponds, determined in Section 6
- Watershed runoff [L^3/T] to FTB ponds, determined in Section 6
- Cell 2W runoff [L^3/T] and constituent mass loading to FTB ponds, determined in Section 6
- NorthMet tailings runoff [L^3/T] to FTB ponds, determined in Section 6
- Water flow [L^3/T] and constituent mass loading from untreated collected toe water pumped into the Cell 1E pond, determined in Section 6
- Water flow [L^3/T] and constituent mass loading from Cell 2E to the beneficiation plant, determined in Section 6
- Water flow [L^3/T] and constituent mass loading from beach runoff to ponds, determined in Section 6
- Pond evaporation [L^3/T], determined in Section 6
- Pond seepage [L^3/T], determined in Section 6
- Pond water entrainment [L^3/T], determined in Section 6
- Water flux [L/T] from Cell 2W embankment runoff to the FTB ponds, determined in Section 7
- Water flow [L^3/T] and constituent mass loading from the “blended” water to the pond, determined in Section 8
- Water flow [L^3/T] and constituent mass loading from Greensand filter outflow, determined in Section 9
- Runoff yield [L^3/T/L^2], determined in Section 11

5.2.2 Beneficiation Plant Water Balance Inputs

1. Total_H2O_Demand.Beneficiation [L^3/T] – Total flow rate required for the concentrator plant to process the mined ore
    - Deterministic input (7590.1 x 10^6 gallons/year)

2. Clean_H2O_Demand.Beneficiation [L^3/T] – Clean water needed for the concentrator process
   - Deterministic input (3.29 gallons/min)
3. Pond_1E_Volume [L^3] – Original ("current") volume of water in Cell 1E
   - Deterministic input (3700 acre-feet)
4. Process_H2O_Discharge.Beneficiation [L^3/T] – Water discharge from the concentrator process (to flotation tailings basin)
   - Deterministic input (7921.7 x 10^6 gallons/year)
5. Other_H2O_Discharge.Beneficiation [L^3/T] – Water discharge from other sources to the flotation tailings basin
   - Deterministic input (26.3 gallons/min)

5.2.3 Hydrometallurgical Plant and Residue Facility Water Balance Inputs

1. Crest_El [L] – Crest elevation of the dams constructed to form the HRF
   - Time-varying deterministic input (Table 1-42 of the WMDP-PS-Attachment B)
2. A_El
   - Lookup table defining the HRF area as a function of elevation
   - Deterministic input (Table 1-41 of the WMDP-PS-Attachment B)
3. Forest_WS_Area [L^2] – Area of the forested watershed contributing to the HRF
   - Time-varying deterministic input (Table 1-42 of the WMDP-PS-Attachment B)
4. Cell2W_WS_Area [L^2] – Area of Cell 2W that contributes runoff to the HRF
   - Time-varying deterministic input (Table 1-42 of the WMDP-PS-Attachment B)
5. Process_H2O_Discharge.Hydromet [L^3/T] – Discharge rate from the hydrometallurgical process
   - Deterministic input (114.4 x 10^6 gallons/year)
6. Other_H2O_Discharge.Hydromet [L^3/T] – Flow rate of water discharged to the HRF from other water uses
   - Deterministic input (26.3 gallons/min)
7. El_V
   - Lookup table defining the HRF elevation as a function of volume
   - Deterministic input (Table 1-41 of the WMDP-PS-Attachment B)
8. HRF_Drainage_Period [T] – Time needed to fully drain the HRF
   - Deterministic input (10 years)
9. Residue_Porosity [-] – Porosity of the hydrometallurgical residue
   - Probabilistic input sampled at start of each realization
   - Triangular distribution (minimum = 0.53; mode = 0.57; maximum = 0.61)
10. Solids_Discharge.Hydromet [M/T] – Flow rate of solids from the hydrometallurgical plant to the HRF
    - Deterministic input (3.342 x 10^5 tonm/year)
11. Residue_Sp_Gr [-] – Specific gravity of the hydrometallurgical residue
    - Deterministic input (2.76)
12. Total_H2O_Demand.Hydromet [L^3/T] – Flow rate of water needed by the hydrometallurgical plant
    - Deterministic input (2.342 x 10^8 gallons/year)

13. Clean_H2O_Demand.Hydromet [L^3/T] – Clean water demand from the hydrometallurgical process
    - Deterministic input (124.9 gallons/minute)
14. Max_Pump_Out [L^3/T] – Maximum pumping rate out of the residue facility
    - Deterministic input (300 gallons/minute)
15. Design_Water_Depth [L] – Desired depth of water above the residue in the HRF pond
    - Deterministic input (6 feet)
16. Maximum_Elevation [L] – Maximum allowable water elevation in the HRF pond
    - Deterministic input (1647 feet)
17. Initial_Residue_Volume [L^3] – Initial volume of residue in the residue facility
    - Deterministic input (zero)
18. V_El
    - Lookup table defining the HRF pond volume as a function of pond elevation
    - Deterministic input (Table 1-41 of the WMDP-PS-Attachment B)

5.2.4 Mass Transport Inputs

1. SO4_S_Regression [M/M/T/%] – Sulfate release as a function of sulfur content
    - Probabilistic input sampled at start of each realization
    - Normal distribution (mean = 13.92 mg/kg/week/%; standard deviation = 0.581 mg/kg/week/%)
2. OSP_Sulfur [-] – Average sulfur content of ore
    - Deterministic input (0.608%)
3. Ore_Processing_Rate [M/T] – Rate of ore processing at the Beneficiation Plant
    - Deterministic input (30,860 tonm/day)
4. Ore_Storage_Time [T] – Length of time that ore is stored in in-pit stockpiles
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 1 month; maximum = 6 months)
5. Size_Factor [-] – Scaling factor to adjust to field scale ore
    - Probabilistic input sampled at start of each realization
    - Truncated normal distribution (minimum = 0; mean = 0.18; standard deviation = 0.061)
6. Contact_Factor [-] – Fraction of ore contacted by water
    - Probabilistic input sampled at start of each realization
    - Triangular distribution (minimum = 0.1; mode= 0.5; maximum = 0.9)
7. Activation_Energy [kJ/mol] – Activation energy of pyrrhotite for the Arrhenius equation
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 47 kJ/mol; maximum = 63 kJ/mol)
8. R [J/mol-K] – Gas constant
    - Deterministic input (8.314472 J/mol-K)
9. Lab_Temp [-] – Laboratory temperature
    - Deterministic input (20°C)
10. Field_Temp [-] – Average annual site air temperature, assumed to be the same temperature as the ore and tailings
    - Probabilistic input resampled each year

- Normal distribution (mean = 2.004°C; standard deviation = 1.388°C)

11. Reagant_Load [M/M] – Mass of $CuSO_4$ used per mass of ore processed
    - Deterministic input (55 g/tonm)
12. CL_Quality [M/L^3] – Water quality in Colby Lake
    - Probabilistic, constituent-specific inputs resampled every time-step
    - Log-normal distribution with means ("*CL_Mean*") and standard deviations ("*CL_SD*") of concentrations given in Table 1-44 of the WMDP-PS-Attachment B

5.3 Calculations

5.3.1 Water Balance Calculations

Beneficiation Plant

Water needs to be supplied to the Beneficiation Plant during operations at the following rate:

Total Plant Demand [L^3/T] = Total_H2O_Demand.Beneficiation * Plant_Uptime **(5-1)**

This demand is met by pumping water from Colby Lake and from the pond in Cell 1E of the Flotation Tailings Basin (FTB). The demand for "clean" water from Colby Lake is:

Clean Water Demand [L^3/T] = Clean_H2O_Demand.Beneficiation * Plant_Uptime **(5-2)**

Prior to the ponds in Cells 1E and 2E combining, the rate of pumping from the Cell 1E pond to the Plant is the lesser of the quantities calculated by Equations 5-3a and 5-3b (when both are greater than zero).

Pumping from Cell 1E Pond to Beneficiation Plant [L^3/T] **=**
Direct Precipitation (Cell 1E Pond) + **Watershed Runoff (Cell 1E Pond)** +
Reclaimed Tailings Basin ("Cell 2W") Runoff (Cell 1E Pond) +
LTVSMC Tailings Runoff to Cell 1E Pond +
Subaqueous Plant Discharge to FTB Pond +
Greensand Filter Backwash (t-1) +
Untreated Collected Flow (Cell 1E) + **Pumping from Cell 2E Pond to Cell 1E Pond** –
[**Pond Evaporation (Cell 1E)** + **Pond Seepage (Cell 1E)** +
Pond Water Entrainment (Cell 1E) +
(Pond_1E_Volume – **Cell 1E Pond Volume**) / *dt*] **(5-3a)**

and

Total Plant Demand – **Clean Water Demand** **(5-3b)**

The quantities in Equation 5-3a are calculated as defined in subsequent parts of this document: the subaqueous discharge to Cell 1E is calculated later in this section, and the remaining flow rates and volumes are determined as described in Section 6. When the quantity calculated by Equation 5-3a is less than zero, no water is pumped from the Cell 1E pond to the Plant.

After the Cell 1E and 2E ponds merge, the rate of pumping from the combined 1E/2E pond to the Plant is the smaller of the quantities calculated by Equation 5-3b and 5-4 (when both are greater than zero):

Pumping from Cell 1E/2E Pond to Beneficiation Plant [L^3/T] **=**
Direct Precipitation (Cell 1E/2E Pond) + **Watershed Runoff (Cell 1E/2E Pond)** +
Reclaimed Tailings Basin ("Cell 2W") Runoff (Cell 1E/2E Pond) +
Tailings Runoff to Cell 1E/2E Pond +
Subaqueous Plant Discharge to FTB Pond + **Pumping from Mine Site** +
Greensand Filter Backwash (t-1) +
Untreated Collected Flow (Cell 1E/2E) + **Blended Water to FTB Pond** –
[**Pond Evaporation (Cell 1E/2E)** + **Pond Seepage (Cell 1E/2E)** +
Pond Water Entrainment (Cell 1E/2E) +
(**Pond Design Volume** (t+1) – **Cell 1E/2E Pond Volume**) / *dt*] **(5-4)**

The flow rate from the "blended" water to the pond is determined in Section 8 (Equation 8-16), and the pond design volume for the next time-step is calculated in Section 4. When the quantity calculated by Equation 5-4 is less than zero, the rate of pumping from the Cell 1E/2E pond to the Plant is zero.

After determining the pumping rates from the Cell 1E or 1E/2E pond to the Plant, any remaining Plant water demand is met by additional pumping from Colby Lake. That is, the quantity calculated by Equation 5-2 is effectively the minimum pumping rate from Colby Lake during operations. The total pumping rate from Colby Lake is thus:

Total Pumping to Plant from Colby Lake [L^3/T] =
Total Plant Demand – Pumping from Pond (1E or 1E/2E) to Plant **(5-5)**

The total discharge from the Plant is calculated independently from the plant water demand:

Total Plant Discharge [L^3/T] = Plant_Uptime *
(Process_H2O_Discharge.Beneficiation + Other_H2O_Discharge.Beneficiation) **(5-6)**

This discharge is split between one of the FTB beaches and subaqueous discharge to either the Cell 2E or Cell 1E/2E pond. The fraction of the plant discharge sent to the tailings beaches is:

Fraction of Plant Discharge to Beaches [-] =
1 / [Perc_Coarse_Feed * (1 + (Perc_Fines_Retained / (1 – Perc_Fines_Retained))) *
(1 + **Ratio of Pond Area to Beach Area** * (1 – Pond_Porosity) / (1 – Beach_Porosity))]
(5-7)

The ratio of pond area to beach area in this equation is calculated by Equation 4-7.

The discharge rate from the Plant to the FTB beaches is therefore:

Plant Discharge to Beaches [L^3/T] =
Total Plant Discharge * **Fraction of Plant Discharge to Beaches** **(5-8)**

The particular FTB beach to which this water (and tailings) is discharged depends upon the time of year. During the first month(s) of each year, the entire discharge amount calculated by Equation 5-8 is directed to the North dam. Thereafter, all the beach-directed discharge is sent to the South dam for a period, then later to the Closure dam (*t*=18-20 years only), and in the last month(s) of the year all of the Plant discharge is sent to the East dam. The exact duration of discharge to each dam depends on a minimum duration and the relative area of each beach. For example, the duration of Plant discharge to the North beach is calculated as described below.

Minimum Discharge Duration to North Beach [months] = 12 * N_Beach_Area **/**
(N_Beach_Area **+** S_Beach_Area **+** C_Beach_Area **+** E_Beach_Area**)** **(5-9)**

The value calculated by Equation 5-9 is rounded down to the nearest integer to account for the model's monthly time-steps. This rounded minimum duration is then used to calculate the probability of this minimum discharge duration occurring:

Probability of Minimum Discharge Duration to North Beach [-] =
1 – [**Minimum Discharge Duration to North Beach** (*before rounding*) **–**
Minimum Discharge Duration to North Beach (*after rounding*)] **(5-10)**

The probability calculated by Equation 5-10 is assigned to the rounded minimum duration value, and the complementary probability is assigned to the rounded value plus one month. At the start of each simulated year, the discharge duration to the North beach is chosen based on these probabilities. Analogous calculations and logic are used to determine the duration of discharge to the other beaches. It is noteworthy that the areas of the South and East beaches are zero before the 1E and 2E ponds combine (at *t*=7 years), and the Closure beach area is zero until two years prior to closure (*t*=18 years). As a result, all of the beach-directed Plant discharge is sent to the North beach (and Cell 2E) prior to merging of the ponds; to the North, East and South beaches between *t*=7-18 years; and to all four beaches from *t*=18 years until plant closure.

The remaining Plant discharge—that which is not sent to one of the four beaches—is discharged to either the Cell 1E or Cell 2E pond subaqueously:

Subaqueous Plant Discharge to FTB Pond [L^3/T] =
Total Plant Discharge – **Plant Discharge to Beaches** **(5-11)**

All of the subaqueous discharge is sent to the Cell 2E pond before the two ponds combine, after which it is all sent to the combined Cell 1E/2E pond.

Hydrometallurgical Plant and Residue Facility

The HRF is scheduled to begin operating 3 years after operations begin at the Beneficiation Plant and remain in operation until the time of closure. The inflows to the HRF pond during this time include direct precipitation onto the pond, runoff from the contributing forested watershed, runoff from Cell 2W, and discharge from the Hydrometallurgical Plant. These inflow rates are calculated by Equations 5-12 through 5-15:

Precipitation onto HRF Pond [L^3/T] =
Monthly Precipitation [L/T] * **HRF Area** [L^2], **(5-12)**

The HRF area in this equation is determined using the time-varying crest elevation ("Crest_El") and the elevation-to-area lookup table ("A_El").

Forested Watershed Runoff to HRF Pond [L^3/T] =
Forest_WS_Area [L^2] * **Runoff Yield** [L^3/T/L^2] **(5-13)**

The runoff yield is determined as described in Section 11.

Cell 2W Runoff to HRF Pond [L^3/T] =
Cell2W_WS_Area [L^2] * **Runoff from Cell 2W Embankment** [L/T] **(5-14)**

The embankment runoff flux is calculated (and adjusted, if necessary) as indicated in Section 7.

Hydrometallurgical Plant Discharge to HRF Pond [L^3/T] = Plant_Uptime *
(Process_H2O_Discharge.Hydromet + Other_H2O_Discharge.Hydromet) **(5-15)**

Leakage from the pond during HRF operations is also calculated in the model, however all of it is captured by the double-liner leakage collection system and returned to the pond until operations cease. The other three outflows from the HRF pond during HRF operations are evaporation, entrainment of pond water in deposited residue, and pumping to the hydrometallurgical plant. The evaporation rate from the pond is determined as a function of the pond surface area:

Evaporation from HRF Pond [L^3/T] =
Open_Water_Evap_OPS_Early * **HRF Pond Surface Area** **(5-16)**

The pond area is determined using the elevation-to-area lookup table ("A_El") and the pond water elevation. The pond water elevation is determined using the volume-to-elevation lookup table ("El_V") and the total accumulated volume of the pond and the residue.

Entrainment of pond water during residue deposition is the product of the residue porosity and the rate at which residue is added to the pond:

HRF Pond Water Entrainment [L^3/T] =
Residue_Porosity * Solids_Discharge.Hydromet [M/T] * Plant_Uptime /
Residue Bulk Density [M/L^3] **(5-17a)**

The bulk density of the hydrometallurgical residue is a constant calculated by Equation 5-17b:

Residue Bulk Density [M/L^3] =
(Residue_Sp_Gr * ρ_{water} * (1 – Residue_Porosity)) **(5-17b)**

The rate of the final outflow from the HRF pond during operations—pumping from the pond to the hydrometallurgical plant—depends on the magnitude of three volumetric flow rates: the maximum pumping rate ("Max_Pump_Out"), and the two rates calculated by Equations 5-18a and 5-18b. When the pond has a water surplus—that is, when the flow rate calculated by Equation 5-18b is positive—the pumping rate to the hydrometallurgical plant is the smallest of these three flow rates. When the pond has a deficit, no water is pumped out of the pond.

Potential HRF Pond to Hydromet. Plant Pumping Rate [L^3/T] = Plant_Uptime * (Total_H2O_Demand.Hydromet – Clean_H2O_Demand.Hydromet) **(5-18a)**

Surplus or Deficit Flow Rate [L^3/T] = (**Precipitation onto HRF Pond** [L^3/T] + **Forested Watershed Runoff to HRF Pond** [L^3/T] + **Cell 2W Runoff to HRF Pond** [L^3/T] + **Hydrometallurgical Plant Discharge to HRF Pond** [L^3/T]**) –** (**Evaporation from HRF Pond** [L^3/T] + **HRF Pond Water Entrainment** [L^3/T]) – (**Desired Pond Water Volume** [L^3] – **Pond Water Volume** [L^3]) / *dt* **(5-18b)**

The desired pond water volume in Equation 5-18b is a time-varying quantity ultimately calculated as a function of the volume of residue in the pond, the design water depth, and the maximum allowable water elevation in the pond. The initial volume of residue in the pond is zero ("Initial_Residue_Volume"), and residue is added to the pond while the HRF is active at the following rate:

Residue Added to Pond [L^3/T] = Solids_Discharge.Hydromet [M/T] * Plant_Uptime / **Residue Bulk Density** [M/L^3] **(5-19a)**

The residue volume at any time during operations is therefore the product of this addition rate and the time since the HRF began operating. The elevation corresponding to the top of the residue is determined using the residue volume and the volume-to-elevation lookup table ("El_V"). The desired water elevation in the HRF is then determined based on the magnitudes of two quantities: the maximum allowable water elevation ("Maximum_Elevation"), and the sum of the elevation at the top of the residue and the design depth ("Design_Water_Depth"). The smaller of these two quantities is considered the desired water elevation in the pond. This elevation is then used with the elevation-to-volume lookup table ("V_El") to determine the desired total volume of the pond, which is subsequently used with the residue volume at the next time-step to determine the desired water volume (Equation 5-19b):

Desired Pond Water Volume [L^3] = **Desired Total Pond Volume** [L^3] – **Residue Volume** (t+1) [L^3] **(5-19b)**

The desired pond water volume is then used to determine the surplus or deficit flow rate needed to meet the desired pond volume during HRF operations (Equation 5-18b).

After the HRF stops operating at the time of plant closure (t=20 years), all inflows to the HRF pond cease and all water in the pond will be drained over a period of 10 years (as prescribed in the "HRF_Drainage_Period" input variable). The rate of water removed from the HRF during this draining period is assumed to be constant with time:

HRF Leakage $[L^3/T]$ =
(**HRF Pond Volume** (*t=20 years*) + **HRF Porewater Volume** (*t=20 years*)) /
HRF_Drainage_Period **(5-20a)**

The porewater volume at the time of plant closure is calculated based on the rate of pond water entrainment during residue deposition (calculated by Equation 5-17a) and the total duration of operations at the HRF (i.e. 17 years):

HRF Porewater Volume (*t=20 years*) $[L^3]$ =
17 years * **HRF Pond Water Entrainment** **(5-20b)**

5.3.2 Mass Transport Calculations

Ore Release Rates

The release rates from ore during processing are determined for some constituents as a function of sulfate (SO_4) release, whereas others are released at rates independent of sulfate release. The constituents with sulfate-independent release rates are alkalinity, B, Cl, Cr, F and Tl, and these release rates are generated using the type of distribution and distribution parameters (i.e. mean/mode, standard deviation, minimum and maximum) defined in Table 1-27 of the Mine Site WMDP-PS-Attachment B.

The sulfate release rate is calculated by Equation 5-21:

Release Rate (SO_4) [M/M/T] **=** SO4_S_Regression * OSP_Sulfur **(5-21)**

A total of six species have release rates that are directly related to the sulfate release rate: Ca, Na, Mn, K, Se and Mg. These release rates are calculated as:

Release Rate (SO_4-Dependent Species) [M/M/T] **= Release Rate (SO_4)** [M/M/T] *
Relative Release Ratio (Species-to-SO_4) [M/M] **(5-22)**

The release ratios relative to sulfate for these six species are given in Table 1-27 of the Mine Site WMDP-PS-Attachment B.

The fourteen remaining species have release rates indirectly related to sulfate release. Five constituents—Ag, As, Cu, Pb and Sb—are dependent on the calculated sulfur release rate, species-specific release ratios relative to sulfur (Table 1-27, Mine Site WMDP-PS-Attachment B) and molar mass ratio of sulfur to sulfate (0.33382):

Release Rates (S-Dependent Species) [M/M/T] **= Release Rate (SO_4)** [M/M/T] *
Relative Release Ratio (Species-to-S) [M/M] *
Molar Mass Ratio (S-to-Sulfate) [M/M] **(5-23)**

Three constituents—Ba, Be and V—are dependent on the potassium release rate (calculated by Equation 5-22) and the release ratios relative to potassium (Table 1-27, Mine Site WMDP-PS-Attachment B):

Release Rates (K-Dependent Species) [M/M/T] **= Release Rate (SO_4)** [M/M/T] *
Relative Release Ratio (Species-to-K) [M/M] *
Relative Release Ratio (K-to-SO_4) [M/M] **(5-24)**

Iron and nickel release rates are calculated as a function of release rates for sulfur and magnesium:

Release Rates (Fe, Ni) [M/M/T] **= Release Rate (SO_4)** [M/M/T] *
(**Relative Release Ratio (Fe- or Ni-to-S)** [M/M] *
Molar Mass Ratio (S-to-Sulfate) [M/M] +
Relative Release Ratio (Fe- or Ni-to-Mg) [M/M] *
Relative Release Ratio (Mg-to-SO_4) [M/M]) **(5-25)**

Cobalt and zinc release rates are subsequently dependent upon the nickel release rate:

Release Rates (Co, Zn) [M/M/T] **= Release Rate (SO_4)** [M/M/T] *
Relative Release Ratio (Co- or Zn-to-Ni) [M/M] *
Relative Release Ratio (Ni-to-SO_4) [M/M] **(5-26)**

The two remaining constituents—Al and Cd—are each calculated in unique ways. Cadmium release is a function of zinc release:

Release Rate (Cd) [M/M/T] **= Release Rate (SO_4)** [M/M/T] *
Relative Release Ratio (Cd-to-Zn) [M/M] *
Relative Release Ratio (Zn-to-SO_4) [M/M] **(5-27)**

Aluminum release is calculated as a function of the calcium and sodium release ratios, and constant coefficients based on weathering of anorthite and albite:

Release Rate (Al) [M/M/T] **= Release Rate (SO_4)** [M/M/T] *
(**Anorthite Weathering Coefficient (Al-to-Calcium)** [M/M] *
Relative Release Ratio (Calcium-to-SO_4) [M/M] +
Albite Weathering Coefficient (Al-to-Sodium) [M/M] *
Relative Release Ratio (Sodium-to-SO_4) [M/M]) **(5-28)**

The distribution types and distribution parameters for the relative release ratios between the target species and non-sulfate species in Equations 5-25 through 5-28 can be found in Table 1-27 of the Mine Site WMDP-PS-Attachment B.

Constituent Mass Loading To Beneficiation Plant

The Beneficiation Plant is represented by a single cell ("Sink_Plant") which has a fixed water volume of 500,000 m^3. The constituent mass loading to the Plant depends on the amount of mass not leached while the ore is stockpiled:

Mass Not Leached from Stockpile (All Species) [M/T] = Ore_Processing_Rate [M/T] * Ore_Storage_Time [T] * **Release Rates (All Species)** [M/M/T] * Size_Factor * Temp_Factor * (1 – Contact_Factor) **(5-29)**

The temperature factor in this equation is calculated by the Arrhenius Equation:

Temp_Factor [-] = *exp*[Activation_Energy / R*((1/Lab_Temp) – (1/Field_Temp))] **(5-30)**

Addition of $CuSO_4$ as a reagent during ore processing adds sulfate to water in the Plant:

Reagent Mass Loading (SO_4 only) [M/T] = Reagant_Load [M/M] * Ore_Processing_Rate [M/T] * **Molar Mass (SO_4)** / (**Molar Mass (SO_4)** + **Molar Mass (Cu)**) **(5-31)**

The constituent mass loading rate from Colby Lake to the Plant is the product of the pumping rate from the lake and baseline lake concentrations ("CL_Quality"):

Colby Lake Mass Loading [M/T] = **Total Pumping to Plant from Colby Lake** [L^3/T] * CL_Quality [M/L^3] **(5-32)**

The fourth and final addition of constituent mass to the Plant comes from the Cell 1E pond. This loading occurs at a rate equal to the product of the pond concentrations and the pumping rate to the Plant (Equations 5-3a through 5-4). The total mass loading rate to the Beneficiation Plant during Plant Site operations is therefore the sum of the loads from the four mass sources:

Total Mass Loading to Plant [M/T] = **Loading from Cell 1E Pond** + **Mass Not Leached from Stockpile (All Species)** + **Colby Lake Mass Loading** + **Reagent Mass Loading (SO_4 only)** **(5-33)**

Constituent Mass Leaving Beneficiation Plant

There are six separate constituent mass fluxes out of the Beneficiation Plant: discharge onto the North, South, East and Closure beaches, and subaqueous discharge to the Cell 2E and 1E/2E ponds. The rates at which mass leaves the cell element representing the plant ("Sink_Plant") are determined by the constituent concentrations in the cell and the volumetric outflow rate of each discharge component. The discharge rates onto the active beach and directly to the Cell 2E and 1E/2E ponds are calculated by Equations 5-8 and 5-11, respectively.

Hydrometallurgical Residue Facility

The only outflow from the HRF that influences an area other than the facility (i.e. the only means of water or mass transport from the facility) is pond leakage during the specified drainage period immediately after operations. This leakage rate (determined by Equation 5-20a) is smaller than the WWTP treatment capacity during closure and is given the highest treatment priority at the WWTP (see Sections 8 and 9). Additionally, because the WWTP has specified maximum effluent concentrations and the remaining constituent mass is precipitated (Section 9), the dissolved constituent mass in the HRF pond leakage would ultimately only influence the amount of precipitated mass removed from the model. Therefore, because it would not influence any loading to the surrounding environment, mass loading from HRF leakage to the WWTP is not modeled.

5.4 Output

The Beneficiation Plant Model ultimately calculates the following flows along with their associated constituent concentrations and loads:

- Subaqueous discharge from the Beneficiation Plant to the active Flotation Tailings Basin pond
- Discharge from the Beneficiation Plant to the Flotation Tailings Basin beaches

The Hydrometallurgical Plant and Residue Facility Model calculates the volumetric HRF pond leakage rate.

6 Flotation Tailings Basin Model (Cells 1E and 2E)

6.1 Purpose

This model is used to simulate water flow and mass transport from the inward-draining portion of the Flotation Tailings Basin located in Cells 1E and 2E. The model calculates water flows and the associated constituent mass loads for all constituents that are routed to other component models, including models of the tailings basin toes, groundwater flow paths, beneficiation plant, and the surface water system.

6.2 Input

6.2.1 Inputs from Other Models

- Monthly precipitation [L/T], determined in Section 3
- FTB pond design volume [L^3], determined in Section 4
- NorthMet tailings infiltration capacity (saturated hydraulic conductivity) [L/T], determined in Section 4
- Residual moisture content of NorthMet tailings, determined in Section 4
- Exposed and active beach areas [L^2], determined in Section 4
- Rate of change in tailings volume [L^3/T] under the FTB pond, determined in Section 4
- Water flow [L^3/T] and constituent mass loading [M/T] from the Beneficiation Plant (discharged subaqueously and to tailings beaches), determined in Section 5
- Water flow [L^3/T] and constituent mass loading [M/T] from untreated collected flow pumped to the FTB pond, determined in Section 8
- Water flow [L^3/T] and constituent mass loading [M/T] from blended flow pumped to the FTB pond, determined in Section 8
- FTB pond water treatment rate [L^3/T], determined in Section 9
- Inflow rate to WWTP [L^3/T], determined in Section 9
- Greensand filter backwash flow rate, determined in Section 9
- Baseline groundwater concentrations [M/L^3], determined in Section 10
- Runoff yield [L^3/T/L^2] and baseflow yield [L^3/T/L^2], determined in Section 11

6.2.2 Water Balance Inputs

1. Beach_RO_Frac [-] – Fraction of precipitation that runs off from the beaches
    - Probabilistic input resampled each year
    - Normal distribution (mean = 0.195; standard deviation = 0.043)
2. Beach_BNT_RO_Frac [-] – Fraction of precipitation that runs off from the bentonite-amended beaches
    - Probabilistic input resampled each year
    - Truncated normal distribution (minimum = 0; mean = 0.126; standard deviation = 0.063)
3. Min_Climate_Infiltration [L/T] – Minimum infiltration for the tailings beaches and dams (created for model stability purposes; eliminates instances of zero as the denominator)
    - Deterministic input (0.1 in/yr)

4. Mine_Site_Flow_Rate [L^3/T] – Flow from the Mine Site WWTF to the FTB
   - Time-varying probabilistic input resampled every time-step
   - Normal distribution (time-varying mean and standard deviation values given in Table 1-8 of the WMDP-PS-Attachment B)
5. Contr_Watershed_2E [L^2] – Forested watershed area that contributes runoff to the Cell 2E pond
   - Time-varying deterministic input
   - Values given in Table 1-32 of the WMDP-PS-Attachment B
6. Cell2W_Bank_RO_Frac [L/T] – Fraction of precipitation that runs off from the Cell 2W embankments
   - Probabilistic input resampled each year
   - Normal distribution (mean = 0.248; standard deviation = 0.038)
7. Contr_Embank_Area_2E [L^2] – Area of the Cell 2W Embankments that contributes runoff to the pond in Cell 2E
   - Time-varying deterministic input
   - Values given in Table 1-32 of the WMDP-PS-Attachment B
8. Cell2E_Fines_RO_Frac [-] – Fraction of precipitation that runs off the fine tailings in Cell 2E
   - Probabilistic input resampled each year
   - Normal distribution (mean = 0.416; standard deviation = 0.064)
9. Cell2E_Coarse_RO_Frac [-] – Fraction of precipitation that runs off the coarse tailings in Cell 2E
   - Probabilistic input resampled each year
10. Normal distribution (mean = 0.373; standard deviation = 0.057)LTVSMC_Ksat_2E [L/T] – Saturated hydraulic conductivity of the three types of LTVSMC tailings in Cell 2E: “fines”, “coarse” and “other”
    - Deterministic inputs (Fines = 8.71 x 10^{-5} cm/s; Coarse = 2.24 x 10^{-3} cm/s; Other = 8.02 x 10^{-5} cm/s)
11. Pond_Seepage_Rate [L/T] – Time-varying seepage rate from the FTB pond (Cell 2E pond prior to combination with Cell 1E pond; combined 1E/2E pond seepage thereafter)
    - Time-varying deterministic input
    - Values given in Table 1-31 of the WMDP-PS-Attachment B
12. Cell1E_Pond_Surf_Area [L^2] – Existing surface area of the Cell 1E pond
    - Deterministic input (1,513,672 m^2)
13. Contr_Watershed_1E [L^2] – Forested watershed area that contributes runoff to the Cell 1E pond
    - Time-varying deterministic input
    - Values given in Table 1-32 of the WMDP-PS-Attachment B
14. Contr_Embank_Area_1E [L^2] – Area of the Cell 2W embankment that runs off to the cell 1E pond
    - Time-varying deterministic input
    - Values given in Table 1-32 of the WMDP-PS-Attachment B
15. LTVSMC_Ksat_1E.Fines [L/T] – Saturated hydraulic conductivity of the three types of LTVSMC tailings in Cell 1E: “fines”, “coarse” and “other”

- Deterministic inputs (Fines = 2.75 x 10^{-5} cm/s; Coarse = 2.40 x 10^{-3} cm/s; Other = 8.02 x 10^{-5} cm/s)

16. Cell1E_Fines_RO_Frac [-] – Fraction of precipitation that runs off the fine tailings in Cell 1E
    - Probabilistic input resampled each year
    - Normal distribution (mean = 0.501; standard deviation = 0.077)
17. Cell1E_Coarse_RO_Frac [-] – Fraction of precipitation that runs off the coarse tailings in Cell 1E
    - Probabilistic input resampled each year
    - Normal distribution (mean = 0.469; standard deviation = 0.072)
18. Rec_Bank_RO_Frac [-] – Fraction of precipitation that runs off the amended dams
    - Probabilistic input resampled each year
    - Truncated normal distribution (minimum = 0; mean = 0.126; standard deviation = 0.063)
19. Cell2E_Fines_RO_Frac [-] – Fraction of precipitation onto the fine tailings in Cell 2E which becomes runoff
    - Probabilistic input resampled each year
    - Normal distribution (mean = 0.416; standard deviation = 0.064)

6.2.3 Mass Transport Inputs

1. Realization_Flush_Load [M/M] – Constituent mass flushed per mass of LTVSMC tailings
    - Probabilistic, constituent-species inputs sampled at start of each realization
    - Beta distributions (means, standard deviations, minima and maxima given in Table 1-20 of the WMDP-PS-Attachment B)
2. N_Dam_Volume [L^3] – Total volume of bulk LTVSMC tailings in the North dam through time
    - Time-varying deterministic input
    - Values given in Table 1-23 of the WMDP-PS-Attachment B
3. LTVSMC_SG [-] – Specific gravity of the different classes of the LTVSMC tailings (“coarse”, “fine” and “other”)
    - Deterministic inputs (coarse = 2.80; fines = 2.90; other = 2.85)
4. LTVSMC_Porosity [-] – Porosity of the different classes of the LTVSMC tailings (“coarse”, “fine” and “other”)
    - Deterministic inputs (coarse = 0.412; fines = 0.493; other = 0.440)
5. SO4_LTVSMC_Release [M/M/T] – Sulfate release rate from existing LTVSMC tailings
    - Probabilistic, constituent-species inputs sampled at start of each realization
    - Beta distribution (mean = 1.87 mg/kg/week; standard deviation = 0.502 mg/kg/week; minimum = 0.813 mg/kg/week; maximum = 2.54 mg/kg/week; see also Table 1-19 of the WMDP-PS-Attachment B)
6. Coarse_Calib_Fact [-] – Calibration factor to modify the sulfate release rate from coarse LTVSMC tailings
    - Deterministic input (0.151)

7. Fine_Calib_Fact [-] – Calibration factor to modify the sulfate release rate from fine LTVSMC tailings
    - Deterministic input (0.207)
8. Sulfate_gen_ratio [mol SO_4/mol O_2] – Moles of sulfate produced per mole of oxygen consumed
    - Deterministic input (0.444 mol/mol)
9. Tortuosity [-] – Tortuosity factor
    - Deterministic input (0.273)
10. O2_Air_Diff [L^2/T] – Free diffusion coefficient of oxygen in air
    - Deterministic input (1.80×10^{-5} m^2/s)
11. C [-] – Empirical coefficient in the Elberling equation
    - Deterministic input (3.28)
12. O2_Water_Diff [L^2/T] – Free diffusion coefficient of oxygen in water
    - Deterministic input (2.20×10^{-9} m^2/s)
13. KH [-] – Henry's constant for oxygen
    - Deterministic input (33.9)
14. BNT_ResMoist [L^3/L^3] –Residual moisture content of the bentonite-amended tailings
    - Deterministic input (0.07)
15. BNT_Porosity [L^3/L^3] –Porosity of the bentonite-amended tailings
    - Deterministic input (0.36)
16. BNT_AirSuct [L^{-1}] –Air entry suction parameter for the bentonite-amended tailings
    - Deterministic input (0.005 cm^{-1})
17. BNT_VGBeta [-] – Van Genuchten beta parameter for the bentonite-amended tailings
    - Deterministic input (1.09)
18. BNT_VGGamma [-] – Van Genuchten gamma parameter, which is a function of the Van Genuchten beta parameter
    - Deterministic input (0.082569)
19. LTVSMC_ResMoist [-] – Residual moisture content of the LTVSMC tailings (“coarse”, “fine” and “other”)
    - Deterministic inputs (coarse = 0.041; fines = 0.059; other = 0.048)
20. LTVSMC_AirSuct [L^{-1}] – Air entry suction parameter for the LTVSMC tailings (“coarse”, “fine” and “other”)
    - Deterministic inputs (coarse = 0.24 cm^{-1}; fines = 0.001 cm^{-1}; other = 0.011 cm^{-1})
21. LTVSMC_VGBeta [-] – Van Genuchten beta parameter for the LTVSMC tailings (“coarse”, “fine” and “other”)
    - Deterministic inputs (coarse = 2; fines = 1.6 ; other = 2)
22. LTVSMC_VGGamma [-] – Van Genuchten gamma parameters for the LTVSMC tailings (“coarse”, “fine” and “other”)
    - Deterministic inputs (coarse = 0.5; fines = 0.375; other = 0.5)
23. Sulfate_Sulfide [M/M] – Mass-to-mass ratio of sulfate to sulfide
    - Deterministic input (2.9956)
24. LTVSMC_Calib_Fact [-] – Calibration factor (applied to each constituent) needed for the theoretical loading to match observed seepage data
    - Species-specific deterministic inputs

- Values given in Table 1-21 of the WMDP-PS-Attachment B

25. N_Outer_Dam_Area [L^2] – Area of the top and outer slope of the FTB's North dam
    - Time-varying deterministic input
    - Values given in Table 1-23 of the WMDP-PS-Attachment B
26. N_Dam_Flow_Dir [-] – Percentage of seepage from North dam that flows to each toe of the Tailings Basin
    - Deterministic input
    - Values given in Table 1-25 of the WMDP-PS-Attachment B
27. E_Outer_Dam_Area [L^2] – Area of the outer slope and top of the East dam
    - Time-varying deterministic input
    - Values given in Table 1-23 of the WMDP-PS-Attachment B
28. E_Dam_Flow_Dir [-] – Percentage of seepage from East dam that flows to each toe of the Tailings Basin
    - Deterministic input
    - Values given in Table 1-25 of the WMDP-PS-Attachment B
29. S_Outer_Dam_Area [L^2] – Area of the outer slope and top of the South dam
    - Time-varying deterministic input
    - Values given in Table 1-23 of the WMDP-PS-Attachment B
30. S_Dam_Flow_Dir [-] – Percentage of seepage from South dam that flows to each toe of the Tailings Basin
    - Deterministic input
    - Values given in Table 1-25 of the WMDP-PS-Attachment B
31. Crest_Elevation [L] – Elevation of the dam crests as the basin is developed
    - Time-varying deterministic input
    - Values given in Table 1-24 of the WMDP-PS-Attachment B
32. BASE_ELEV_North [L] – Base elevation of NorthMet tailings in Cell 2E
    - Deterministic input (1570 ft)
33. O2_Conc_Air [mol/L^3] – Concentration of oxygen in the air
    - Deterministic input (8.89 mol/m^3)
34. Dam_Transport_Time [T] – Subsurface transport time for flow and load from the dams of the FTB
    - Deterministic input (10 years)
35. Interior_Transport_Time [T] – Subsurface transport time for flow and loading from the NorthMet beaches and the coarse and fine interior LTVSMC tailings
    - Deterministic input (7 years)
36. Pond_Transport_Time [T] – Subsurface transport time for flow and load from under the Tailings Basin ponds
    - Deterministic input (5 years)
37. Erlang_Dispersion [-] – Erlang dispersion value
    - Deterministic input (25)
38. SO4_NMFine_Release [M/M/T] – Release rate of sulfate from NorthMet fine tailings
    - Probabilistic input sampled at start of each realization
    - Beta distribution (mean = 18.8 mg/kg/week; standard deviation = 2.87 mg/kg/week; minimum = 2.66 mg/kg/week; maximum = 23.2 mg/kg/week)

39. SO4_NMCoarse_Release [M/M/T] – Release rate of sulfate from NorthMet coarse tailings
    - Probabilistic input sampled at start of each realization
    - Beta distribution (mean = 11.9 mg/kg/week; standard deviation = 2.55 mg/kg/week; minimum = 4.37 mg/kg/week; maximum = 21.3 mg/kg/week)
40. NM_SG [-] – Specific gravity of the NorthMet tailings
    - Deterministic inputs (coarse = 3.0; fine = 3.0)
41. N_Beach_WT_Depth [L] – Depth to water table under the north flotation tailings beach
    - Time-varying deterministic input
    - Values given in Table 1-29 of the WMDP-PS-Attachment B
42. Beach_Elevation [L] – Elevation of the beaches as designed
    - Time-varying deterministic input
    - Values given in Table 1-24 of the WMDP-PS-Attachment B
43. N_Beach_Flow_Dir [-] – Percentage of north beach seepage that flows to each of the Tailings Basin toes
    - Time-varying deterministic input
    - Values given in Table 1-27 of the WMDP-PS-Attachment B
44. E_Beach_Flow_Dir [-] – Percentage of east beach seepage that flows to each of the Tailings Basin toes
    - Time-varying deterministic input
    - Values given in Table 1-27 of the WMDP-PS-Attachment B
45. S_Beach_Flow_Dir [-] – Percentage of south beach seepage that flows to each of the Tailings Basin toes
    - Time-varying deterministic input
    - Values given in Table 1-27 of the WMDP-PS-Attachment B
46. C_Beach_Flow_Dir [-] – Percentage of closure beach seepage that flows to each of the Tailings Basin toes
    - Time-varying deterministic input
    - Values given in Table 1-27 of the WMDP-PS-Attachment B
47. Cell2E_Areas [L^2] – Areas of the different tailings zones in Cell 2E (i.e. coarse, fine, other)
    - Time-varying deterministic input
    - Values given in Table 1-33 of the WMDP-PS-Attachment B
48. Cell2E_WT_Depths [L] – Depth to the phreatic surface under the LTVSMC tailings zones in Cell 2E (coarse, fine, and other)
    - Time-varying deterministic input
    - Values given in Table 1-34 of the WMDP-PS-Attachment B
49. Cell2E_Seepage_Direction [-] – Percentage of flow from each tailings zone that flows to each toe of the Tailings Basin
    - Time-varying deterministic input
    - Values given in Table 1-37 of the WMDP-PS-Attachment B
50. Initial_Pond_Volume [L^3] – Volume of the water currently in Cell 2E pond
    - Deterministic input (1800 acre-ft)

51. Initial_Pond_Concs_2E [M/ L^3] – Initial concentrations in the pond water in Cell 2E
    - Constituent-specific deterministic input
    - Values given in Table 1-44 of the WMDP-PS-Attachment B
52. Coarse_Weathering [M/L^2/T] – Weathering rates of coarse flotation tailings
    - Time-varying deterministic input
    - Values given in Table 1-17 of the WMDP-PS-Attachment B
53. Fines_Weathering [M/L^2/T] – Weathering rates of fine flotation tailings
    - Time-varying deterministic input
    - Values given in Table 1-17 of the WMDP-PS-Attachment B
54. Pond_DO_Mean [M/L^3] – Average dissolved oxygen concentration in the tailings basin ponds
    - Time-varying deterministic input
    - Monthly values given in Table 1-18 of the WMDP-PS-Attachment B
55. Pond_DO_SD [M/L^3] – Standard deviation of dissolved oxygen concentration in the tailings basin ponds
    - Time-varying deterministic input
    - Zero from November–March; 0.5 mg/L remainder of year (Table 1-18 of the WMDP-PS-Attachment B)
56. Pond_Seepage_Dir [-] – Percentage of pond seepage that flows to each of the tailings basin toes
    - Time-varying deterministic input
    - Values given in Table 1-31 of the WMDP-PS-Attachment B
57. Cell1E_Areas [L^2] – Areas of the different tailings zones in Cell 1E (i.e. coarse, fine, other)
    - Time-varying deterministic input
    - Values given in Table 1-33 of the WMDP-PS-Attachment B
58. Cell1E_WT_Depths [L] – Depth to the phreatic surface under the LTVSMC tailings zones in Cell 1E (coarse and fine)
    - Time-varying deterministic input
    - Values given in Table 1-34 of the WMDP-PS-Attachment B
59. Cell1E_Seepage_Direction [-] – Percent of flow that leaves the different classes of LTVSMC tailings in Cell 1E and travels to each toe of the FTB (coarse and fine)
    - Time-varying deterministic input
    - Values given in Table 1-39 of the WMDP-PS-Attachment B
60. Initial_Pond_Concs_1E [M/L^3] – Initial concentrations in the pond water in Cell 1E
    - Constituent-specific deterministic input
    - Values given in Table 1-44 of the WMDP-PS-Attachment B
61. Mine_Site_Conc [M/L^3] – Concentrations in water pumped from the Mine Site WWTF to the FTB
    - Time-varying probabilistic input resampled every time-step
    - Truncated normal distribution (minimum = 0 mg/L)
    - Time-varying average concentrations given in Table 1-9 of the WMDP-PS-Attachment B

- Time-varying standard deviation concentrations given in Table 1-10 of the WMDP-PS-Attachment B

6.3 Calculations

6.3.1 Water Balance Calculations

Tailings Beaches

Precipitation falling on the tailings beaches (calculated by Equation 3-2) either runs off, evapotranspires, or infiltrates into the tailings. These fluxes are calculated as follows.

Natural Runoff from Tailings Beaches [L/T] =
Monthly Precipitation [L/T] * **Beach Runoff Fraction** [-] **(6-1)**

The beach runoff fraction in this equation is equal to "Beach_RO_Frac" during operations, and after closure it is equal to "Beach_BNT_RO_Frac". This change accounts for the addition of a bentonite layer to the beaches.

The evaporation rate from the tailings beaches is the smaller of the following two calculated quantities:

Evaporation of Rainfall from Tailings Beaches [L/T] = **Monthly Precipitation** [L/T] – **Natural Runoff from Tailings Beaches** [L/T] – Min_Climate_Infiltration **(6-2a)**

and

Evaporation of Rainfall from Tailings Beaches [L/T] = **Monthly Precipitation** [L/T] * **Beach Evaporation Fraction** [-] **(6-2b)**

The evaporation fraction in Equation 6-2b is "Beach_Evap_Frac" during operations and after closure it is "Beach_BNT_Evap_Frac".

The infiltration rate is the remaining portion of rainfall after runoff and evaporation have been accounted for:

Rainfall Infiltration into Tailings Beaches [L/T] =
Monthly Precipitation – **Natural Runoff from Tailings Beaches** –
Evaporation of Rainfall from Tailings Beaches **(6-3)**

Water and tailings are discharged from the Beneficiation Plant to one of the four flotation tailings beaches as described in Section 5. During the first seven years of operations—the only period when separate ponds exist in Cells 1E and 2E—all water and tailings are discharged to Cell 2E subaqueously, or onto the North beach. As with rainfall, the water in the Plant discharge to the North beach evaporates, infiltrates into the underlying tailings, or runs off to the pond. The evaporation rate from the portion of the beach wetted by Plant discharge (i.e. the "delta") is:

Evaporation of Plant Discharge from Delta [L/T] =
Delta_Evap – **Evaporation of Rainfall from Tailings Beaches** **(6-4)**

The portion of the plant discharge infiltrating into the tailings is:

Infiltration of Plant Discharge into Tailings [L/T] =
Tailings Infiltration Capacity [L/T] – **Rainfall Infiltration into Tailings Beaches** **(6-5)**

The tailings infiltration capacity during operations is calculated by Equation 4-9, and after closure it is equal to "BNT_Ksat".

The volumetric infiltration rate for each beach is then calculated using this infiltration flux and the active beach area:

Plant Discharge Infiltration into Beach [L^3/T] = **Active Beach Area** [L^2] *
Infiltration of Plant Discharge into Tailings [L/T] **(6-6)**

The portion of the beach-directed Plant discharge which does not evaporate or infiltrate into the tailings beach runs off to one of the ponds:

Plant Discharge (Runoff to Pond) [L/T] =
(**Plant Discharge to Beach** [L^3/T] / **Active Beach Area** [L^2]) –
Evaporation of Plant Discharge from Delta –
Infiltration of Plant Discharge into Tailings **(6-7)**

Cell 2E Pond (Before Combining with Cell 1E Pond)

There are seven inflows to the Cell 2E pond: subaqueous Plant discharge; pumping from the Mine Site; pumping of untreated collected water back into the pond; direct precipitation onto the pond; and runoff from the surrounding forested watershed, tailings beaches, and the reclaimed LTVSMC ("Cell 2W") tailings basin. Each runoff inflow is calculated separately. The subaqueous plant discharge to the pond is calculated by Equation 5-11, and the pumping rate of untreated collected water into the pond is determined as indicated in Section 8 (see "*Routing of Collection System Water*" subsection). The uncertain inflow rate to the pond from the Mine Site WWTF ("Mine_Site_Flow_Rate") is estimated using a normal distribution and specified mean and standard deviation values.

The direct precipitation rate onto the pond is:

Direct Precipitation (Cell 2E Pond) [L^3/T] =
Monthly Precipitation [L/T] * **Pond Surface Area** [L^2], **(6-8)**

and the three runoff inputs to the pond are:

Watershed Runoff (Cell 2E Pond) [L^3/T] =
Runoff Yield [L^3/T/L^2] * **Contributing Area (Cell 2E Pond)** [L^2] , **(6-9a)**

where the contributing area is a deterministic, time-varying value ("Contr_Watershed_2E"),

Reclaimed Tailings Basin ("Cell 2W") Runoff (Cell 2E Pond) [L^3/T] =
Cell2W_Bank_RO_Frac [-] * **Monthly Precipitation** [L/T] *
Contr_Embank_Area_2E [L^2], **(6-9b)**

and

Beach Runoff (Cell 2E Pond) [L^3/T] =
Plant Discharge (Runoff to Pond) [L/T] * **Active Beach Area** [L^2] +
Natural Runoff from Tailings Beaches [L/T] * **Exposed North Beach Area** [L^2] +
Fine Tailings Runoff (Cell 2E) [L/T] * **Fine Tailings Area (Cell 2E)** [L^2] +
Coarse Tailings Runoff (Cell 2E) [L/T] * **Coarse Tailings Area (Cell 2E)** [L^2]
(6-9c)

The fine and coarse LTVSMC tailings runoff rates used to determine the rate of beach runoff in Equation 6-9c are determined as follows:

- When Equation 6-3 is applied to the tailings areas and the resulting infiltration rate is less than or equal to the saturated hydraulic conductivity of the tailings (i.e. "LTVSMC_Ksat_2E.Fines" and "LTVSMC_Ksat_2E.Coarse"), Equation 6-1 is used to calculate the total runoff rate from the LTVSMC tailings to the Cell 2E pond (using "Cell2E_Fines_RO_Frac" and "Cell2E_Coarse_RO_Frac" as the runoff fractions).
- If either the calculated fine or coarse infiltration rates (Equation 6-3) are greater than the corresponding saturated hydraulic conductivities of the tailings, the associated runoff rate is calculated by Equation 6-9d:

LTVSMC Tailings Runoff [L/T] = **Monthly Precipitation** –
Evaporation of Rainfall from Tailings –
Saturated Hydraulic Conductivity of Tailings **(6-9d)**

The total inflow to the Cell 2E pond is therefore the sum of these seven inflows:

Total Inflow (Cell 2E Pond) [L^3/T] =
Subaqueous Plant Discharge to FTB Pond + **Pumping from Mine Site** +
Direct Precipitation (Cell 2E Pond) + **Untreated Collected Flow (Cell 2E)** +
Watershed Runoff (Cell 2E Pond) + **Beach Runoff (Cell 2E Pond)** +
Reclaimed Tailings Basin ("Cell 2W") Runoff (Cell 2E Pond) **(6-10)**

There are only four outflows of water from the Cell 2E pond: evaporation, entrainment of pond water in newly-deposited flotation tailings, pond seepage, and pumping to Cell 1E. The rate of pond water loss via evaporation is:

Pond Evaporation (Cell 2E) [L^3/T] = Open_Water_Evap_OPS_Early *
Pond Surface Area * Annual_E_Variation (*current month*) **(6-11)**

and the pond seepage rate is:

Pond Seepage (Cell 2E) [L^3/T] = **Pond Surface Area** * Pond_Seepage_Rate **(6-12)**

Entrainment of pond water in the pore spaces within freshly deposited tailings is a function of the rate of change in the volume of tailings under the pond (calculated by Equation 4-13) and the tailings' porosity:

Pond Water Entrainment (Cell 2E) [L^3/T] =
Rate of Change in Tailings Volume [L^3/T] * Pond_Porosity **(6-13)**

The pumping rate from the Cell 2E pond to the Cell 1E pond is calculated by Equation 6-14 and has a prescribed upper limit of 10^6 gallons per minute (gpm). If this quantity is less than zero, no pumping occurs between the two ponds:

Pumping from Cell 2E Pond to Cell 1E Pond [L^3/T] =
Total Inflow (Cell 2E Pond) – **Pond Evaporation (Cell 2E)** –
Pond Seepage (Cell 2E) – **Pond Water Entrainment (Cell 2E)** –
(**Pond Design Volume** (t+1) – **Cell 2E Pond Volume**) / *dt* **(6-14)**

The total outflow rate from the Cell 2E pond is then equal to:

Total Outflow (Cell 2E Pond) [L^3/T] = **Pond Evaporation (Cell 2E)** +
Pond Seepage (Cell 2E) + **Pond Water Entrainment (Cell 2E)** +
Pumping from Cell 2E Pond to Cell 1E Pond **(6-15)**

Cell 1E Pond (Before Combining with Cell 2E Pond)

The Beneficiation Plant does not discharge to Cell 1E before the ponds combine. However, many of the other inflows to the Cell 1E pond are similar to those calculated for the Cell 2E pond. Direct precipitation onto the Cell 1E pond is calculated using Equation 6-8 (with the input variable "Cell1E_Pond_Surf_Area" used as the pond surface area term). Runoff to the pond from the surrounding forested watershed is calculated by Equation 6-9a using the contributing area to the Cell 1E pond ("Contr_Watershed_1E"). Runoff from the Cell 2W embankment is calculated with Equation 6-9b and the appropriate contributing area ("Contr_Embank_Area_1E"). The rate at which untreated collected water is pumped into the pond is determined as described in Section 8 (see "*Routing of Collection System Water*" subsection), and the rate of pumping from the Cell 2E pond is given by Equation 6-14.

The volumetric runoff rate from the LTVSMC tailings is calculated differently than for Cell 2E:

Tailings Runoff (Cell 1E Pond) [L^3/T] =
Fine Tailings Runoff (Cell 1E) [L/T] * **Fine Tailings Area (Cell 1E)** [L^2] +
Coarse Tailings Runoff (Cell 1E) [L/T] * **Coarse Tailings Area (Cell 1E)** [L^2]
(6-16)

The fine and coarse LTVSMC tailings runoff rates are determined using appropriately substituted values (i.e. "LTVSMC_Ksat_1E.Fines", "LTVSMC_Ksat_1E.Coarse", "Cell1E_Fines_RO_Frac", and "Cell1E_Coarse_RO_Frac") and the same criteria used in determining the runoff rates for Cell 2E (above).

The final inflow to the Cell 1E pond comes from backwashing of the Greensand filter at the FTB WWTP. The backwash from the previous time-step is sent to the Cell 1E pond, and the backwash rate at a given time step (Section 9) is calculated based on the total inflow rate to the WWTP.

Outflows from the 1E pond are evaporation, seepage, and pumping to the Beneficiation Plant for usage during ore processing. The evaporation and seepage rates are calculated using Equations 6-11 and 6-12, respectively, using the constant surface area of the existing Cell 1E pond and the constant seepage rate from the Cell 1E pond ("Cell1E_Pond_Surf_Area" and "Cell1E_Exist_Seepage" respectively). Pumping to the plant is the lesser of the quantities calculated by Equations 5-3a and 5-3b as long as both are positive; otherwise there is no pumping of pond water to the plant.

Combined Cell 1E/2E Pond

The Cell 1E and 2E ponds combine seven years after operations begin, and many of the inflows to the combined pond are identical to those for one or the other ponds when they were separate. Subaqueous discharge from the Beneficiation Plant to the combined pond is again calculated using Equation 5-11. Runoff from the Cell 2W embankment and the forested watershed are calculated in the same way as for the Cell 1E pond. Uncertain pumping from the Mine Site WWTF is estimated in the same way as for the pond in Cell 2E. Direct precipitation onto the pond and pumping of greensand filter backwash are calculated by Equations 6-8 and 9-4, respectively. Prior to closure, all of the water captured by the collection systems which is left untreated is pumped directly to the pond.

Runoff from the NorthMet tailings occurs from the active ("deltas") and exposed, inactive areas of all four beaches, as well as from the only exposed LTVSMC tailings remaining (coarse tailings in Cell 1E):

NorthMet Tailings Runoff to Cell 1E/2E Pond [L^3/T] =
Plant Discharge (Runoff to Pond, North Beach) [L/T] * **Active North Beach Area** +
Plant Discharge (Runoff to Pond, East Beach) [L/T] * **Active East Beach Area** +
Plant Discharge (Runoff to Pond, South Beach) [L/T] * **Active South Beach Area** +
Plant Discharge (Runoff to Pond, Closure Beach) [L/T] * **Active Closure Beach Area** +
Natural Runoff from North Beach [L/T] * **Exposed North Beach Area** +
Natural Runoff from East Beach [L/T] * **Exposed East Beach Area** +
Natural Runoff from South Beach [L/T] * **Exposed South Beach Area** +
Natural Runoff from Closure Beach [L/T] * **Exposed Closure Beach Area** +
Coarse LTVSMC Tailings Runoff (Cell 1E) [L/T] * **Coarse Tailings Area (Cell 1E)**
(6-17)

Treated water from the WWTP will be blended with untreated water from the FTB collection system, and a portion of this blended water is sent to the Cell 1E/2E pond during closure. The rate of this pumping is calculated by Equation 8-16.

There are a total of five outflows from the Cell 1E/2E pond: pond seepage, pumping to the Beneficiation Plant, evaporation, entrainment of pond water in tailings deposits, and removal of pond water for treatment. Pond seepage is calculated using Equation 6-12, and pumping to the plant is determined in the same manner as before the two ponds merged. Open water evaporation is calculated using Equation 6-11 with the following substitutions for the evaporation fraction: "Open_Water_Evap_OPS_Late" until closure, and "Open_Water_Evap_CLSR" thereafter. Entrainment of pond water occurs at the rate determined by Equation 6-13 until operations cease. Removal of pond water for treatment occurs as necessary after operations, during which time it is calculated by Equation 9-2a or 9-2b.

Tailings Basin Dams

Equations 6-1 through 6-3 are also used to determine the runoff, infiltration and evapotranspiration rates for the tailings dams by using appropriate substituted values (i.e. "Rec_Bank_RO_Frac" for the beach runoff fraction in Equation 6-1; and "Rec_Bank_Evap_Frac" for the beach evaporation fraction in Equation 6-2b). As was the case with the tailings beaches, the calculated infiltration rate is compared to the saturated hydraulic conductivity of the bentonite-amended dams (e.g. "LTVSMC_Ksat_2E.Other" for the north dam) and, if the infiltration rate from Equation 6-3 is greater than the conductivity value, then the infiltration rate is set equal to the conductivity and the runoff rate is calculated by Equation 6-9d.

The outflow rates from the north dam to each of the four FTB toes (i.e. north, northwest, west and south) is calculated based on the dam area and the percentage of the total seepage that flows to each toe ("N_Dam_Flow_Dir"):

Outflow from Unsaturated Zone (North Dam) $[L^3/T]$ = N_Outer_Dam_Area $[L^2]$ * **Infiltration Rate (North Dam)** [L/T] * N_Dam_Flow_Dir **(6-18)**

Similar outflow rates are calculated for the east and south dams using dam-specific areas ("E_Outer_Dam_Area" and "E_Dam_Flow_Dir"; "S_Outer_Dam_Area" and "S_Dam_Flow_Dir"). The actual percentages in the flow direction tables dictate that all of the north and east dam outflows from the unsaturated zones flow to the north toe, and all south dam outflow flows to the south toe. Runoff from the north and south dams flows to the north and south collection systems, respectively (Section 8). Runoff from the east dam flows to Mud Lake Creek (Section 11).

Unsaturated Cell 2E Embankment

Runoff from the Cell 2E embankment is determined using Equation 6-1 and the runoff fraction for the Cell 2W embankment ("Cell2W_Bank_RO_Frac"). Evapotranspiration from the embankment is the smaller of the quantities calculated by Equation 6-2a or 6-2b, with "Cell2E_Bank_Evap_Frac" used as the evaporation fraction in the latter. The embankment infiltration rate is then calculated by Equation 6-3. The infiltration rate is limited to the saturated hydraulic conductivity of the coarse LTVSMC tailings in Cell 2E ("LTVSMC_Ksat_2E.Coarse"), and when the calculated rate is greater than this limit the difference between the calculated value and the saturated conductivity is added to runoff.

6.3.2 Mass Transport Calculations

Flotation Tailings Basin Dams

The unsaturated portions of each of the three tailings dams (north, east, and south) generate constituent mass which ultimately reaches the FTB toes. The constituent mass loading rate to each dam's unsaturated zone is determined as a function of the leaching rate of mass from the LTVSMC tailings (used to construct the dams) and the amount of mass flushed while disturbing oxidized material. This "flushing load" is calculated for the North Dam by Equation 6-19a:

Flushing Load (North Dam, All Species) [M/T] = Realization_Flush_Load [M/M] * *d/dt*(N_Dam_Volume) [L^3/T] * **LTVSMC Bulk Density (Other)** [M/L^3] **(6-19a)**

The bulk density of the LTVSMC tailings used to construct the dam is calculated based on the specific gravity and porosity of the tailings:

LTVSMC Bulk Density (Other) [M/L^3] = LTVSMC_SG.Other [-] * ρ_{water} [M/L^3] * (1 – LTVSMC_Porosity.Other [-]) **(6-19b)**

Mass loading due to in situ leaching from the LTVSMC tailings is determined for each constituent by either sulfur-dependent release ratios, or specified concentrations. For the sulfur-dependent species (with the exception of Ba), the leaching rate is dependent upon the oxygen consumption and sulfur mass production rates, which are calculated as follows:

Oxygen Consumption Rate in Tailings (North Dam) [mol/L^3/T] = SO4_LTVSMC_Release [M/M/T] * 0.5 * (Coarse_Calib_Fact + Fine_Calib_Fact) * Temp_Factor * (1 – Frozen_Period [T] / 1 year) * LTVSMC_SG.Other [-] * ρ_{water} [M/L^3] / (*Molar Mass (SO_4)* [g/mol SO_4] * Sulfate_gen_ratio [mol SO_4/mol O_2] * LTVSMC_Porosity.Other / (1 – LTVSMC_Porosity.Other)) **(6-20)**

Sulfur Mass Production Rate (North Dam) [M/ L^2/T] = **Oxygen Consumption Rate in Tailings (North Dam)** [mol/L^3/T] * Sulfate_gen_ratio [mol SO_4/mol O_2]* 32.07 [g/mol] * LTVSMC_Porosity.Other [-] * ***Depth Term*** [L] **(6-21)**

The "Depth Term" in Equation 6-21 is either the smallest of the following three terms, or zero (if any of the terms are negative):

- **Depth of LTVSMC Tailings Within the North Dam** [L] = Crest_Elevation [L] – BASE_ELEV_North [L] **(6-22a)**
- **Depth to Water Table (North Dam)** [L] = N_Dam_WT_Depth [L] **(6-22b)**

and

- **Oxygen Penetration Depth** [L] =
  (2 * O2_Conc_Air [mol/L^3] * **Effective Diffusion Coefficient** [L^2/T] /
  Oxygen Consumption Rate in Tailings (North Dam) [mol/L^3/T]$)^{0.5}$ **(6-22c)**

The effective diffusion coefficient in Equation 6-22c is calculated as a function of the percent saturation in the bentonite layer by the Elberling equation:

Effective Diffusion Coefficient [L^2/T] =
Tortuosity * O2_Air_Diff * (1 – **Bentonite Layer Saturation** [%]$)^C$ +
(Tortuosity * **Bentonite Layer Saturation** [%] * O2_Water_Diff / KH) **(6-23)**

The bentonite layer saturation in this equation is a function of the hydraulic pressure head at the interface between the tailings and the dam's bentonite layer, as well as the predefined hydraulic parameters of the bentonite-amended tailings (i.e. residual moisture content, porosity, air entry parameter, and the Van Genuchten beta and gamma parameters):

Bentonite Layer Saturation [%] =
[BNT_ResMoist + (BNT_Porosity – BNT_ResMoist) /
(1 + BNT_AirSuct * (**Negative Boundary Pressure**$)^{BNT\_VGBeta})^{BNT\_VGGamma}$] /
BNT_Porosity **(6-24)**

The negative pressure head at the bentonite-tailings boundary is a function of the hydraulic parameters for the LTVSMC tailings, as well as the tailings' current degree of saturation:

Negative Boundary Pressure [L] =
((([(LTVSMC_Porosity.Other – LTVSMC_ResMoist.Other) /
(**LTVSMC Tailings Saturation** * LTVSMC_Porosity.Other –
LTVSMC_ResMoist.Other)$]^{1 / LTVSMC\_VGGamma.Other}$) – 1$)^{1 / LTVSMC_VGBeta.Other}$) /
LTVSMC_AirSuct.Other **(6-25)**

The LTVSMC tailings saturation ("TLNGS_Curr_Saturation") needed to solve Equation 6-25 is updated at the start of each year during the simulation:

LTVSMC Tailings Saturation [%] =
(**Steady State Saturation** – *Previous Year Tailings Saturation*) * *dt* / 1 year **(6-26)**

The LTVSMC tailings saturation has an initial value of 48% at *t*=0 and the steady state saturation is calculated using the following equations:

Steady State Saturation [%] = **Water Content** / LTVSMC_Porosity.Other **(6-27)**

Water Content [L^3/L^3] = LTVSMC_ResMoist.Other +
Effective Saturation * (LTVSMC_Porosity.Other – LTVSMC_ResMoist.Other) **(6-28)**

The effective saturation term in Equation 6-28 is calculated differently depending on the infiltration rate into the dam, which is calculated using the following set of equations:

Infiltration to Tailings Dam [L/T] =
Annual Precipitation – **Tailings Dam Runoff** – **Tailings Dam ET** **(6-29a)**

Tailings Dam Runoff [L/T] = **Annual Precipitation** * Cell2W_RO_Frac **(6-29b)**

The evaportranspiration rate from the tailings dam is the smaller of the following calculated values:

Tailings Dam ET [L/T] =
Annual Precipitation * (1 – Cell2W_RO_Frac) – Min_Climate_Infiltration **(6-29c)**

Tailings Dam ET [L/T] = **Annual Precipitation** * LTVSMC_Tailings_Evap_frac **(6-29d)**

If either of the following conditions is met, then the effective saturation of the LTVSMC tailings is equal to 1:

- During operations: the infiltration rate into the dam (Equation 6-29a) is equal to the saturated hydraulic conductivity of the LTVSMC tailings used to build the dam ("LTVSMC_Ksat_2E.Other")
- During closure: the infiltration rate into the dam is equal to the saturated hydraulic conductivity of the bentonite layer.

If neither of these conditions is met, then the effective saturation is less than one and is solved iteratively within GoldSim. An initial estimate of the effective saturation ("$S_{eff,\ estimated}\ (i)$") is made and used to calculate a relative (and unitless) hydraulic conductivity value ("$K_{rel,\ estimated}\ (i)$"). The exact relative hydraulic conductivity value ("$K_{rel,\ exact}$") is then calculated as the (unitless) ratio of the infiltration rate to the saturated hydraulic conductivity of the LTVSMC tailings used to build the dam ("LTVSMC_Ksat_2E.Other"). A second effective saturation estimate is made based on the previous one using the Newton-Raphson method:

$$S_{eff,\ estimated}(i+1)\ [-] = S_{eff,\ estimated}(i) + (K_{rel,\ estimated}(i) - K_{rel,\ exact}) / (\partial K_{rel} / \partial S_{eff}) \quad \textbf{(6-30a)}$$

where "$\partial K_{rel} / \partial S_{eff}$" is the change in relative hydraulic conductivity with respect to effective saturation evaluated at the current estimated value.

The Van Genuchten function for relative conductivity as a function of saturation is assumed:

$$K_{rel} = (S_{eff})^{0.5} * [1 - (1 - (S_{eff})^{1\ /\ \mathrm{LTVSMC\_VGGamma.Other}})^{\mathrm{LTVSMC\_VGGamma.Other}}]^2 \quad \textbf{(6-30b)}$$

and the differential of this equation with respect to saturation is:

$$\partial K_{rel} / \partial S_{eff} = 0.5 * K_{rel}/S_{eff} + 2 * (K_{rel} * (S_{eff})^{0.5})^{0.5} * [1 - S_{eff}^{1/\mathrm{LTVSMC\_VGGamma.Other}})]^{\mathrm{LTVSMC\_VGGamma.Other} - 1} * S_{eff}^{1/\mathrm{LTVSMC\_VGGamma.Other} - 1} \quad \textbf{(6-30c)}$$

After calculating a new effective saturation estimate using Equations 6-30a through 6-30c, S_{eff} is compared to the previous estimate. Additional iterations of this estimation procedure are initiated only when two sequential estimates differ by more than 0.0001. The effective saturation

value from the final iteration is then used when calculating Equation 6-28 and, subsequently, Equations 6-21 through 6-27 to determine the sulfur mass production rate.
In addition to their dependence upon the oxygen consumption and sulfur mass production rates, constituent loading rates for the sulfur-dependent species are also a function of release ratios relative to sulfide. These ratios can be found in Table 1-19 of the WMDP-PS-Attachment B. The two ratios given in terms of sulfate (Se and Zn) are multiplied by the mass ratio of sulfate to sulfur ("Sulfate_Sulfide") to determine the release ratios relative to sulfur. The leaching rates for the species directly dependent upon sulfur release (Ag, As, Cd, Co, Cu, Fe, Ni, Pb, Sb, Se, Tl, and Zn) are calculated by Equation 6-31:

Tailings Leaching Rate (North Dam, Sulfur-Dependent Species) [M/T] =
Sulfur Mass Production Rate (North Dam) [M/L^2/T] * N_Outer_Dam_Area [L^2] *
Sulfur Release Ratios (Species-to-S) [M/M] * LTVSMC_Calib_Fact [-] **(6-31)**

The leaching rates for Al, B, Be, Ca, Cl, Cr, K, Mn, Na and V are all calculated by Equation 6-32:

Tailings Leaching Rate (North Dam, Sulfur-Independent Species) [M/T] =
Infiltration Rate (North Dam) [L/T] * N_Outer_Dam_Area [L^3] *
LTVSMC Tailings Seepage Concentrations [M/L^3] * LTVSMC_Calib_Fact **(6-32)**

The tailings seepage concentrations used in this equation are uncertain values (identified in Table 1-19 of the WMDP-PS-Attachment B) and are based on water quality data from wells at the toes of the Tailings Basin.

Leaching rates for alkalinity, Ba, F and Mg are all calculated in unique ways:

Tailings Leaching Rate (North Dam, Alkalinity) [M/T] =
Infiltration Rate (North Dam) [L/T] * N_Outer_Dam_Area [L^2] *
(0.11 mg/L + 2.42 * **LTVSMC Tailings Seepage Concentration (Ca)**) **(6-33a)**

Tailings Leaching Rate (North Dam, Ba) [M/T] =
Infiltration Rate (North Dam) [L/T] * N_Outer_Dam_Area [L^2] *
10^(-0.32 * log(**Sulfur Mass Production Rate (North Dam)** * Sulfate_Sulfide /
Infiltration Rate (North Dam)) – 0.87) [mg/L] **(6-33b)**

Tailings Leaching Rate (North Dam, F) [M/T] =
Infiltration Rate (North Dam) [L/T] * N_Outer_Dam_Area [L^2] *
[10^(-0.298 * log(**LTVSMC Tailings Seepage Concentration (Ca)** [mg/L]) – 0.817)] *
LTVSMC_Calib_Fact **(6-33c)**

Tailings Leaching Rate (North Dam, Mg) [M/T] = **Infiltration Rate (North Dam)** [L/T] *
N_Outer_Dam_Area [L^2] * **LTVSMC Tailings Seepage Concentration (Ca)** *
Magnesium-to-Calcium Ratio * LTVSMC_Calib_Fact **(6-33d)**

The magnesium-to-calcium ratio is also given in Table 1-19 of the WMDP-PS-Attachment B. The total rate of constituent removal from the North Dam tailings for each species is then the sum of the flushing load and leaching load rates:

Total Loading Rate (North Dam, All Species) [M/T] =
Flushing Load (North Dam, All Species) +
Tailings Leaching Rate (North Dam, All Species) **(6-34)**

The volume of the cell used to represent the north dam's unsaturated zone is:

Unsaturated Zone Water Volume (North Dam) [L^3] =
0.5 * N_Outer_Dam_Area [L^2] * *Depth Term* [L] * LTVSMC_Porosity.Other *
LTVSMC Tailings Saturation **(6-35)**

The "Depth Term" in this equation is the smaller of two values calculated by Equations 6-22a and 6-22b.

All of the constituent loading from the north dam flows to the north toe of the FTB. The mass loading rate for each constituent is the product of the volumetric outflow rate (Equation 6-18) and the north dam unsaturated zone concentrations. Before reaching the north toe, however, a ten-year lag (as specified in the "Dam_Transport_Time" input variable) and Erlang dispersion value of 25 ("Erlang_Dispersion") are applied to this loading.

The constituent mass loading rates for the east and south dams are calculated similarly to the procedure described above for the north dam.

Tailings Beaches (Comprised of NorthMet Tailings)

Loading from the four tailings beaches (i.e. north, east, south and closure) to the underlying, unsaturated material is generally calculated similarly to the loading from dams to their underlying material. One major difference is that loading from the beaches does not have the "flushing" component calculated by Equation 6-19a. Therefore, the source of all constituent mass loading from the NorthMet flotation tailings is in-situ leaching, which is calculated as follows:

The oxygen consumption rate is calculated by Equation 6-36, which differs slightly from Equation 6-20:

Oxygen Consumption Rate in Tailings (N. Beach) [mol/L^3/T] = (SO4_NMFine_Release *
Perc_Fines_Retained + SO4_NMCoarse_Release * (1 – Perc_Fines_Retained)) *
Temp_Factor * (1 – Frozen_Period / 1 year) * NM_SG * ρ_{water} /
(*Molar Mass* (SO_4) * Sulfate_gen_ratio * Beach_Porosity / (1 – Beach_Porosity))
(6-36)

The sulfur mass production rate is subsequently calculated by Equation 6-21, with the NorthMet tailings porosity ("Beach_Porosity", introduced in Section 4) substituted for the LTVSMC tailings porosity ("LTVSMC_Porosity.Other"). The "Depth Term" in Equation 6-21 is the smallest of three quantities: (1) the total depth of NorthMet tailings (calculated by Equation 6-22a, "Beach_Elevation" substituted for "Crest_Elevation"); (2) the water table depth ("N_Beach_WT_Depth"); and (3) the oxygen penetration depth calculated by Equation 6-22c.

After closure the effective diffusion coefficient is calculated by Equation 6-23; the bentonite layer saturation is calculated by Equation 6-24; and the negative boundary pressure is calculated by Equation 6-25 with the following substitutions:

- "Beach_Porosity" is substituted for "LTVSMC_Porosity.Other"
- "TLNGS_ResMoist" (calculated in Section 4) is substituted for "LTVSMC_ResMoist.Other"
- The NorthMet Tailings Saturation (defined as described below) is substituted for the LTVSMC Tailings Saturation
- "TLNGS_VGGamma" is substituted for "LTVSMC_VGGamma.Other"
- "TLNGS_VGBeta" is substituted for "LTVSMC_VGBeta.Other", and
- "TLNGS_AirSuct" is substituted for "LTVSMC_AirSuct.Other".

Before closure, the effective diffusion coefficient is again calculated using the Elberling equation:

Effective Diffusion Coefficient $[L^2/T]$ =
Tortuosity * O2_Air_Diff * (1 – **NorthMet Tailings Saturation**)^C +
(Tortuosity * **NorthMet Tailings Saturation** * O2_Water_Diff / KH) **(6-37)**

The NorthMet tailings saturation—needed to solve Equation 6-37 before closure and Equations 6-23 through 6-25 after closure—is determined differently than its dam counterpart. Instead of using the steady-state saturation to calculate the tailings saturation by Equation 6-26, the steady-state saturation itself—calculated by Equation 6-27—is lagged by one year, dispersed using an Erlang dispersion factor of 1, and is then utilized as the tailings saturation value in Equation 6-37. The water content in Equation 6-27 is again calculated using Equation 6-28, with NorthMet tailings-specific values substituted for the residual moisture content and porosity ("TLNGS_ResMoist" and "Beach_Porosity").

The effective saturation in Equation 6-28 also varies with the infiltration rate through the beaches. If either of the follow conditions is met, then the effective saturation of the tailings is equal to 1:

- During operations: the infiltration rate into the beach (calculated by Equation 6-38) is equal to the saturated hydraulic conductivity of the NorthMet tailings (Equation 4-9), or
- During closure: the beach infiltration rate is equal to the saturated hydraulic conductivity of the bentonite layer ("BNT_Ksat").

When neither condition is met, the effective saturation is solved iteratively, much like the analogous values for the dams. The initial effective saturation estimate is made, and the corresponding relative hydraulic conductivity value is calculated using Equation 6-30b and the initial saturation estimate. A new estimate is made using Equations 6-30a through 6-30c in conjunction with the exact relative hydraulic conductivity value, which is the ratio of the area-weighted average beach infiltration rate to the saturated hydraulic conductivity of the NorthMet tailings (calculated by Equation 4-9). Before closure, the area-weighted beach infiltration rate is:

Average Infiltration Rate (North Beach) [L^3/T] =
(**K_{sat} (Beaches)** [L/T] * **Active Beach Area** [L^2] +
Rainfall Infiltration into Tailings Beaches (North Beach) [L/T] *
(**Exposed North Beach Area** [L^2] – **Active Beach Area** [L^2])) /
Exposed North Beach Area [L^2] **(6-38)**

After closure, the average beach infiltration rate is equal to the rainfall infiltration rate calculated by Equation 6-3. The new effective saturation value is compared to the original estimate and if the difference exceeds the specified tolerance (which is again 0.0001), another iteration loop is initiated. When the tolerance is ultimately satisfied, all of the values needed to calculate the sulfur mass production rate can be calculated. Leaching rates from the tailings under the beaches are then calculated for nineteen of the sulfur-dependent constituents (Ag, As, Ba, Be, Ca, Cd, Co, Cu, K, Mg, Mn, Na, Ni, Pb, Sb, Se, Tl, V and Zn) by Equation 6-39.

Tailings Leaching Rate (North Beach, Sulfur-Dependent Species) [M/T] =
Sulfur Mass Production Rate (North Beach) * **Exposed North Beach Area** *
(**Release Ratio (Constituent-to-S, Fine Tailings)** [M/M] * Perc_Fines_Retained +
Release Ratio (Constituent-to-S, Coarse Tailings) [M/M] * (1 – Perc_Fines_Retained))
(6-39)

The fine and coarse release ratios for each constituent are either given directly in Tables 1-13 and 1-14 of the WMDP-PS-Attachment B, or are calculated using the ratios specified in the tables and the release ratio of the intermediate species. For example:

Release Ratio (Be-to-S, Fine Tailings) = **Release Ratio (Be-to-K, Fine Tailings)** *
Release Ratio (K-to-S, Fine Tailings) **(6-40)**

Aluminum and iron leaching rates are dependent upon the release ratios of multiple species:

Tailings Leaching Rate (North Beach, Al) [M/T] =
Sulfur Mass Production Rate (North Beach) * **Exposed North Beach Area** *
[(**Release Ratio (Al-to-Ca, Fine Tailings)** * **Release Ratio (Ca-to-S, Fine Tailings) +**
Release Ratio (Al-to-Na, Fine Tailings) * **Release Ratio (Na-to-S, Fine Tailings)**) *
Perc_Fines_Retained +
(**Release Ratio (Al-to-Ca, Coarse Tailings)** * **Release Ratio (Ca-to-S, Coarse Tailings) +**
Release Ratio (Al-to-Na, Coarse Tailings) * **Release Ratio (Na-to-S, Coarse Tailings)**) *
(1 – Perc_Fines_Retained)] **(6-41)**

Tailings Leaching Rate (North Beach, Fe) [M/T] =
Sulfur Mass Production Rate (North Beach) * **Exposed North Beach Area** *
[(**Release Ratio (Fe-to-Mg, Fine Tailings)** * **Release Ratio (Mg-to-S, Fine Tailings) +**
Release Ratio (Fe-to-S, Fine Tailings)) * Perc_Fines_Retained +
(**Release Ratio (Fe-to-Mg, Coarse Tailings)** * **Release Ratio (Mg-to-S, Coarse Tailings) +**

Release Ratio (Fe-to-S, Coarse Tailings)) * (1 – Perc_Fines_Retained)]
(6-42)

Leaching rates for alkalinity and fluoride are calculated uniquely:

Tailings Leaching Rate (North Beach, Alkalinity) [M/T] =
Average Infiltration Rate (North Beach) [L/T] * **Exposed North Beach Area** *
(0.110 mg/L + (2.42 * **Tailings Leaching Rate (North Beach, Ca)** /
(**Average Infiltration Rate (North Beach)** [L/T] * **Exposed North Beach Area**)))
(6-43)

and

Tailings Leaching Rate (North Beach, F) [M/T] =
Average Infiltration Rate (North Beach) [L/T] * **Exposed North Beach Area** *
10^[-0.298 * log(**Tailings Leaching Rate (North Beach, Ca)** [ton/yr] /
(**Average Infiltration Rate (North Beach)** [in/yr] *
Exposed North Beach Area [acre])) – 0.817] **(6-44)**

The result of the exponential term in Equation 6-44 is expressed in [mg/L].

No chloride is released from either the fine or coarse tailings. The leaching rates for the two remaining species (B and Cr) are a function of constant concentrations in the leachate given in Tables 1-13 (fine tailings) and 1-14 (coarse tailings) of the WMDP-PS-Attachment B:

Tailings Leaching Rate (North Beach, Sulfur-Independent Species) [M/T] =
Average Infiltration Rate (North Beach) [L/T] * **Exposed North Beach Area** [L^2] *
(**Release Concentration (Fine Tailings)** [M/L^3] * Perc_Fines_Retained +
Release Concentrations (Coarse Tailings) [M/L^3] * (1 – Perc_Fines_Retained))
(6-45)

In addition to the mass leached from the NorthMet flotation tailings themselves (described above), the unsaturated zones beneath the beaches also contain mass and water derived from Beneficiation Plant discharge that infiltrates on the beaches. The volumetric infiltration rate of this discharge is calculated by Equation 6-6 and has the geochemical composition of Plant discharge.

The volume of unsaturated zone water beneath the north beach is calculated by Equation 6-46:

Unsaturated Zone Water Volume (North Beach) [L^3] =
Exposed North Beach Area [L^2] * *Depth Term* [L] * Beach_Porosity *
NorthMet Tailings Saturation **(6-46a)**

The "Depth Term" is again the smaller of the following quantities:

Depth of NorthMet Tailings (North Beach) =
Beach_Elevation – BASE_ELEV_North **(6-46b)**

and

Depth to Water Table (North Beach) = N_Beach_WT_Depth **(6-46c)**

The constituent mass loading rates from the east, south and closure beaches are calculated similarly to those outlined above, with substitutions for the beach-specific parameters.

Just as was the case with percolation through the FTB dams, the only outflow from the unsaturated zones under the FTB beaches is seepage to the FTB toes. This flow—and the associated constituent mass loading—is lagged by seven years (as specified by the "Interior_Transport_Time" variable) and dispersed using the same dimensionless Erlang dispersion value as that used for the FTB dams (25). The resulting time-series of loadings from each beach's unsaturated zone is sent to one or more of the FTB toes based on the percentages specified in the beach-specific flow direction tables ("N_Beach_Flow_Dir", "E_Beach_Flow_Dir", "S_Beach_Flow_Dir" and "C_Beach_Flow_Dir").

Unsaturated Embankment in Cell 2E (Comprised of LTVSMC Tailings)

The volume of water in the unsaturated embankments is the product of the embankment area ("Cell2E_Areas.Other"), water table depth ("Cell2E_WT_Depths.Other"), porosity ("LTVSMC_Porosity.Coarse") and percent saturation (calculated by Equation 6-26, as described below).

Constituent mass loading from the unsaturated Cell 2E embankment to the Tailings Basin toes comes entirely from in-situ leaching of the LTVSMC tailings used to construct the embankment. Calculation of these leaching rates follows generally the same procedure (described above) for the tailings beaches. However, because the embankments are constructed from coarse LTVSMC tailings, the embankment leaching calculations differ slightly from those for the beaches.

The oxygen consumption rate is:

Oxygen Consumption Rate in Tailings (Cell 2E Embankment) [mol/L^3/T] =
SO4_LTVSMC_Release [M/M/T] * Coarse_Calib_Fact * Temp_Factor *
(1 – Frozen_Period [T] / 1 year) * LTVSMC_SG.Coarse [-] * ρ_{water} [M/L^3] /
(*Molar Mass (SO_4)* [g/mol SO_4] * Sulfate_gen_ratio [mol SO_4/mol O_2] *
LTVSMC_Porosity.Coarse / (1 – LTVSMC_Porosity.Coarse)) **(6-47)**

The sulfur mass production rate is calculated by Equation 6-21 using the embankment oxygen consumption rate (Equation 6-47) and the porosity of coarse LTVSMC tailings ("LTVSMC_Porosity.Coarse"). The depth term used to calculate the sulfur mass production rate is again the smaller of two quantities: the specified depth to the water table in the Cell 2E embankment ("Cell2E_WT_Depths.Other"), and the oxygen penetration depth (calculated by Equation 6-22c). The effective diffusion coefficient used to calculate the oxygen penetration depth is calculated using Equation 6-23 and the percent saturation of the embankment instead of the bentonite layer, which is calculated using the same iterative procedure described previously for the tailings dams (i.e. Equations 6-26 through 6-30c and their associated criteria), with the following exceptions:

- The LTVSMC tailings in Cell 2E embankment are assigned an initial saturation of 28.2%, and the percent saturation is calculated by Equation 6-26 after *t*=0.
- The coarse tailings residual soil moisture ("LTVSMC_ResMoist.Coarse") and porosity ("LTVSMC_Porosity.Coarse") are substituted for the "other" values in Equations 6-27 and 6-28.
- The effective saturation in Equation 6-28 is only equal to one when the embankment infiltration rate (calculated as described in the "*Unsaturated Cell 2E Embankment*" water balance subsection of this section) is equal to the saturated hydraulic conductivity of the coarse LTVSMC tailings ("LTVSMC_Ksat_2E.Coarse").
- The Van Genuchten gamma parameter for coarse tailings ("LTVSMC_VGGamma.Coarse") is substituted for the analogous "other" value in Equations 6-30b and 6-30c.

Release rates from the LTVSMC tailings in the Cell 2E embankment are identical to those calculated for the dams (i.e. Equations 6-31 through 6-33d), except that substitutions are made for the embankment infiltration rate and area ("Cell2E_Areas.Other").

Mass loading from the embankments' unsaturated zone is lagged by ten years (based on the dam transport time), dispersed (Erlang dispersion value = 25), and is directed to the various Tailings Basin toes based on the percentages given in the flow direction input table ("Cell2E_Seepage_Direction.Other").

Coarse LTVSMC Tailings in Cell 2E

Leaching rates from the coarse tailings in Cell 2E are calculated similarly to those for the unsaturated embankment, with the following differences:

- The coarse tailings area ("Cell2E_Areas.Coarse") replaces the "other" tailings area ("Cell2E_Areas.Other").
- The water table depths used are those specified in the input variable "Cell2E_WT_Depths.Coarse".
- The coarse tailings runoff fraction ("Cell2E_Coarse_RO_Frac") and evaporation fraction ("LTVSMC_Tailings_Evap_frac") are used to determine the runoff and evaporation rates in Equations 6-1 through 6-2b.

The mass loadings from the coarse LTVSMC tailings are lagged by the interior transport time (seven years), dispersed (Erlang dispersion value = 25) and are divided amongst the four Tailings Basin toes using the flow direction input table ("Cell2E_Seepage_Direction.Coarse").

Fine LTVSMC Tailings in Cell 2E

The fine tailings leaching rates are also calculated in a similar manner to those for the unsaturated embankments. As with the coarse tailings area (above), values are substituted for the fine tailings area ("Cell2E_Areas.Fines"), water table depths ("Cell2E_WT_Depths.Fines"), and runoff fraction ("Cell2E_Fines_RO_Frac") to make these calculations. Additional substitutions are also made for the following tailings parameters:

- Porosity (“LTVSMC_Porosity.Fines”)
- Specific gravity (“LTVSMC_SG.Fines”)
- Residual soil moisture (“LTVSMC_ResMoist.Fines”)
- Van Genuchten gamma parameter (“LTVSMC_VGGamma.Fines”)
- Saturated hydraulic conductivity (“LTVSMC_Ksat_2E.Fines”)

The difference in particle size between the fine and coarse tailings in the embankment affects the percent saturation of the fine tailings, which are assigned an initial saturation of 57.78% and subsequently calculated by Equation 6-26.

Mass loading to the Tailings Basin toes from the fine tailings in Cell 2E is lagged by the interior transport time (seven years), dispersed (Erlang dispersion value = 25), and all of the water and mass are routed to the north toe (as specified in the “Cell2E_Seepage_Direction.Fines” flow direction table, see Table 1-37 of the WMDP-PS-Attachment B).

Cell 2E Pond (Before Combining with Cell 1E Pond)

The initial mass in the pond is the product of the initial volume (“Initial_Pond_Volume”) and concentrations (“Initial_Pond_Concs_2E”) of the pond.

Constituent mass loading to the Cell 2E pond is the sum of loading from watershed runoff, weathering of north beach tailings, untreated FTB seepage that is pumped back into the pond, and inflows from the Mine Site WWTF and Beneficiation Plant. Watershed loading is determined as a function of the forested contributing area to the Cell 2E pond (“Contr_Watershed_2E”):

Loading from Watershed (Cell 2E Pond) [M/T] = Contr_Watershed_2E [L^2] *
(**Runoff Yield** [$L^3/T/L^2$] * **Surface Runoff Concentrations** [M/L^3] +
Baseflow Yield [$L^3/T/L^2$] * **Baseline Groundwater Concentrations** [M/L^3]) **(6-48)**

The runoff and baseflow yields are calculated as indicated in Section 11. The surface runoff concentrations are an uncertain input defined by a log-normal distribution with the mean and standard deviations values given in Table 1-6 of the WMDP-PS-Attachment B. Baseline groundwater concentrations are determined as described in Section 10.

Tailings beach weathering rates (“Coarse_Weathering” and “Fine_Weathering”) are deterministic inputs given in Table 1-17 of the WMDP-PS-Attachment B. The resultant mass loading rates to the Cell 2E pond from the north beach are then determined based on the fraction of tailings present on the beach that are fine:

Loading from Tailings Weathering (Cell 2E Pond) [M/T] =
Exposed North Beach Area [L^2] *
(Fines_Weathering [$M/L^2/T$] * Perc_Fines_Retained +
Coarse_Weathering [$M/L^2/T$] * (1 – Perc_Fines_Retained)) **(6-49)**

Flow to the FTB pond from the Mine Site WWTF occurs at the volumetric rate described earlier in this section. The concentration assigned to this inflow ("Mine_Site_Conc") is defined by a truncated normal distribution (minimum of 0 mg/L) with the time-varying mean values given in Table 1-9 of the WMDP-PS-Attachment B, and the time-varying standard deviation values in Table 1-10 of the WMDP-PS-Attachment B.

Mass loading from the Beneficiation Plant is equal to the products of the Plant discharge rates—subaqueous discharge (Section 5) and runoff of discharge onto beaches (Section 6)—and the calculated Plant discharge concentrations (Section 5). The final source of constituent mass loading to the pond—untreated water from the interception system that is pumped back into the pond—occurs at the rate indicated in Section 8 ("*Routing of Collection System Water*" water balance subsection).

Mass outflows from the Cell 2E pond include seepage, entrainment of pond water in recently deposited tailings, and pumping of pond water to the Cell 1E pond. Constituent mass is removed from the pond at loading rates equal to the product of the pond concentrations and the volumetric outflow rates (Equations 6-12, 6-13 and 6-14, respectively). All constituent mass precipitated in the pond—which GoldSim determines automatically based on the concentration caps applied to the pond (see Section 12)—is removed from the pond during the same time-step. This mass is then considered to be entrained (and available for re-dissolution) within the tailings underlying the pond.

During transit through the FTB, pond seepage and entrained pond water acquire additional solute mass by means of the oxidation of sulfur within the tailings by oxygen dissolved in the infiltrating pond water. The release ratios for LTVSMC tailings (Table 1-19, WMDP-PS-Attachment B) used in Equation 6-31 are also used to calculate this supplemental leaching rate:

FTB Tailings Leaching Rate (Sulfur-Dependent Species) [M/T] =
Sulfur Mass Production Rate [M/T] *
Sulfur Release Ratios (Species-to-S) [M/M] * LTVSMC_Calib_Fact [-] **(6-50a)**

where:

FTB Sulfur Mass Production Rate [M/T] =
FTB Oxygen Consumption Rate in Tailings [M/T] *
Sulfate_gen_ratio [mol SO_4/mol O_2] * *Molar Mass (Sulfur)* / *Molar Mass (O_2)* **(6-50b)**

FTB Oxygen Consumption Rate in Tailings [M/T] = **Pond Seepage (Cell 2E)** [L^3/T] *
Pond Dissolved Oxygen Concentration [M/L^3] **(6-50c)**

The pond dissolved oxygen concentration is defined by a normal distribution with monthly-varying mean ("Pond_DO_Mean") and standard deviation values ("Pond_DO_SD").

All water and mass loading from the Cell 2E pond is:

- Dispersed using the same Erlang dispersion factor used for other areas (25),

- Lagged by five years from when it seeps into the tailings (per the "Pond_Transport_Time" variable), and
- Divided between the four Tailings Basin toes based on the time-varying percentages in the flow direction input tables ("Pond_Seepage_Dir").

Coarse LTVSMC Tailings in Cell 1E

Like those for the coarse tailings in Cell 2E, leaching rates from the coarse tailings in Cell 1E are calculated similarly to those for the Cell 2E unsaturated embankment. There are, however, several necessary substitutions prior to making these calculations:

- The 1E coarse tailings area ("Cell1E_Areas.Coarse") replaces the embankment area ("Cell2E_Areas.Other").
- The water table depths used are those specified in the input variable "Cell1E_WT_Depths.Coarse".
- The "Depth Term" used to calculate the sulfur mass production rate (by Equation 6-21) is the smaller of the quantities calculated by Equation 6-22c (oxygen penetration depth) and the depth to the water table ("Cell1E_WT_Depths.Coarse").
- The percent saturation of the tailings is 24.85% initially and calculated thereafter by Equation 6-26.
- The saturated hydraulic conductivity of the coarse tailings ("LTVSMC_Ksat_1E.Coarse") is used to determine the effective saturation of the tailings.
- The coarse tailings runoff fraction ("Cell1E_Coarse_RO_Frac") and evaporation fraction ("LTVSMC_Tailings_Evap_frac") are used to calculate the runoff and evaporation rates in Equations 6-1 through 6-2b.

The mass loadings from the coarse LTVSMC tailings are determined similarly to those for the coarse LTVSMC tailings in Cell 2E. Mass loading is lagged by the interior transport time (seven years), dispersed (Erlang dispersion value = 25), and divided amongst the four Tailings Basin toes using the percentages in the appropriate flow direction input table ("Cell1E_Seepage_Direction.Coarse", see Table 1-39 of the WMDP-PS-Attachment B).

Fine LTVSMC Tailings in Cell 1E

Leaching rates from the Cell 1E fine tailings are also calculated similarly to those in the Cell 2E embankment. As was the case with the Cell 2E fine tailings, however, different values are substituted for the tailings area ("Cell1E_Areas.Fines"), water table depths ("Cell1E_WT_Depths.Fines"), runoff fraction ("Cell1E_Fine_RO_Frac") and saturated hydraulic conductivity ("LTVSMC_Ksat_1E.Fines").

The percent saturation of the Cell 1E fine tailings is initially defined as 58.98% and is calculated by Equation 6-26 after t=0.

Mass loading to the Tailings Basin toes from this area is lagged by the interior transport time, dispersed (Erlang dispersion value = 25), and the water and mass are routed to the four Tailings Basin toes based on the percentages given in the "Cell1E_Seepage_Direction.Fines" flow direction table (Table 1-39 of the WMDP-PS-Attachment B).

Cell 1E Pond

The initial mass in the pond is the product of the initial pond volume ("Pond_1E_Volume") and concentrations ("Initial_Pond_Concs_1E"). Constituent mass is added to the pond based on the concentrations in the various source waters and the corresponding volumetric inflow rates from:

- Mine Site WWTF (flow rate = "Mine_Site_Flow_Rate"; concentrations = "Mine_Site_Conc")
- Subaqueous Plant discharge (Section 5)
- Plant discharge runoff from beaches (Section 6)
- Pumping from the Cell 2E pond prior to pond merging (Section 6)
- Untreated collection system water pumped back to the FTB pond (Section 8)
- Blended water (Section 8)
- Greensand filter backwash (Section 9)

Mass in the pond is also derived from , from the one-time addition of all mass in the Cell 2E pond when the ponds merge, from the contributing forested watershed, and from weathering of the exposed Flotation Tailings. Natural loading from the forested watershed to the pond is calculated using Equation 6-48 (with the Cell 1E contributing area, "Contr_Watershed_1E", substituted for the analogous Cell 2E area, "Contr_Watershed_2E"). Weathering of exposed tailings in the tailings beaches after the ponds combine is calculated similarly to the analogous weathering rate for the Cell 2E pond:

Loading from Tailings Weathering (Cell 1E Pond) [M/T] =
(Exposed North Beach Area [L^2] + **Exposed East Beach Area** [L^2] +
Exposed South Beach Area [L^2] + **Exposed Closure Beach Area** [L^2]) *
(Fines_Weathering [$M/L^2/T$] * Perc_Fines_Retained +
Coarse_Weathering [$M/L^2/T$] * (1 – Perc_Fines_Retained)) **(6-51)**

Constituent mass can be removed from the pond by means of:

- Pumping to the Beneficiation Plant for use in ore processing (flow rate determined by Equations 5-3a through 5-4)
- Pond seepage (flow rate calculated by Equation 6-12)
- Entrainment of water in tailings during deposition (flow rate calculated by Equation 6-13)
- Treatment of pond water after closure (flow rate calculated by Equation 9-2a or 9-2b)

The mass removal rate by any of these means is equal to the product of the pond concentration and the indicated flow rates. Mass is also removed from the Cell 1E pond by burial of precipitated mass during tailings deposition and by the pond overflowing. As with mass precipitated in the Cell 2E pond, mass precipitated in the Cell 1E pond is entrained within the tailings beneath the pond and is available for re-dissolution and transport. The pond overflow rate is calculated automatically by GoldSim based on the pond's water balance and the maximum pond volume, which is specified as 10,000 acre-feet during operations and 7,600 acre-feet in closure.

Like the Cell 2E pond seepage, mass contained within the Cell 1E and 1E/2E seepage is affected by dispersion (Erlang dispersion value = 25) and is lagged by the pond transport time (five years) before reaching one of the four FTB toes. Cell 1E seepage is directed to the Tailings Basin toes based on the percentages in Table 1-39 of the WMDP-PS-Attachment B (prior to the ponds combining at *t*=7 years), and the seepage direction percentages in Table 1-31 of the WMDP-PS-Attachment B determine the amount of pond seepage reaching each toe after the two ponds combine.

6.4 Output

The Flotation Tailings Basin Model ultimately calculates the following flows along with their associated constituent concentrations and loads:

- Pond seepage and unsaturated infiltration to the tailings basin toes
- Pond overflow

The model also calculates the following quantities used by other models:

- FTB pond volume
- Direct precipitation onto the pond

7 Cell 2W Model

7.1 Purpose

This model is used to simulate water flow and mass transport from the LTVSMC tailings in Cell 2W. The model calculates water flows and associated constituent mass loads for all constituents that are routed to other component models, including models for the Seepage Containment Systems, Hydrometallurgical Residue Facility, and Flotation Tailings Basin.

7.2 Input

7.2.1 Inputs from Other Models

- Monthly precipitation [L/T], determined in Section 3

7.2.2 Water Balance Inputs

1. LTVSMC_Ksat_2W [L/T] – Saturated hydraulic conductivity of the three types of LTVSMC tailings in Cell 2W: "coarse", "fines" and "other"
    - Deterministic inputs (Fines = 1.1 x 10^{-4} cm/s; Coarse = 1.17 x 10^{-3} cm/s; Other = 8.02 x 10^{-5} cm/s)
2. Cell2W_Areas [L^2] – Areas of the different tailings zones in Cell 2W (i.e. coarse, fine, other)
    - Time-varying deterministic input
    - Values given in Table 1-33 of the WMDP-PS-Attachment B
3. Cell2W_Seepage_Direction [-] – Percent of flow from the tailings in Cell 2W to each toe of the Tailings Basin
    - Time-varying deterministic input
    - Values given in Table 1-35 of the WMDP-PS-Attachment B
4. Cell2W_RO_Frac [-] – Fraction of precipitation that runs off the coarse tailings in Cell 2W
    - Probabilistic input resampled each year
    - Normal distribution (mean = 0.074; standard deviation = 0.011)

7.2.3 Mass Transport Inputs

1. Cell2W_WT_Depths [L^2] – Depth to the phreatic surface under the LTVSMC tailings zones in Cell 2W (coarse, fine, and other)
    - Time-varying deterministic input
    - Values given in Table 1-34 of the WMDP-PS-Attachment B

7.3 Calculations

7.3.1 Water Balance Calculations

Unsaturated Embankment

The partitioning of precipitation falling onto the embankment into runoff, evapotranspiration and infiltration is governed by equations similar to Equations 6-1 through 6-3:

Runoff from Cell 2W Embankment [L/T] =
Cell2W_Bank_RO_Frac [-] * **Monthly Precipitation** [L/T] **(7-1)**

Evapotranspiration from the embankment is the smaller of these two quantities (analogous to Equations 6-2a and 6-2b):

Evapotranspiration from Cell 2W Unsaturated Embankment [L/T] =
Monthly Precipitation [L/T] – **Runoff from Cell 2W Embankment** [L/T] –
Min_Climate_Infiltration **(7-2a)**

and

Evapotranspiration from Cell 2W Unsaturated Embankment [L/T] =
Annual Precipitation [L/T] * Annual_E_Variation (*current month*) *
Cell2W_Bank_Evap_Frac **(7-2b)**

Infiltration is the remaining fraction of precipitation:

Rainfall Infiltration into Embankment [L/T] =
Monthly Precipitation – **Runoff from Cell 2W Embankment** –
Evapotranspiration from Cell 2W Unsaturated Embankment **(7-3)**

When this calculated infiltration exceeds the saturated hydraulic conductivity of Cell 2W coarse tailings ("LTVSMC_Ksat_2W.Coarse"), the infiltration rate is reduced to this conductivity value and the difference between the infiltration rate calculated by Equation 7-3 and the saturated conductivity is added to runoff (Equation 7-1). The resulting infiltration flux is then multiplied by the time-varying embankment area ("Cell2W_Areas.Other") to give the volumetric infiltration rate, which is divided amongst the Tailings Basin toes based on the flow-direction percentages in Table 1-35 of the WMDP-PS-Attachment B ("Cell2W_Seepage_Direction.Other"). As with the Cell 2E embankment, infiltration through the 2W embankment reappears at one or more of the Tailings Basin toes 10 years after falling as precipitation (i.e. it is lagged by the "Dam_Transport_Time" and dispersed using the global Erlang dispersion value of 25).

Runoff from the embankment flows to the West and Northwest collection systems (Section 8), and to the Cell 1E and Cell 2E ponds (Section 6).

Coarse Tailings

Runoff, evapotranspiration and infiltration rates for the coarse 2W tailings are calculated very similarly to those for the 2W embankment. Runoff is calculated by Equation 7-1 using the appropriate runoff fraction ("Cell2W_RO_Frac"). Evapotranspiration is the smaller of the following values:

Evapotranspiration from Cell 2W Coarse Tailings [L/T] =
Monthly Precipitation [L/T] – **Runoff from Cell 2W Coarse Tailings** [L/T] –
Min_Climate_Infiltration **(7-4a)**

and

Evapotranspiration from Cell 2W Coarse Tailings [L/T] = **Annual Precipitation** * Annual_E_Variation (*current month*) * LTVSMC_Tailings_Evap_frac **(7-4b)**

The infiltration rate is then calculated using Equation 7-3 with these runoff and evapotranspiration rates. The saturated hydraulic conductivity of coarse LTVSMC tailings ("LTVSMC_Ksat_2W.Coarse") is again imposed as an upper limit to the infiltration rate and, if necessary, the infiltration and runoff rates are updated to reflect this restriction. The infiltration flux is then used to determine the volumetric infiltration rate by multiplying by the coarse tailings area ("Cell2W_Areas.Coarse"). This volumetric rate is divided between the Tailings Basin toes using the flow direction table ("Cell2W_Seepage_Direction.Coarse", Table 1-35 of the WMDP-PS-Attachment B), lagged by the interior transport time (seven years) and dispersed using the global Erlang dispersion value (25).

Runoff from the coarse tailings flows onto the fine tailings downslope.

Fine Tailings

Because the fine tailings area is internally draining (i.e. it is a closed basin), there is no runoff component of the precipitation budget. Thus, the evaporation flux is not calculated as above. It is instead the smaller of the following quantities:

Evapotranspiration from Cell 2W Fine Tailings [L/T] = **Monthly Precipitation** + (**Runoff from Cell 2W Coarse Tailings** * Cell2W_Areas.Coarse / Cell2W_Areas.Fines) – Min_Climate_Infiltration **(7-5a)**

and

Evapotranspiration from Cell 2W Fine Tailings [L/T] = **Annual Precipitation** * Annual_E_Variation (*current month*) * LTVSMC_Tailings_Evap_frac **(7-5b)**

Infiltration is then determined to be the smaller of two values: the saturated hydraulic conductivity of the tailings ("LTVSMC_Ksat_2W.Fines") and:

Rainfall Infiltration into Fine Tailings [L/T] = **Monthly Precipitation + Runoff from Cell 2W Coarse Tailings * Cell2W_Areas.Coarse / Cell2W_Areas.Fines** – **Evapotranspiration from Cell 2W Fine Tailings** **(7-6)**

The volumetric infiltration rate is calculated (using the infiltration flux and the fine tailings area, "Cell2W_Areas.Fines") and divided between the Tailings Basin toes using the flow direction table in Table 1-35 of the WMDP-PS-Attachment B ("Cell2W_Seepage_Direction.Fines"). This infiltration is then lagged by the interior transport time (seven years) and dispersed using the global Erlang dispersion value (25).

7.3.2 Mass Transport Calculations

Unsaturated Embankment

The mass loading rates from the unsaturated embankment are calculated similarly to those from the Cell 2E embankment (Section 6). The volume of water in the unsaturated embankment is the product of the embankment area ("Cell2W_Areas.Other"), water table depth ("Cell2W_WT_Depths.Other"), porosity ("LTVSMC_Porosity.Coarse") and percent saturation (which is given an initial value of 32.83% at t=0 and calculated by Equation 6-26 thereafter).

The steady-state saturation value is calculated iteratively—as described for the Cell 2E embankment (Section 6)—using the same Van Genuchten parameters and the 2W hydraulic conductivity ("LTVSMC_Ksat_2W.Coarse").

The initial constituent masses present in the embankment are given in Table 1-52 of the WMDP-PS-Attachment B.

Release rates from the 2W embankment are calculated by Equations 6-31 through 6-33d with substitutions for the appropriate area ("Cell2W_Areas.Other") and infiltration rate (calculated as described in the water balance subsection of this section).

Coarse Tailings

The volume of water within and leaching rates from the Cell 2W coarse tailings are determined the same way as for the Cell 2E coarse tailings (Section 6). Substitutions are made for the tailings area ("Cell2W_Areas.Coarse"), water table depth ("Cell2W_WT_Depths.Coarse"), saturated hydraulic conductivity ("LTVSMC_Ksat_2W.Coarse"), and tailings saturation (which is assigned an initial value of 35.64% and subsequently calculated by Equation 6-26).

The initial masses of each constituent in the coarse tailings are also given in Table 1-52 of the WMDP-PS-Attachment B.

Fine Tailings

As with the Cell 2W embankment and coarse tailings, the fine tailings in Cell 2W are treated almost identically to the fine tailings in Cell 2E. Cell-specific values for the fine tailings area ("Cell2W_Areas.Fines"), depth of the water table ("Cell2W_WT_Depths.Fines") and saturated hydraulic conductivity ("LTVSMC_Ksat_2W.Fines") are substituted for the corresponding Cell 2E values. The percent saturation is assigned an initial value of 67.5% and is calculated by Equation 6-26 (after t=0).

The initial constituent masses for these tailings are also given in Table 1-52 of the WMDP-PS-Attachment B.

7.4 Output

The Cell 2W Model calculates the following flows used by other component models, along with their associated constituent concentrations and loads:

- Seepage to the four Tailings Basin toes
- Runoff to the West and Northwest Collection Systems

8 Flotation Tailings Basin Toes and Flow Collection Systems

8.1 Purpose

This portion of the model is used to simulate water flow and mass transport from the outward-draining portions of the Tailings Basin. The model calculates water flows and associated constituent mass loads for all constituents that are routed to other component models, including models for the inward-draining Tailings Basin areas, groundwater flow paths, and waste water treatment plant (WWTP).

8.2 Input

8.2.1 Inputs from Other Models

- Monthly precipitation [L/T], determined in Section 3
- FTB pond design volume [L^3], determined in Section 4
- Leakage rate from the HRF pond [L^3/T], determined in Section 5
- Subaqueous Beneficiation Plant discharge to the Flotation Tailings Basin pond, determined in Section 5
- Direct precipitation [L^3/T] on FTB ponds, determined in Section 6
- FTB pond volume [L^3], determined in Section 6
- Cell 2E embankment runoff flux [L/T], determined in Section 6
- Water flow and constituent mass loading from infiltration into Cell 1E and 2E tailings basin dams, determined in Section 6
- Water flow and constituent mass loading from infiltration into Cell 1E and 2E tailings beaches, determined in Section 6
- Water flow and constituent mass loading from infiltration into Cell 1E tailings, determined in Section 6
- Water flow and constituent mass loading from infiltration into Cell 2E tailings, determined in Section 6
- Water flow and constituent mass loading from pond seepage, determined in Section 6
- Water flow and constituent mass loading from infiltration into Cell 2W embankment and tailings, determined in Section 7
- Cell 2W embankment runoff rate [L/T], determined in Section 7
- WWTP capacity and the excess system water production rate, determined in Section 9
- Water flow and constituent mass loading from WWTP effluent discharged to the flow blender, determined in Section 9
- Pond water treatment rate, determined in Section 9
- Greensand filter backwash flow rate, determined in Section 9
- Water flow and constituent mass loading from the Tailings Basin to each Tailings Basin toe, determined in Section 10
- Runoff yield [L^3/T/L^2], determined in Section 11

8.2.2 Water Balance Inputs

1. Bare_RO [-] – Runoff from bare waste rock as a fraction of precipitation

- Deterministic input (zero)

2. Buttress_Area [L^2] – Bare area of North and South buttresses
   - Time-varying, deterministic inputs
   - Values for both buttresses given in Table 1-23 of the WMDP-PS-Attachment B
3. Max_Vol_To_Mine [L^3] – Maximum volume that can be sent to the Mine Site
   - Deterministic input (60,000 acre-feet)

8.2.3 Mass Transport Inputs

1. N_Buttress [L^3] – Volume of the north buttress
   - Time-varying deterministic input
   - Values given in Table 1-23 of the WMDP-PS-Attachment B
2. S_Buttress [L^3] – Volume of the south buttress
   - Time-varying deterministic input
   - Values given in Table 1-23 of the WMDP-PS-Attachment B
3. Buttress_Bulk_Density [M/L^3] – Bulk density of the material used to form the buttresses
   - Deterministic input (140 lb/ft^3)
4. Buttress_Content [M/M] – Content of constituents in waste rock
   - Deterministic input
   - Values given in Table 1-16 of the WMDP-PS-Attachment B
5. Cat1_Sulfur [-] – Mass-weighted average sulfur content of Category 1 rock
   - Deterministic input (0.063%)
6. Cat1_Release_Indep [M/M/T] – Constituent release rates (independent of sulfate)
   - For further explanation, see Section 13 of the companion Mine Site documentation
7. Cat1_Ratio_SO4 [M/M] – Constituent release ratios (dependent upon sulfate)
   - For further explanation, see Section 13 of the companion Mine Site documentation
8. Scale_Factor_LAM [-] – MDNR bulk scaling factor for Category 1 rock
   - Probabilistic input resampled at start of each year
   - Beta distribution (mean = 0.128; standard deviation = 0.085; minimum = 0.019; maximum = 0.687)
   - Note: Identical factor is used to scale Category 1 rock in the Mine Site Model
9. All_Release_Cl [M/M] – One-time chloride 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)
   - Note: Identical to release rate used in the Mine Site Model
10. Water_Depth [L] – Average depth of water at the bottom of the buttress
    - Deterministic input (0.1 inch)
11. Surficial_Porosity [-] – Porosity of surficial aquifer
    - Deterministic input (0.3)
12. SW_RO_Concentration [M/L^3] – Concentration of surface runoff in the un-impacted watershed
    - Probabilistic input resampled at each time-step

- Log-normal distribution (means and standard deviations of concentrations given in Table 1-6 of the WMDP-PS-Attachment B)

8.3 Calculations

8.3.1 Water Balance Calculations

Flotation Tailings Basin Seepage to Toes

Flows into the saturated zone underlying Cells 1E, 2E and 2W are calculated as described in Sections 6 and 7. Outward flow ("seepage") to the Tailings Basin toes from these areas originates from a total of seventeen different modeled areas, which can be grouped into the following categories:

- Infiltration into the Flotation Tailings Basin dams (North, East, and South dams)
- Infiltration into the Flotation Tailings beaches (North, East, South and Closure beaches)
- Infiltration into Cell 1E tailings (coarse tailings and fine tailings areas)
- Infiltration into Cell 2E tailings (embankment, coarse tailings and fine tailings areas)
- Infiltration into Cell 2W tailings (embankment, coarse tailings and fine tailings areas)
- Pond seepage (Cell 1E and 2E ponds)

These influxes to the saturated zone are time-lagged and divided between the four Tailings Basin toes (see Sections 6 and 7).

Buttresses

The two tailings basin buttresses are modeled separately from the other portions of the FTB. All infiltration into the north and south buttresses is ultimately captured by the north and south collection systems, respectively. The amount of water infiltrating into the buttresses is:

Buttress Infiltration $[L^3/T]$ =
Monthly Precipitation * (1 – Bare_RO – Bare_ET) * Buttress_Area **(8-1)**

It is noteworthy that, because the variable "Bare_RO" is defined to be zero, there is never any runoff from either of the buttresses.

North Collection System

The natural runoff, evapotranspiration and infiltration fluxes for the North dam are calculated using Equations 6-1 through 6-3 with the appropriate, dam-specific substitutions and adjustments (if necessary), which are described in detail in the "*Tailings Basin Dams*" water balance calculation subsection of Section 6. The resulting runoff flux is then multiplied by the North Dam area to give the volumetric runoff rate from the dam to the North Collection System:

North Dam Runoff to North Collection System $[L^3/T]$ =
Runoff Rate (North Dam) [L/T] * N_Outer_Dam_Area $[L^2]$ **(8-2)**

Additional surface runoff also enters the north collection system from natural areas (Equation 8-3) and from the Cell 2E unsaturated embankment (Equation 8-4):

Natural Runoff to North Collection System [L^3/T] = **Runoff Yield** [$L^3/T/L^2$] *
Contributing Area (Natural Areas to North Collection System) [L^2] **(8-3)**

Cell 2E Embankment Runoff to North Collection System [L^3/T] =
Embankment Runoff Rate [L/T] *
Embankment Contributing Area to North Collection System [L^2] **(8-4)**

The quantities in these formulas are determined as follows:

- Runoff yield is calculated as described in Section 11,
- The embankment runoff rate is calculated as described in Section 6 (i.e. by Equation 6-1 with substituted runoff fraction and adjusted to account for the embankment hydraulic conductivity, if necessary), and
- The natural and Cell 2E embankment (dam) contributing areas to the north collection system are 0.08 square miles and 0.12 square miles, respectively (Table 1-49b of the WMDP-PS-Attachment B).

The other inflows to the North Collection System are:

- North Buttress seepage (equal to infiltration; calculated by Equation 8-1),
- FTB groundwater seepage (at the rate given by Equation 10-7), and
- FTB surface discharge

The rate of surface discharge from the FTB is calculated as the difference between the total northbound seepage rate and the rate of FTB groundwater outflow ("Qu_Max.North", calculated by Equation 10-3):

Surface Discharge to North Collection System [L^3/T] =
Total Northbound FTB Seepage – Qu_Max.North **(8-5)**

The total rate of water collection by the north collection system is therefore:

Total Flow Captured by North Collection System [L^3/T] =
North Dam Runoff to North Collection System +
Natural Runoff to North Collection System +
Cell 2E Embankment Runoff to North Collection System +
North Buttress Seepage (*equal to North Buttress Infiltration*) +
Groundwater Flow to North Collection System +
Surface Discharge to North Collection System **(8-6)**

Water captured by the north collection system is either treated at the WWTP or is routed elsewhere within the model. The exact destination of this captured water is defined in the "*Routing of Collection System Water*" water balance subsection later in this section.

Northwest Collection System

Water in the northwest collection system comes from four sources:

- Runoff from the surrounding forested watershed (calculated by Equation 8-3 using a natural surface water contributing area of 0.05 mi^2, given in Table 1-49b of the WMDP-PS-Attachment B)
- Runoff from the Cell 2W embankment (calculated by Equation 8-4 using the embankment runoff rate calculated—and adjusted, if necessary—as described in Section 7, and a contributing area of 0.16 mi^2, as defined in Table 1-49b of the WMDP-PS-Attachment B)
- FTB groundwater seepage (at the rate described in Section 10), and
- FTB surface discharge

The rate of surface discharge to the northwest collection system is calculated by Equation 8-5 using the total northwest-bound saturated seepage and the maximum northwest flow path flow ("Qu_Max.Northwest", calculated by Equation 10-3).

The total rate of water collection by the northwest collection system is therefore:

Total Flow Captured by Northwest Collection System [L^3/T] =
Natural Runoff to Northwest Collection System +
Cell 2W Embankment Runoff to Northwest Collection System +
Groundwater Flow to Northwest Collection System +
Surface Discharge to Northwest Collection System **(8-7)**

As noted above for the north collection system, the exact destination of this intercepted flow is defined in the "*Routing of Collection System Water*" water balance subsection later in this section.

West Collection System

Water entering the west collection system originates from five sources:

- Runoff from the surrounding forested watershed (calculated by Equation 8-3 using a natural surface water contributing area of 0.10 mi^2, given in Table 1-49b of the WMDP-PS-Attachment B),
- Runoff from the Cell 2W embankment (calculated by Equation 8-4 using the embankment runoff rate calculated—and adjusted, if necessary—as described in Section 7, and a contributing area of 0.37 mi^2, as defined in Table 1-49b of the WMDP-PS-Attachment B),
- FTB groundwater seepage (at the rate described in Section 10),
- FTB surface discharge, and
- Cell 2W tailings basin runoff to evaluation point *UC-1*

The rate of surface discharge to the west collection system is calculated by Equation 8-5 using the total west-bound saturated seepage and the maximum west flow path flow ("Qu_Max.West", calculated by Equation 10-3). The rate of tailings basin runoff to "*UC-1*" is calculated using the Cell 2W embankment runoff rate (adjusted as needed, per Section 7):

Tailings Basin Runoff to UC-1 [L^3/T] = **Runoff from Cell 2W Embankment** [L/T] * **Contributing Area (Cell 2W Dams to UC-1)** [L^2] **(8-8)**

The contributing area term in Equation 8-8 equals 0.03 square miles (Table 1-49b of the WMDP-PS-Attachment B).

The total rate at which water is collected by the west collection system is therefore the sum of these five inflows:

Total Flow Captured by West Collection System [L^3/T] =
Natural Runoff to West Collection System +
Cell 2W Embankment Runoff to West Collection System +
Groundwater Flow to West Collection System +
Surface Discharge to West Collection System +
Tailings Basin Runoff to UC-1 **(8-9)**

The destination of this intercepted flow is also specified in the "*Routing of Collection System Water*" water balance subsection later in this section.

South Collection System

Natural runoff, evapotranspiration and infiltration fluxes for the South dam are calculated by Equations 6-1 through 6-3 with the appropriate, dam-specific substitutions and adjustments (if necessary) described in the "*Tailings Basin Dams*" water balance calculation subsection of Section 6. The resulting runoff flux is then multiplied by the south dam area to give the volumetric runoff rate from the dam to the South Collection System:

South Dam Runoff to South Collection System [L^3/T] =
Runoff Rate (South Dam) [L/T] * S_Outer_Dam_Area [L^2] **(8-10)**

Additional water collected by the South Collection System comes from:

- Southbound saturated seepage (all saturated flow directed to the south toe is captured, therefore this rate equals the sum of the flow rates from all seventeen toe water source areas), and
- South buttress seepage (equal to infiltration rate calculated by Equation 8-1).

The total rate at which water is collected by the south collection system is therefore:

Total Flow Captured by South Collection System [L^3/T] =
South Dam Runoff to South Collection System +
Total Southbound FTB Seepage +
South Buttress Seepage (*equal to South Buttress Infiltration*) **(8-11)**

The destination of this intercepted flow is also determined as described in the next subsection.

Routing of Collection System Water

The water captured by the four collection systems is either treated at the WWTP or is pumped elsewhere within the model, depending on a number of factors. Chief among these factors is the desired treatment rate, which varies with time.

During operations, the desired rate of treatment for collection system water is the smaller of two quantities: the WWTP capacity (defined in Section 9) and the excess system water production rate. If the excess system water production rate is less than zero, the desired treatment rate is zero. Prior to the Cell 1E and 2E ponds combining the rate at which excess system water is produced is calculated as:

Excess System Water [L^3/T] = **Total Collected Flow (North Collection System) +**
Total Collected Flow (Northwest Collection System) +
Total Collected Flow (West Collection System) +
Total Collected Flow (South Collection System) +
Direct Precipitation (Cell 2E Pond) +
Direct Precipitation (Cell 1E Pond) +
Watershed Runoff (Cell 2E Pond) +
Watershed Runoff (Cell 1E Pond) +
Reclaimed Tailings Basin ("Cell 2W") Runoff (Cell 2E Pond) +
Reclaimed Tailings Basin ("Cell 2W") Runoff (Cell 1E Pond) +
Pumping from Mine Site (to Cell 2E) +**Subaqueous Plant Discharge to FTB Pond +**
Tailings Runoff to Cell 2E Pond [L^3/T] +
Greensand Filter Backwash (t-1) –
(**Pond Evaporation (Cell 1E)** + **Pond Evaporation (Cell 2E)** +
Pond Seepage (Cell 1E) + Pond Seepage (Cell 2E) +
Pond Water Entrainment (Cell 1E) + Pond Water Entrainment (Cell 2E)) –
(Pond_1E_Volume – **Cell 1E Pond Volume**) / *dt* –
(**Pond Design Volume** (t+1) – **Cell 2E Pond Volume**) / *dt* –
[Total Plant Demand – **Clean Water Demand**] **(8-12)**

Between when the two ponds combine and the end of plant operations the rate of excess water production is:

Excess System Water [L^3/T] = **Total Collected Flow (North Collection System) +**
Total Collected Flow (Northwest Collection System) +
Total Collected Flow (West Collection System) +
Total Collected Flow (South Collection System) +
Direct Precipitation (Cell 1E/2E Pond) +
Watershed Runoff (Cell 1E/2E Pond) +
Reclaimed Tailings Basin ("Cell 2W") Runoff (Cell 1E/2E Pond) +
Pumping from Mine Site (to Cell 1E/2E) +
Subaqueous Plant Discharge to FTB Pond +
Tailings Runoff to Cell 1E/2E Pond [L^3/T] +

Greensand Filter Backwash (t-1) –
(**Pond Evaporation (Cell 1E/2E)** + **Pond Seepage (Cell 1E/2E) +**
Pond Water Entrainment (Cell 1E/2E)) –
(**Pond Design Volume** (t+1) – **Cell 1E/2E Pond Volume**) / *dt* –
[Total Plant Demand – **Clean Water Demand**] **(8-13)**

During closure, the desired treatment rate depends on whether or not the maximum allowable volume of blended water (described later in this section) that can be sent to the Mine Site ("Max_Vol_To_Mine") has been sent. If blended water is still being pumped to the Mine Site—that is, if the total volume pumped is less than the allowable volume—then the desired treatment rate equals the WWTP capacity. If blended water is no longer being pumped to the Mine Site, the desired treatment rate is the larger of two values: (1) the sum of all collected flows (i.e. the sum of Equations 8-6, 8-7, 8-9, 8-11), and (2) the WWTP capacity or the excess system water production rate, whichever is smaller. The rate of excess system water during closure is calculated by the following formula:

Excess System Water [L^3/T] = **Total Collected Flow (North Collection System) +**
Total Collected Flow (Northwest Collection System) +
Total Collected Flow (West Collection System) +
Total Collected Flow (South Collection System) +
HRF Leakage +
Direct Precipitation (Cell 1E/2E Pond) +
Watershed Runoff (Cell 1E/2E Pond) +
Reclaimed Tailings Basin ("Cell 2W") Runoff (Cell 1E/2E Pond) +
Tailings Runoff to Cell 1E/2E Pond [L^3/T] +
Greensand Filter Backwash (t-1, *while blended flow is being sent to the Mine Site*) –
(**Pond Evaporation (Cell 1E/2E)** + **Pond Seepage (Cell 1E/2E)**) –
(**Pond Design Volume** (t+1) – **Cell 1E Pond Volume**) / *dt* **(8-14)**

The following order of preference is given to determine which collected flows are sent to the WWTP for treatment:

- Leakage from the HRF (Equation 5-20a)
- Flow collected by South Collection System (Equation 8-11)
- Flow collected by North Collection System (Equation 8-6)
- Flow collected by Northwest Collection System (Equation 8-7)
- Flow collected by West Collection System (Equation 8-9)

In the event that the desired treatment rate does not allow for all of the collected flows to be treated, the remaining portion(s) of water from the collection system(s) given lowest priority is left untreated. The untreated water is then mixed together and pumped either to one (or more) of the FTB ponds or to a location where it is blended with treated discharge from the WWTP (see below).

The pumping rate to the 1E, 2E and/or 1E/2E ponds varies with time. Before the Cell 1E and 2E ponds combine, all of the untreated water collected by the collection systems is divided between the two ponds as follows:

- If the WWTP capacity (Equation 9-1a) is less than the excess system water (Equation 8-12), the rate at which untreated collection system water is pumped to the Cell 1E pond is:

  Excess System Water – **WWTP Capacity** **(8-15a)**

  and the pumping rate to the Cell 2E pond is:

  Total Untreated Collected Flow – (**Excess System Water** – **WWTP Capacity**) **(8-15b)**

- If the WWTP capacity is greater than the excess system water production rate, then all of the untreated collected flow is pumped to the Cell 2E pond.

After the FTB ponds combine—but prior to closure—all of the untreated collected flow is pumped to the Cell 1E/2E pond. After closure, all of the untreated water is pumped to the flow blender.

Blending of Treated and Untreated Flows

After Plant closure, all of the untreated water collected by the four collection systems and a portion of the WWTP effluent are combined at a single location (referred to as the "flow blender"). The inflow rate from the collection systems is the sum of the untreated collected flows (determined as described above) and the inflow rate from the WWTP (determined in Section 9). This blended flow is then pumped either to the Cell 1E/2E pond, or to the Mine Site. While water is still being pumped to the Mine Site the pumping rate to the pond is a function of the rate of pond water treatment (Equation 9-2a or 9-2b), the pond volume, and the inflows to and outflows from the pond:

Blended Water to FTB Pond [L^3/T] = **Pond Water Treatment Rate** –
[(**Direct Precipitation (Cell 1E Pond)** + **Watershed Runoff (Cell 1E Pond)** +
Reclaimed Tailings Basin ("Cell 2W") Runoff (Cell 1E Pond) +
Tailings Runoff to Cell 1E/2E Pond [L^3/T] +
Greensand Filter Backwash (t-1)) –
(**Pond Evaporation (Cell 1E)** + **Pond Seepage (Cell 1E)**) –
(**Pond Design Volume** (t+1) **– Cell 1E Pond Volume**) / *dt*] **(8-16)**

The remaining portion of outflow from the flow blender (i.e. the sum of both inflows minus the outflow rate calculated by Equation 8-16) is sent to the Mine Site:

Blended Water to Mine Site [L^3/T] = **WWTP Outflow to Blended Flow** +
Total Untreated Collected Flow (All Collection Systems) –
Blended Water to FTB Pond **(8-17)**

Once the maximum allowable volume of water ("Max_Vol_To_Mine") has been sent to the Mine Site, blending of treated and untreated water ceases because all of the collected water is treated.

8.3.2 Mass Transport Calculations

Flotation Tailings Basin Seepage to Toes

The time-lagged and dispersed mass loadings from the seventeen source areas identified earlier in this section to each Tailings Basin toe are determined as described in Sections 6 and 7. The volumes of water in the model cell elements used to represent each toe are:

North Toe Water Volume [L^3] =
1920 m * 7 m * 1 m * LTVSMC_Porosity.Coarse **(8-18)**

Northwest Toe Water Volume [L^3] =
2090 m * 7 m * 1 m * LTVSMC_Porosity.Coarse **(8-19)**

West Toe Water Volume [L^3] =
2920 m * 7 m * 1 m * LTVSMC_Porosity.Coarse **(8-20)**

South Toe Water Volume [L^3] =
(1920 m + 2090 m) * 7 m * 1 m * LTVSMC_Porosity.Coarse **(8-21)**

The north, northwest and west toes have two outflows each: groundwater outflow and surface discharge. The south toe seepage is not divided into these two components because all southbound seepage is assumed to be captured by the south collection system (see below).

Buttresses

The buttresses will be constructed of Category 1 waste rock. During construction, the volume of rock in each buttress ("N_Buttress" and "S_Buttress") varies, thus the constituent mass available for leaching in each buttress also varies temporally and is calculated as:

Buttress Mass [M] = **Buttress Volume** [L^3] * Buttress_Bulk_Density [M/L^3] **(8-22)**

The constituent mass available for transport is therefore also time-varying, and depends on the waste rock constituent content:

Constituent Mass in Buttress [M] =
Buttress Mass [M] * Buttress_Content [M/M] **(8-23)**

The fractional rate of constituent mass release from the bare buttress rock to water within the buttress rock is calculated by Equation 8-24:

Mass Transfer from Bare Buttress Rock to Water in Buttress Rock [1/T] =
Category 1 Release Rates (All Species, Scaled) [M/M/T] * **Buttress Mass** (t-1) [M] /
Constituent Mass in Buttress (t-1) [M] **(8-24)**

The procedure used to calculate and scale the Category 1 release rates in this equation are similar to those used in the Mine Site model. The rate of sulfate release from the stockpile per mass of waste rock present is calculated as:

Release Rate (SO_4, Unscaled) [M/M/T] **=** SO4_S_Regression * Cat1_Sulfur **(8-25)**

Sulfate-dependent release rates are calculated for a subset of the other constituents using applicable ratios:

Release Rates (SO_4-Dependent, Unscaled) [M/M/T] **=**
Cat1_Ratio_SO4 * **Release Rate (SO_4, Unscaled)** [M/M/T] **(8-26)**

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

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

Release Rates (Scaled) [M/M/T] **=**
Release Rates (Unscaled) [M/M/T] * Scale_Factor_LAM **(8-27)**

Chloride release is conceptualized differently from other species; it is assumed to be released only from freshly-mined rock. Consequently, it is also calculated differently from the other species as a function of the change in mass of buttress rock with time:

Release Rate (Cl, Scaled) [M/M/T] **=** All_Release_Cl * Scale_Factor_LAM *
(*d/dt*(**Buttress Mass**)) **/ Buttress Mass** (t-1) **(8-28)**

The scaled release rates calculated by Equations 8-27 and 8-28 are used to determine the rate of mass transfer from buttress rock to porewater within the buttress by Equation 8-24. The volume of porewater in the buttress is:

Volume of Porewater in Buttresses [L^3] = Water_Depth * Buttress_Area **(8-29)**

The rates of constituent mass movement from porewater in the buttresses to either the north or south toe collection systems are equal to the product of the infiltration rates (given by Equation 8-1) and the buttress concentrations. These mass loadings are then added directly to the north and south collection systems.

North Collection System

The volume of water within the north toe collection system is constant through time and is calculated based on the physical dimensions of the system:

North Collection System Water Volume [L^3] =
1 m * 30 m * 1920 m * Surficial_Porosity **(8-30)**

Constituent mass is added to this volume from four sources. The mass loading rate from each is the product of the dissolved concentration in the source water and the volumetric flow rate:

- North-toe-derived groundwater seepage from the second north flow path cell (volumetric seepage flow rate calculated by Equation 10-7),
- North-toe-derived surface discharge (discharge rate calculated by Equation 8-5),
- North buttress seepage (seepage rate equal to infiltration rate calculated by Equation 8-1).
- Surface runoff from contributing natural area (calculated by Equation 8-31)

Surface Runoff Loading to North Collection System [M/T] =
SW_RO_Concentration [M/L^3] *
Natural Runoff to North Collection System [L^3/T] **(8-31)**

Mass loading from the north collection system is then directed to the WWTP, the FTB pond or the flow blender (as described in the "*Routing of Collection System Water*" subsection above).

Northwest Collection System

The volume of water contained by the northwest toe collection system is calculated similarly to the north collection system volume:

Northwest Collection System Water Volume [L^3] =
1 m * 30 m * 2090 m * Surficial_Porosity **(8-32)**

Constituent mass is added to this volume from three sources at loading rates equal to the products of :

- Northwest-toe-derived groundwater seepage from the second northwest flow path cell (seepage rate calculated as indicated in Section 10),
- Northwest-toe-derived surface discharge (discharge rate calculated by Equation 8-5), and
- Surface runoff from contributing natural area (calculated by Equation 8-31, with the rate of natural runoff to the northwest collection system substituted for the runoff rate to the north collection system).

Water and constituent mass loading from this collection system is also directed to the WWTP, the FTB pond or the flow blender as described in the "*Routing of Collection System Water*" subsection (above).

West Collection System

The volume of water in the west toe collection system is a constant value equal to:

West Collection System Water Volume [L^3] =
1 m * 30 m * 2920 m * Surficial_Porosity **(8-33)**

Constituent mass is added to the west collection system at mass loading rates equal to the products of the source concentrations and volumetric inflow rates from four sources:

- West-toe-derived groundwater seepage from the second northwest flow path cell (volumetric seepage rate determined as indicated in Section 10)
- West-toe-derived surface discharge (discharge rate calculated by Equation 8-5)
- Runoff from the Cell 2W embankment (runoff rate determined by Equation 8-8)
- Runoff from contributing natural area (calculated using Equation 8-31 and the rate of natural runoff to the west collection system, which is calculated as described earlier in this section)

Water and constituent mass loading from this collection system is also directed to the WWTP, FTB pond or the flow blender as described in the "*Routing of Collection System Water*" subsection.

South Collection System

The volume of water in the south toe collection system does not vary with time and is equal to 4 acre-feet. Constituent mass is added to this volume from two sources at mass loading rates equal to the products of the source water concentrations and the volumetric flow rates:

- South-toe-derived seepage (all southbound Tailings Basin seepage—determined in Sections 6 and 7—is assumed to be captured)
- South buttress seepage (seepage rate equal to infiltration, calculated by Equation 8-1)

Water and mass from this collection system is also directed to the WWTP, FTB pond or flow blender (per the "*Routing of Collection System Water*" subsection above).

Blended Flow

The model cell used to represent the location where blending of treated and untreated flows occurs has a fixed volume of 100 m^3. Constituent mass in this cell is derived from two sources: dissolved mass remaining in WWTP effluent, and constituent mass in the mixture of untreated flows captured by one or more of the collection systems. Mass loading from the treated portion of the blended flow is the product of the discharge rate and the effluent concentration from the previous time-step:

WWTP Mass Loading to Blended Flow [M/T] =
WWTP Effluent Concentration (t-1) [M/L^3] *
WWTP Outflow to Blended Flow [L^3/T] **(8-34)**

In Equation 8-34 the WWTP effluent concentrations and discharge rate from the WWTP to the flow blender are calculated as described in Section 9.

Untreated water collected by the four collection systems and sent to the flow blender is first routed through a constant-volume (5,000 m^3) cell element representing the untreated pumping station. The mass loadings to this pumping station from each of the collection systems with untreated flow components are the products of the volumetric flow rate (determined as described above) and the constituent concentrations in the collection system water. Constituent mass loadings from the pumping station to the flow blender are similarly the products of the pumping station concentrations and the total untreated flow rate to the flow blender.

The constituent mass loading rates from the flow blender to the FTB pond and the Mine Site are the products of the volumetric flow rates (calculated by Equations 8-16 and 8-17) and the concentrations calculated in the blended flow cell element.

8.4 Output

Models of the Tailings Basin toes, Seepage Containment Systems and the flow blender ultimately calculate the following flows (along with their associated constituent concentrations and loads):

- Flow from the toe collection systems to the WWTP, FTB ponds, and flow blender
- Flow from the flow blender to the FTB pond and Mine Site during closure

9 Waste Water Treatment Plant (WWTP) Model

9.1 Purpose

This model is used to simulate water flow and mass transport within and from the waste water treatment plant (WWTP). The model calculates water flows and associated constituent mass loads for all constituents that are routed to other component models, including models for the Tailings Basin and the surface water system.

9.2 Input

9.2.1 Inputs from Other Models

- FTB pond design volume [L^3], determined in Section 4
- Beneficiation Plant water demands and discharge to the FTB ponds, determined in Section 5
- Hydrometallurgical residue facility pond leakage rate, determined in Section 5
- FTB pond volume [L^3], determined in Section 6
- Water flow and constituent mass loads associated with water pumped from the FTB pond for treatment, determined in Section 6
- Precipitation, runoff, evaporation, seepage and pond water entrainment rates for the various FTB ponds, determined in Section 6
- Pumping rates from the Mine Site to the FTB ponds, determined in Section 6
- Water flow and constituent mass loads associated with water collected by the four tailings basin toe collection systems, determined in Section 8
- Desired treatment rate of flow collected by each of the collection systems, determined in Section 8

9.2.2 Water Balance Inputs

1. OPS_Treatment_Capacity [L^3/T] – Treatment capacity of the FTB WWTP during operations
    - Deterministic input (2000 gallons per minute)
2. CLSR_Treatment_Capacity [L^3/T] – Flow to the treatment plant during reclamation
    - Deterministic input (3500 gallons per minute)
3. Backwash_Perc_Influent [-] – Portion of WWTP influent flow required for backwashing the greensand filter
    - Deterministic input (5%)
4. Effluent_Perc_Influent [-] – Percentage of the WWTP influent flow that is discharged (i.e. not retained as concentrate)
    - Deterministic input (95%)
5. Trib_Demand_Fracs_Early [-] – Fractional WWTP discharge to each tributary prior to Cell 1E and 2E ponds combining
    - Deterministic inputs (5.53% to Mud Lake Creek; 54.09% to Trimble Creek; 16.63% to Unnamed Creek; 23.75% to Second Creek)
6. Trib_Demand_Fracs_Late [-] – Fractional WWTP discharge to each tributary after Cell 1E and 2E ponds combine

- Deterministic inputs (0% to Mud Lake Creek; 57.26% to Trimble Creek; 17.6% to Unnamed Creek; 25.14% to Second Creek)

9.2.3 Mass Transport Inputs

1. Effluent_Conc [M/L^3] – Maximum constituent concentrations in Flotation Tailings Basin WWTP effluent
   - Deterministic inputs
   - Values given in Table 1-43 of the WMDP-PS-Attachment B
2. Fe_Backwash_Conc [M/L^3] – Iron concentration in the Greensand filter backwash
   - Deterministic input (4 mg/L)
3. K_Backwash_Conc [M/L^3] – Potassium concentration in the Greensand filter backwash
   - Deterministic input (11 mg/L)
4. Mn_Backwash_Conc [M/L^3] – Manganese concentration in the Greensand filter backwash
   - Deterministic input (30 mg/L)

9.3 Calculations

9.3.1 Water Balance Calculations

WWTP Inflows

The treatment capacity of the WWTP varies in time. Initially it is:

WWTP Capacity [L^3/T] = OPS_Treatment_Capacity **(9-1a)**

and after eight years of operations (i.e. $t \geq 8$ years):

WWTP Capacity [L^3/T] = CLSR_Treatment_Capacity **(9-1b)**

This treatment capacity is used to treat water from up to six different areas at the Plant Site:

- Hydrometallurgical residue facility (HRF) leakage (calculated by Equation 5-20a),
- Flow collected at one or all four of the Tailings Basin toe collection systems, and
- FTB pond water (during reclamation and closure only).

The amount of water treated from each of the collection systems is based on the desired rate of water treatment, the amount of flow collected from the four systems, and the treatment preference order described in Section 8. During the earliest part of the closure phase—while flow is sent from the WWTP to the Mine Site West Pit—if the desired rate of treatment (see Section 8) is greater than the cumulative rate of flow collection from the HRF and the four collection systems, then the remaining treatment capacity (calculated by Equation 9-2a or 9-2b) is used to treat water in the Cell 1E/2E pond. When this condition is met during this time, the rate of pond water treatment is:

Pond Water Treatment Rate [L^3/T] = **WWTP Capacity –**
[**HRF Leakage +**

Total Collected Flow (North Collection System) +
Total Collected Flow (Northwest Collection System) +
Total Collected Flow (West Collection System) +
Total Collected Flow (South Collection System)] **(9-2a)**

Once the WWTP is no longer sending water to the Mine Site, the pond water treatment rate is dependent upon the desired treatment rate (Section 8):

Pond Water Treatment Rate [L^3/T] = **Desired Treatment Rate –**
[**HRF Leakage +**
Total Collected Flow (North Collection System) +
Total Collected Flow (Northwest Collection System) +
Total Collected Flow (West Collection System) +
Total Collected Flow (South Collection System)] **(9-2b)**

The total WWTP treatment rate is therefore the sum of the pond water treatment rate, the HRF leakage rate, and the rate(s) of treatment from the collection system(s):

Total Inflow to WWTP [L^3/T] = **Pond Water Treatment Rate** + **HRF Leakage** +
Total Treated Collected Flow (North Collection System) +
Total Treated Collected Flow (Northwest Collection System) +
Total Treated Collected Flow (West Collection System) +
Total Treated Collected Flow (South Collection System) **(9-3)**

WWTP Outflows (Effluent)

The outflow rate from the WWTP to the Greensand filter is calculated as a defined percentage of the WWTP inflow rate:

Greensand Filter Backwash [L^3/T] =
Backwash_Perc_Influent * **Total Inflow to WWTP** **(9-4)**

A constant percentage of the inflow to the WWTP is also removed in the form of concentrate that is sent to the Mine Site WWTF:

WWTP Concentrate Removal [L^3/T] =
(1 – Effluent_Perc_Influent) * **Total Inflow to WWTP** **(9-5)**

The remaining portion of the WWTP effluent—after the Greensand flow and concentrate are removed—is therefore:

WWTP Effluent [L^3/T] = **Total Inflow to WWTP –**
Greensand Filter Backwash – WWTP Concentrate Removal **(9-6)**

This outflow is then either blended with untreated water from one or more collection system, or is discharged to the surface water system. The partitioning of WWTP effluent between these two areas is dependent upon two conditions being simultaneously true:

- The Beneficiation Plant is no longer operating (i.e. the closure phase has begun), and
- The amount of water sent to the Mine Site from the flow blender is less than the maximum allowable volume ("Max_Vol_To_Mine").

Both of these conditions are not met during plant operations, during which time all of the WWTP effluent is discharged to the surface water system. The discharge rates to each of the four creeks (Mud Lake Creek, Trimble Creek, Unnamed Creek and Second Creek) are calculated based on the fraction of WWTP discharge that each creek receives. These fractions are different before and after the Cell 1E and 2E ponds combine. Before the ponds combine the creek-specific fractions are defined by the "Trib_Demand_Fracs_Early" input variable, and the discharge to the creeks are calculated as:

WWTP Discharge (*MLC-3*) [L^3/T] = **WWTP Effluent** [L^3/T] * Trib_Demand_Fracs_Early (*Mud Lake Creek fraction*) **(9-7a)**

WWTP Discharge (*TC-1*) [L^3/T] = **WWTP Effluent** [L^3/T] * Trib_Demand_Fracs_Early (*Trimble Creek fraction*) **(9-7b)**

WWTP Discharge (*PM-11*) [L^3/T] = **WWTP Effluent** [L^3/T] * Trib_Demand_Fracs_Early (*Unnamed Creek fraction*) **(9-7c)**

WWTP Discharge (*Second Creek*) [L^3/T] = **WWTP Effluent** [L^3/T] * Trib_Demand_Fracs_Early (*Second Creek fraction*) **(9-7d)**

After the ponds combine the creek-specific fractional discharge values specified by "Trib_Demand_Fracs_Late" are substituted for those given by "Trib_Demand_Fracs_Early" in these equations.

The two conditions described above are first met at the time of closure, at which point WWTP discharge to the surface water system ceases. All of the WWTP effluent remaining after the concentrate and Greensand flow have been removed is then sent to the flow blender. Once the maximum allowable amount of water has been sent to the Mine Site, all of the WWTP effluent is again discharged to the four creeks as indicated above.

9.3.2 Mass Transport Calculations

WWTP Inflows

The two mass inputs to the WWTP that are modeled—water collected from the toe collection systems, and (when applicable) FTB pond water—have the concentrations of their respective source waters. The mass loadings to the WWTP from these sources are therefore the products of the source water concentrations and the volumetric inflow rates to the WWTP.

WWTP Outflows (Effluent)

A prescribed maximum WWTP effluent concentration ("Effluent_Conc") is defined for each constituent, and the dissolved concentrations of calcium and magnesium in the effluent are assumed to always equal these values to define the hardness in the WWTP effluent. The effluent concentration for each of the other species is defined as either the prescribed concentration or the concentration of the mixed WWTP influent, whichever is smaller. The mass loading rates from the WWTP to the surface water system, Greensand filter, and the flow blender are the products of these outflow concentrations and the volumetric outflow rates (described above).

The remaining constituent mass in the WWTP after accounting for these three mass outflows is contained within the concentrate that is sent to the Mine Site for treatment.

Greensand Filter

The Greensand filter backwash is assigned constant concentrations for iron ("Fe_Backwash_Conc"), potassium ("K_Backwash_Conc") and manganese ("Mn_Backwash_Conc"). All other constituent concentrations in the outflow are the same as the inflow. The constituent mass loadings to the Cell 1E pond are therefore the product of these concentrations and the volumetric backwash flow rate (Equation 9-4). This loading source continues until the WWTP stops sending water to the Mine Site in closure.

9.4 Output

The WWTP model ultimately calculates the following flows along with their associated constituent concentration and loads:

- WWTP effluent discharged to the surface water system
- WWTP effluent sent to the flow blender
- Greensand filter backwash to the Cell 1E pond

10 Flow Path Models

10.1 Purpose

The flow path models are used to simulate water flow and mass transport through the surficial aquifer from the flotation tailings basin. The model calculates water flows and associated constituent mass loads for all constituents that are routed to the surface water system.

10.2 Input

10.2.1 Inputs from Other Models

- Constituent concentrations in the North, Northwest and West toe water, determined in Section 8

10.2.2 Water Balance Inputs

1. Eval_Loc1 [L] – Length from the upstream end of each flow path to the first evaluation location
    - Deterministic inputs (North flow path = 1205 m; Northwest flow path = 1325 m; West flow path = 3110 m; South flow path = 0 m)
2. w [-] – Average flow path width
    - Deterministic inputs (North flow path = 1920 m; Northwest flow path = 2090 m; West flow path = 2920 m; South flow path = 0 m)
3. D [L] – Aquifer thickness
    - Deterministic input (7 meters)
4. K_Surficial [L/T] – Flow path hydraulic conductivity
    - Probabilistic input sampled at start of each realization
    - Log-normal distribution (mean = 4.0 meters/day; standard deviation = 1.6 meters/day)
5. Init_Grad [-] – Initial hydraulic gradient for each flow path
    - Deterministic inputs (North flow path = -0.00444; Northwest flow path = -0.00514; West flow path = -0.00736; South flow path = 0)
6. Recharge [L/T] – Net recharge rate to the surficial aquifers
    - Probabilistic input sampled at start of each realization
    - Triangular distribution (minimum = 0.3 inches/year; mode = 0.6 inches/year; maximum = 1.5 inches/year)
7. La [L] – Total length of each flow path
    - Deterministic inputs (North flow path = 3260 m; Northwest flow path = 3715 m; West flow path = 5410 m; South flow path = 1 m)
8. GW_Capture_Eff [-] – Efficiency of the groundwater containment system
    - Deterministic input (90%)
9. Perc_Flow_to_PM12_4 [-] – Percent of the West groundwater flow path discharge that goes to the reach of the Embarrass River upstream of evaluation point "PM-12.4"
    - Deterministic input (7.21%)

10.2.3 Mass Transport Inputs

1. Expected_Toe_Conc [M/L^3] – Expected concentrations at the toes of the Tailings Basin
   - Deterministic inputs
   - Values given in Table 1-54 of the WMDP-PS-Attachment B
2. GW_Alpha_Rand [-] – Groundwater concentration parameter
   - Probabilistic, constituent-specific inputs sampled at start of each realization
   - Normal distribution with mean ("*GW_Alpha_Mean*") and standard deviation values ("*GW_Alpha_Stdev*") given in Table 1-5 of the WMDP-PS-Attachment B
3. GW_Beta [-] – Groundwater concentration parameter
   - Deterministic, constituent-specific inputs
   - Values given in Table 1-5 of the WMDP-PS-Attachment B

10.3 Calculations

Three groundwater flow paths originating from the Plant Site are modeled: one flowing to the north, another to the northwest, and a third flowing to the west. Water and constituent mass transport through the flow paths are each modeled by two sequential segments made up of a series of cell elements. The number of cells in each flow path's segments is determined as a function of the total length of each flow path, the dispersion length (see WMDP-PS, Section 5.4.5.4) and the distance between each FTB toe and the groundwater evaluation location. The North flow path consists of 95 cells: 35 in the first (upgradient) segment and 60 in the second segment. The Northwest flow path consists of 104 cells: 37 in the first segment and 67 in the second. The West flow path is considerably longer than the other two flow paths and subsequently consists of more cells: 78 cells are used to represent the upgradient segment and 58 used to model the downgradient segment.

The first two cells in each flow path represent the portion of the flow path between the tailings basin toe and the collection system. Collected groundwater flows are therefore removed from the second cell in each flow path, and groundwater flow which is not collected enters the third flow path cell and continues downgradient.

10.3.1 Water Balance Calculations

General Flow Path Calculations

The flow path length ("La"), width ("w"), and distance between the FTB toe and the evaluation location ("Eval_Loc1") all vary between flow paths. Therefore, the volume of water in each flow path cell also varies by flow path, and by segment. Cell water volumes are determined as follows:

Segment 1 Cell Volumes [L^3] =
Eval_Loc1 * w * D * Surficial_Porosity / **Number of Cells in Segment 1** **(10-1)**

Segment 2 Cell Volumes [L^3] =
(La – Eval_Loc1) * w * D * Surficial_Porosity / **Number of Cells in Segment 2** **(10-2)**

The maximum seepage rate from the FTB toe to the first flow path cell ("Qu_Max") is also calculated separately for each flow path based on the flow path properties:

Qu_Max [L^3/T] = – K_Surficial [L/T] * Init_Grad * D [L] * w [L] **(10-3)**

North Flow Path

The amount of flow into the first North flow path cell is calculated by Equation 10-3, and the flow rate out of the cell is the sum of this inflow and the recharge rate into the cell:

Groundwater Outflow (Cell 1) [L^3/T] =
Segment 1 Recharge Rate [L^3/T] + Qu_Max.North **(10-4)**

The same recharge flow rate is applied to all 35 cells in the first flow path segment and is calculated as a function of the flow path dimensions:

Segment 1 Recharge Rate [L^3/T] =
Recharge.North [L/T] * w.North [L] * Eval_Loc1.North [L] /
Number of Cells in Segment 1 **(10-5)**

The outflow from the second flow path cell is calculated similarly to outflow from the first:

Groundwater Outflow (Cell 2) [L^3/T] =
Segment 1 Recharge Rate + **Groundwater Outflow (Cell 1)** **(10-6)**

The rate at which groundwater outflow from the second flow path cell is captured by the collection system is then calculated based upon the amount of flow which bypasses the collection system and the flow leaving the second flow path cell:

Groundwater Flow to North Collection System [L^3/T] =
Groundwater Outflow (Cell 2) – Groundwater Flow (Not Collected) **(10-7)**

The northbound groundwater outflow from the Plant Site which bypasses the collection system is calculated as a fraction of the maximum seepage rate from the FTB toe:

Groundwater Flow (Not Collected) [L^3/T] = (1 – GW_Capture_Eff) * Qu_Max.North
(10-8)

Groundwater flow not captured by the collection system enters the third flow path cell, which represents the area immediately downgradient of the collection system. The groundwater flow rates leaving each of the cells downgradient of the collection system—that is, the remaining cells in Segment 1 and all of Segment 2 of the flow path—are subsequently calculated as:

Groundwater Outflow [L^3/T] =
Groundwater Inflow + Segment Recharge Rate **(10-9)**

The recharge rate to Segment 2 cells in the north flow path is calculated slightly differently from the Segment 1 recharge rate because Segment 2 is longer and contains more cells (60):

Segment 2 Recharge Rate [L^3/T] =
Recharge.North * w.North * (La.North – Eval_Loc1.North) /
Number of Cells in Segment 2 **(10-10)**

The North flow path terminates in the reach of Mud Lake Creek above surface water evaluation point "MLC-2" and the volumetric discharge rate to this reach is equal to the outflow from the final Segment 2 flow path cell.

Northwest Flow Path

The flow rates out of the first and second northwest flow path cells are calculated similarly to those for the north flow path by substituting northwest flow path values of "Recharge", "w", "La" and "Eval_Loc1" into Equations 10-3 through 10-10. The capture rate for the northwest collection system, recharge rates and outflows from all the remaining cells are calculated in the same manner as for the north flow path. The northwest flow path terminates in the reach of Trimble Creek between surface water evaluation points "TC-1" and "PM-19".

West Flow Path

The flow rates out of the first two west flow path cells and into the collection system are calculated in the same ways as for the north and northwest flow paths (again substituting west flow path values of "Recharge", "w", "La" and "Eval_Loc1" into the appropriate equations). Groundwater flow rates through the remaining flow path cells are also calculated in the same manner as those for the north and northwest flow paths.

Discharge from the west flow path is split between two different reaches of the Embarrass River: the reaches immediately upstream of evaluation points "PM-12.4" and "PM-13". The percent of the total flow path discharge that enters the reach upstream of PM-12.4 is defined by the input variable "Perc_Flow_to_PM12_4"; the remainder is discharged to the other reach.

10.3.2 Mass Transport Calculations

General Calculations

Initial constituent concentrations are calculated differently for each flow path cell. Concentrations in the *n*th cell in each flow path also depend upon which segment the cell is in:

Initial Constituent Concentration (Segment 1, Cell *n*) [M/L^3] =
[Expected_Toe_Conc * Qu_Max +
(**Baseline Groundwater Concentrations** * w * Recharge * Eval_Loc1 * *n* /
Number of Cells in Segment 1)] /
[Qu_Max + w * Recharge * Eval_Loc1 * *n* / **Number of Cells in Segment 1**] **(10-11a)**

Initial Constituent Concentration (Segment 2, Cell *n*) [M/L^3] =
[Expected_Toe_Conc * Qu_Max +
(**Baseline Groundwater Concentrations** * w * Recharge *
(Eval_Loc1 + (La – Eval_Loc1) * (*n* – **Number of Cells in Segment 1**)) /
Number of Cells in Segment 2] /
[(Qu_Max +
w * Recharge * (Eval_Loc1 + (La – Eval_Loc1) * (*n* – **Number of Cells in Segment 1**))/
Number of Cells in Segment 2] **(10-11b)**

In addition to the length ("La"), width ("w") and distance from the toe to the evaluation location ("Eval_Loc1"), the expected basin toe concentrations ("Expected_Toe_Conc") and Qu_Max also vary by flow path. The baseline groundwater concentrations are calculated based on a transformation of groundwater quality data:

Baseline Groundwater Concentrations [mg/L] =
exp(GW_Alpha_Rand + (0.5 * (GW_Beta)^2)) * (0.001 mg/L) **(10-12)**

The standard deviation of the distribution (represented by the "GW_Beta" parameter in Equation 10-12) for each constituent is treated as deterministic. The means of the distributions for each species (i.e. the "GW_Alpha_Rand" values) are treated as uncertain parameters, which are themselves defined by a normal distribution with a specified mean and standard deviation. The mean GW_Alpha_Rand values, standard deviations of the GW_Alpha_Rand values, and the GW_Beta values for each species are given in Table 1-5 of the WMDP-PS-Attachment B.

North Flow Path

Constituent mass loading to each north flow path cell is derived from two sources: the cell immediately upgradient, and natural recharge. The mass added from the upgradient cell is the product of the volumetric inflow rate and the continually-varying concentration in that cell. In the case of the first flow path cell, the mass loading is the product of the upstream inflow from the FTB ("Qu_Max.North") and the calculated constituent concentrations in the north toe water (Section 8). Constituent mass loading from natural recharge is a product of the segment-specific volumetric recharge rate and the baseline groundwater concentrations.

The mass loading rate from the second flow path cell to the north collection system for each constituent is the product of the cell concentration and the volumetric rate of collection. Constituent mass loading from the last flow path cell enters the reach of Mud Lake Creek upstream of MLC-2.

Northwest Flow Path

Mass loadings to and from each cell in the northwest flow path are calculated in the same manner as for the north flow path. The mass added to the first flow path cell from upgradient is derived directly from the northwest toe (Section 8). Constituent mass leaving the last flow path cell is added to the reach of Trimble Creek upstream of PM-19.

West Flow Path

Each cell in the west flow path receives constituent mass from the same sources as the other two flow paths. Also like the other flow paths, an FTB toe (in this case the west toe) adds constituent mass to the first flow path cell, 90% of the mass leaving the second cell is captured by the west collection system (Section 8), and the remaining mass enters the third cell. Mass loading out of the last flow path cell is divided between the river reaches upstream of PM-12.4 and PM-13 using the predetermined percentage that flows to PM-12.4 ("Perc_Flow_to_PM12_4").

10.4 Output

The Flow Path Models ultimately calculate the following flows along with their associated constituent concentration and loads to the surface water system:

- Groundwater flow from the north Flotation Tailings Basin toe to Mud Lake Creek (stream reach upstream of surface water evaluation point MLC-2)
- Groundwater flow from the northwest Flotation Tailings Basin toe to Trimble Creek (stream reach upstream of surface water evaluation point PM-19)
- Groundwater flow from the west Flotation Tailings Basin toe to the Embarrass River (river reaches upstream of surface water evaluation points PM-12.4 and PM-13)

11 Surface Water System Model

11.1 Purpose

The model of the surface water system is used to simulate water flow and mass transport into and through the Embarrass River in addition to three of its tributaries: Mud Lake Creek, Trimble Creek, and Unnamed creek. The model calculates water flows and the associated constituent mass loads of all constituents from natural areas and the Plant Site to the surface water system. This is the terminal model in the system, and, as such, it produces no water flows or mass loadings used by any other component models.

11.2 Input

11.2.1 Inputs from Other Models

- Duration of the three climatic seasons, determined in Section 3
- Water flow and mass loading from FTB pond overflow if it occurs, determined in Section 6
- Runoff rate from the FTB east dam, determined in Section 6
- Water flow and mass loading from WWTP discharge to the surface water system, determined in Section 9
- Water flow and mass loading from the North, Northwest and West Flow Path Models, determined in Section 10

11.2.2 Water Balance Inputs

1. Watershed_Yield [$L^3/T/L^2$] – Volumetric flow derived from contributing watershed per unit watershed area
    - Lookup table defining the total watershed yield by month and percentile
    - Deterministic input (Table 1-50 of the WMDP-PS-Attachment B)
2. Area5_Summer [L^3/T] – Flow from Area 5NW during summer months
    - Probabilistic input resampled every time-step
    - Log-normal distribution (mean = 2.127 ft^3/s; standard deviation = 1.798 ft^3/s)
3. Area5_Winter [L^3/T] – Flow from Area 5NW during winter months
    - Probabilistic input resampled every time-step
    - Log-normal distribution (mean = 1.177 ft^3/s; standard deviation = 0.888 ft^3/s)
4. Area5_Snowmelt [L^3/T] – Flow from Area 5NW during snowmelt months
    - Probabilistic input resampled every time-step
    - Uniform distribution (minimum = 0.774 ft^3/s; maximum = 7.271 ft^3/s)
5. Embarrass_Baseflow [$L^3/T/L^2$] – Baseflow added to surface water nodes per area
    - Deterministic input (0.045 $ft^3/sec/mi^2$)
6. GW_Contr_Areas [L^2] – Groundwater contributing area to each surface water reach (one value per evaluation point)
    - Deterministic inputs
    - Values given in Table 1-49b of the WMDP-PS-Attachment B ("*Non-Modeled Flow Path*")

7. SW_Contr_Areas [L^2] – Surface water contributing area to each surface water reach before the Cell 1E and 2E ponds combine (one value per evaluation point)
    - Deterministic inputs
    - Values given in Table 1-49b of the WMDP-PS-Attachment B ("*Natural Areas*")
8. SW_Contr_Areas_Late [L^2] – Surface water contributing area to each surface water reach after the Cell 1E and 2E ponds combine (one value per evaluation point)
    - Deterministic inputs
    - Values other than for the reach above evaluation point "MLC-3" are the same as "SW_Contr_Areas" (see Table 1-49b of the WMDP-PS-Attachment B, "*Natural Areas*")
9. Min_Flow_To_4Tribs_Early [L^3/T] – Minimum flow to the four tributaries (including Second Creek)
    - Deterministic input (1700 gallons/min)
10. Min_Flow_To_4Tribs_Late [L^3/T] – Minimum flow to the four tributaries (including Second Creek)
    - Deterministic input (1600 gallons/min)
11. Overflow_Distribution [-] – Distribution of FTB pond overflow to surface water reaches
    - Deterministic inputs
    - 45% to "MLC-3"; 55% to "TC-1"; zero to all other reaches
12. Babbitt_Flow [-] – Flow from the Babbitt WWTP
    - Deterministic input (0.33 ft^3/sec)

11.3 Calculations

11.3.1 Water Balance Calculations

The Embarrass River has three direct tributaries which drain the area that includes the Plant Site: Mud Lake Creek, Trimble Creek, and Unnamed creek. The tributaries are each represented by two surface water reaches. All river reaches are identified by the surface water evaluation point located at the downstream end of the reach.

Mud Lake Creek

The reach of Mud Lake Creek immediately downstream of the Plant Site is directly upstream of the "*MLC-3*" evaluation point. The sources of water to this reach are Cell 1E/2E pond overflow if it occurs (Section 6) and groundwater and runoff inflows which originate from upstream areas that are not explicitly modeled. The sum of these natural inflow rates is:

Natural Inflows to Mud Lake Creek (*MLC-3*) [L^3/T] =
Incremental Runoff Addition Rate (*MLC-3*) [L^3/T] +
Incremental Baseflow Addition Rate (*MLC-3*) [L^3/T] **(11-1)**

The two incremental flow terms in this equation are calculated using the calculated amounts of streamflow added to the river per contributing area from baseflow and runoff (i.e. the baseflow yield and runoff yield). The two yield terms are calculated internally by the model and depend on the total watershed yield. The total watershed yield is determined using a month-specific lookup table ("Watershed_Yield") and the same seasonally-varying cumulative probability densities of flow used to determine discharge coming from Area 5NW. These probabilities ("Area5_Summer", "Area5_Winter" and "Area5_Snowmelt") vary by season, and the appropriate distribution is resampled every time-step so that all months within a single season do not have the same flow probability.

When the total watershed yield exceeds the area-averaged Embarrass River baseflow yield rate (Embarrass_Baseflow), the baseflow yield is equal to the area-averaged value and the runoff yield is the difference between the two:

Runoff Yield [L^3/T/L^2] =
Total Watershed Yield [L^3/T/L^2] – Embarrass_Baseflow **(11-2)**

Alternatively, if the watershed yield generated by the procedure described above is less than "Embarrass_Baseflow" then the baseflow is made equal to the watershed yield, and the runoff yield is zero.

The incremental runoff and baseflow addition rates in Equation 11-1 are subsequently calculated based on these yield terms and the surface water and groundwater contributing areas to the river reach. The groundwater contributing areas ("GW_Contr_Areas") are constants throughout the entire simulation period:

Incremental Baseflow Addition Rate (*MLC-3*) [L^3/T] =
Baseflow Yield [L^3/T/L^2] * GW_Contr_Areas (*MLC-3*) [L^2] **(11-3a)**

The surface water contributing areas before the Cell 1E and 2E ponds combine ("SW_Contr_Areas") differ from those after the ponds combine ("SW_Contr_Areas_Late"), and the incremental runoff rates are calculated differently during the two time periods as a result:

Incremental Runoff Addition Rate (*MLC-3, Prior to t=7 years*) [L^3/T] =
Runoff Yield [L^3/T/L^2] * SW_Contr_Areas (*MLC-3*) [L^2] **(11-3b)**

Incremental Runoff Addition Rate (*MLC-3, After t=7 years*) [L^3/T] =
Runoff Yield [L^3/T/L^2] * SW_Contr_Areas_Late (*MLC-3*) [L^2] **(11-3c)**

Runoff from the flotation tailings basin's east dam is the final water source to the MLC-3 reach. The east dam runoff flux is calculated (and adjusted, if necessary) as described in Section 6. This flux is then multiplied by the dam's outer area to give the runoff flow rate to MLC-3:

East Dam Runoff Flow (*MLC-3*) [L^3/T] =
East Dam Runoff [L/T] * E_Outer_Dam_Area [L^2] **(11-4)**

Flow in the reach above MLC-3 is augmented by water from Colby Lake before the maximum allowable volume of water has been transferred to the Mine Site from the flow blender (Section 8). The amount of Colby Lake water introduced into this reach varies with time, and with the amount of WWTP effluent discharged to the reach (Section 9). Prior to the Cell 1E and 2E ponds combining the flow added from Colby Lake is determined using a total flow rate from Colby Lake ("Min_Flow_To_4Tribs_Early") and the fraction of the flow that is added to the

MLC-3 reach (5.53%, based on the value specified in the "Trib_Demand_Fracs_Early" input array):

Additional Flow from Colby Lake (*MLC-3, Prior to t=7 years*) [L^3/T] =
0.0553 * Min_Flow_To_4Tribs_Early [L^3/T] –
WWTP Discharge (*MLC-3*) [L^3/T] **(11-5)**

When this quantity is negative no additional water is added to the reach from Colby Lake. After the two FTB ponds combine, no WWTP effluent or Colby Lake water is sent to MLC-3

Forty-five percent of the Cell 1E/2E pond overflow also enters the reach (based on the reach-specific value in the "Overflow_Distribution" variable), and the total discharge rate out of the reach is the sum of the inflow rates from all water sources:

Streamflow (*MLC-3*) [L^3/T] = **WWTP Discharge** (*MLC-3, Prior to t=7 years*) [L^3/T] +
Natural Inflows to Mud Lake Creek (*MLC-3*) [L^3/T] +
East Dam Runoff Flow (*MLC-3*) [L^3/T] +
Additional Flow from Colby Lake (*MLC-3, Prior to t=7 years*) [L^3/T] +
0.45 * **FTB Pond Overflow** [L^3/T] **(11-6)**

This discharge flows to the next reach downstream, which is upstream of the "MLC-2" surface water evaluation point. Natural inflows to this reach are calculated in a similar manner to those for the reach upstream using the reach-specific contributing areas. This reach receives water from the North Flow path (Section 10). The total flow at MLC-2 is therefore:

Streamflow (*MLC-2*) [L^3/T] = **Streamflow** (*MLC-3*) +
Natural Inflows to Mud Lake Creek (*MLC-2*) +
Discharge from North Flow Path [L^3/T] **(11-7)**

The remainder of Mud Lake Creek—between MLC-2 and the mainstem Embarrass River—is modeled as part of the Embarrass River reach upstream of the "PM-12.3" evaluation point.

Trimble Creek

The upstream reach of Trimble Creek is located above evaluation point "TC-1". This reach receives natural runoff inflow, the remaining 55% of the FTB pond overflow (based on "Overflow_Distribution"), a fraction of the WWTP effluent, and flow added from Colby Lake. The natural inflow rate is calculated in the same manner as the incremental Mud Lake Creek runoff inflow (see above). The amount of water added from Colby Lake—which, again, only occurs before the maximum volume has been transferred from the flow blender to the Mine Site—is calculated differently through time:

Additional Flow from Colby Lake (*TC-1, Prior to t=7 years*) [L^3/T] =
0.5409 * Min_Flow_To_4Tribs_Early [L^3/T] – **WWTP Discharge** (*TC-1*) [L^3/T] **(11-8a)**

Additional Flow from Colby Lake (*TC-1, After t=7 years*) [L^3/T] =
0.5726 * Min_Flow_To_4Tribs_Late [L^3/T] – **WWTP Discharge** (*TC-1*) [L^3/T] **(11-8b)**

The two coefficients in these equations are again specified by the "Trib_Demand_Fracs_Early" and "Trib_Demand_Fracs_Late" input variables. If the calculated flow added from Colby Lake is negative, then no flow is added to the reach from Colby Lake.

The total outflow from this reach to the reach upstream of "PM-19" is equal to the sum of the inflows:

Streamflow (*TC-1*) [L^3/T] = **WWTP Discharge** (*TC-1*) [L^3/T] +
Incremental Runoff Addition Rate (*TC-1*) [L^3/T] +
Additional Flow from Colby Lake (*TC-1*) [L^3/T] +
0.55 * **FTB Pond Overflow** [L^3/T] **(11-9)**

The Northwest flow path terminates in the reach of Trimble Creek upstream of PM-19. The inflow rate from the northwest flow path is calculated as indicated in Section 10. This reach also receives incremental natural runoff inflow (calculated similarly to the aforementioned reaches) and streamflow from upstream. The discharge at PM-19 is therefore the sum of these three inflows. The remaining length of Trimble Creek—between PM-19 and the Embarrass River—is modeled as part of the Embarrass River reach upstream of PM-12.3.

Unnamed Creek

The upstream reach of Unnamed Creek is located above the "UC-1" evaluation point. This reach differs from the other creek and river reaches because flow from it does not enter another surface water reach: all of the inflows to the reach—Cell 2W embankment runoff (Section 8) and incremental runoff—flow to the West collection system. From there, the flow is directed as described in Section 8.

The second reach of Unnamed Creek—which is above surface evaluation point PM-11—therefore does not receive any surface water inflow from upstream. Flow in this reach is derived from the natural runoff inflow (calculated as described previously), WWTP effluent (Section 9), and Colby Lake. The flow added from Colby Lake is calculated similarly to the flow added to the reach above TC-1:

Additional Flow from Colby Lake (*PM-11*, *Prior to t=7 years*) [L^3/T] =
0.1663 * Min_Flow_To_4Tribs_Early [L^3/T] – **WWTP Discharge** (*PM-11*) [L^3/T]
(11-10a)

Additional Flow from Colby Lake (*PM-11*, *After t=7 years*) [L^3/T] =
0.176 * Min_Flow_To_4Tribs_Late [L^3/T] – **WWTP Discharge** (*PM-11*) [L^3/T]
(11-10b)

As before, the coefficients in these equations are specified by "Trib_Demand_Fracs_Early" and "Trib_Demand_Fracs_Late", and if the calculated flow value is negative no flow is added from Colby Lake.

The discharge at PM-11 is therefore the sum of the three inflows:

Streamflow (*PM-11*) [L^3/T] = **WWTP Discharge** (*PM-11*) [L^3/T] +
Incremental Runoff Addition Rate (*PM-11*) [L^3/T] +
Additional Flow from Colby Lake (*PM-11*) [L^3/T] **(11-11)**

The portion of Unnamed Creek between PM-11 and the Embarrass River is modeled as part of the Embarrass River reach upstream of PM-13.

Embarrass River

The farthest upstream reach of the Embarrass River that is modeled is upstream of the "PM-12" surface water evaluation point. The two sources of streamflow at this point are natural inflows (i.e. incremental runoff and groundwater additions) and the Babbitt WWTP. The natural inflows are calculated for this reach as they were for all of the previously mentioned reaches, and the Babbitt WWTP discharges to this reach at a constant rate (defined by "Babbitt_Flow"). The outflow from this reach to the next reach downstream, which is above the "PM-12.2" evaluation point, is therefore the sum of these inflows:

Streamflow (*PM-12*) [L^3/T] = Babbitt_Flow [L^3/T] +
Natural Inflows to Embarrass River (*PM-12*) [L^3/T] **(11-12)**

In addition to this inflow from upstream and the two natural inflows, the reach upstream of PM-12.2 also receives surface flow from the area identified as "Area 5". This inflow is uncertain and varies seasonally: a flow value equal to "Area5_Summer", "Area5_Winter" or "Area5_Snowmelt" is used depending on whether a given time-step falls within summer, winter or the snowmelt period (Section 3). The outflow from this reach is therefore calculated as:

Streamflow (*PM-12.2*) [L^3/T] = **Streamflow** (*PM-12*) + **Area 5 Flow** [L^3/T] +
Natural Inflows to Embarrass River (*PM-12.2*) **(11-13)**

The Embarrass River reach upstream of PM-12.3 receives flow from natural baseflow and runoff in addition to the three tributary reaches: the Embarrass River reach above PM-12.2, Mud Lake Creek and Trimble Creek. The total streamflow at PM-12.3 is calculated as the sum of these inflows:

Streamflow (*PM-12.3*) [L^3/T] = **Streamflow** (*PM-12.2*) +
Streamflow (*MLC-2*) + **Streamflow** (*PM-19*) +
Natural Inflows to Embarrass River (*PM-12.3*) **(11-14)**

The outflow from this reach enters the reach upstream of evaluation point "PM-12.4", which—in addition to the natural inflows—also receives a portion of the outflow from the west flow path (Section 10). The total streamflow at PM-12.4 is the sum of these inflows:

Streamflow (*PM-12.4*) [L^3/T] = **Streamflow** (*PM-12.3*) +
Natural Inflows to Embarrass River (*PM-12.4*) +
Perc_Flow_to_PM12_4 * **Discharge from West Flow Path** [L^3/T] **(11-15)**

The remaining fraction of west flow path discharge enters the Embarrass River between the "PM-12.4" and "PM-13" evaluation points. This is the final reach of the river that is modeled, and it also receives flow from Unnamed creek (reach upstream of PM-11), the natural inflows and the river reach directly upstream:

Streamflow (*PM-13*) [L^3/T] = **Streamflow** (*PM-12.4*) + **Streamflow** (*PM-11*)
Natural Inflows to Embarrass River (*PM-13*) +
(1 – Perc_Flow_to_PM12_4) * **Discharge from West Flow Path** **(11-16)**

Mass Transport Calculations

The volume of water in the cell element used to represent each river reach is the product of the length and cross-sectional area of the reach, which are both given in Table 1-48 of the WMDP-PS-Attachment B.

Mud Lake Creek

Constituent mass loadings from the natural groundwater and runoff contributions to the first reach in Mud Lake Creek are the products of the volumetric inflow rates and the baseline runoff and groundwater concentrations. Collectively, these two mass loading sources constitute all the constituent mass derived from unmodeled areas that contribute water to this reach:

Mass Loading from Unmodeled Areas (*MLC-3*) [M/T] =
(**Baseline Groundwater Concentrations** [M/L^3] *
Incremental Baseflow Addition Rate (*MLC-3*) [L^3/T]) +
(**Surface Runoff Concentrations** [M/L^3] *
Incremental Runoff Addition Rate (*MLC-3*) [L^3/T]) **(11-17)**

The baseline groundwater and surface runoff concentrations are determined as described in Section 10, and the incremental inflow rates are calculated as indicated earlier in this section. No constituent mass is derived from the east dam runoff to this reach. Mass loading from FTB pond overflow is the product of the overflow rate (i.e. 45% of the total pond overflow rate) and the FTB pond constituent concentrations (Section 6). Similarly, mass loading from the WWTP effluent is the product of the effluent concentration and discharge rate (Section 9). Loading from Colby Lake is the product of the flow rate (Equation 11-5) and the temporally-varying lake concentrations ("CL_Quality"). The mass outflow rate from this reach to the downstream reach for each constituent is the product of the concentration in the reach and the streamflow rate at MLC-3.

This loading from upstream is transferred to the downstream reach between MLC-3 and MLC-2. Natural runoff and groundwater inflows as well as discharge from the north flow path also add mass to the reach. Mass loading from the north flow path for each constituent occurs at the rate equal to the product of the volumetric outflow rate from the last cell of the flow path and the constituent concentration in the last north flow path cell. Natural mass loadings from unmodeled areas are calculated identically to those for the previous reach.

Trimble Creek

Unlike Mud Lake Creek, there is no background constituent mass loading to Trimble Creek from unmodeled groundwater areas because all groundwater is contained and modeled within the northwest flow path. Mass loading from runoff is therefore the only "natural" source of constituent mass to the upstream reach, and is calculated in the same manner as for Mud Lake Creek:

Mass Loading from Unmodeled Areas (*TC-1*) [M/T] =
Surface Runoff Concentrations [M/L^3] *
Incremental Runoff Addition Rate (*TC-1*) [L^3/T] **(11-18)**

Constituent mass additions to this reach from the WWTP, FTB pond overflow and Colby Lake are the products of the flow rates from each of these sources and the concentrations of each source (see above). The mass loading to the reach downstream is calculated based on the streamflow discharge at TC-1 and the reach concentrations.

Aside from this loading from upstream, mass in the reach between TC-1 and PM-19 is also derived from the northwest flow path. As with the north flow path, this mass loading from the northwest flow path occurs at a rate equal to the product of the constituent concentration in the last flow path cell and the volumetric outflow rate from the last cell of the flow path.

The mass loading rate to the mainstem Embarrass River from Trimble Creek is the product of the streamflow discharge at PM-19 and the constituent concentrations in the reach upstream of PM-19.

Unnamed Creek

Like Trimble Creek there is no mass loading to Unnamed creek from unmodeled groundwater areas. Therefore, Equation 11-18 is used to calculate the unmodeled area mass loading to the reach upstream of PM-11. The other sources of constituent mass to this reach are WWTP effluent and flow added from Colby Lake. Mass loading from the WWTP occurs at a rate equal to the volumetric discharge rate multiplied by the WWTP effluent concentrations (Section 9). Loading from Colby Lake is similarly the product of the lake concentrations ("CL_Quality") and the prescribed flow rate (Equation 11-10a or 11-10b).

The mass loading rates from Unnamed creek to the Embarrass River are calculated as the product of the streamflow discharge at PM-11 and the constituent concentrations in the reach between PM-11 and the west collection system.

Embarrass River

Constituent mass loading to the farthest upstream reach of the Embarrass River ("PM-12") originates from unmodeled upstream areas and the Babbitt WWTP. Mass loading from the unmodeled areas comes from both natural runoff and groundwater inflows and is therefore calculated by Equation 11-17. Because the water quality from the Babbitt WWTP is assumed to equal natural watershed runoff, the Babbitt WWTP loading rate to the reach is the product of the WWTP discharge rate and the uncertain runoff concentration:

Mass Loading from Babbitt WWTP [M/T] =
SW_RO_Concentration [M/L^3] * Babbitt_Flow [L^3/T] **(11-19)**

The total mass loading for each constituent to the uppermost reach of the Embarrass River is therefore the sum of these loadings:

Constituent Mass Inflow Rate (*PM-12*) [M/T] =
Mass Loading from Unmodeled Areas (*PM-12*) +
Mass Loading from Babbitt WWTP **(11-20)**

Constituent mass leaves this reach and enters the reach above PM-12.3 at a rate equal to the product of the reach concentrations and the streamflow at PM-12 (calculated above). The next downstream reach (i.e. the reach upstream of PM-12.2) receives mass loading from this reach, natural groundwater and runoff inflows (calculated by Equation 11-17), and from Area 5. The mass loading rate from Area 5 is equal to the volumetric inflow rate times the concentrations in the Area 5NW pit. These concentrations are calculated or defined one of two ways. For alkalinity, fluoride and vanadium the Area 5NW pit concentrations are equal to the baseline groundwater concentrations defined for groundwater inflows from natural areas (Section 10). Area 5NW pit concentrations for the remaining constituents are those defined in Table 1-44 of the WMDP-PS-Attachment B.

Constituent Mass Inflow Rate (*PM-12.2*) [M/T] =
Constituent Mass Outflow Rate (*PM-12*) +
Mass Loading from Unmodeled Areas (*PM-12.2*) +
Area 5NW Pit Concentrations [M/L^3] * **Area 5 Flow** [L^3/T] **(11-21)**

Mass loading from this reach to the reach above PM-12.3 occurs at a rate equal to the product of the reach concentrations and the volumetric discharge rate at PM-12.2. The other sources of loading to this reach are the natural runoff and groundwater loadings (Equation 11-17) and the aforementioned loadings from Mud Lake and Trimble Creeks. The total mass inflow rate to this reach is therefore:

Constituent Mass Inflow Rate (*PM-12.3*) [M/T] =
Constituent Mass Outflow Rate (*PM-12.2*) +
Constituent Mass Outflow Rate (*MLC-2*) +
Constituent Mass Outflow Rate (*PM-19*) +
Mass Loading from Unmodeled Areas (*PM-12.3*) **(11-22)**

The mass leaving this reach flows into the next downstream reach (PM-12.4) at a mass flow rate equal to the concentrations in this reach and the streamflow discharge at PM-12.3. The PM-12.4 reach also receives water and constituent mass from natural loading (runoff and groundwater), and from the west flow path. The mass loading rate from natural sources is calculated by Equation 11-17 and loading from the west flow path occurs at a rate equal to the flow path discharge to the reach times the concentration in the final flow path cell (Section 10). The total mass inflow rate to the reach is:

Constituent Mass Inflow Rate (*PM-12.4*) [M/T] =
Constituent Mass Outflow Rate (*PM-12.3*) +
Mass Loading from West Flow Path (*PM-12.4*) +
Mass Loading from Unmodeled Areas (*PM-12.4*) **(11-23)**

Constituent mass leaves this reach and enters the final river reach (upstream of PM-13) at a rate equal to the product of the streamflow discharge at PM-12.4 and the concentrations in the reach upstream of PM-12.4. Additional mass loading to the final river reach comes from natural inflows, Unnamed creek, and the remaining fraction of discharge from the west flow path:

Constituent Mass Inflow Rate (*PM-13*) [M/T] =
Constituent Mass Outflow Rate (*PM-12.4*) +
Constituent Mass Outflow Rate (*PM-11*) +
Mass Loading from West Flow Path (*PM-13*) +
Mass Loading from Unmodeled Areas (*PM-13*) **(11-24)**

Mass flows out of this reach (and into a sink cell) are calculated based on the reach concentrations and the discharge at PM-13.

11.4 Output

The surface water system model calculates river discharge and constituent concentrations in Mud Lake Creek, Trimble Creek, Unnamed creek, and the Embarrass River.

12 Concentration Caps

12.1 Purpose

The purpose of this section is to define how the concentration caps applied to different modeled areas are determined. The criteria and data upon which these calculations depend are referenced in this section.

12.2 Input

1. Cat1_Cap_Percent_LAM [-] – 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_LAM [-] – Assumed distribution of porewater pH in Category 1 waste rock
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 7.0; maximum = 7.5)
3. Sb_Cap [mg/L] – Antimony concentration cap
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 0.0083 mg/L; maximum = 0.1 mg/L)
4. 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 can be found in Table 1-24 of the Mine Site WMDP-PS-Attachment B
5. Cat1_Ratio_Se_SO4 [M/M] – Selenium-to-sulfate release ratio from Category 1 rock
    - Probabilistic input sampled at start of each realization
    - Distribution type and parameters can be found in Table 1-24 of the Mine Site WMDP-PS-Attachment B
6. Atmospheric_pH [-] – Estimate of the pH in the areas of the FTB dominated by advection of surface water
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 7.8; maximum = 8.1)
7. Random_Number [-] – Percentile for generating atmospheric concentration caps
    - Probabilistic input sampled at start of each realization
    - Uniform distribution (minimum = 0.95; maximum = 1)
8. Alk_func_pH
    - Deterministic lookup table which determines the alkalinity concentration cap as a function of sampled pH and percentile values (Table 1-15, WMDP-PS-Attachment B)
9. Co_func_pH
    - Deterministic lookup table which determines the cobalt concentration cap as a function of sampled pH and percentile values (Table 1-15, WMDP-PS-Attachment B)
10. Cu_func_pH

- Deterministic lookup table which determines the copper concentration cap as a function of sampled pH and percentile values (Table 1-15, WMDP-PS-Attachment B)

11. Fe_func_pH
    - Deterministic lookup table which determines the iron concentration cap as a function of sampled pH and percentile values (Table 1-15, WMDP-PS-Attachment B)
12. K_func_pH
    - Deterministic lookup table which determines the potassium concentration cap as a function of sampled pH and percentile values (Table 1-15, WMDP-PS-Attachment B)
13. Mn_func_pH
    - Deterministic lookup table which determines the manganese concentration cap as a function of sampled pH and percentile values (Table 1-15, WMDP-PS-Attachment B)
14. Na_func_pH
    - Deterministic lookup table which determines the sodium concentration cap as a function of sampled pH and percentile values (Table 1-15, WMDP-PS-Attachment B)
15. Ni_func_pH
    - Deterministic lookup table which determines the nickel concentration cap as a function of sampled pH and percentile values (Table 1-15, WMDP-PS-Attachment B)
16. Zn_func_pH
    - Deterministic lookup table which determines the zinc concentration cap as a function of sampled pH and percentile values (Table 1-15, WMDP-PS-Attachment B)
17. Mean_Perc_Fines [-] – Average percentage of the flotation tailings beach that is made up of fine flotation tailings
    - Deterministic input (35%)
18. Ca_NMFine_Rel_SO4 [M/M] – Calcium-to-sulfate release ratio from NorthMet fine tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-13 of the WMDP-PS-Attachment B
19. Ca_NMCoarse_Rel_SO4 [M/M] – Calcium-to-sulfate release ratio from NorthMet coarse tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-14 of the WMDP-PS-Attachment B
20. K_NMFine_Rel_SO4 [M/M] – Potassium-to-sulfate release ratio from NorthMet fine tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-13 of the WMDP-PS-Attachment B

21. K_NMCoarse_Rel_SO4 [M/M] – Potassium-to-sulfate release ratio from NorthMet coarse tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-14 of the WMDP-PS-Attachment B
22. Na_NMFine_Rel_SO4 [M/M] – Sodium-to-sulfate release ratio from NorthMet fine tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-13 of the WMDP-PS-Attachment B
23. Na_NMCoarse_Rel_SO4 [M/M] – Sodium-to-sulfate release ratio from NorthMet coarse tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-14 of the WMDP-PS-Attachment B
24. Mg_NMFine_Rel_SO4 [M/M] – Magnesium-to-sulfate release ratio from NorthMet fine tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-13 of the WMDP-PS-Attachment B
25. Mg_NMCoarse_Rel_SO4 [M/M] – Magnesium-to-sulfate release ratio from NorthMet coarse tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-14 of the WMDP-PS-Attachment B
26. Se_NMFine_Rel_SO4 [M/M] – Selenium-to-sulfate release ratio from NorthMet fine tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-13 of the WMDP-PS-Attachment B
27. Se_NMCoarse_Rel_SO4 [M/M] – Selenium-to-sulfate release ratio from NorthMet coarse tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-14 of the WMDP-PS-Attachment B
28. Cd_NMFine_Rel_Zn [M/M] – Cadmium-to-zinc release ratio from NorthMet fine tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-13 of the WMDP-PS-Attachment B
29. Cd_NMCoarse_Rel_Zn [M/M] – Cadmium-to-zinc release ratio from NorthMet coarse tailings
    - Probabilistic input sampled at the start of each realization
    - Distribution type and parameters can be found in Table 1-14 of the WMDP-PS-Attachment B

30. Enriched_pH [-] – Estimate of the pH in the areas of the FTB dominated by diffusion rather than advection
    - Deterministic input (pH = 7.1)

12.3 Calculations

Category 1 Concentration Caps

Category 1 concentration caps for Ag, As, B, Be, Cr, Pb, Tl and V are constant values, and the Sb concentration cap is sampled from a uniform distribution (Table 1-15, WMDP-PS-Attachment B). Caps for alkalinity, Co, Cu, Fe, K, Mn, Na, Ni and Zn concentrations are calculated using two uncertain inputs: a percentile ("Cat1_Cap_Percent_LAM") and a pH value ("Cat1_pH_LAM"). The sampled pH value is employed to determine the 95th and 100th percentile concentration cap values given the data in Table 1-30 of Attachment B to the Water Modeling Data Package Volume 1 – Mine Site ("Mine Site WMDP-PS-Attachment B"). These bounding percentiles are subsequently used to interpolate the concentration cap that corresponds to the sampled percentile.

The concentrations caps for Cd and Se are calculated as follows:

Concentration Cap (Cd, Category 1) [M/L^3] =
Concentration Cap (Zn, Category 1) * Cat1_Ratio_Cd_Zn **(12-1)**

Concentration Cap (Se, Category 1) [M/L^3] =
Concentration Cap (SO_4, Category 1) * Cat1_Ratio_Se_SO4 **(12-2)**

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 Mine Site WMDP-PS-Attachment B. It is worthy of note that, because the caps for Ba and F are dependent upon the concentrations of other constituents (SO_4 and Ca), these two concentration caps are calculated locally in both areas where the Category 1 concentration caps are applied: the North buttress and South buttress.

Atmospheric Concentration Caps

A similar pH- and percentile-based lookup procedure to the one described above for the Category 1 caps is used to determine the atmospheric concentration caps for some constituents. The sampled pH value ("Atmospheric_pH") and percentile ("Random_Number") values differ from those for the Category 1 rock, as do the lookup tables for alkalinity, Co, Cu, Fe, K, Mn, Na, Ni and Zn ("Alk_func_pH", "Co_func_pH", "Cu_func_pH", "Fe_func_pH", "K_func_pH", "Mn_func_pH", "Na_func_pH", "Ni_func_pH" and "Zn_func_pH"). Atmospheric concentration caps for Ag, As, B, Be, Cr, Pb, Sb, Tl and V are the same as for Category 1 waste rock. There are no atmospheric caps on chloride or fluoride concentrations.

The sulfate concentration cap is calculated as a function of the average Ca, K, Na and Mg release rates, which are calculated based upon the percentage of the tailings beaches made up of fine tailings ("Mean_Perc_Fines") and the sulfate release rates and constituent-specific release ratios from fine and coarse tailings:

Average Release Rate (Ca) [mol/M/T] =
(Mean_Perc_Fines * SO4_NMFine_Release [M/M/T] * Ca_NMFine_Rel_SO4 +
(1 – Mean_Perc_Fines) * SO4_NMCoarse_Release [M/M/T] *
Ca_NMCoarse_Rel_SO4) /
Molar Mass (Ca) [M/mol] **(12-3a)**

Average Release Rate (K) [mol/M/T] =
(Mean_Perc_Fines * SO4_NMFine_Release [M/M/T] * K_NMFine_Rel_SO4 +
(1 – Mean_Perc_Fines) * SO4_NMCoarse_Release [M/M/T] * K_NMCoarse_Rel_SO4) /
Molar Mass (K) [M/mol] **(12-3b)**

Average Release Rate (Na) [mol/M/T] =
(Mean_Perc_Fines * SO4_NMFine_Release [M/M/T] * Na_NMFine_Rel_SO4 +
(1 – Mean_Perc_Fines) * SO4_NMCoarse_Release [M/M/T] *
Na_NMCoarse_Rel_SO4) /
Molar Mass (Na) [M/mol] **(12-3c)**

Average Release Rate (Mg) [mol/M/T] =
(Mean_Perc_Fines * SO4_NMFine_Release [M/M/T] * Mg_NMFine_Rel_SO4 +
(1 – Mean_Perc_Fines) * SO4_NMCoarse_Release [M/M/T] *
Mg_NMCoarse_Rel_SO4) /
Molar Mass (Mg) [M/mol] **(12-3d)**

The sulfate concentration cap is subsequently calculated using these four release rates and the sulfate solubility equation (Table 1-30 of the Mine Site WMDP-PS-Attachment B):

Concentration Cap (SO_4, Atmospheric) [mg/L] = 1760 mg/L + 1294 mg/L *
[**Average Release Rate (Mg)** + 0.5 * **Average Release Rate (Na)** +
0.5 * **Average Release Rate (K)**] / **Average Release Rate (Ca)** **(12-4)**

The SO_4, alkalinity and K concentration caps are used to calculate the Ca cap, which is subsequently used to calculate the Mg cap:

Concentration Cap (Ca, Atmospheric) [M/L^3] = **Molar Mass (Ca)** *
[(2 * **Concentration Cap (SO_4, Atmospheric)** / **Molar Mass (SO_4)** [M/mol] +
Concentration Cap (Alkalinity, Atmospheric) / **Molar Mass (Alkalinity)** [M/mol] –
Concentration Cap (K, Atmospheric) / **Molar Mass (K)** [M/mol]) /
(2 + (2 * **Average Release Rate (Mg)** + **Average Release Rate (Na)**) /
Average Release Rate (Ca))] **(12-5)**

Concentration Cap (Mg, Atmospheric) [M/L^3] = **Concentration Cap (Ca, Atmospheric)***
[(Mean_Perc_Fines * Mg_NMFine_Rel_SO4 / Ca_NMFine_Rel_SO4) +
(1 – Mean_Perc_Fines) * Mg_NMCoarse_Rel_SO4 / Ca_NMCoarse_Rel_SO4] **(12-6)**

The selenium concentration cap is also calculated as a function of the sulfate cap and selenium-to-sulfate release ratios:

Concentration Cap (Se, Atmospheric) [M/L^3] =
Concentration Cap (SO_4, Atmospheric) *
[Mean_Perc_Fines * Se_NMFine_Rel_SO4 +
(1 – Mean_Perc_Fines) * Se_NMCoarse_Rel_SO4] **(12-7)**

The aluminum concentration cap is calculated directly from the sampled pH value:

Concentration Cap (Al, Atmospheric) [mg/L] = 10^(0.909 * Atmospheric_pH – 9.44) **(12-8)**

The concentration cap for the one remaining constituent with a global concentration cap—cadmium—is calculated as a function of the zinc cap:

Concentration Cap (Cd, Atmospheric) [M/L^3] =
Concentration Cap (Zn, Atmospheric) *
[Mean_Perc_Fines * Cd_NMFine_Rel_Zn +
(1 – Mean_Perc_Fines) * Cd_NMCoarse_Rel_Zn] **(12-9)**

Concentration caps for the final constituent—barium—are calculated locally everywhere these atmospheric caps apply as a function of the local sulfate concentration (in mg/L) from the previous time-step:

Concentration Cap (Ba, Atmospheric) [mg/L] =
10^(-0.87 – 0.32*log(**Sulfate Concentration** (t-1) [mg/L])) **(12-10)**

These atmospheric caps are applied to the FTB ponds.

Enriched Concentration Caps

Enriched concentration caps for Ag, As, B, Be, Cr, Pb, Sb, Se, SO_4, Tl and V are the same as the atmospheric caps. The enriched pH value ("Enriched_pH") is used along with the same percentile ("Random_Number") and lookup tables used to determine the atmospheric caps (above) to determine the enriched caps for alkalinity, Co, Cu, Fe, K, Mn, Na, Ni and Zn. Enriched caps for Ca, Mg, Al and Cd are calculated using the same formulas used to calculate the analogous atmospheric concentration caps.

Ba concentration caps are also calculated locally by Equation 12-10 in all areas where these caps apply. These areas include the unsaturated portions of the four tailings beaches (East, North, South and Closure), and the entrained water beneath the FTB ponds. There are no chloride or fluoride concentration caps in any of these areas.

12.4 Output

The concentration caps calculated in this section are applied to water in the following areas:

- North and South buttresses
- East, North, South and Closure beaches
- Cell 1E, 2E and 1E/2E ponds
- Deposited tailings beneath the active FTB pond (entrained water only)

No concentration caps are applied to water in the other modeled areas.