Stibnite Gold Project
Geochemical Modeling Work Plan

Midas Gold Idaho, Inc.

MIDAS GOLD

November 2017

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CHAPTER 1: INTRODUCTION

1.1   Purpose and Scope

Midas Gold Idaho, Inc. (MGII or Midas Gold) is currently conducting numerical geochemical modeling to assess future water quality associated with the Stibnite Gold Project in Valley County, Idaho. The Project is in the advanced exploration/feasibility study phase in the historic Stibnite-Yellow Pine Mining District. Mining has occurred in this district for over 100 years producing gold, silver, antimony, and tungsten from deposits that include West End, Hangar Flats, Yellow Pine, and others.

The objective of the geochemical modeling effort is to determine the potential for groundwater and surface water impacts from the proposed open pits, development rock storage facilities (DRSFs), and tailings storage facility (TSF) described in the Plan of Restoration and Operations (PRO) (MGII, 2016). Numerical geochemical predictions are necessary to support analysis of the proposed action and alternatives in the National Environmental Policy Act (NEPA) process.

This work plan describes the conceptual models and numerical modeling approach, and details the assumptions made. The results of the geochemical modeling will be presented in a stand-alone report.

CHAPTER 2: GENERAL MODELING APPROACH

2.1   Conceptual Model

The facilities in the PRO mine plan are shown in Figure 3-1. Conceptual models have been developed for the Project from a review of background and site-specific data, including the hydrologic model (JSAI, *in progress*) and facilities in the PRO mine plan. Conceptual models have been developed for the following scenarios:

- Operational:
    - Scenario 1 – assumes full build-out of the facilities (i.e., year 12 of mine life)
    - Scenario 2 – assumes partial build out of the facilities at the mid-point in the mine life (i.e., approximately year 6)
- Post-closure – following closure and reclamation of the facilities

The conceptual models are shown in Figure 2-2 and 2-3 and incorporate the following proposed facilities:

- Yellow Pine pit and backfill;
- Hangar Flats pit;
- West End pit;
- Fiddle DRSF;
- Hangar Flats DRSF;
- West End DRSF; and
- TSF and embankment.

Based on the geochemical characterization program (SRK, 2017), the potential for acid generation and metal leaching associated with these facilities is low; however, these proposed facilities have the potential to contribute some solute loading (e.g., arsenic) to the surface water system under neutral pH conditions. The geochemical modeling program is being completed to determine if the solute loading from the proposed facilities will result in an appreciable increase in constituent concentrations under post closure conditions following reclamation of the facilities. In cases where an existing facility is removed or mitigated, the source term for the facility will be removed from the post-closure scenario, e.g., Spent Ore Disposal Area (SODA) facility and historic Bradley tailings.

The conceptual models in Figure 2-2 and Figure 2-3 show the relationship of the geochemical prediction models (source terms) for each of these mine facilities. The approaches for the facility models are presented in Chapters 3, 4, and 5 for the DRSFs, TSF, and pits, respectively. These facility source terms will be incorporated into a Site-Wide Water Chemistry (SWWC) model to predict surface water chemistry at key points downgradient of the mine facilities. The approach for the SWWC model is presented in Section 5. Data that will be used as inputs to the geochemical models are derived from the following sources:

- Geological and mine planning information from the Preliminary Feasibility Study (PFS) resource model (M3, 2014), PRO (MGII, 2016) development rock production schedule and mine design.

- Hydrogeologic and hydrologic water balance information from the hydrologic model developed by JSAI (JSAI, *in progress*) that incorporates both surface water and groundwater flow components under operational and post closure conditions.

- Geochemical data from laboratory static and kinetic tests performed on representative materials that are scaled to field conditions. These data have been collected as part of the Phase 1 and Phase 2 geochemical characterization programs (SRK, 2017) and are utilized to provide source term data for chemical leaching of geologic materials exposed in the DRSFs, pit walls, and TSF.

- Precipitation chemistry data from long-term monitoring at the Smiths Ferry meteorological station, Idaho (NADP, 2015).

- Groundwater chemistry data from the Groundwater Quality Baseline Study (HDR, 2016).

- Surface water chemistry data from the Surface Water Quality Baseline Study (HDR, 2017).

Details of the assumptions used in the geochemical modeling, the conceptual models, the input data, and numerical modeling approach are provided in the following sections.
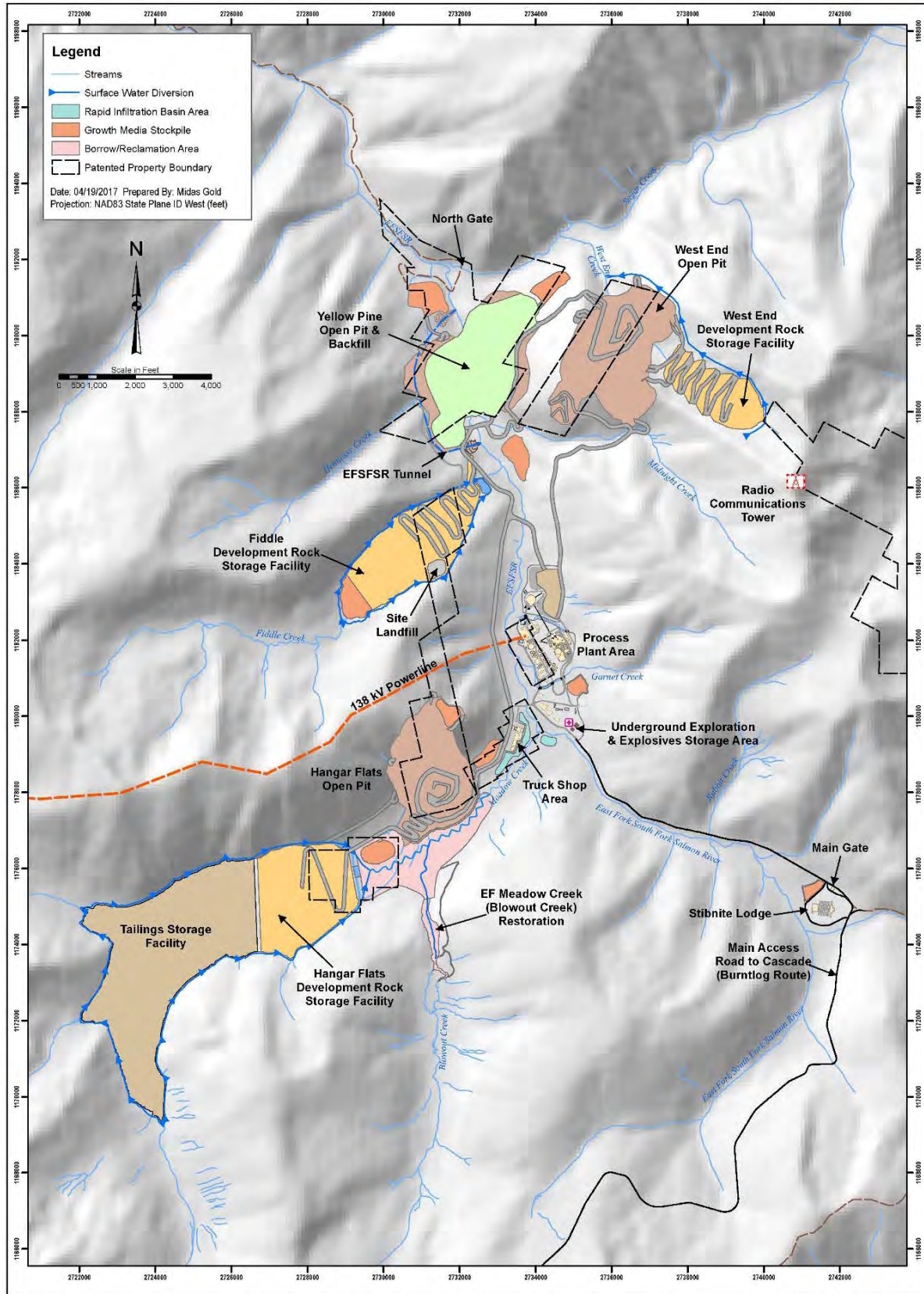
Figure 2-1: PRO Mine Plan (MMGI, 2016)
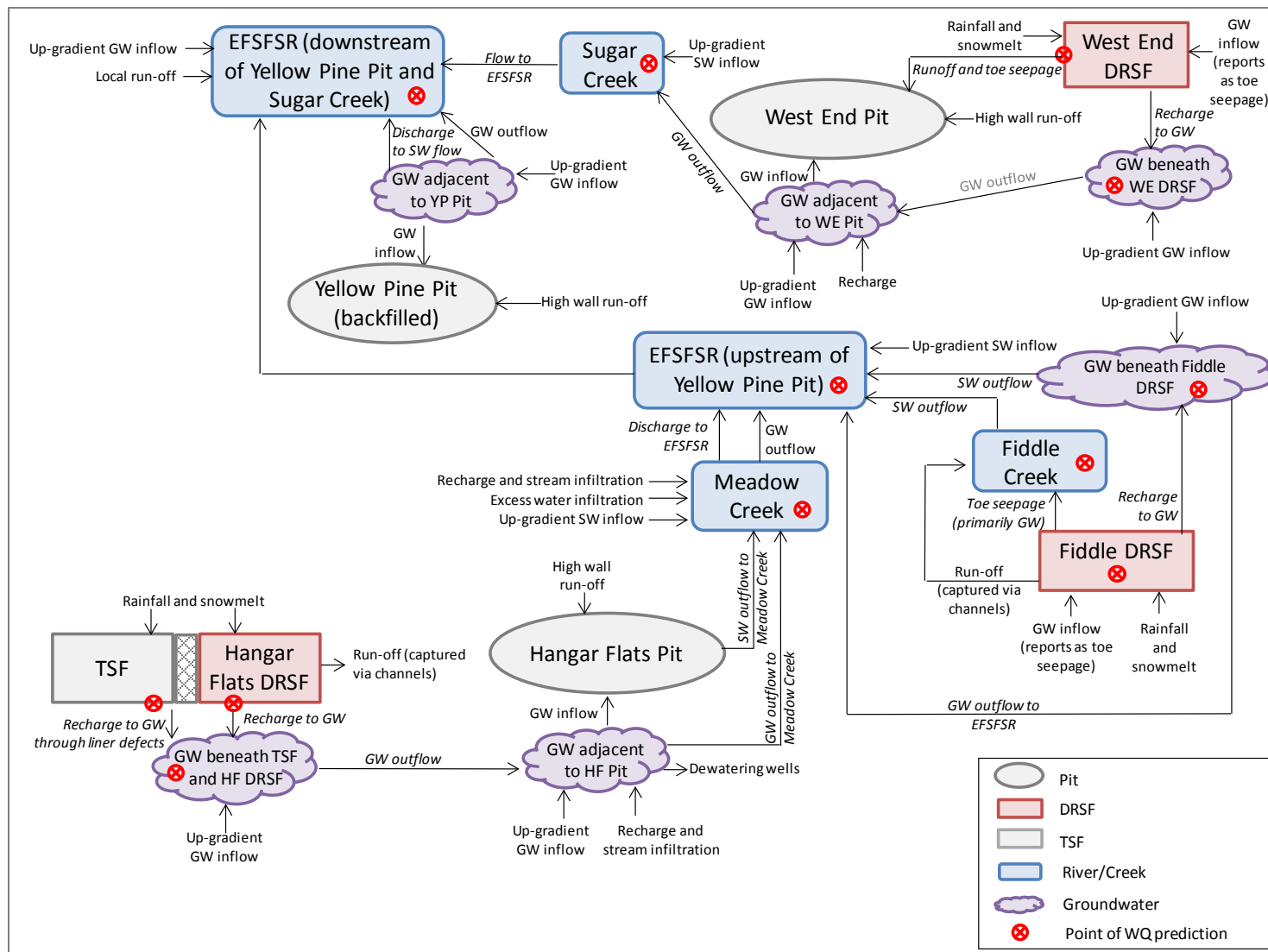
Figure 2-2: Operational Conceptual Model
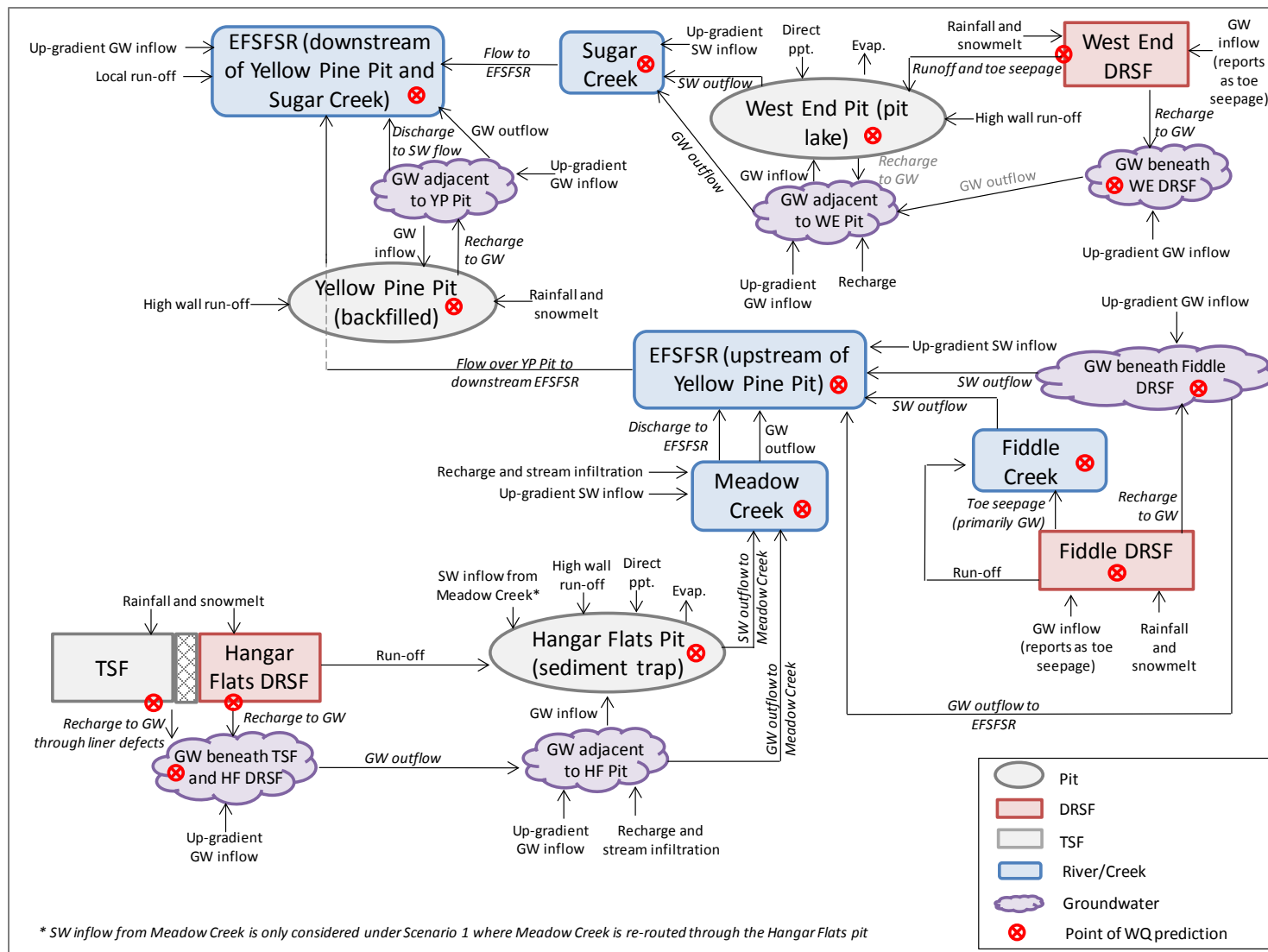
Figure 2-3: Post-Closure Conceptual Model

2.2   Comparative Guidelines

The results of the geochemical modeling will be compared to potentially applicable regulatory groundwater and surface water criteria to provide a context in which to understand and interpret the data. HDR Inc. (HDR) undertook a compilation of potentially applicable criteria as part of the Groundwater Quality Baseline Study (HDR, 2016) and Surface Water Quality Baseline Study (HDR, 2017). These criteria represent a combination of drinking water standards and cold water aquatic criteria, and have been used herein as a means of providing a frame of reference for the results of the geochemical modeling. It is emphasized, however, that these criteria do not represent regulatory standards or permitted discharge concentrations at the site; these comparisons will be provided strictly for context and may not necessarily be applicable for all sites. The guidelines that will be used in the assessment are listed in Table 2-1.

Table 2-1: Water Quality Guidelines

Parameter	Units	Idaho Groundwater Quality Guideline (IDAPA 58.01.11)	Strictest Surface Water Quality Criteria (HDR, 2017)	
			Value	Source
pH	s.u.	≥6.5 and ≤8.5*	≥6.5 and ≤9.0	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]
Alkalinity	mg/L as CaCO$_3$	-	>20	USEPA Freshwater Aquatic Life Criteria[2]
Aluminum	mg/L	0.2*	0.05	USEPA Secondary Drinking Water Standards[3]
Antimony	mg/L	0.006	0.0052	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]
Arsenic	mg/L	0.01	0.01	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]/Idaho Domestic Water Supply Use[4]/USEPA Drinking Water MCL[5]
Barium	mg/L	2	2	USEPA Drinking Water MCL[5]
Beryllium	mg/L	0.004	0.004	USEPA Drinking Water MCL[5]
Boron	mg/L	-	120	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]
Cadmium	mg/L	0.005	0.00025	USEPA Freshwater Aquatic Life Criteria[2]
Chloride	mg/L	250*	230	USEPA Freshwater Aquatic Life Criteria[2]
Chromium, total	mg/L	0.1	0.1	USEPA Drinking Water MCL[5]
Copper	mg/L	1.3	0.009	USEPA Freshwater Aquatic Life Criteria[2]
Cyanide, total	mg/L	0.2	0.0052	Idaho Criteria for Aquatic Life[1]
Cyanide, WAD	mg/L	-	0.0052	Idaho Criteria for Aquatic Life[1]/USEPA Freshwater Aquatic Life Criteria[2]
Iron	mg/L	0.3*	0.3	USEPA Secondary Drinking Water Standards[3]
Fluoride	mg/L	4	2	USEPA Secondary Drinking Water Standards[3]
Lead	mg/L	0.015	0.0025	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]/USEPA Freshwater Aquatic Life Criteria[2]
Manganese	mg/L	0.05*	0.05	USEPA Secondary Drinking Water Standards[3]
Mercury	mg/L	0.002	0.000012	IDAPA 58.01.02 Water Quality Standards. (Surface Water)
Molybdenum	mg/L	-	0.6	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]
Nickel	mg/L	-	0.052	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]/USEPA Freshwater Aquatic Life Criteria[2]
Nitrate + nitrite	mg/L	10	-	USEPA Drinking Water MCL[5]
Selenium	mg/L	0.05	0.005	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]/USEPA Freshwater Aquatic Life Criteria[2]
Silver	mg/L	0.1*	0.0032	USEPA Freshwater Aquatic Life Criteria[2]
Total Dissolved Solids	mg/L	500*	500	USEPA Secondary Drinking Water Standards[3]
Sulfate	mg/L	250*	250	USEPA Secondary Drinking Water Standards[3]
Thallium	mg/L	0.002	0.000017	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]
Vanadium	mg/L	-	0.835	IDAPA 58.01.02 Water Quality Standards. (Surface Water)[1]
Zinc	mg/L	5*	0.12	IDAPA 58.01.02 Water Quality Standards. (Surface Water) /USEPA Freshwater Aquatic Life Criteria[2]

Source: From HDR, 2016; 2017

'-' indicates no guideline for parameter

* Indicates secondary guideline

[1] IDAPA 58.01.02 Water Quality Standards. (Surface Water) (IDAPA, 2017)

[2] US EPA National Recommended Water Quality Criteria for Aquatic Life, https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

[3] US EPA National Primary Drinking Water Regulations, Secondary Standards, https://www.epa.gov/dwstandardsregulations

[4] IDAPA 58.01.02 Section 210, Numeric Criteria for Toxic Substances for Waters Designated for Domestic Water Supply Use, https://adminrules.idaho.gov/rules/2012/58/0102.pdf

[5] US EPA National Primary Drinking Water Standards, https://www.epa.gov/dwstandardsregulations

CHAPTER 3: DRSF MODELING

3.1   DRSF Conceptual Models

Source terms will be developed for the Fiddle, Hangar Flats, and West End DRSFs (Figure 2-1). The general modeling approach is to quantify the solute concentrations in water that will potentially seep from the base of the facilities during operations and post-closure, and to predict the likely solute concentrations in the underlying groundwater and downgradient surface water. For the operational model, this will include an assessment of blast residue leaching from the DRSFs. The conceptual models for the DRSFs have been developed using the following estimates and assumptions derived from the MGII exploration database, PFS resource model, PRO mine plan, preliminary water balance, best available data, and modeler judgment. The assumptions relating to the water balance are subject to variation depending on the results of the hydrologic modeling currently underway.

- An estimate of the proportion of each lithology (both PAG and non-PAG) that will be produced during mining operations and deposited in the DRSFs has been made from the PFS resource model and geologic modeling completed by Midas Gold:

    - The Hangar Flats DRSF will contain 81.2 million tons (Mt) of development rock, comprising 49.9 Mt (61%) of non-PAG development rock from the Hangar Flats pit, 26.5 Mt (33%) of non-PAG development rock from the Yellow Pine pit and 4.79 Mt (6%) of PAG development rock from both Hangar Flats and Yellow Pine pits. Directly adjacent to the Hangar Flats DRSF will be the TSF embankment, which will contain 60.7 Mt of development rock, comprising 31.4 Mt (52%) of non-PAG development rock from the Yellow Pine pit, 23.1 Mt (38%) of non-PAG development rock from the Hangar Flats pit, 0.6 Mt of non-PAG development rock from the West End pit (1%) and 5.8 Mt (9%) of spent ore from SODA.

    - The West End DRSF will contain 25.1 Mt (99.4%) of non-PAG development rock and 0.14 Mt (0.6%) of PAG rock that will be sourced entirely from the West End pit.

    - The Fiddle DRSF will contain 68.2 Mt of development rock, comprising 56.9 Mt (83%) of non-PAG development rock from the Yellow Pine pit, 4.8 Mt (7%) of non-PAG development rock from the West End pit and 6.47 Mt (10%) of PAG development rock from both Hangar Flats and Yellow Pine pits.

- A site-specific Neutralization Potential Ratio (NPR) cut-off of 1.5, calculated using the results from the Phase 1 geochemical characterization (SRK, 2017), is used to differentiate between Potentially Acid Generating (PAG) and non-PAG development rock. An NPR cut-off of 1 is typically applied to define PAG material (INAP 2014); therefore, the site-specific NPR cut-off is a more conservative estimate of PAG material. Sensitivity analysis will be conducted for a range of NPR values to determine the effect of this PAG cut-off on the predictions.

- Each lithology within the DRSF will have similar physical characteristics in terms of grain size distribution and fracture density. This is a simplifying assumption that is being made for the modeling effort and active 'blending' of the development rock during operations is not proposed.

- The primary source of contact water is assumed to be rainwater and snowmelt. In the absence of any site-specific rainwater chemistry, the chemistry of representative rainwater will be obtained from monthly monitoring carried out between 1984 and 2006 at the Smiths Ferry Meteorological Station, Valley County, Idaho, approximately 55 miles from Stibnite (NADP, 2015).

- Representative leachate chemistries for the PAG and non-PAG development rock will be obtained from site-specific humidity cell tests (HCTs) from the Phase 1 and Phase 2 geochemical characterization studies, scaled to field conditions. The method for scaling laboratory data to field conditions is outlined in Section 0.

- At closure, the development rock facilities will be re-graded to promote positive drainage and a growth media cover will be established on the facilities. Any surface runoff from the facilities will only contact the growth media cover and will not come into contact with the underlying development rock. As such, post-closure runoff from the facilities can be represented by rainwater chemistry from NADP (2015). In addition, the surface streams that are re-established across the facilities will be underlain by synthetic liners; therefore, surface water from those channels will not come into contact with the underlying DRSF material.

- The water balance for the West End and Fiddle DRSFs shows that there will be inflow of groundwater to the facilities (JSAI, *in progress*). This water will move through a drain in the valley bottom at the base of the facility and will discharge at the toe of the dump (JSAI, pers. comm.). The drain layer will be constructed using non-PAG material that is geochemically benign. This water will have minimal contact with development rock within the facility and is thus not treated as contact water for the purpose of the geochemical model.

- Precipitation that infiltrates the DRSFs has the potential to recharge to groundwater. This water will interact with groundwater in the uppermost 32.8 feet (10 meters) of the aquifer beneath the footprint of the facility (JSAI, pers. comm). The aquifers below the DRSFs consist of a mixture of fractured bedrock and alluvium. Specific yields within these units are 1% and 10% for the bedrock and alluvium, respectively (JSAI, pers. comm.). Sensitivity analysis will be performed to assess the uncertainty associated with this parameter.

- The residence time in the aquifer will be short and on the order of one month to a few months at most (JSAI, pers. comm.). In the case of Hangar Flats and West End DRSFs, this water will quickly report to the adjacent pits. Recharge to groundwater from Fiddle DRSF will report to surface water and the alluvial aquifer in the lower Fiddle Creek valley and then to the EFSFSR.

- Any infiltration recharging to groundwater will migrate directly to the water table and no allowance for solute attenuation will be accounted for along the flow path. Oxidation is minimal in the bedrock, therefore there is likely to be minimal iron oxides to provide adsorption surfaces for solutes to attenuate. Furthermore, the shallow groundwater in the project area means that the flow path to groundwater will be extremely short, thereby limiting the potential for attenuation in the vadose zone. The flux of groundwater beneath the DRSFs will be incorporated into the geochemical model by accounting for the volumes of groundwater that move through the groundwater system beneath each DRSF on an annual basis.

The data sources for the DRSF geochemical model inputs are listed in Table 3-1. Conceptual model diagrams for the Fiddle, Hangar Flats, and West End DRSFs are provided in Figure 3-1 through Figure 3-3, respectively.
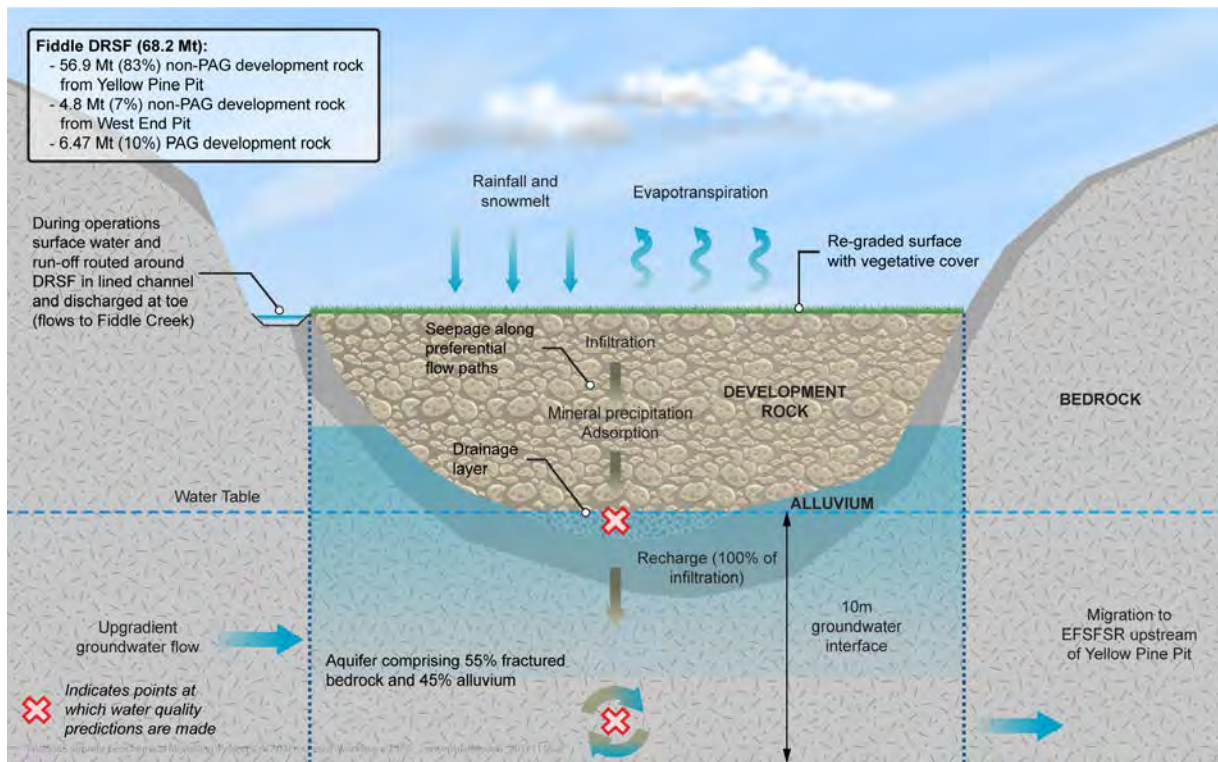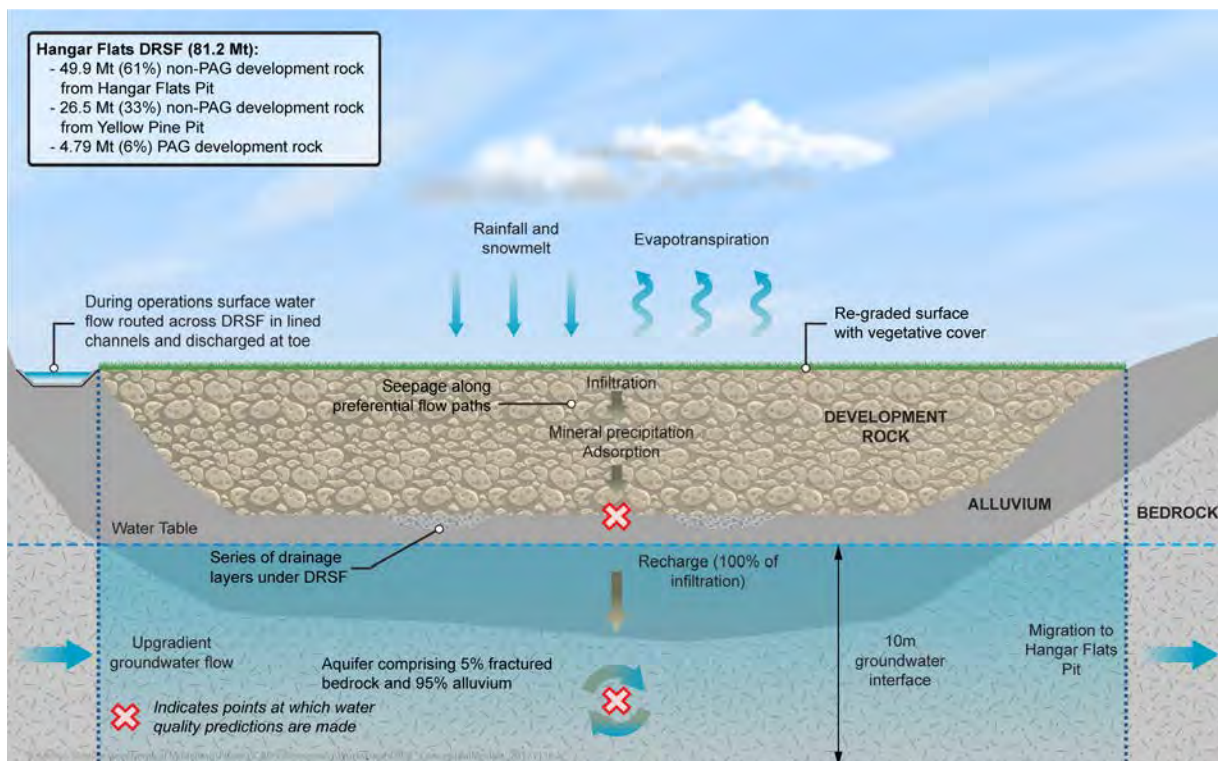

Figure 3-1: Fiddle DRSF Conceptual Model
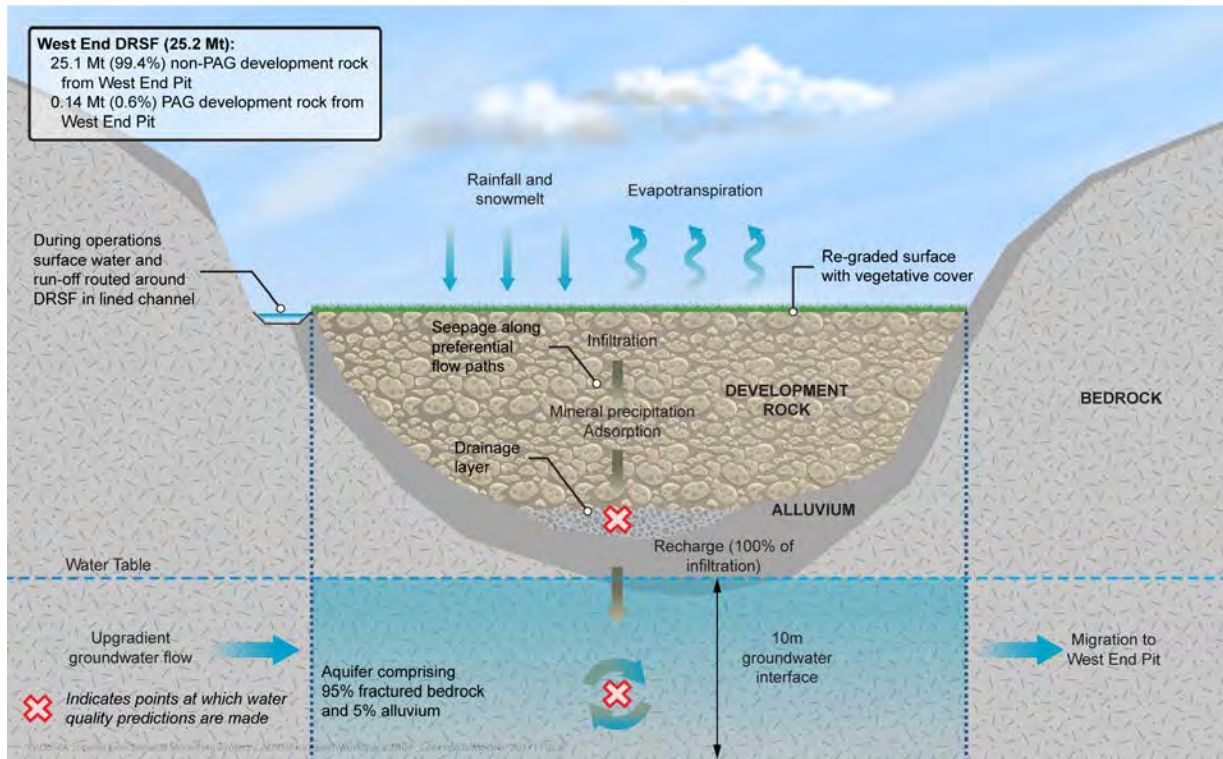

Figure 3-2: Hangar Flats DRSF Conceptual Model

Figure 3-3: West End DRSF Conceptual Model

Table 3-1: DRSF Model Data Sources

Component	Source	Details
Water balance	JSAI (*in progress*)	A site-wide water balance has been developed by JSAI from the hydrologic model for operational and closure scenarios using available site data. This provides details of average annual rainfall/snowmelt, runoff, toe seepage and recharge to groundwater for each of the DRSFs, in addition to the interaction of these solutions with surface water and groundwater.
Development rock tonnages	Midas Gold PRO Mine Plan development rock schedule (MGII, 2016)	Development rock tonnages for each of the DRSFs will be obtained from the Midas Gold PRO Mine Plan development rock schedule. This assumes that the Hangar Flats DRSF will contain 81.2 Mt, the West End DRSF will contain 25.2 Mt and the Fiddle DRSF will contain 68.2 Mt of development rock.
Development rock lithological composition	Midas Gold PFS resource model (M3, 2014)	The development rock lithological composition will be determined from the PFS resource model and an assumed NPR cut-off of 1.5 to differentiate between PAG and non-PAG material.
Precipitation chemistry	NADP (2015)	Representative rainwater chemistry data from monthly monitoring carried out between 1984 and 2006 at the Smiths Ferry Meteorological Station, Idaho.
Groundwater chemistry	HDR groundwater baseline (September 2012 – September 2016) (HDR, 2016)	Representative groundwater chemistry data from the Groundwater Geochemistry Baseline Study (HDR, 2016).
Non-PAG development rock chemistry	SRK Phase 1 humidity cell program (SRK, 2017)	Scaled humidity cell data will be used to develop separate source terms for the non-PAG lithologies present in the development rock facilities. The data will be scaled to field conditions based on the difference in temperature and liquid to solid ratio between the lab humidity cell test (HCT) and field conditions, in addition to other assumptions, including: • Precipitation infiltrating the facility will only contact 20% of the total rock volume, due to water movement along preferential flow paths; and • 20% of total mass in the DRSFs will consist of 'fines' and available for chemical weathering reactions.
PAG development rock chemistry	SRK Phase 1 humidity cell program (cell 14) (SRK, 2017)	HC-14 will be selected to represent PAG development rock since this cell has the highest total sulfur and highest sulfate leaching rate which corresponds to the maximum sulfide oxidation[1]. The data will be scaled to field conditions based on the difference in temperature and liquid to solid ratio between the lab HCT and field conditions, in addition to other assumptions about preferential flow paths, oxygen and grain size.
Thermodynamic data	minteq.v4 database (Parkhurst and Appelo, 1999)	The minteq.v4 thermodynamic database supplied with version 3.3.8.11728 of PHREEQC will be used

3.2   Derivation of Rock Weathering and Leaching Rates

Source terms for development rock facilities are typically developed using the results of site-specific laboratory leach tests (i.e., HCT) that are scaled to field conditions. A scaling factor is applied in order to account for the differences in reaction rates, temperature, and liquid-to-solid ratios between the laboratory test and field conditions. Site-specific scaling factors are typically developed based on information relating to the water balance, geological model, and mine plan.

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[1] Additional humidity cell testing is currently being carried out as part of the Phase 2 Geochemical Characterization Program. In the instance that one of these cells develops acidic conditions, the chemistry from that cell will be used to represent PAG development rock chemistry.

Only a small fraction of the total mass of material within a development rock facility will be effectively contacted by infiltrating meteoric waters. This fraction is termed the 'contacted mass', which is a result of the combined influence of preferential fluid flow pathways within the facility, in addition to temperature, wetting, and grain size effects, whereby a proportion of the total mass will be effectively isolated within larger particles and therefore unavailable for weathering and mobilization of constituents.

The reactive portion of development rock facilities is generally assumed to be associated with the fine-grained material (i.e., material less than 2 mm in size) due to the high proportion of the surface area represented by finer fractions. According to Schafer (2007), Price and Kwong (1997), and Murray (1977), the typical proportion of fines within a waste rock facility is between 10% and 30%. For the purpose of the Stibnite DRSF source term predictions, 20% of total mass in the DRSFs will consist of 'fines' and available for chemical weathering reactions. This is a reasonable estimate for unsaturated development rock and is within the 10 to 30% range reported by Schafer (2007), Price and Kwong (1997), Murray (1977), and Schneider et al. (2010). In addition, infiltration to the Stibnite DRSFs will be restricted to movement along preferential flow paths contacting approximately 20% of the rock volume. This is consistent with information provided by El Boushi (1975) as reported in MEND (1995), which assumes that flow within development rock facilities is restricted to movement along preferential flow paths contacting approximately 20% of the rock volume. The combined effects of grain size (assumed to be 20% fine particles) and flow paths (assumed to be 20% of the rock volume) mean that only 4% of the total rock mass within the DRSFs is considered available for geochemical weathering reactions (i.e., 20% x 20%). The weathering rates from the HCTs will then be applied to this 4% rock mass to define source term chemistry as described below. Sensitivity analysis will be conducted to assess the uncertainty associated with these input parameters.

In addition to wetting and grain size effects within the development rock facilities, the ambient temperature in the field will also affect reaction rates and solute release; therefore, an additional scaling factor will be applied that considers the difference in air temperature between the laboratory HCT (conducted at 25°C according to ASTM 5744-13e1) and annual average field conditions. This is developed from the calculated difference in rate constant, as determined from the Arrhenius equation in equation [1]:

[1] $$K = Ae^{\frac{E_A}{RT}}$$

Where: K =   rate constant

A =   frequency factor (assumed to be approximately constant)

E_A =   Activation energy (assumed to be 88,000 J/mol (Nicholson et al., 1988)

R =   Gas constant (8.31 J/K/mol)

T =   Temperature (kelvin)

Rate constants (K) are developed for both laboratory temperature conditions (K_{lab}) and annual average field temperature conditions (K_{field})[2] and the temperature scaling factor (T) is defined as K_{field}/K_{lab}. Sensitivity analysis will be conducted to evaluate how temperature variations may affect reaction rates and associated source term chemistry. As with the laboratory HCTs, the DRSFs are assumed to be fully oxygenated and therefore no additional oxygen scaling factor will be applied.

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[2] K_{lab} and K_{field} are both calculated using the Arrhenius equation (see equation *[1]*)

Based on these assumptions, the humidity cell chemistry data will be scaled as described in equation [2]:

[2]
$$C_i = \frac{R_i \times M \times F \times P \times T \times O}{Q}$$

Where: $C_i =$ *scaled concentration of element i (mg/L)*

$R_i =$ *average release rate of element i in the humidity cell tests (mg/kg/week)*

$M =$ *total mass of material in development rock facility (kg)*

$F =$ *proportion of fines in the development rock facility (%)*

$P =$ *proportion of material contacted by infiltration in the development rock facility (%)*

$T =$ *temperature scaling factor based on Arrhenius equation (unitless) defined by K_{field}/K_{lab}*

$O =$ *oxygen scaling factor (unitless), assumed to be 1 for this analysis (i.e. no oxygen scaling factor applied)*

$Q =$ *average weekly infiltration (L/week)*

Using this approach, source terms will be developed for each material type within the DRSF. These source terms will then be mixed according to the relative proportion of each material type to develop a combined source term for the facility using equation *[3]* as follows:

[3] $$DRSF_{ST} = (Ci_A \times Li_A) + (Ci_B \times Li_B) + (Ci_C \times Li_C) \dots etc$$

Where: $DRSF_{ST}$ = combined development rock facility source term

$Ci_A =$ *scaled concentration of element i for lithology A (mg/L)*

$Li_A =$ *proportion of lithology A in development rock storage facility*

3.3   Solubility Controls and Trace Element Adsorption

Under field conditions, leachates produced from the various lithologies within the DRSFs will mix and solutes in these waters will react with each other and may form chemical precipitates if the concentrations and macro-geochemical conditions (Eh, pH, pCO_2, pO_2, and ionic strength) allow saturation to occur. In order to evaluate whether certain mineral phases are close to saturation in the DRSF solutions, the predicted mass balanced chemistry will be equilibrated in the USGS-developed software program PHREEQC version 3.0.0-7430 (Parkhurst and Appelo, 1999). The relative saturation of all minerals will be computed by comparing the calculated concentration of dissolved ionic pairs with their theoretical thermodynamic limit. Where these values are equal, the saturation index is zero and the solution is said to be at equilibrium with that mineral. At equilibrium, any amount of the mineral that dissolves will precipitate to maintain the relative solute:mineral balance.

In addition to mineral precipitation/co-precipitation, adsorption onto the surfaces of common mineral phases such as iron oxides and clays represents a potential primary control on trace element concentrations. Ferrihydrite ($5Fe_2O_3.9H_2O$) is assumed to represent the primary sorption surface because it is a common sorption substrate in oxygenated natural waters and because the thermodynamic properties of trace element sorption reactions with ferrihydrite are well defined by numerous empirical studies. Adsorption of soluble phases to ferric oxides (HFO) is highly pH dependent as is the solubility of HFO itself. Below a pH of around 4.5, only minimal sorption of

most dissolved metal species is observed (Stumm and Morgan, 1996). The mass of ferrihydrite that will be used in the models will be identical to the mass of the mineral phase ferrihydrite precipitated in the previous model iterations as controlled by the chemistry of the system. Ferrihydrite is characterized in the model by both strong (HFO_s) and weak (HFO_w) surface adsorption sites. In order to be consistent with the published properties of ferrihydrite (Dzombak and Morel, 1990), the geochemical models will use a surface site density of 0.2 moles of weak sites and 0.005 moles of strong sites per mole of ferrihydrite.

CHAPTER 4: TSF MODELING

4.1   Conceptual Model

Tailings generated by the Stibnite Gold Project will be deposited in a lined facility with an engineered rockfill dam and extensive development rock buttress. The entire TSF will be lined with a composite liner system to prevent seepage of process water; however, there could be minor seepage from manufacturing defects and other larger holes in the liner or the seams developed during placement. Under-liner drains and downgradient wells will be monitored for the presence of seepage. During operations, pore water released from the tailings during consolidation will report to the supernatant pool or to the over-liner drainage/collection system, and from there collected and pumped either to the supernatant pool or directly to the reclaim system.

At closure, Midas Gold will dewater, close, and reclaim the TSF (MGII, 2016). The facility will be graded and contoured and a non-acid generating development rock cover will be placed on top of the tailings and capped by growth medium to inhibit erosion and dust generation and to promote revegetation. Application of a store-and-release type evapotranspiration cover is not feasible in this environment, as the storage required (based on an annual precipitation rate of 32 inches, most of which falls as snow which runs off or infiltrates the ground during the spring melt, and an evaporation rate of 20.5 inches) would occupy a soil column significantly in excess of the rooting depth.

Seepage and run-off source terms will be developed for the TSF (Figure 4-1). The general modeling approach is to quantify:

- Solute concentrations in waters that will potentially seep through defects in the liner;

- Solute concentrations in waters that will infiltrate the soil-rock cover post-closure, interact with the uppermost layer of tailings and run off the facility; and

- Solute concentrations in downgradient surface water and groundwater underlying the TSF.

The conceptual model for the TSF has been developed using the assumptions listed below. The assumptions relating to the water balance are subject to variation depending on the results of the hydrologic modeling currently underway.

- Tailings will be deposited in a lined facility with an engineered rockfill dam. The TSF will be confined on approximately 90% of its perimeter by natural topography that considerably exceeds the final height of the facility.

- Approximately 100 Mt of tailings solids will be stored in the TSF at full buildout (MGII, 2016). Tailings will be thickened and neutralized and will contain approximately 55% solids by weight.

- At closure, a soil-rock cover will be placed on top of the facility and the surface channel of Meadow Creek and wetlands will be re-established over the TSF. A synthetic liner will be placed under the portion of the Meadow Creek surface channel that is re-routed over the tailings.

- Based on climate conditions, it is assumed that the majority of annual precipitation will infiltrate the cover, and seasonally saturate the base of the cover. The infiltrating water will

contact the cover and the surface of the underlying tailings, therefore, the thickness of the cover material will not affect the predicted chemistry of the water draining from the surface of the TSF. Sensitivity analysis will be conducted on the assumptions surrounding the cover thickness to address the uncertainty associated with this assumption.

- Any entrained solution within the tailings will comprise a mixture of residual process solution, plus any meteoric water that has infiltrated the tailings during and after operations.

- The tailings draindown solution is assumed to be represented by the results of Synthetic Precipitation Leaching Procedure (SPLP) testing carried out on ten samples as part of the SRK Geochemistry Baseline (SRK, 2017) and scaled to field conditions. These data will be supplemented by results from the ongoing characterization program that includes additional testing of future metallurgical samples representative of tailings, as described in the Phase 2 Characterization Work Plan (SRK, 2017).

- Any seepage from defects in the TSF liner will ultimately recharge to groundwater. This solution will interact with groundwater in the uppermost 32.8 feet (10 meters) of the aquifer beneath the footprint of the facility. The aquifer below the TSF consists of a mixture of fractured bedrock and alluvium. Specific yield within these units is estimated at 1% and 10% for the bedrock and alluvium, respectively (JSAI, pers. comm.). The residence time in the aquifer will be short and of the order of one month to a few months at most (JSAI, pers. comm.).

The data sources for the TSF geochemical model inputs are listed in Table 4-1. A conceptual model for the TSF is provided in Figure 4-1.
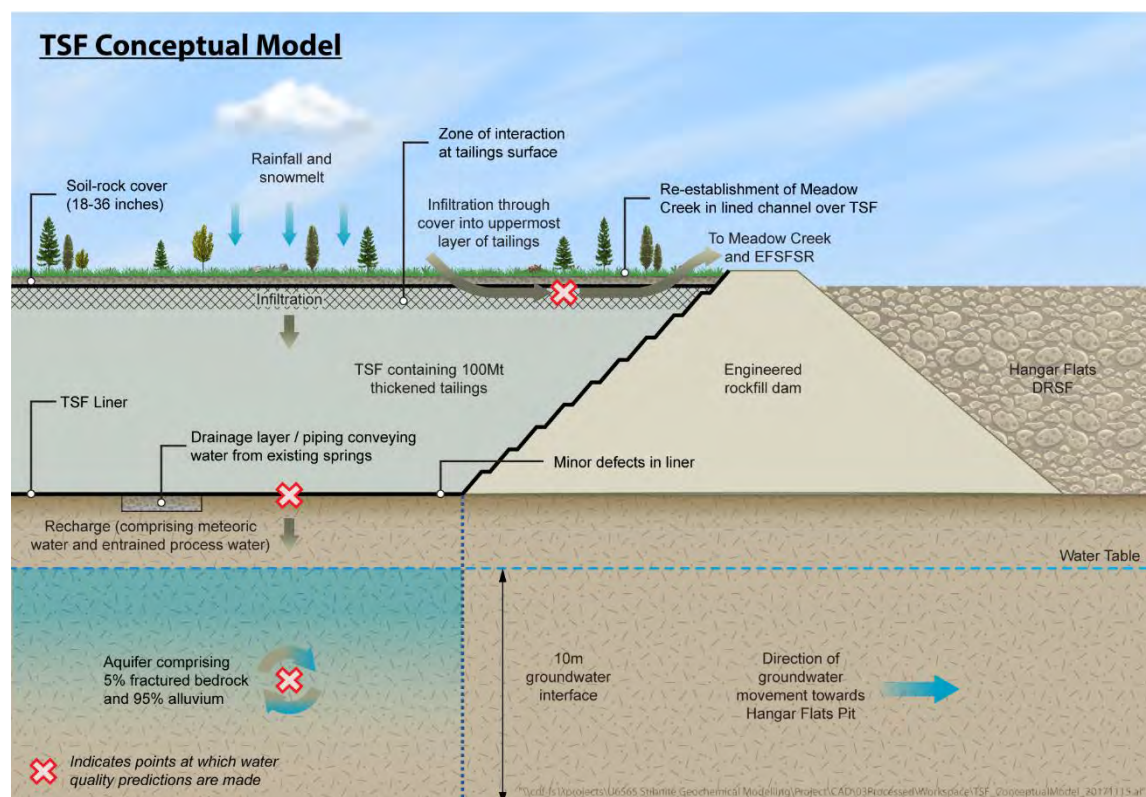

Figure 4-1: TSF Conceptual Model

Table 4-1: TSF Model Data Sources

Component	Source	Details
Water balance	JSAI (2017 *in progress*)	A water balance is being developed by JSAI from the hydrologic model, which provides details of runoff and seepage for the TSF, in addition to the interaction of these solutions with surface water and groundwater.
Tailings tonnages	Midas Gold PRO (MGII, 2016	Tailings tonnages will be obtained from the Midas Gold PRO, which assumes that the TSF will contain approximately 100 Mt of tailings.
Tailings chemistry	Synthetic Precipitation Leaching Procedure (SPLP) data (SRK, 2017)	The tailings consolidation fluid is assumed to be represented by the results of Synthetic Precipitation Leaching Procedure (SPLP) testing (USEPA, 1998) carried out on ten samples as part of the SRK Geochemistry Baseline (SRK, 2017). The data will be scaled to field conditions based on the difference in temperature and liquid to solid ratio between the lab test and field conditions. These data will be supplemented by results from the ongoing characterization program that includes additional testing of future metallurgical samples representative of tailings, as described in the Phase 2 Characterization Work Plan (SRK, 2017).
Precipitation chemistry	NADP (2015)	Representative rainwater chemistry data from monthly monitoring carried out between 1984 and 2006 at the Smiths Ferry Meteorological Station, Idaho.
Groundwater chemistry	HDR groundwater baseline (September 2012 – September 2016) (HDR, 2016)	Representative groundwater chemistry data from the Groundwater Geochemistry Baseline Study (HDR, 2016).
Thermodynamic data	minteq.v4 database (Parkhurst and Appelo, 1999)	The minteq.v4 thermodynamic database supplied with version 3.3.8.11728 of PHREEQC will be used

CHAPTER 5: PIT LAKE AND YELLOW PINE BACKFILLED PIT MODELING

5.1   Conceptual Model

During mining operations, dewatering will keep the pits dry and therefore limited water will pond within the pits themselves. At the end of open pit mining operations, dewatering will cease and pit lakes will ultimately form in the West End and Hangar Flats pits. The Yellow Pine pit will be backfilled with development rock, sourced mostly from the West End pit.

Conceptual geochemical models have been developed for the Hangar Flats, West End, and Yellow Pine pits after closure from a review of the hydrologic model (JSAI, *in progress*) and background and site-specific data, in addition to SRK's experience with similar projects. The conceptual models are shown in Figure 5-1 through Figure 5-3 and were developed using the following estimates and assumptions derived from the MGII exploration database, PFS resource model, PRO mine plan, and restoration/mitigation plan, best available data, and modeler judgment. The assumptions relating to the water balance are subject to variation depending on the results of the hydrologic modeling currently underway.

- At closure, the Hangar Flats pit will function as a sedimentation basin downstream of the TSF, Hangar Flats DRSF, and East Fork Meadow Creek (also known as Blowout Creek) (Figure 2-1). Surface water and runoff from the Hangar Flats DRSF will be routed through this sediment trap prior to flowing into Meadow Creek. Two models will be run for the Hangar Flats pit, including scenarios with and without re-routing of Meadow Creek and East Fork Meadow Creek through Hangar Flats pit.

- The Yellow Pine pit will be backfilled with approximately 111.4 Mt of non-PAG development rock from the Hangar Flats pit (10.7% of backfill) and carbonate-rich rock from the West End pit (89.3% of backfill). No PAG material will be backfilled in the Yellow Pine pit. At closure, a cover will be placed over the top of the Yellow Pine pit backfill and the EFSFSR stream channel will be re-routed through the pit over the top of the backfill surface. Based on climate conditions, it is assumed that the majority of mean annual precipitation will infiltrate the cover. The same amount of water will infiltrate and come into contact with the backfill material for all cover thickness scenarios, therefore, the thickness of the cover material will not affect the resulting predictions. In addition, an impermeable liner will be placed under the EFSFSR channel and associated wetlands areas. The EFSFSR will flow over this liner and will not contact the development rock backfill under normal or high flow conditions.

- The West End pit will ultimately form a pit lake at closure and will be a groundwater sink (but not an overall hydrologic sink) with only very minor outflow to groundwater; however, discharge to surface water will begin approximately 9 years following closure when the pit lake will reach a spill point (JSAI, 2017 *in progress*). At this point, the lake will reach a steady state whereby it will discharge excess water each month (except late summer in the driest years) whilst maintaining the lake level. Discharge will report to the EFSFSR via Sugar Creek.

- Solute loading into the pits will come from groundwater, surface water, and run-off waters entering the pits. These waters will pick up additional solute loading from fractures in the pit walls. There will also be solute contribution from seepage from the adjacent DRSFs and talus remaining on the pit benches. For the Yellow Pine backfilled pit, there will be additional solute loading from development rock backfill within the pit.

- Representative leachate chemistry for the non-PAG and PAG pit wall rock and talus (and backfill for Yellow Pine) will be obtained from site-specific HCTs that are scaled to field conditions.

- Representative leachate chemistry for the PAG pit wall rock and talus will be obtained from humidity cell HC-14 carried out as part of the Phase 1 HCT Program (SRK, 2017) and scaled to field conditions. HC-14 has been selected to represent PAG development rock since this humidity cell has the highest total sulfur and highest sulfate leaching rate which corresponds to the maximum sulfide oxidation, even though it did not develop acidic conditions. Additional humidity cell testing is currently being carried out as part of the Phase 2 Geochemical Characterization Program. In the instance that one of these cells develops acidic conditions, the chemistry from that cell will be used to represent PAG development rock chemistry.

- The pit lake models will predict chemistry under annual average conditions; however, the potential for stratification and seasonal turnover will be assessed based on information regarding the elevation, latitude and relative depths of the future pit lakes. This will be assessed through QUAL2K and the USGS GLM (General Lake Model) software coupled with PHREEQC (Brown and Caldwell, 2017b). These are all publicly available software packages and QUAL2K is supported by the United States Environmental Protection Agency (US EPA).

The conceptual models developed for the Hangar Flats, West End, and Yellow Pine pits provide the basis for the development of quantitative predictive calculations using the USGS code PHREEQC.
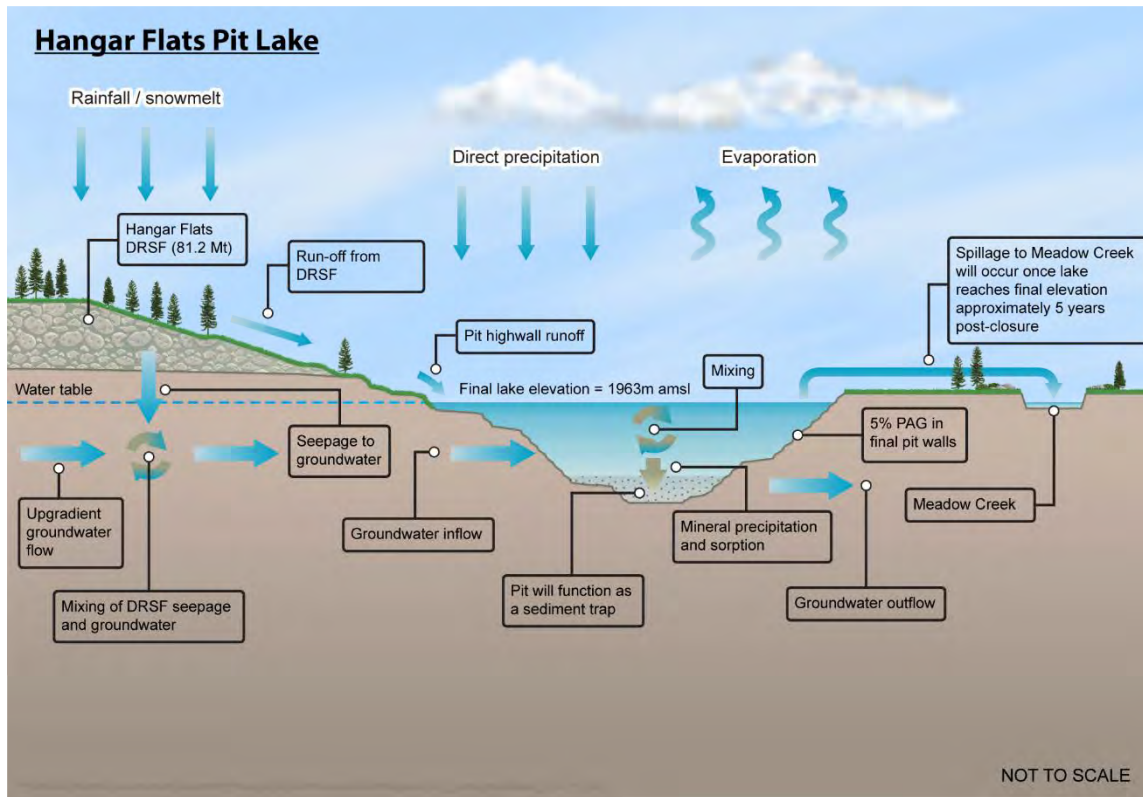
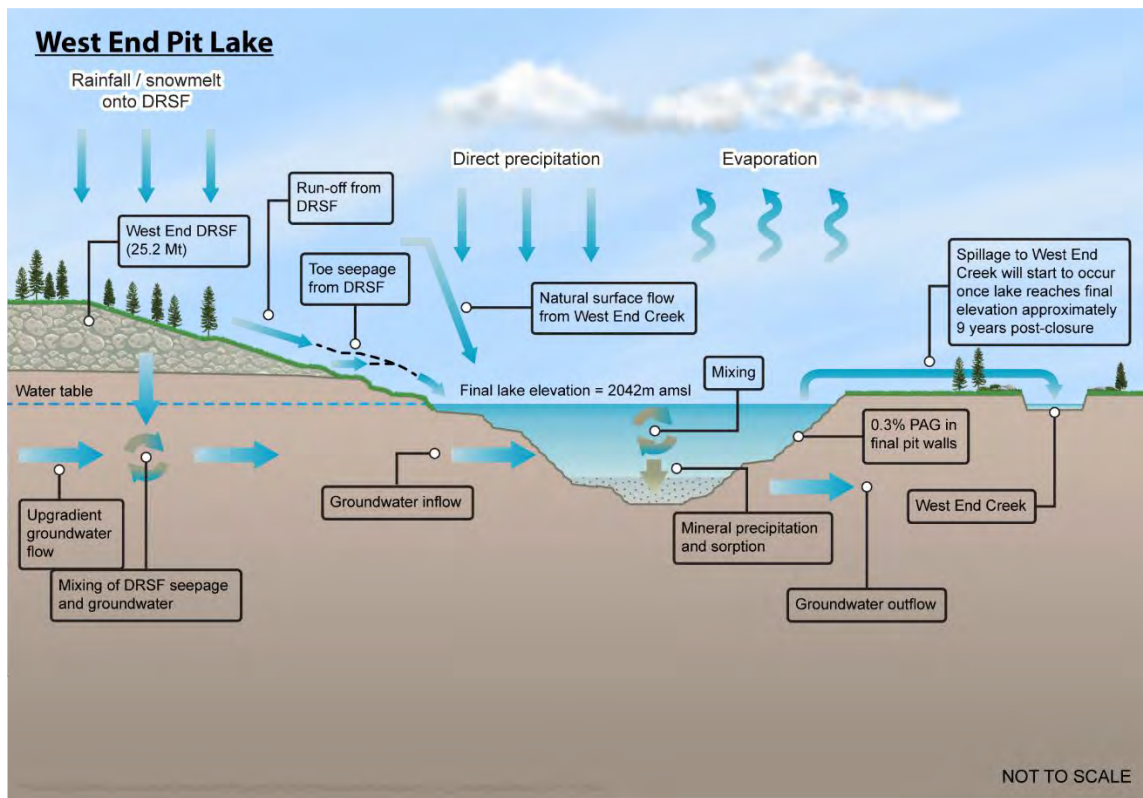Figure 5-1: Hangar Flats Pit Lake Conceptual Model

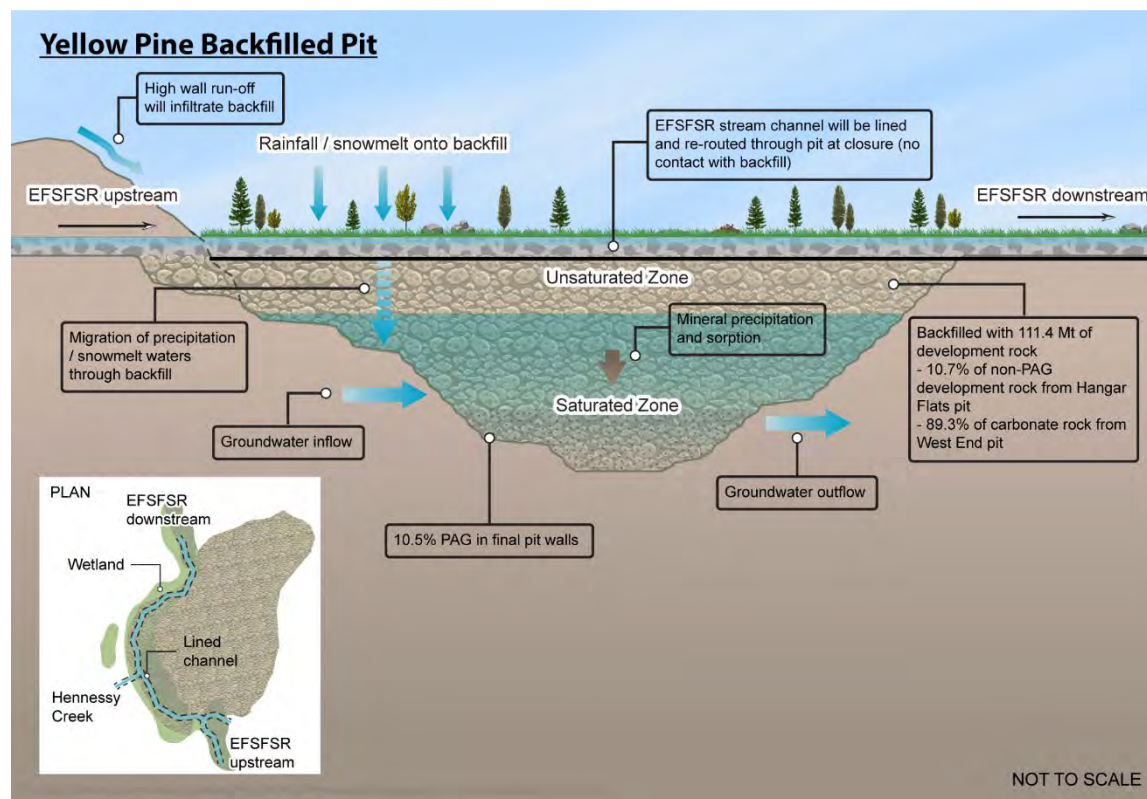Figure 5-2: West End Pit Lake Conceptual Model

Figure 5-3: Yellow Pine Backfilled Pit Conceptual Model

5.2   Approach

The pit lake geochemical predictions are based on the mixing of solutions from different sources (groundwater, pit wall runoff, precipitation, surface water, and groundwater) in ratios defined by the hydrologic model and water balance developed by JSAI (2017 *in progress*). Water balances for the pits have been developed using available site data and based on the JSAI groundwater modeling. The water balances provide details of time-dependent surface water inflow, groundwater inflow, direct precipitation, pit wall runoff, and evaporation for each of the pits post-closure.

Water quality predictions will be made for the following time steps after the start of pit lake formation:

- Hangar Flats Pit – 1, 2, 3, 5, 6, 10, 20, 50, 75, 100, 300 and 500 years;

- West End Pit - 1, 2, 3, 5, 7, 10, 20, 50, 75, 100, 300 and 500 years; and

- Yellow Pine Pit - 1, 2, 3, 5, 10, 15, 20, 30, 50, 75, 100, 300 and 500 years.

The time steps are defined by the pit lake water balance and filling curves. During the early stages of pit filling, predictions are made at regular time steps (every one to two years); however, as the pits fill and reach equilibrium, the frequency of predictions is decreased.

During mining operations, the pit walls will be exposed to air and water under oxygenated conditions and will weather to form secondary minerals, including soluble salts. As the pit walls re-saturate during rebound of the groundwater table, soluble salts and other weathering products will dissolve into the ambient groundwater that drains into the pit. In addition, dissolution of these solutes by runoff waters in the unsaturated high wall of the pit may occur. The chemistry of

these solutions is represented by the results of HCTs that are appropriately scaled to reflect the mass release of solutes under field leaching conditions, compared to the laboratory scale tests that are operated at a fixed liquid-to-solid ratio.

The HCT data will be scaled from laboratory to field conditions based on the volume of inflowing water (groundwater/runoff) during each time step, as defined by the water balance and the reactive mass of material in the pit walls and on the horizontal benches. This reactive mass is calculated using assumptions regarding pit wall fracturing, material density, surface areas, and likely thickness of talus remaining on the pit benches at closure (Sections 4.3 and 4.4).

The data sources for the pit lake/backfill geochemical model inputs are listed in Table 5-1. More detailed information on these inputs is provided in the following sections.

Table 5-1: Pit Lake/Backfill Model Data Sources

Component	Source	Details
Pit Lake Water balance	JSAI (*in progress*)	Water balances for the pits have been developed by JSAI from the hydrologic model using available site data. The water balances provide details of time-dependent surface water inflow, groundwater inflow, direct precipitation, pit wall runoff and evaporation for each of the pits post-closure. They also provide information on the interaction of pit lake waters with adjacent surface water and groundwater.
Pit wall surface areas	Midas Gold PFS resource model (M3, 2014)	The PFS resource model will be used to calculate three-dimensional surface areas for each lithology that will be exposed in the final pit walls. Surface areas will be calculated for each of the modeled time steps. An NPR cut-off of 1.5 will be used to differentiate between PAG and non-PAG material.
Backfill tonnage (Yellow Pine pit only)	Midas Gold PRO Mine Plan development rock schedule (MGII, 2016)	The tonnage of development rock backfill in the Yellow Pine pit will be obtained from the Midas Gold PRO Mine Plan development rock schedule. This assumes that the Yellow Pine pit will be backfilled with approximately 111.4 Mt non-PAG development rock from the Hangar Flats pit (11% of backfill) and non-PAG development rock from the West End pit (89% of backfill).
Precipitation chemistry	NADP (2015)	Representative rainwater chemistry data will be obtained from monthly monitoring carried out between 1984 and 2006 at the Smiths Ferry Meteorological station, Idaho.
Groundwater chemistry upgradient of mine facilities	HDR groundwater baseline (September 2012 – September 2016) (HDR, 2016)	Representative groundwater chemistry data upgradient of the mine facilities will be obtained from the HDR Groundwater Quality Baseline Study (HDR, 2016).
Groundwater chemistry in aquifers under DRSFs adjacent to pits	Predicted groundwater chemistry from DRSF models	A portion of groundwater that enters the Hangar Flats and West End pits will originate from the alluvial and bedrock aquifers underlying the adjacent DRSFs. The predicted groundwater chemistry underneath the DRSFs will be used as the model input chemistry for these source terms.
Surface water chemistry	HDR surface water baseline (April 2012 – September 2016) (HDR, 2017)	Representative surface water chemistry data from the HDR Surface Water Quality Baseline study (HDR, 2017).
Non-PAG wall rock chemistry	SRK Phase 1 HCT program (SRK, 2017)	Scaled humidity cell data will be used to develop source terms for metals release rates for each of the non-PAG lithologies that will be exposed in the future pit walls. The data will be scaled to field conditions based on the difference in temperature and liquid to solid ratio between the lab HCT and field conditions, in addition to other assumptions about pit wall fracturing and talus remaining on the pit benches.
PAG wall rock chemistry	SRK Phase 1 HCT program (HC- 14) (SRK, 2017)	Scaled humidity cell data for HC-14 will be used to develop a source term for metals release rates for the PAG material that will be exposed in the future pit walls. HC-14 has been selected to represent PAG development rock since this cell has the highest total sulfur and highest sulfate leaching rate which corresponds to the maximum sulfide oxidation[3]. The data will be scaled to field conditions based on the difference in temperature and liquid to solid ratio between the lab HCT and field conditions, in addition to other assumptions about pit wall fracturing and talus remaining on the pit benches.
Backfill chemistry (Yellow Pine pit only)	SRK Phase 1 HCT program (SRK, 2017)	Scaled HCT data will be used to develop source terms for the development rock backfill in the Yellow Pine pit. The data are scaled to field conditions based on the difference in temperature and liquid to solid ratio between the lab HCT and field conditions in addition to other assumptions about preferential flow paths, oxygen and grain size.
Thermodynamic data	minteq.v4 database (Parkhurst and Apello, 1999)	The minteq.v4 thermodynamic database supplied with version 3.3.8.11728 of PHREEQC will be used

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[3] Additional humidity cell testing is currently being carried out as part of the Phase 2 Geochemical Characterization Program. In the instance that one of these cells develops acidic conditions, the chemistry from that cell will be used to represent PAG development rock chemistry.

5.3   Calculation of Pit Wall Rock Available for Leaching

During operations, the pit walls will be exposed to oxygenated conditions and will weather to form secondary minerals, including soluble salts. As the pit wall re-saturates post-closure, soluble salts and other weathering products will dissolve into the ambient groundwater that drains into the pit and the pit lake as the walls are inundated. In addition, dissolution of these soluble salts by runoff waters in the unsaturated high wall of the pit may occur. In order that laboratory HCT data can be appropriately scaled to reflect the mass release of solutes under field leaching conditions, it is necessary to determine the total mass of material available for leaching in the pit walls based on the exposed surface areas and density of each material type in both the unsaturated high wall and in the submerged pit walls. This information is coupled with an estimate of the density and thickness of fracturing in the pit walls to calculate a mass of reactive rock.

Published literature on blast-induced fracturing in pit wall rocks shows there is a significant range in both the density of fracturing and the depth of fracture penetration. In particular, the reported depth to which fractures propagate ranges from a minimum of 1 foot (0.3 meters) for low-charge blast methods (Kelsall et al., 1984) to a maximum of 50 feet or 15.2 meters (Radian, 1997). In general, the depth of fracture propagation is typically in the range of 2 to 6 feet (0.6 to 1.8 meters), with a typical fracture density of 10%; however, this will depend on factors such as lithological composition and blast methods used.

The future operations at Stibnite are expected to use pre-splitting to help control the blast and reduce energy from travelling into the highwall causing fracturing and "back break". Modern blasting practices are different from the past blasting practices and will likely result in less fracturing due to the practice of pre-splitting, therefore, blast-related fractures from past mining activities cannot be directly compared to future conditions and some assumptions have been made regarding future pit wall fracturing. An estimate of the reactive mass in the future pit walls has been made based on information on blasting practices, fracture density and rock density. The Stibnite pit lake models will assume that fracturing will propagate to a depth of 3 feet (0.9 meters) in the pit walls and the density of fracturing in this zone will average 10%. This is consistent with published information (e.g. Siskind and Fumanti, 1974; Kelsall et al., 1984). Additional sensitivity analyses will be conducted using fracture thicknesses of 1 foot (0.3 meters, lower bound) and 6 feet (1.8 meters, upper bound) to bracket the range of possible pit wall fracturing depths.

In addition to the fracture zone described above, mineralogy work carried out by SRK on HCTs for other projects identified that particles generally show water infiltration and products of reactivity up to 0.04 feet (0.012 meters) on the surfaces of rock fragments. A reactive rim or 'oxidized rind' of 0.04 feet thickness has therefore also been assumed in the pit wall surface (Figure 5-4). Given these assumed fracture densities and using the pit wall surface areas, it is possible to calculate a reactive volume of rock in the pit walls. The calculated volumes will then be multiplied by average material densities from the geological model to give a reactive mass of material for either the unsaturated high wall or submerged pit walls.

5.3.1 Scaling of Laboratory Data to Field Conditions for the Pit Walls

The HCT data will be scaled to field conditions based on the difference in liquid to solid ratio between the laboratory-scale HCT and field-scale conditions (as defined by the water balance and geological model). The reactive mass (R_m) of material in the pit walls will be defined by equation [1] below.

$$R_m = S \times F_D \times T_{FZ} \times D \qquad\qquad [1]$$

Where: S = three-dimensional pit wall surface area in square meters

F_D = fracture density (assumed to be 10%)

T_{FZ} = thickness of the fracture zone in meters (assumed to be three feet or 0.9 meters)

D = rock density in kg/m^3

This mass will then be coupled with HCT data and pit wall runoff/groundwater inflow volumes from the water balance to define a scaling factor as shown in equation [2].

$$C_i = \frac{r_i \times R_m \times T}{Q} \qquad\qquad [2]$$

Where: Ci = the scaled concentration (in mg/L) of element i

r_i = the average steady-state release rate of element i in mg/kg/week in the laboratory humidity cell tests

R_m = the pit wall reactive mass in kg

T = the temperature scaling factor based on the Arrhenius equation

Q = either the rate of groundwater inflow into the pit or the rate of pit wall runoff in L/week
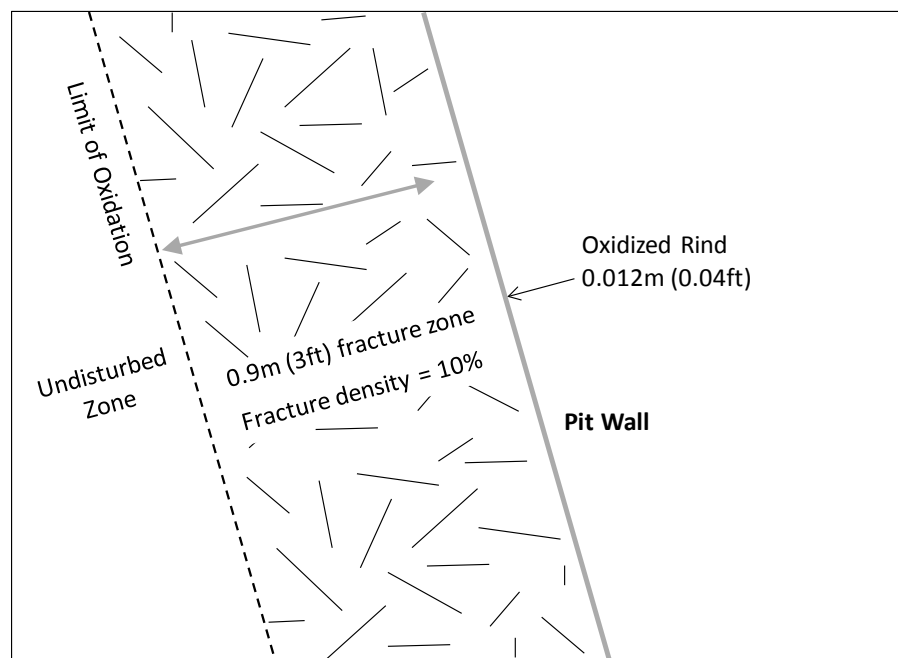
Source: SRK, Stibnite_pit_wall_conceptual_model.pptx

Figure 5-4: Pit Wall Conceptual Model

5.4   Talus on Pit Benches

In addition to solute loading from fractures in the pit walls, there will also be contribution from talus material remaining on pit benches. It is assumed that the talus thickness will be 6 feet (1.8 meters), which will comprise a mixture of fine and coarse-grained material. The bench surface area will be determined from the geologic model and mine plan. The model assumes that only a small fraction of the total mass of talus remaining on the pit benches within the unsaturated portion of the pit will be effectively contacted by run-off water entering the pit. As with the DRSF models, this 'contacted mass' is a result of the combined influence of preferential fluid flow pathways, in addition to temperature, wetting and grain size effects.

The talus source term will be developed from the results of site-specific HCT tests that are scaled to field conditions. The scaling methodology is identical to that used for the future Hangar Flats, West End and Yellow Pine DRSFs (Chapter 3).

5.5   Yellow Pine Pit Backfill Chemistry

The Yellow Pine pit will be backfilled with approximately 111.4 Mt non-PAG development rock from the Hangar Flats pit (10.7% of the total) and non-PAG development rock from the West End pit (89.3% of the total). No PAG development rock will be placed in the Yellow Pine pit backfill. At closure, a liner/cover will be placed on top of the backfill underneath the EFSFSR stream channel in order to re-route the stream through the pit. It is assumed that the EFSFSR will flow over this liner and will not contact the development rock backfill under normal or high flow conditions. According to the water balance, there will also be inflow of water to the pit from groundwater and rainfall/snowmelt onto the backfill surface that is assumed to infiltrate the backfill. These solutions will contact the rock mass and generate a specific source term associated with the material contacted. This model will also take into account the potential for surface water to flow over the liner (or through minor defects in the liner) and the resulting effects on downgradient surface water and groundwater chemistry.

The source term for the backfill material will be developed from the results of site-specific HCTs that are scaled to field conditions. The scaling methodology will be identical to that used for the future Hangar Flats, West End and Yellow Pine DRSFs (see Chapter 3 above).

5.6   Pit Wall Rock and Backfill Flushing

The model assumes flushing of solutes from pit wall fractures and the Yellow Pine pit backfill by groundwater will only take place in the 'active' zone of groundwater inflow (Figure 5-5) and the flushing of oxidation products will end once a particular portion of the pit becomes submerged. As such, groundwater flowing into the 'active' zone of groundwater flow will be represented by groundwater chemistry from the Groundwater Quality Baseline Study (HDR, 2016) plus a mass of solute derived from the HCT geochemical data (SRK, 2017). Groundwater flowing into the fully submerged portion of the pit will be represented by groundwater chemistry from the Groundwater Quality Baseline Study to reflect the cessation of oxidation within the subaqueous pit wall material.
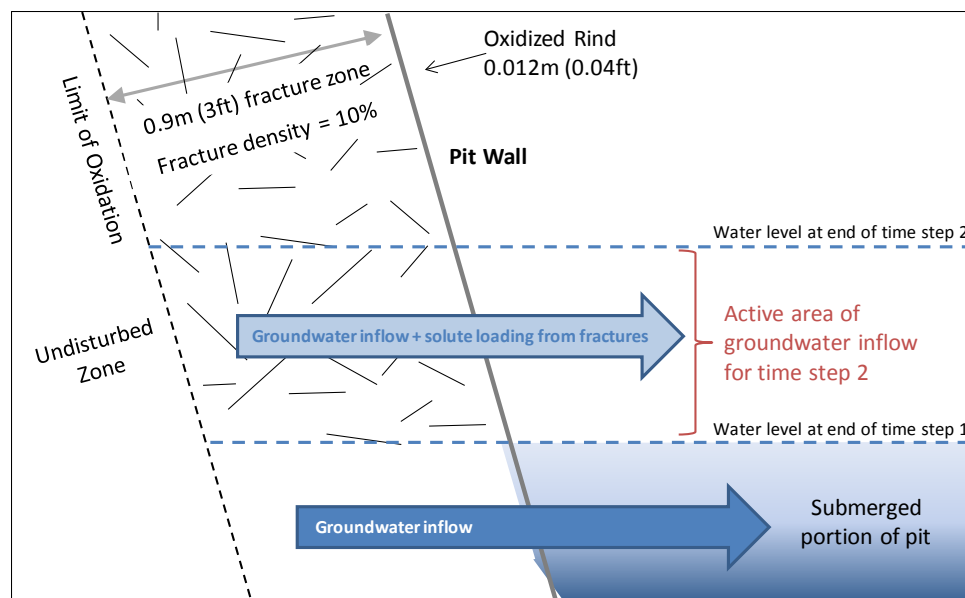
Figure 5-5: Pit Wall Conceptual Model showing Zone of Active Groundwater Inflow

5.7   Solubility Controls and Trace Element Adsorption

For the base case, it is assumed that any waters entering the pits will mix evenly and completely. The potential for stratification and seasonal turnover will be assessed as part of the Stream and Pit Lake Network Temperature (SPLNT) Modeling (Brown and Caldwell, 2017b). If stratification is considered likely for the West End and Hangar Flat pit lakes based on the results of the QUAL2K/GLM modeling results, potential future pit lake chemistry will be assessed at various depths within the pit lakes.

Under mixed conditions, the solutes in these waters will react with each other and may form chemical precipitates if the concentrations and geochemical conditions (Eh, pH, pCO_2, pO_2, and ionic strength) allow minerals to become oversaturated. The geochemical model requires the specification of a number of equilibrium phases that are allowed to precipitate if they become oversaturated. The suite of minerals chosen will be based on the geology and mineralization of the Stibnite Gold Project deposits, an understanding of the types of parameters commonly observed in the resulting leachates and an assessment of mineral phases that are close to saturation based on the initial model iterations.

The model assumes that precipitates will sink to the bottom of the pit lake and be removed from future chemical interactions as a sediment layer accumulates on the pit bottom. These precipitated mineral phases are unlikely to re-dissolve unless the pH or redox conditions of the pit lake change substantially. Significant changes in pH are considered unlikely based on the neutral humidity cell effluent chemistry observed in the Phase 1 HCT program, and the circum-neutral pit lake, surface water, and groundwater chemistry currently observed on site. If, however, pit lake stratification and/or significant changes in redox conditions are predicted for the West End and Hangar Flats pit lakes from the results of the QUAL2K/ GLM modeling (Brown and Caldwell, 2017b), then these predicted changes in redox conditions will be incorporated into the PHREEQC models.

In solution, trace element concentrations are mostly controlled by adsorption onto common mineral phases or are removed from solution through a process of co-precipitation. The models will assume that trace metals may be removed from solution via sorption onto freshly generated mineral precipitates such as iron oxides. Ferrihydrite ($5Fe_2O_3.9H_2O$) will represent the primary sorption surface. The mass of ferrihydrite used in the models is assumed to be identical to the mass of the mineral phase ferrihydrite precipitated in the previous model reaction step and is controlled by the chemistry of the system (i.e., the Year 2 calculations relied on the mass of ferrihydrite precipitate produced in the Year 1 model step and so forth).

As with mineral phase precipitation, the mass of trace elements removed through adsorption is assumed to be permanently removed from the system following incorporation and co-precipitation with the HFO phase, because it is unlikely that desorption due a major shift in pH or redox conditions will occur.

CHAPTER 6: SITE-WIDE WATER CHEMISTRY (SWWC) MODEL

6.1   Model Approach

The results of the facility geochemical models for the Hangar Flats, Fiddle, and West End DRSFs, the West and Hangar Flats pit lakes, and the Yellow Pine backfilled pit will be incorporated into a Site-Wide Water Chemistry (SWWC) model to assess surface water chemistry at a series of prediction nodes downgradient of the facilities under high and low flow conditions during operations and at closure. The prediction nodes and associated inputs are illustrated on Figure 6-1. The flow rates (i.e., mixing ratios) for each of these nodes under future conditions will be obtained from the JSAI water balance that is based on the hydrologic model (JSAI, *in progress*). The information regarding contributing water sources at each of these nodes will be obtained from the Surface Water Quality Baseline Study (HDR, 2017) and Water Resources Summary Report (Brown and Caldwell, 2017a). The future conditions SWWC model will also incorporate the water quality predictions from the DRSFs, pit lakes, TSF and Yellow Pine backfilled pit (described in Chapters 3 to 5, above).

In order to verify the modelling approach, a SWWC model will also be developed to predict surface water quality under current conditions. This will take into consideration existing surface water and groundwater quality data, in addition to information on historic material tonnages, and characteristics from inventories completed by Midas. The flow rates (i.e., mixing ratios) and chemistry data for the current conditions SWWC will be obtained from the Surface Water Quality Baseline Study (HDR, 2017) and Water Resources Summary Report (Brown and Caldwell, 2017a).

- The purpose of the SWWC model for the current conditions is to: Determine whether current surface water chemistry at each of the nodes can be predicted using available data.

- Identify potential data gaps, for example diffuse seeps or groundwater flows that are not accounted for in the baseline water quality dataset (HDR, 2016; 2017) or water balance/ hydrologic model (JSAI, *in progress*).

The chemistry inputs that will be used to develop predictions for each of these nodes are outlined in Table 6-1 and Table 6-2.

for the future proposed action and current conditions models, respectively

6.2   Sensitivity Analysis

Sensitivity analyses will be performed on the DRSF, pit lake, and backfill models to address uncertainties in the model inputs. Analysis will be undertaken to identify the parameters that most influence the model results. Sensitivity analyses will then be conducted on these parameters. These sensitivity analyses may include, but are not limited to:

- DRSF scaling assumptions relating to proportion of flow paths, fine particles and temperature;

- Pit wall fracture thickness and density;

- Backfill scaling relating to proportion of flow paths and fine particles;
- Re-routing of Meadow Creek around, rather than through, Hangar Flats pit;
- NPR cut-off value for defining PAG and non-PAG material;
- Assumptions regarding specific yield within the bedrock and alluvial aquifers; and
- TSF cover thickness.

The results of these sensitivity analyses will be incorporated into the SWWC model to determine the effects surface water chemistry across the Project area.
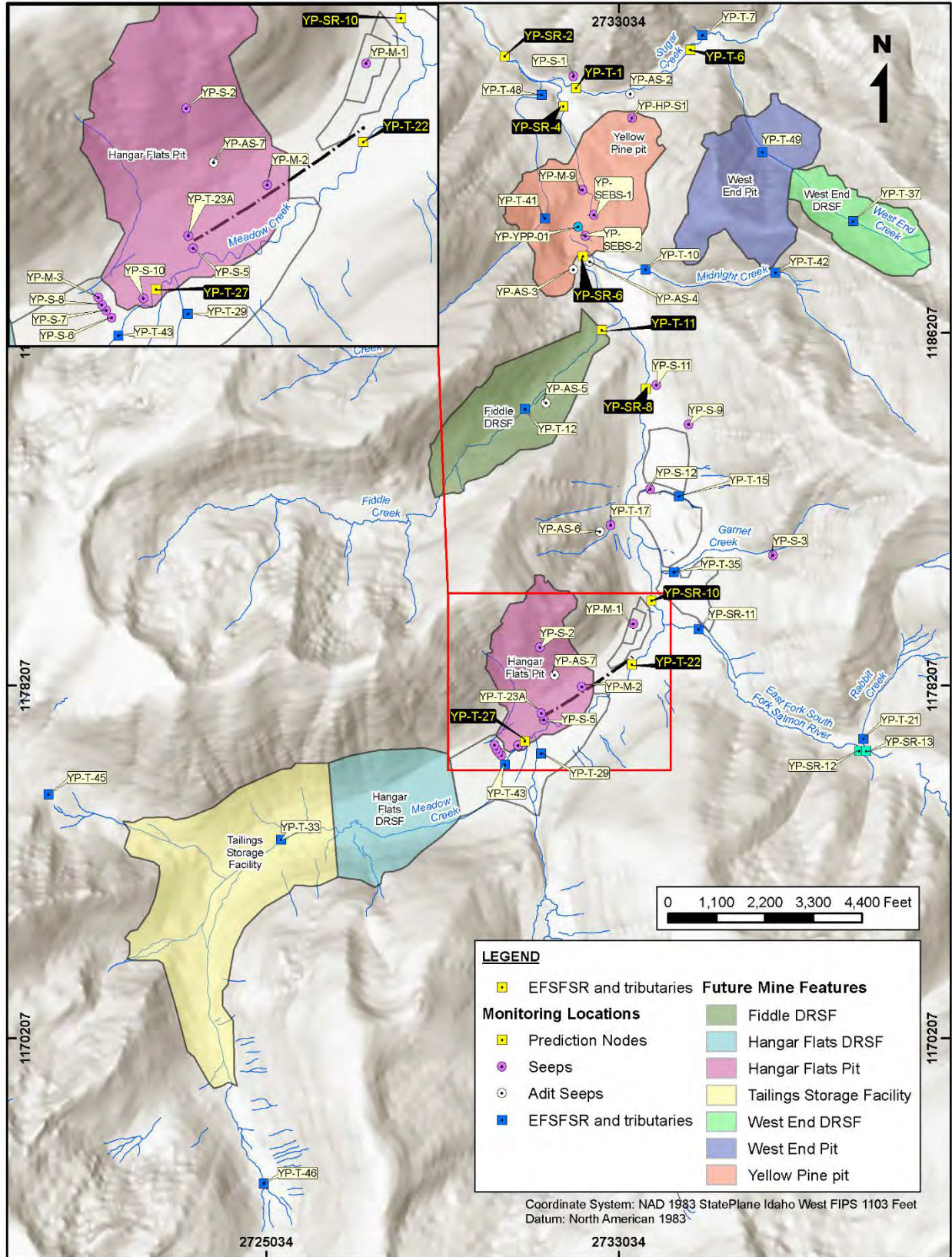
Figure 6-1: Site-Wide Water Quality Model Prediction Nodes

Table 6-1: Proposed Action Site-Wide Water Quality Model Chemistry Sources[4]

Location	Details in Context of Proposed Action Mine Plan	Contributing Water Sources	Source of Chemistry Data for Model
YP-T-27	Meadow Creek downstream of TSF and Hangar Flats DRSF	Upgradient SW inflow in Meadow Creek	SW monitoring data from YP-T-43 (HDR, 2017)
		Run-off from Hangar Flats DRSF	Predicted chemistry from Hangar Flats DRSF model
		SW flow over surface of TSF	Predicted chemistry from TSF model
		SW flow from South Keyway Dam Seep	SW monitoring data from YP-S-6 (HDR, 2017)
		SW flow from North Keyway Dam Seep	SW monitoring data from YP-S-8 (HDR, 2017)
		SW flow from Keyway Marsh Outlet	SW monitoring data from YP-S-10 (HDR, 2017)
TP-T-22	Meadow Creek downstream of Hangar Flats Pit	Upgradient SW inflow in Meadow Creek	Chemistry predicted for YP-T-27
		SW flow from Blowout Creek	SW monitoring data from YP-T-29 (HDR, 2017)
		SW flow from Meadow Creek fault seep	SW monitoring data from YP-S-2 (HDR, 2017)
		SW flow from Smelter Flats seep	SW monitoring data from YP-S-5 (HDR, 2017)
		SW flow from Meadow Creek Mine adit seep	SW monitoring data from YP-AS-7 (HDR, 2017)
		SW flow from heap leach seep	SW monitoring data from YP-T-23A (HDR, 2017)
		SW flow from Hangar Flats Pit	Predicted chemistry from Hangar Flats Pit lake model
		GW flow from aquifer beneath Hangar Flats Pit	Predicted chemistry from Hangar Flats Pit lake model
YP-SR-10	EFSFSR after confluence with Meadow Creek but before confluence with Garnet and Scout Creeks	SW flow from Meadow Creek	Chemistry predicted for YP-T-22
		Upgradient SW flow in EFSFSR	SW monitoring data from YP-SR-11 (HDR, 2017)
		Assumed GW inflow (from Gain-Loss analysis)	GW monitoring data from MWH-A08 (HDR, 2016)
YP-SR-8	EFSFSR after confluence with Garnet and Scout Creeks but before confluence with Fiddle Creek	Upgradient SW flow in EFSFSR	Chemistry predicted for YP-SR-10
		SW flow from Garnet Creek	SW monitoring data from YP-T-35 (HDR, 2017)
		SW flow from Scout Creek	SW monitoring data from YP-T-15 (HDR, 2017)
		SW flow from DMEA waste rock seep	SW monitoring data from YP-T-17 (HDR, 2017)
		SW flow from DMEA adit seep	SW monitoring data from YP-AS-6 (HDR, 2017)
		SW flow from Garnet Pit seep	SW monitoring data from YP-S-3 (HDR, 2017)
		SW flow from Old Haul Road seep	SW monitoring data from YP-S-9 (HDR, 2017)

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[4] Information in this table is subject to variation depending on the outcome of the hydrologic modelling currently underway

Location	Details in Context of Proposed Action Mine Plan	Contributing Water Sources	Source of Chemistry Data for Model
YP-T-11	Fiddle Creek downstream of Fiddle DRSF before confluence with EFSFSR	Toe seepage from Fiddle DRSF	Primarily upgradient GW chemistry (MWH-A15) with a small amount of contact with the DRSF assumed
		Upgradient SW flow in Fiddle Creek	SW monitoring data from YP-T-12 (HDR, 2017)
		GW outflow from aquifer beneath Fiddle DRSF	Predicted chemistry from Fiddle DRSF model
YP-SR-6	EFSFSR upstream of Yellow Pine Pit, but downstream of Fiddle DRSF and Hangar Flats DRSF/Pit	SW flow from Fiddle Creek	Chemistry predicted for YP-T-11
		Upgradient SW flow in EFSFSR	Chemistry predicted for YP-SR-8
		SW flow from Monday Tunnel adit seep	SW monitoring data from YP-AS-3 (HDR, 2017)
		SW flow from Cinnabar Tunnel adit seep	SW monitoring data from YP-AS-4 (HDR, 2017)
		Assumed GW inflow (from Gain-Loss analysis)	GW monitoring data from MWH-A09, MWH-A10, MWH-A12, MWH-A13 (HDR, 2016)
YP-T-6	West End Creek downstream of West End Pit and DRSF before confluence with Sugar Creek	SW outflow from West End Pit lake	Predicted chemistry from West End Pit lake model
		Upgradient SW flow in West End Creek	SW monitoring data from YP-T-37 (HDR, 2017)
		GW outflow from aquifer beneath West End Pit	Predicted chemistry from West End Pit lake model
YP-T-1	Sugar Creek before the confluence with the EFSFSR	SW flow from West End Creek	Chemistry predicted for YP-T-6
		Upgradient SW flow from Sugar Creek	SW monitoring data from YP-T-7 (HDR, 2017)
YP-SR-4	EFSFSR downstream of all proposed mining activities before the confluence with Sugar Creek	Upgradient SW flow from EFSFSR	Chemistry predicted for YP-SR-6
		GW outflow from Yellow Pine Pit	Predicted chemistry from Yellow Pine Pit lake model
		SW flow from Midnight Creek	SW monitoring data from YP-T-10 (HDR, 2017)
		SW flow from Hennessy Creek	SW monitoring data from YP-T-41 (HDR, 2017)
YP-SR-2	EFSFSR downstream of all proposed mining activities after the confluence with Sugar Creek	Upgradient SW flow from Sugar Creek	Chemistry predicted for YP-T-1
		Upgradient SW flow from EFSFSR	Chemistry predicted from YP-SR-4
		SW flow from Bonanza Adit Seep	SW monitoring data from YP-AS-1 (HDR, 2017)
		SW flow from Bailey Tunnel Adit Seep	SW monitoring data from YP-AS-2 (HDR, 2017)
		SW flow from Hennessy Creek	SW monitoring data from YP-T-48 (HDR, 2017)
		SW flow from Hillside seep	SW monitoring data from YP-S-1 (HDR, 2017)

Table 6-2: Current Conditions Site-Wide Water Quality Model Chemistry Sources

Location	Details	Contributing Water Sources	Source of Chemistry Data for Model
YP-T-22	Meadow Creek above EFSFSR	Upgradient SW inflow in Meadow Creek	SW monitoring data from YP-T-27 (HDR, 2017)
		Upgradient SW inflow from Blowout Creek	SW monitoring data from YP-T-29 (HDR, 2017)
		SW flow from settling pond on NE corner of SODA	SW monitoring data from YP-M-3 (HDR, 2017)
		SW flow from South Keyway Dam Seep	SW monitoring data from YP-S-6 (HDR, 2017)
		SW flow from North Keyway Dam Seep	SW monitoring data from YP-S-8 (HDR, 2017)
		SW flow from Keyway Marsh Outlet	SW monitoring data from YP-S-10 (HDR, 2017)
		SW flow from Meadow Creek fault seep	SW monitoring data from YP-S-2 (HDR, 2017)
		SW flow from Smelter Flats seep	SW monitoring data from YP-S-5 (HDR, 2017)
		SW flow from Meadow Creek Mine adit seep	SW monitoring data from YP-AS-7 (HDR, 2017)
		SW flow from heap leach seep	SW monitoring data from YP-T-23A (HDR, 2017)
YP-SR-10	EFSFSR below Meadow Creek	SW flow from Meadow Creek	Chemistry predicted for YP-T-22
		Upgradient SW flow in EFSFSR	SW monitoring data from YP-SR-11 (HDR, 2017)
		Assumed GW inflow (from Gain-Loss analysis)	GW monitoring data from MWH-A08
YP-SR-8	EFSFSR above Fiddle Creek	Upgradient SW flow in EFSFSR	Chemistry predicted from YP-SR-10
		SW flow from Garnet Creek	SW monitoring data from YP-T-35 (HDR, 2017)
		SW flow from Scout Creek	SW monitoring data from YP-T-15 (HDR, 2017)
		SW flow from DMEA waste rock seep	SW monitoring data from YP-T-17 (HDR, 2017)
		SW flow from DMEA adit seep	SW monitoring data from YP-AS-6 (HDR, 2017)
		SW flow from Garnet pit seep	SW monitoring data from YP-S-3 (HDR, 2017)
		SW flow from Old Haul Road seep	SW monitoring data from YP-S-9 (HDR, 2017)
YP-SR-6	EFSFSR above Yellow Pine Pit	Upgradient SW flow from Fiddle Creek	SW monitoring data for YP-T-11 (HDR, 2017)
		Upgradient SW flow in EFSFSR	Chemistry predicted from YP-SR-8
		SW flow from Monday Tunnel adit seep	SW monitoring data from YP-AS-3 (HDR, 2017)
		SW flow from Cinnabar Tunnel adit seep	SW monitoring data from YP-AS-4 (HDR, 2017)
		Seepage from BMC SE DRSF	Calculated source term from inventories completed by Midas
		Seepage from BMC Monday Camp DRSF	Calculated source term from inventories completed by Midas
		Assumed GW inflow (from Gain-Loss analysis)	GW monitoring data from MWH-A09, MWH-A10, MWH-A12, MWH-A13 (HDR, 2016)
YP-SR-4	EFSFSR below Yellow Pine Pit	Upgradient SW flow from EFSFSR	Chemistry predicted for YP-SR-6

Location	Details	Contributing Water Sources	Source of Chemistry Data for Model
		SW flow from Midnight Creek	SW monitoring data for YP-T-10 (HDR, 2017)
		SW flow from Bradley Dump seep 1	SW monitoring data for YP-SEBS-1 (HDR, 2017)
		SW flow from Bradley Dump seep 2	SW monitoring data for YP-SEBS-2 (HDR, 2017)
		SW flow from Hennessy Creek	SW monitoring data for YP-T-41 (HDR, 2017)
		SW flow from Yellow Pine Pit	SW monitoring data for YP-YPP-01 (HDR, 2017)
		Seepage from BMC NE Oxide stockpile #1	Calculated source term from inventories completed by Midas
		Seepage from BMC NE Oxide stockpile #2	Calculated source term from inventories completed by Midas
		Seepage from BMC West Lower DRSF	Calculated source term from inventories completed by Midas
		Seepage from BMC NW DRSF	Calculated source term from inventories completed by Midas
		Seepage from BMC West Middle DRSF	Calculated source term from inventories completed by Midas
		Seepage from BMC West Upper DRSF	Calculated source term from inventories completed by Midas
		SW flow from pond downgradient of Yellow Pine Pit	SW monitoring data for YP-M-9 (HDR, 2017)
YP-SR-2	EFSFSR below Sugar Creek	Upgradient SW flow from Sugar Creek	SW monitoring data for YP-T-1 (HDR, 2017)
		SW flow from Bonanza Adit Seep	SW monitoring data for YP-AS-1 (HDR, 2017)
		SW flow from Bailey Tunnel Adit Seep	SW monitoring data for YP-AS-2 (HDR, 2017)
		SW flow from Hennessy Creek	SW monitoring data for YP-T-48 (HDR, 2017)
		SW flow from Hillside seep	SW monitoring data for YP-S-1 (HDR, 2017)
		Upgradient SW flow from EFSFSR	Chemistry predicted for YP-SR-4
		Seepage from Lower West End DRSF	Calculated source term from inventories completed by Midas
		Seepage from Upper West End DRSF	Calculated source term from inventories completed by Midas
		Seepage from HMC Homestake Pit Backfill	Calculated source term from inventories completed by Midas

CHAPTER 7: SUMMARY

In summary, the geochemical modeling exercise being undertaken for the Stibnite Gold Project includes the development of numerical prediction models for the following:

- Yellow Pine pit and backfill;
- Hangar Flats pit;
- West End pit;
- Fiddle DRSF;
- Hangar Flats DRSF;
- West End DRSF; and
- TSF.

These facility source terms will be incorporated into a site-wide water quality model to predict surface water quality downgradient of the proposed mine facilities during operations (maximum buildout, year 12 of mine life) and post-closure.

The results of the geochemical model evaluation will be presented in a stand-alone report that describes the conceptual models and numerical modeling approach, details the assumptions made and presents the results of the facility and site-wide water quality models.

CHAPTER 8: REFERENCES

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