***Final* Environmental Impact Statement**

Thacker Pass Lithium Mine Project

Appendix P, Part 1 of 8

Water Information

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PITEAU 2020 HYDROLOGY IMPACTS ASSESSMENT
REVISION I

THACKER PASS PROJECT

WATER QUANTITY AND QUALITY IMPACTS REPORT
REVISION 1

Prepared for

LITHIUM NEVADA CORPORATION

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LIST OF ABBREVIATIONS

°F	degrees Fahrenheit
afy	acre-feet per year
atm	atmospheres
amsl	above mean sea level
AOI	area of interest
ANP:AGP	acid neutralization potential/acid generation potential
bgs	below ground surface
BLM	Department of the Interior, Bureau of Land Management, Winnemucca District, Humboldt River Field Office
CESA	cumulative effects study area
CRF	chemical release function
Cfs	cubic feet per second
DRZ	damaged rock zone
EIS	environmental impact statement
ERA	ecological risk assessment
ET	evapotranspiration
ft	feet
ft/d	feet per day
gpm	gallons per minute
HCT	humidity cell test
HFB	horizontal flow barrier
HLP	heap leach pad
in/yr	inches per year
K	hydraulic conductivity
LNC	Lithium Nevada Corporation
Ma	Million years ago
MAP	mean annual precipitation
mg/l	milligrams per liter
NDWR	Nevada Division of Water Resources
NEPA	National Environmental Policy Act
non-PAG	non-potentially acid generating
NRVs	Nevada Reference Values
PAG	potentially acid generating
pE	redox condition, negative log of the concentration of electrons (e^-)
PEST	parameter estimation
pH	negative log of dissolved protons (H^+)
SF	scaling factors
SI	saturation indices
Ss	specific storage
s.u.	standard unit
Sy	specific yield
TDS	total dissolved solids
µm	micrometers
USG	unstructured grid
WRF	Waste Rock Facility
WRMP	Waste Rock Management Plan

1 INTRODUCTION

The following Water Quality and Quantity Impacts Assessment Report was completed for Lithium Nevada Corporation (LNC) in connection with the prospective Thacker Pass Project. The report documents the water quantity and quality impacts analysis of the proposed open pit lithium claystone, waste rock facilities (WRFs), Gangue Stockpile, and associated activities located in Thacker Pass (Figure 1.1). The report was developed for submission to the Department of the Interior, Bureau of Land Management, Winnemucca District, Humboldt River Field Office (BLM). The impacts assessment follows the separately submitted Baseline and Model Workplan (Piteau, 2018) and the Baseline Hydrologic Data Collection Report (Piteau, 2019a). This report meets the BLM Data Adequacy Standards as well as NDEP guidance outlined in the following guidance documents:

- “Nevada Bureau of Land Management Rock Characterization and Water Resources Analysis Guidance for Mining Activities” (IM No. NV-2013-046) (BLM, 2013);
- “Water Resources Data and Analysis Policy for Mining Activities” (IM No. NV 2008-032) (BLM, 2008a); and
- “Groundwater Modeling Guidance for Mining Activities” (IM No. NV-2008-035) (BLM, 2008b).
- “Guidance for Hydrogeologic Flow Modeling at Mine Sites (NDEP, 2018a)
- “Guidance for Geochemical Modeling at Mine Sites (NDEP, 2018b)

1.1 PROJECT DESCRIPTION

The Thacker Pass Project is a proposed lithium mine and processing facility located approximately 20 miles west-northwest of Orovada, in Humboldt County, Nevada (Figure 1.1). Lithium ore is hosted in moat sediments, consisting of various claystones, in the southern portion of the McDermitt Caldera. The proposed project area of mining interest (AOI) and facility map is shown in Figure 1.2.

The Thacker Pass Project mine proposes an open-pit operation that requires minimal blasting given the soft nature of material. Claystone ore will be excavated, mechanically crushed, separated, made into a slurry, and placed in a leaching circuit using sulfuric acid as a lixiviant to liberate lithium from the claystone. Pregnant leach solution will be purified and processed to ultimately produce battery grade lithium carbonate (Li_2CO_3), lithium hydroxide (LiOH), and other lithium products. Tailings will be filter pressed and dry stacked on a synthetically lined, zero discharge facility. Two small waste rock facilities (WRF) will be located to the southwest and east of the pit. Pit closure alternatives of a backfilled and open pit are assessed herein.

Mining is anticipated to occur in two phases. Phase 1 will last for approximately 4 years at a production rate of approximately 33,000 tonnes per annum (tpa) Li_2CO_3. The construction of Phase 2 processing facilities is contingent upon economic and market conditions. Phase 2 will increase the mining rate to 66,000 tpa Li_2CO_3 and last for approximately 37 years. Thus, the total projected mine life is approximately 41 years. While the operation will continue at the Phase 1 production rates absent a decision to construct Phase 2, this report assumed the construction of Phase 2 to assess maximum impacts. Construction and operations of the mine facilities include:

- Open pit mining below the water table;
- Slurry pipeline from mine to plant;
- Sulfuric acid plant;
- Lithium processing plant;
- Filter stack clay tailings facility;
- Waste rock facilities (WRF);
- Coarse-gangue storage facility;
- Growth media stockpile;
- Production wellfield located in Quinn River Valley and raw water pipeline to plant.

The open pit consists of three smaller sub-pits or catchments which reside in the overall open pit footprint (North, West, and South as shown in Figure 1.2). The open pit is planned to be approximately 300 ft to 400 ft deep. Pit floor elevations of the North, West and South sub-pits are 4,757 ft, 4,774 ft, and 4,593 ft respectively (Figure 1.3). Measured groundwater elevations at the project area range from 4,810 ft to 5,270 ft, therefore the pit will intersect the water table. Some dewatering is anticipated to stabilize slopes, otherwise groundwater seepage to the pit will be managed using in-pit sumps and pumps. After approximately year 6, the open pit will be continuously backfilled with waste rock material and revegetated simultaneously with mining to minimize the footprint of above-ground storage facilities, support open-pit recontouring for closure, reduce dewatering requirements, and eliminate the potential for formation of a post-closure pit lake.

Process and potable water for the project will be sourced from an alluvial groundwater wellfield in Quinn River Valley and conveyed to the project site via pipeline. Projected water demand for operation is 2,600 afy (1,615 gpm) for Phase 1 and 5,200 afy (3,230 gpm) for Phase 2.

Mine facilities with potential to impact surface and groundwater resources include:

- Open pit mine requiring dewatering and/or sump pumping;
- Placement of backfill or pit lake formation within the open pit;

- Water supply pumping for the duration of mine life via a wellfield located in Quinn River Valley;
- Waste rock facility construction;
- Gangue stockpile
- Filter stack tailings storage facility construction (zero discharge facility).

1.2 PREVIOUS STUDIES AND DATA SOURCES

The hydrologic database was updated through March 31, 2019 for this study. This date serves as the "data cutoff" point. Primary data sources are detailed in the Baseline Hydrologic Data Collection Report (Piteau, 2019a) and are briefly summarized as follows:

- 2011 groundwater investigation – Lumos: A groundwater investigation was conducted by Lumos and Associates between February 2011 to March 2011 (Lumos, 2011a). Four (4) wells were drilled and tested (WSH-3, WSH-4, WSH-5, and WSH-6) in the vicinity of earlier pit designs. Only WSH-3 remains operational (Figure 1.2), all other wells were abandoned shortly after drilling.
- 2011 groundwater investigation – Schlumberger Water Services (SWS): Additional groundwater investigations were designed and executed between August 2011 to October 2011. This campaign drilled 7 wells (WSH-7, WSH-8, WSH-11, WSH-13, WSH-14, WSH-17, PH-1 (Figure 1.2)), 5 of which have been continuously monitored for groundwater levels (SWS, 2013).
- 2011 to 2013 seep and spring surveys – SRK: Seep and spring surveying was conducted for 36 potential locations. New springs were continuously added to the data set, extending the survey period to 7 quarters, although not all springs were monitored for the entire period. Data sets for springs monitored for a period of at least 4 quarters were considered to represent a complete dataset (Lumos, 2011b) (SRK, 2011a, 2011b, 2012a, 2012b, 2012c, 2012d, 2013).
- 2018 hydrologic investigation – Piteau: A comprehensive hydrologic investigation was developed to collect additional baseline data for an expanded project footprint represented by the current Thacker Pass Project area of interest (AOI). Key elements from this investigation were:
    - Established 3 surface water gaging stations at Crowley, Upper Thacker Creek, and Lower Thacker Creek.
    - Installation of 9 new vibrating wire piezometer (VWP) locations, with multiple transducers deployed in each piezometer. In total 27 transducers are installed among the 9 new VWPs.
    - Drilling and construction of 4 new monitoring wells.

- o Seep and spring evaluation identifying 56 potential sites. Quarterly surveys were performed for 34 of these springs in 2018 and 2019. The other springs were sufficiently characterized previously.

The study also incorporates privately collected information prepared by LNC and public data relative to Quinn River and Kings River Basin hydrology. Examples of the existing information incorporated in the groundwater and geochemical models include:

- Geologic data, including lithology, stratigraphy, structure, geologic interpretations, and information from the geologic models developed for the TPP pre-feasibility study;
- Geologic logs contained in Nevada Division of Water Resources (NDWR) driller's reports (NDWR, 2019);
- Water levels maintained by NDWR (NDWR, 2019)
- Maxey-Eakin groundwater recharge estimates (Maxey and Eakin, 1949);
- Water Resource Bulletins prepared for Quinn River and Kings River Basins (Malmberg, 1966; Huxel, 1966; Visher, 1957; Zones, 1963); and
- Water chemistry data from monitoring and production wells from 2011 through March 2019.

2 HYDROLOGIC BACKGROUND AND CONCEPTUAL MODEL

2.1 HYDROGRAPHIC SETTING AND CLIMATE

The Thacker Pass Project straddles the topographic divide separating the Kings River Valley hydrographic basin (Rio King Subarea) and the Quinn River Valley hydrographic basin (Orovada Subarea) (Figure 2.1). The Kings River Valley hydrographic basin is divided into the Rio King Subarea to the north and the Sod House Subarea to the south. The Quinn River Valley hydrographic basin is divided into several subareas beginning with the Oregon Subarea furthest north, the McDermitt Subarea, the Orovada Subarea, and the Silver State Subarea furthest south. Topography surrounding the mine is typical of the Basin and Range province, consisting of narrow, short mountain ranges with moderate to high relief which are separated by broad valleys composed of basin fill and lacustrine deposits.

An onsite meteorological station (Thacker Pass Station) was installed in August 2011 and has continuously collected data to the present day (LNC, 2019a). General climate conditions are characterized as arid, high desert with mild-cool winters and hot-dry summers. Average winter temperature is near freezing (32.5° F), with daily temperatures ranging from highs of ~50°F to lows of ~10°F. Summer temperatures range from highs of ~95°F to lows of ~50°F. Air moisture is generally arid, with relative humidity ranging from ~25% during summers to ~65% in winter.

2.1.1 Precipitation

The mean annual precipitation (MAP) recorded at the Thacker Pass Station is approximately 12.22 inches per year (Table 2.1) (LNC, 2019a). The average monthly precipitation ranges between 0.32 inches (July) and 1.63 inches (December). Most precipitation occurs between November and May when Pacific storms track across northern Nevada. On-site precipitation trends compare well to the nearby Orovada and Kings River Valley Stations, where average annual precipitation was 9.18 inches/yr and 9.12 inches/yr, respectively (WRCC, 2019).

Table 2.1: Average monthly precipitation and PET (2011-2018)

Month	Thacker Pass Station Precipitation (in)	Calculated PET (in)
January	1.35	1.5
February	0.83	2.2
March	1.32	3.7
April	1.21	4.9
May	1.59	6.1
June	0.56	8.6
July	0.32	9.9
August	0.39	8.7
September	0.88	6.4
October	1.02	3.9
November	0.91	2.4
December	1.84	1.4
Total	**12.22**	**59.6**

Site specific potential evaporation rates (PET) were calculated from hourly meteorological data continuously collected from the LNC station using the Penman-Monteith (ASCE-EWRI, 2004). Average annual PET rates are 59.6 in/yr, with the highest periods of evaporation occurring during July (9.9 inches). Winter months are calculated to have 1.4 inches to 2.2 inches of evaporation, notably higher values compared to pan evaporation data. Pan evaporation data is influenced by freezing conditions which can lead to underestimation of evaporation during the winter.

2.2 SURFACE WATER

2.2.1 Springs

A review of the Thacker Pass Project AOI and of potential seeps and springs from previous surveys, aerial photography, and topographic maps identified 56 seeps and springs within an expanded spring survey boundary (Figure 2.2). Key conclusions from the seeps and spring surveys are as follows:

- Twelve (12) identified seep and spring locations are not truly expressions of groundwater and should not be classified as springs (BLM-01, BLM-05, BLM-06, SP-003, SP-007, SP-015, SP-017, SP-018, SP-025, SP-053, SP-058, and SP-059). These locations are generally developed stock ponds, pipelines from upgradient springs, or runoff catchments. In some cases, there has never been evidence of a groundwater expression (BLM-01, BLM-05, BLM-06, SP-003, SP-025).

- Twenty-three (23) springs are classified as ephemeral. Spring discharge peaks during Q2 and the sites are dry during Q3 or Q4. The majority of the springs in Pole and Rock Creeks are ephemeral, such that the streamflow flow is not maintained perennially. In particular, the headwater of Rock Creek is seasonally dry as observed at SP-056, which was a surface water monitoring location.
- Twenty-one (21) springs are classified as perennial. These springs include the Thacker Creek spring system which is evaluated for potential impacts by mining. Range front springs in Kings River Valley are anticipated to be too far away to be impacted by activities at Thacker Pass.

Additional spring site descriptions and water chemistry samples can be reviewed in the spring and seep survey reports (Lumos, 2011) and (SRK, 2011a, 2011b, 2012a, 2012b, 2012c, 2012d, 2013) and (Piteau, 2018b, 2018c, 2018d, 2019b, 2019c).

Spring locations in the Montana Mountains are generally aligned with faults and geologic contacts as shown in plan view in Figure 2.3 and in cross section on Figures 2.4 and 2.5. Springs SP-051, SP-055, SP-052, SP-053, and SP-004 as well as SP-007 and SP-008 (although not true springs) are all located adjacent to mapped faults. Additionally, SP-006 is located at a geologic contact and potentially an unmapped structure and SP-039 behaves as being structurally controlled as evidenced by short lived (2 to 4 months), high flow (>180 gpm) peak discharge rates during freshet followed by dry conditions (Piteau, 2019a). Hydrogeologic testing in the Thacker Pass Project area demonstrated that geologic structures compartmentalize the groundwater system as evidenced by:

- Stair-stepping groundwater levels between PH-1 (5034 ft), WSH-17 (4861 ft), and WSH-11 (4817 ft).
- Steep groundwater gradients between MW18-04, WSH-7, and PH-1 caused by the principal E-W fault.
- Boundaries to drawdown propagation during the TW18-02 35-day pumping test.
- Boundary effects to PH-1 during its pumping test.
- The projected hydraulic gradient developed from connecting spring elevations throughout the Montana Mountains would yield many more surface water expressions than exist, and higher water levels in the Thacker Pass Project area than observed (Figure 2.4 and Figure 2.5).

The manifestation of springs coincident to mapped structures in the Montanas (Henry et al. 2017, Figure 2.3) further supports the conceptual understanding that faults function as groundwater flow barriers in the Montana Mountains as they do in the Thacker Pass Project area.

2.2.2 Streams

Perennial and ephemeral surface water features located near Thacker Pass Project include Thacker Creek, Pole Creek, Rock Creek, and Crowley Creek (Figure 2.2). Background information for each is described as follows:

- **Thacker Creek**: Streamflow monitoring conducted by LNC measured flows ranging from 82 gpm to 334 gpm with an average annual baseflow estimate of 234 gpm measured at the inlet to Thacker Pond (Figure 2.2). During spring and fall, surface water runoff and interflow components of stream discharge are roughly equal to 50% to 100% of baseflow. Thacker Creek is a gaining stream, beginning at its headwaters near SP-010 to its discharge point at Thacker Pond. The annual average flow rates at Thacker Creek headwaters is ~66 gpm (Upper Thacker Surface Water Monitoring location). Several rheocrene springs in the area, as well as groundwater upwelling in the stream channel contribute flow along the creek's reach. For this reason, Thacker Creek can be conceptualized as a large rheocrene spring, or groundwater discharge system. Stream flow declines by approximately 94 gpm during summer months when water consumption by phreatophytes increase.
- **Pole Creek:** Pole creek is an ephemeral stream which originates in the Montana Range and infiltrates (loses) water as it flows across alluvium substrate. The upper reaches of the creek may flow perennially in intermittent sections, but are not continuous year round. The lower reach of the creek is seasonally dry as observed through seep and spring monitoring (SP-036, SP-039, SP-043). Two perennial springs have been observed (SP-028, SP-050 in Figure 2.2). There is no observed year-round baseflow in Lower Pole Creek across the Thacker Pass Project AOI, however during freshet flow from SP-039 and SP-040 as well as interflow and surface runoff generate flow in this reach.
- **Rock Creek:** Rock creek also originates in the Montana range and is an ephemeral stream. The stream channel at the headwaters (SP-056) is seasonally dry. Ephemeral flows are observed in the creek bed from the confluence with Crowley Creek extending well into the Montana Range.
- **Crowley Creek:** Crowley Creek originates north of Indian Springs (SP-035) and goes through a series of gaining and losing reaches (Figure 2.2). Generally Crowley Creek flows perennially north of the confluence with Rock Creek and is ephemeral south of the confluence. Ephemeral flow in Crowley Creek associated with spring freshet (surface water runoff and interflow) flows past Sentinel Rock and into Quinn River Valley (observed January to April 2018). Peak flow in excess of 8,000 gpm have been observed during spring runoff and storm events. The stream goes dry south of the confluence with Rock Creek during July to November, indicating there is no baseflow component of streamflow that far south. Average baseflow conditions are estimated to be 492 gpm from groundwater, all of which is consumed by ET or re-infiltrated to groundwater during summer months. Lower Crowley Creek is a losing stream which infiltrates water across alluvium between Rock Creek and Quinn River Valley.

2.3 GEOLOGY

The Thacker Pass Project is located in north-central Nevada at the northern end of the Basin and Range tectonic province. This province stretches from southern Oregon to Mexico and is characterized by a series of extension-related normal faults trending roughly north-south resulting in a repetitive series of mountain ranges separated by valleys. The project site is located in one of the mountain ranges of this province; bounded to the north by the Montana Mountains; to the south by the Double H Mountains; to the west by the Kings River Valley; and to the east by the Quinn River Valley (Figure 2.6).

Local geology of the Thacker Pass Project is controlled by the McDermitt Volcanic Field, a volcanic complex containing four large calderas (or “super volcanoes”) that formed in the middle Miocene. The McDermitt Volcanic Field is located within the southeastern-propagating swarm of volcanism from Steens Mountain into north-central Nevada. The largest and southeasternmost caldera of the McDermitt Volcanic Field, the McDermitt Caldera, hosts the ore body of the Thacker Pass Project. Prior to collapse of the McDermitt Caldera at 16.33 Ma, volcanism in the northern portion of the McDermitt Volcanic Field and locally small volumes of lavas erupted near the present-day Oregon-Nevada border (Figure 2.6). These lavas and the flood basalts are exposed along walls of the McDermitt Caldera and are ~16.5 Ma to ~16.3 Ma years old (Benson et al., 2017a; Henry et al., 2017).

A large lake formed in the caldera basin following the eruptions in the McDermitt Volcanic Field. Associated caldera lake sediments that host the Thacker Pass deposit were deposited on top of the horsts and grabens formed during the faulting associated with the Tuff of Thacker Creek (Figure 2.7). The lake captured sediments that were eroded from the surrounding drainage areas. A cross-section of the caldera deposits at Thacker Pass is shown in Figure 2.8.

Lacustrine claystone sediments which host lithium ore are found intimately interbedded with thin, repetitive water lain ash sequences. Ash layers are well sorted, medium to coarse sized lapilli grains deposited across wide extents, particularly in the Southwest Basin where thick sequences of basal Ash beds were encountered across multiple exploration boreholes. Diagenesis at depth has silicified claystone beds in finely laminated, mudstone sequences. The ratio of ash to claystone in these lacustrine units is a continuum, with thick sequences of ash beds (~30 ft in LNC-126) found more abundantly in basal lacustrine deposits in the Southwest Basin Area, and greater components of claystone found in the open pit footprint. The rhyolitic Tuff of Long Ridge is found underlying lacustrine sediments and is present in latite textures of felsic phenocrysts to a fine-grained groundmass. In some instances, the Tuff of Long Ridge was deposited as viscous lava, forming flows and pseudo bedding planes. These deposits are referred to as Rheomorphic Tuffs

2.3.1 Geologic Structure

Faults in the Thacker Pass Project are characterized over several episodes and structural trends. Key faults affecting geologic control are discussed as follows:

1. **Range front faults**: Major faults near the Thacker Pass Project are associated with Basin and Range extension to form the alluvial basin boundaries of Kings River and Quinn River Valleys. These faults began to form around 12 Ma, when the North American lithosphere began its extension in this area (Colgan et al., 2006; Lerch et al., 2008). Several thousand feet of offset have occurred, as noted by the steep topographic change in the western fringe of the Montana Mountains in Kings River Valley (Figure 2.6).
2. **Ring faults:** Ring faults form along the boundary of the western and southern extents of the McDermitt Caldera (Figure 2.7). The combination of ring faults and minor intra-caldera normal faults associated with the Tuff of Thacker Creek formed a graben in the Thacker Pass Project area, preserving the Li-enriched lake sediments which have otherwise eroded from the Montana Mountain range. Ring faults control the western, southern, and eastern extents of Thacker Pass geology.
3. **E-W fault:** The principal E-W normal fault resides at the northern extent of the Thacker Pass Project, juxtaposing claystone sediments against the Tuff of Long Ridge by down dropping the southern footwall (Figure 2.7). The fault runs nearly east to west through Thacker Pass, and may also be associated with the secondary explosion of Thacker Creek Tuff. The E-W fault is an important feature bounding the Thacker Pass Project geologically together with southern extent of ring faults.
4. **Radial vent faults**: Younger faulting associated with the venting of Thacker Creek Tuff extend from the main vents above the headwaters of Thacker Creek into the surrounding claystone and volcanic tuff units (Figure 2.7). Vent faults form the topographically high ridges, such as Silica Hill, comprised of the Tuff of Long Ridge which separate northern lake sediments in the pit vicinity from southern lake and ash sediments. Vent faults also form several N-S trending structures in Thacker itself and the ridgeline west. Offset along vent faults is ~165 ft.
5. **Minor NE – SW faults:** Several minor NE-SW trending faults offset claystone and ash beds (Figure 2.7). The magnitude of offset in these faults is minor, on the order of tens of feet. However, their presence is hydrogeologically important in compartmentalizing groundwater flow by truncating thin but transmissive ash beds inter-deposited within claystone.

2.4 HYDROGEOLOGIC SETTING

The conceptual hydrogeology is similar to most basin and range settings, beginning with precipitation derived recharge in higher elevations entering the groundwater system and flowing towards alluvial basins (Huxel, 1966 and Malmberg, 1966). Groundwater is ultimately discharged to springs and seeps, phreatophytes, groundwater flow out of basins, or anthropogenic consumption (via irrigation, stock watering, commercial, etc.). Recharge reaches the alluvial basin via two processes:

- Percolation into bedrock at high elevations and eventually discharging at depth in alluvial basins. This is referred to as “deep bedrock recharge” and comprises the smaller component of recharge in Quinn and Kings River Valleys (Huxel, 1966 and Malmberg, 1966).
- Infiltration from surface water runoff as it flows across alluvium material along basin margins. This is referred to as “runoff recharge” and comprises the majority of recharge to the basins. Excellent examples of runoff recharge are the ephemeral flows in Pole, Rock, and Crowley Creek all of which fully infiltrate to groundwater when flowing.

Groundwater gradients and flows are controlled by the transmissivity of rock materials and the presence of geologic structures. Groundwater flow in bedrock units is generally dominated by discrete fractures, fissures, and structural fabrics which provide conduits to transmit water and is referred to as secondary permeability that occurs at the mesoscopic scale (1s to 10s of feet) (Fetter, 2001). Secondary permeability tends to normalize to bulk hydraulic conductivity values at the macroscopic scale (100s of ft), but is still fundamentally controlled by fracture density, aperture width, and tortuosity. In the Thacker Pass Project area, the presence of interbedded ash layers function as an additional pathway to transmit groundwater flow which can be characterized as secondary permeability because they interconnect transmissive beds of ash in a broader fabric of claystone at the mesoscopic scale. On a macroscale claystone/ash beds exhibit somewhat homogenous properties, which break down at small scales and particularly when coupled with vertical offsets from faulting. Thus, the presence of faults is particularly important because they discretely impede groundwater flow by both truncating ash beds and intrinsically possess low permeability material themselves.

Steep groundwater gradients occur across faults and in low permeability bedrock units such as volcanic tuffs and lava flows. These materials possess crystalline rock matrices with very little intrinsic permeability. Claystone / ash bedrock units are more transmissive owing to the greater abundance of ash layers, and thus exhibit somewhat lower groundwater gradients. The lowest groundwater gradients are present in alluvial sediments, which have greater pore spaces and connectivity depending on grain size, degree of sorting, and compaction. Key observations and conclusions for the groundwater system at Thacker Pass are summarized as follows:

- Stair-stepping water levels across minor faults is evidence for hydraulic barriers to flow (WSH-11 to WSH-17 to WSH-13). Likewise, the continuous drainage of WSH-17 suggests the borehole intercepted the fault barrier and is slowly re-equilibrating to the downgradient hydrologic block.

- Steep groundwater gradients occur south of the E-W vent fault as evidenced by the contrast in water levels between WSH-7 (5,285 ft amsl) versus WSH-8 and MW18-04 (4,827 ft amsl). Contrast in water levels across the E-W fault is attributable to the intrinsic properties of the fault itself because geologic logs of WSH-7 and MW18-04 indicated both wells are completed in rhyolitic volcanic tuff.
- Water levels in the Thacker Pass Project have remained steady through time after equilibrating over a period of weeks to months. Recharge is thus interpreted as steady and predominantly from bedrock sources located at higher and wetter elevations rather than from surface runoff.
- Although measured water levels in the Thacker Pass Project show no seasonal change, spring flows in drainage channels (i.e. Pole and Rock Creeks) exhibit seasonal trends. Discharge at SP-039 in Pole Creek seasonally peaks in April and May and is dry by mid-summer. The strong seasonal response suggests stream channels can behave as transmissive bedrock corridors, hydraulically well connected along trend to upgradient recharge zones but poorly connected laterally to adjacent bedrock. Likewise, seasonal spring flow at Thacker Creek is attributable to enhanced transmissivity along the stream channel into the Montana Range because spring flow increases with limited surface water runoff from the headwaters north of SP-010.
- Groundwater gradients across the claystone/ash sediments are generally flatter ranging from 0.007 ft/ft to 0.014 ft/ft. Interbedded ash layers function as pathways to transmit groundwater flow, thus the abundance of ash affects the transmissivity of claystone/ash sediments. Drilling and testing suggest claystone/ash can be partitioned into three zones where the abundance of ash is fairly uniform.
- Claystone/ash in the area of the proposed open pit. Claystone is the dominant rock type but is frequently deposited with ash beds of <1 ft to 5 ft thick.
- Indurated claystone. This is claystone located in the north east portion of the Thacker Pass Project and is conceptually composed of thick sections of well indurated claystone devoid of ash layers.
- Basal ash is an important unit present in the Southwestern Basin of the Thacker Pass Project. Basal ash is characterized as having thick (~30 ft) sequences of ash at the bottom of lacustrine sediments.
- In volcanic tuff, groundwater gradients are steeper, ~0.025 ft/ft suggesting lower transmissivity of materials. Volcanic tuff comprised of rhyolitic to andesitic groundmass with few pore spaces in the rock matrix to transmit water. Thus, volcanic tuff is conceptually characterized as low permeability material unless tectonic stress and shearing has opened fractures to transmit water, such as those inferred in the stream channels of Pole, Rock, and Thacker Creeks.

2.4.1 Groundwater Levels

Groundwater levels in the vicinity of Thacker Pass are shown in Figure 2.9. Water levels tend to reside between 4,625 ft amsl to 5,034 ft amsl across the Thacker Pass Project and open pit area. Highest water levels are observed at WSH-7 (~ 5,285 ft amsl) that was drilled north of the principal E-W fault which functions as a hydraulic flow barrier. Water levels in the western portion of the Thacker Pass Project decline to an elevation of ~4,625 ft amsl (PZ18-05), which is approximately 20 ft higher than the headwaters of Thacker Creek (4,604 ft amsl). To the east, water levels decline to 4,513 ft amsl at MW18-02 which serves as the down gradient monitoring point. Water level data indicates the groundwater divide is shifted ~3,500 ft east of the hydrographic divide. The groundwater divide corresponds with a corridor of elevated water levels from WSH-7 (5,285 ft amsl), PH-1 (5,034 ft amsl), and WSH-17 (4,861 ft amsl) which are compartmentalized by minor faults (Figure 2.9).

Groundwater flow in Quinn River Valley is from north to south, ultimately discharging to Silver State Subarea or into Kings River Valley. Water levels in the northern extent of the conceptual model are 4,214 ft, amsl (NDWR Site ID 033A N45 E37 24BCDC1) and decline to ~4,110 ft amsl (NDWR Site IDs 033A N42 E37 04BADD2, 033A N42 E37 04BADD1, and 033A N42 E37 08DADD1). Overall water level gradients are very flat (Figure 2.10). Water level gradients in the north portion of the conceptual model are slightly steeper (0.003 ft/ft), whereas the central and southern portions possess a very flat gradient <0.0003 ft/ft suggesting very transmissive materials. Steeper gradients and higher water levels are found along basin margins corresponding to older alluvial fan, lakebed, and colluvial deposits. Water levels immediately south of Orovada are slightly elevated, likely caused by runoff recharge and alluvial fan geomorphology deposited by Horse Canyon and Buffalo Canyon Creeks. A corridor of low groundwater levels is found along the eastern portion of the basin, coincident with irrigation pivots and agricultural pumping.

Basin scale groundwater flow in Kings River Valley is from north to south, ultimately discharging south to Sod House. Water levels are very flat across the conceptual model domain, ranging from ~4,110 ft amsl north (NDWR Site ID 030A N45 E33 24BCCC2) and ~4,100 ft amsl in the south (Figure 2.11). Kings Valley possesses a very flat gradient <0.0002 ft/ft suggesting transmissive materials. Agricultural pumping has produced a 12-mile long cone of depression in the western central portion of the valley, where water level declines of 30 ft to 70 ft are observed during the last 30 years. This drawdown is a result of coalescing cones of depression between production wells in the very transmissive alluvium. Steeper gradients and higher water levels are inferred along basin margins using the gradient between Kings Valley and Thacker Pass as a guideline.

2.4.2 Well Inventory and Water Rights

Kings River Valley and Quinn River Valley are both designated basins that have fully allocated water rights, with perennial yields of 17,000 afy and 60,000 afy respectively. A survey of well logs from the state database identified 64 wells in Kings River Valley and 44 wells in Quinn River Valley drilled within a 5-mile radius of the Thacker Pass Project AOI (Figure 2.12). The majority are irrigation wells located in the alluvial basins with several stock and domestic wells also drilled in the alluvium. All wells within the AOI are owned by LNC, except for well log 380 located just inside the AOI boundary. This well may be associated with several abandoned wells adjacent to SP-058.

There are 246 points of diversion located within a five-mile radius of the Thacker Pass Project AOI (Figure 2.13). The diversion rate of allocated water rights ranges from 0.01 to 160 cubic feet per second (cfs) with annual duties ranging from 0 to 6,827 afy. Predominant usage is irrigation, constituting 99% of appropriated water and 78% of the water right permits. Stock watering is used to a much lesser extent (0.3% of appropriated water and 19% of permits). The nearest water right not owned by LNC are permit numbers 87008 and 79742, both of which are owned by Lyman and sourced from spring SP-028 (Figure 2.13).

2.4.3 Hydrogeologic Units

Geologic units were grouped and subdivided into unique hydrogeologic units (HGUs) or zones of similar properties. A two-step approach was used to delineate HGUs:

1. Group geologic units of similar hydrogeologic properties into a bulk HGU. For example, beds of brown claystone, grey claystone, and interbedded white ash would be grouped together as claystone/ash.
2. Spatially divide and differentiate HGUs according to their location in Kings River Valley, Thacker Pass, and Quinn River Valley. Natural spatial variability is incorporated by delineating HGUs across these three areas of interest, which possess unique geologic and depositional settings.

A description of conceptual HGUs is provided as follows and summarized in Table 2.2.

- **Quinn River Valley (QRV)-Basement McDermitt Tuff:** The majority of the Montana mountains is comprised of undifferentiated McDermitt Tuff, also referred to as the Tuff of Long Ridge. Tuff thickness varies between 0 to over 2,000 ft, such as is found in the Montana mountains. McDermitt tuff is stratigraphically lower than claystone/ash sedimentary units and is the basement HGU in the Montanas. Stream channels in the Montana Range represent corridors of elevated transmissivity and are broken out as a unique HGU.

- **QRV-Basalt:** Andesite and basalt flows are co-deposited throughout the McDermitt caldera, and generally lie unconformably above older volcanic tuff or interbedded within claystone/ash units. Hydrogeologic properties are analogous to basalt tested in the Thacker Pass Project, namely moderate permeability along secondary fractures or weathering planes.
- **QRV-Rhyolitic flows and younger extrusive rocks:** This HGU is comprised of rhyolitic flows and extrusive rocks in the McDermitt Caldera.
- **QRV-Dacite:** Dacite deposits in the Santa Rosa mountains. The conceptual model is relatively insensitive to this HGU owing to its distal location to the Thacker Pass Project.
- **QRV-Jurassic granodiorite:** Granodiorite deposits in the Santa Rosa mountains represent the oldest rocks in the conceptual model domain and form bold outcrops such as Sawtooth mountain east of Orovada.
- **QRV-Undifferentiated rhyolite flows, lavas, tuffs:** Undifferentiated rhyolite flows, lavas, and tuffs outside the McDermitt Caldera comprise the Double H mountain range. These tuffs preceded the McDermitt Tuff. Bulk transmissivity of rhyolite flows is inherently low, with limited capacity to transmit groundwater except through secondary fractures and fissures. Hydrogeologic properties are analogous to volcanic tuffs tested at the Thacker Pass Project.
- **QRV-Winnemucca formation:** The Winnemucca formation is comprised of siltstone, quartzite, and shale in the Santa Rosa mountains.
- **Older alluvium (Quinn River and Kings River Valleys):** Older alluvium sediments are exposed along the basin margins. The alluvium is highly variable and is composed of unconsolidated sand, silt, and clay. Older alluvium is composed of paleo-channels and floodplains, ancient alluvial fans, and basin fill. Towards the center of the valleys, older alluvium becomes better sorted, less angular, and has smaller grain sizes. Transmissivity measured in the older alluvium is estimated to range from 1,350 to 6,740 ft^2/d (Malmberg, 1966). Older alluvium pinches out at the basin margins, reducing the unit's thickness and transmissivity. Both older and younger alluvium units have horizontal hydraulic conductivity values several times larger than vertical hydraulic conductivity.
- **Basin fill alluvium (Quinn River and Kings River Valleys):** Basin fill alluvium transitions from the basin margins towards the basin center and are formed by bulk alluvial, younger alluvial fans, and floodplain deposits. Materials are comprised of sub-angular gravels, sands, and silts, with generally < 30% fine-grain content. QRPW18-01 was tested in mostly basin fill alluvium, yielding a transmissivity value of 26,935 ft^2/d and in agreement with other observed values in the basin (Huxel, 1966). Basin fill is incised by younger reworked alluvium and pinches out towards the basin margins.
- **Younger alluvium (Quinn River and Kings River Valleys):** Younger alluvium and playa sediments are found in both Kings River Valley and Quinn River Valley along the central axis of the basins. These sediments consist of unconsolidated gravel, sand, and silt which has

been reworked in alluvial fan deposits and historic river channels during wetter climate epochs. Younger alluvium thickness is approximately 200 ft in channel deposits and pinches out laterally towards the basin margin. Geologic logs of QRPW18-01 correlate with this thickness, encountering well sorted gravel and cobble beds between 40 ft to 120 ft depths. Younger alluvium has the highest transmissivity and storage of any material in the conceptual model. Transmissivity values ranging from 70,000 ft^2/d to 100,000 ft^2/d have been measured (Huxel, 1966), and the recharge boundary encountered at QRPW18-01 supports the presence of higher transmissivity units in the basin. The storage coefficient (specific yield) was identified at 0.17 (Malmberg, 1966), and correlates well with calculated storage values at the West Windmill Well.

- **Thacker Pass alluvium:** Alluvium in Thacker Pass is generally thin, ranging from a few feet up to 100 ft, and comprised of fine-grained sands, silt, and clays. Alluvial hydrogeologic properties are envisioned to be similar to that of older basin margin alluvium, which would be relatively higher than underlying volcanic tuff and slightly higher than claystone/ash beds. Alluvium is thicker near structural fault boundaries (as observed in PZ18-04) where deposition is actively ongoing. Stream drainages, such as Thacker Creek, are thought to have some structural control, thus relatively thicker sequences of alluvial materials are anticipated.
- **Thacker Pass basalt:** Basalt in the Thacker Pass Project area is conformably deposited within and above claystone/ash beds. Basalt can be a key marker bed in the ore body. Shallow basalt flows are found in the ridge near PZ18-06, and in the eastern portions of Pole and Rock Creeks. A 300-foot thick sequence of basalt was observed in WSH-3 and at other exploration holes on the eastern fringe of the project area. This data and aerial magnetic surveys suggest that thicker basalt flows lie east of the project area beneath older alluvium sediments. Hydrologic testing indicates that basalt can be very permeable (30.1 ft/d at WSH-3).
- **Thacker Pass claystone/ash:** The claystone/ash unit is dominantly composed of moat sediments in the form of clays, lithified claystone, and ash. Thin beds of volcanic ash, ranging from less <1 ft to 5 ft in thickness are regularly interbedded within claystone deposits. Ash beds are comprised of well sorted fine to coarse-grained lapilli sands and are the primary flow conduits in the unit. It is because of the abundance of ash lain beds that the claystone/ash unit is more susceptible to groundwater compartmentalization than other units. Slight offsets due to faulting (such as the network of minor faults through the ore body) juxtapose more transmissive ash beds against claystone beds, effectively disrupting groundwater flow.
- Claystone/ash is generally well indurated with good recovery during drilling. This suggests that bedding planes and fractures can remain open as conduits for groundwater flow and serve as the primary flow mechanism. The claystone unit is approximately 300 ft to 400 ft thick in the Thacker Pass Project. This unit hosts the Li-rich hectorite clays which compose the ore body and is the unit in which open pit mining will occur.

- **Thacker Pass indurated claystone**: Indurated claystone is comprised of compacted, and possibly silicified, claystone beds with less abundant ash beds. They are located in the northeast sector of the Thacker Pass Project, delineated through surface geophysics which characterizes the area as low magnetic resonance (indicative of claystone) and moderate resistivity (a result of cementation and the absence of ash).
- **Thacker Pass basal ash**: The basal ash unit is found in the Southwest basin, south of Silica Hill and lies stratigraphically below the claystone/ash unit. Basal ash is primarily composed of rhyolitic volcanic lapilli ranging from 50 ft to 200 ft thick. Claystone is interbedded in the ash, but less abundant than in the claystone/ash unit. Thus, vertical hydraulic conductivity is limited by thin interbeds of claystone and several times lower than horizontal hydraulic conductivity.
- **Thacker Pass volcanic tuff:** Volcanic tuff (primarily the Tuff of Long Ridge or McDermitt Tuff) is located stratigraphically below the claystone/ash unit. The top of the lithic tuff is a lithified, competent silicic volcanic rock which serves as the boundary between claystone and tuff. Groundwater flow principally occurs through secondary fractures and along structural features. The overall permeability and storage are quite low, even after accounting for fractures. In some instances, pseudo folded-bedding planes are observed due to the high viscosity of the tuff at deposition, this is referred to as rheomorphic tuff. In the project area, the tuff unit dips to the west-southwest until it is overlain by the ring faults at the caldera margins. Lithic tuff represents the deepest bedrock unit encountered by exploration drilling.
- **Thacker Pass drainages:** Stream channels in the Montana Range represent corridors of enhanced transmissivity, interpreted as tectonic shear zones. These zones connect springs and streams to upgradient recharge areas but are enveloped by unfractured bedrock.

Table 2.2: Summary of hydrogeologic units

Lithology Unit	K_h Range (ft/d)	K_v Ratio	S_s Range (1/ft)	S_y Range	Source
QRV-Basement McDermitt Tuff	$1x10^{-4} – 1x10^{-1}$	1 - 10	$1x10^{-7} – 1x10^{-5}$	0.01 – 0.005	2018 Testing
QRV-Regional Basalt	$1x10^{-2}$ – 10	1	$1x10^{-7} – 1x10^{-5}$	0.04 – 0.01	2018 Injection / recovery tests
QRV-Rhyolitic flows and younger intrusive rocks	$1x10^{-4} – 1x10^{-1}$	1 - 10	$1x10^{-7} – 1x10^{-5}$	0.01 – 0.005	2018 Testing
QRV-Dacite	$1x10^{-4} – 1x10^{-1}$	1 - 10	$1x10^{-7} – 1x10^{-5}$	0.01 – 0.005	Literature estimates
QRV-Jurassic granite	$1x10^{-4} – 1x10^{-2}$	1	$1x10^{-7} – 1x10^{-5}$	0.01 – 0.005	Literature estimates
QRV-Undifferentiated rhyolite flows, lavas, tuffs	$1x10^{-4} – 1x10^{-1}$	1 - 10	$1x10^{-7} – 1x10^{-5}$	0.01 – 0.005	2018 Testing
QRV-Winnemucca fmn: Shale, siltstone, sandstone and carbonate	$1x10^{-3} – 1x10^{0}$	1 - 100	$1x10^{-7} – 1x10^{-5}$	0.01 – 0.005	Literature estimates
QRV - Older alluvium	$1x10^{-1} – 1x10^{1}$	1 - 100	$1x10^{-6} – 1x10^{-4}$	0.17 – 0.03	Water Resource Bulletin 34
QRV – Basin fill alluvium	$2x10^{1} – 1x10^{2}$	1 - 100	$1x10^{-6} – 1x10^{-4}$	0.20 – 0.05	QRPW18-01 pumping test
QRV- Younger alluvium / gravel beds	$2x10^{1} – 2x10^{2}$	1 - 10	$1x10^{-6} – 1x10^{-4}$	0.20 – 0.05	Recharge boundary observed in QRPW18-01
Thacker Pass - Alluvium	$1x10^{-1} – 1x10^{1}$	1 - 100	$1x10^{-6} – 1x10^{-4}$	0.17 – 0.03	Literature estimates
Thacker Pass – Claystone/ash	$5x10^{-2} – 5x10^{0}$	1 - 1000	$1x10^{-7} – 1x10^{-5}$	0.04 – 0.01	2018 Testing
Thacker Pass – Indurated claystone	$5x10^{-2} – 5x10^{-1}$	1 - 1000	$1x10^{-7} – 1x10^{-5}$	0.04 – 0.01	2018 Testing
Thacker Pass Basal ash	$1x10^{-1} – 5x10^{0}$	1 - 100	$1x10^{-6} – 1x10^{-5}$	0.04 – 0.01	2018 Testing
Thacker Pass – Volcanic tuff	$9x10^{-3} – 1x10^{0}$	1 - 10	$5x10^{-7} – 5x10^{-5}$	0.01 – 0.005	2018 Testing
Thacker Pass - Basalts	$1x10^{-2}$ – 10	1	$1x10^{-7} – 1x10^{-5}$	0.04 – 0.01	2018 Testing
Thacker Pass - Drainages	$1x10^{-1} – 1x10^{0}$	1 - 10	$1x10^{-6} – 1x10^{-5}$	0.01 – 0.005	2018 Testing
KRV – Undifferentiated rhyolite flows, lavas, tuffs	$1x10^{-4} – 1x10^{-1}$	1 - 10	$1x10^{-7} – 1x10^{-5}$	0.01 – 0.005	2018 Testing
KRV - Older alluvium	$1x10^{-1} – 1x10^{1}$	1 - 100	$1x10^{-6} – 1x10^{-4}$	0.17 – 0.03	Water Resource Bulletin 31
KRV – Basin fill alluvium,	$5x10^{0} – 1x10^{2}$	1 - 100	$1x10^{-6} – 1x10^{-4}$	0.20 – 0.05	Water Resource Bulletin 31
KRV – Younger alluvium, playa	$2x10^{1} – 2x10^{2}$	1 - 10	$1x10^{-6} – 1x10^{-4}$	0.20 – 0.05	Analogous QRPW18-01 pumping test

K_h – Horizontal hydraulic conductivity

K_v – Vertical anisotropy ratio (K_h / K_z)

S_s – Specific storage

S_y – Specific yield

3 WATER QUANTITY IMPACTS ASSESSMENT MODEL AND CALIBRATION

Water quantity impacts analysis for the Thacker Pass Project was completed utilizing the Thacker Pass Project numerical groundwater model. The basis for the numerical groundwater model was developed from the conceptual hydrogeologic framework discussed in the Hydrologic Baseline Data Collection Report (Piteau, 2019a).

3.1 MODEL DESCRIPTION

The Thacker Pass Project model is a MODFLOW-USG (USG) finite difference numerical groundwater model (Panday et al., 2017). The model simulates saturated / unsaturated groundwater flow in bedrock and alluvial hydrostratigraphic units. MODFLOW-USG was selected as the numerical code because it provides several mathematical advantages and numerical efficiencies over contemporary codes such as:

- MODFLOW-USG is a peer-reviewed code accepted by the scientific community to accurately solve the variably saturated groundwater flow equation for conditions similar to the present study.
- MODFLOW-USG uses a mathematical formulation that is superior for solving problems with cell wetting and drying, such as those to be encountered in and around the areas of pit dewatering and water supply pumping.
- MODFLOW-USG incorporates quadtree grid refinement and ghost nodes more efficiently represent key areas in the numerical grid and incorporate hydrogeologic detail.
- MODFLOW-USG pseudo soil function allow for the simulation of seepage faces, a condition commonly found in open pit environments.
- MODFLOW-USG includes the connected linear network (CLN) package that intrinsically connects discrete conduits (i.e. well bores, tunnels, horizontal drains) to adjacent porous media nodes and boundary conditions to generate a simultaneous head solution in the governing equations.
- MODFLOW-USG uses the Hydrologic Flow Barrier (HFB) package which more effectively simulates faults that impede groundwater flow.

3.1.1 Model Grid

From east to west, the model spans approximately 37 miles, and from north to south it spans approximately 14 miles (Figure 3.1). The numerical model grid is comprised of 23 layers with a total of 319,652 active cells. The highest cell size resolution is 100 ft by 100 ft in the vicinity of the proposed pit. Cell sizes are also reduced to 200 ft by 200 ft surrounding the Quinn River production well QRPQ18-01. Maximum cell dimensions reach 3,200 ft by 3,200 ft towards the margins of the model where groundwater levels do not change substantially with time. The vertical layer discretization is shown in Figure 3.2 to Figure 3.5. and described as follows:

- Layers 1 to 4: 500 ft
- Layer 5: 300 ft
- Layer 6: 100 ft
- Layers 7 to 18: 50 ft
- Layers 19 to 20: 100 ft
- Layer 21: 300 ft
- Layers 22 to 23: 500 ft

More vertical resolution is implemented across the proposed pit elevations to resolve the open pit, simulate groundwater levels, and evaluate the groundwater response the proposed mine plan. Ground surface elevations for the model were obtained from the United States Geological Survey digital elevation model.

3.1.2 Boundary Conditions

The model domain was selected to be sufficiently large to identify potential groundwater related impacts related to mining operations without incurring any boundary conditions effects. Two hydrographic basins are covered by the model domain, with the Thacker Pass Project placed in the center (Figure 3.1).

External boundaries

Constant Head Boundaries

Constant head boundaries for the Thacker Pass Project model were implemented as follows (Figure 3.6):

- *Kings River Valley northern boundary*: Gaging station at the crossing of Kings River and Rio King Ranch Road (a perennially dry channel). An estimated groundwater elevation of 4,110 ft amsl is assigned at this location based upon water levels at NDWR Site ID 030A N45 E33.
- *Kings River Valley southern boundary*: Subarea boundary between Rio King and Sod House Subareas. A groundwater elevation of 4,100 ft amsl is estimated based upon interpolated

water levels measurements dating to pre-1980 from the NDWR well sites (030A N44 E34 17DBBB1, 030B N44 E33 24DDBA1, and 030B N43 E34 13BBCA1).

- *Quinn River Valley northern boundary*: Boundary between the McDermitt and Orovada Subarea coincident with the Quinn River gage station (USGS 10353500), with historic annual average flow rate of 35.3 cubic feet per second (cfs) flow in the Quinn River. A groundwater elevation of 4214 ft amsl (~40 ft below ground surface) is assigned based on interpolated water level measurements from the NDWR database.
- *Quinn River Valley southern boundary*: Identified at location of NDWR well permits 2954, 2992, 7570 with outflow in the Quinn River. A groundwater elevation of 4,125 ft amsl is assigned based on water levels from NDWR well sites (033A N42 E37 04BADD2, 033A N42 E37 04BADD1, and 033A N42 E37 08DADD1).

The depth to which the boundary conditions extend is not known with certainty. For the purposes of the current report, it was assumed that groundwater flow is primarily horizontal, so that vertical gradients at the boundaries located several miles from the area of interest could be considered negligible.

No Flow

No flow boundaries were implemented along most of the model perimeter (Figure 3.6). North and south no-flow boundaries correspond to topographic ridges and surface water flow divides. The western boundary corresponds to the hydrographic divide between Pine Forest Valley and Kings River Valley Basins. The eastern boundary corresponds to the hydrographic divide between Paradise Valley and Quinn River Valley Basins.

Internal boundaries

Recharge

Recharge in Quinn River and Kings River Valleys begins in mountain blocks with elevations above 5,000 ft amsl, and is distributed to the alluvial basin via two processes (Huxel, 1966 and Malmberg, 1966):

- Deep Bedrock Recharge representing precipitation and snowmelt percolation in bedrock mountain blocks.
- Runoff Recharge derived from infiltration of surface water runoff as it flows across alluvium material along basin margins.

Recharge rates were specified on a zone-by-zone basis in the model using the MODFLOW-USG recharge package. Recharge rates were scaled from NDWR resource bulletins using the Hardman map through a process of catchment delineation, as follows:

1. Delineate major catchments for in Kings River and Quinn River Valleys. Catchments are sub-divided into a “bedrock” catchment and a “runoff” sub-catchment at the contact between alluvium and bedrock (Figure 3.7). A total of 18 catchments were defined (14 in Quinn River hydrographic basin and 4 in Kings River). No catchments are defined in the basin axis because it is a groundwater discharge zone.
2. Calculate the volume of recharge in each basin using an area weighted average of recharge from the Hardman map (Hardman, 1936). The total values derived from the Hardman map were 532 afy in Kings River and 7,236 afy in Quinn River, both of which are less than estimates from NDWR Resource bulletins.
3. Estimate the relative percentage of recharge contributed from each catchment to the overall basin by calculating the percentage of recharge for each catchment ($R_{catchment}$ / $R_{total\ basin}$). For example, Catchment I contributes 90 afy out of 532 afy in Kings River Valley, it represents 17% of the basin’s recharge.
4. Scale the NDWR Resource Bulletin estimates for Deep Bedrock and Runoff Recharge for each basin across the catchments by multiplying the catchments relative percentage (calculated in step 3) by the total basin value.

Catchment recharge summaries are shown in Figure 3.7 and are described in more detail in the Thacker Pass Project Baseline Hydrologic Data Collection Report (Piteau, 2019a). Numerical model recharge zones are shown in Figure 3.8.

Evapotranspiration

Groundwater ET was simulated with the evapotranspiration package in MODFLOW-USG.

Evapotranspiration in Quinn River prior to the 1950s was estimated to be 63,000 afy across 161,600 acres of phreatophyte vegetation. Evapotranspiration was primarily from greasewood and rabbitbrush (~29,000 afy) and native meadow grass (~22,000 afy) (Huxel, 1966). Irrigation pumping has reduced natural evapotranspiration discharge by lowering the water table below the root depths of phreatophytes. Evapotranspiration in the conceptual model area was developed by estimating the footprint of existing phreatophyte features from aerial photography (~14,640 acres) and scaling evapotranspiration from the current area to the historic area. The calculations are summarized in Table 3.1.

Evapotranspiration in Kings River prior to the 1950s was estimated to be 16,400 afy across 64,000 acres of phreatophyte vegetation. The majority of evapotranspiration occurred in the Rio King sub-area (9,400 afy) from greasewood and salt grass (Malmberg, 1966). Modern evapotranspiration acreage was estimated to be 8,200 acres using the same method as Quinn River Valley and is summarized in Table 3.1 and Figure 3.9.

Table 3.1: Conceptual evapotranspiration summary

Basin	Units	Orovada Subarea	Rio King Subarea
Pre-1950s ET Estimate	afy	34,000	9,400
Pre-1950s ET Area	acres	92,000	29,000
Average ET Rate	ft/yr	0.37	0.32
Modern ET Area	acres	14,640	8,200
Modern ET Estimate	**afy**	**5,410**	**2,660**

Faults

The horizontal flow barrier (HFB) package was used to simulate flow-barrier features. The HFB package reduces the inter-block conductance between cells proportionally to the specified HFB hydraulic conductivity. In this way the conductance between cells straddling the HFB is reduced in a similar manner as the actual hydraulic flow barrier. The following faults were simulated in the model domain as barriers to flow (Figure 3.10):

- Range front faults which form the alluvial basin boundaries of Kings River and Quinn River Valley.
- Ring faults which form along the boundary of the western and southern extents of the McDermitt Caldera and control the western, southern, and eastern extents of Thacker Pass geology.
- The principal E-W normal fault which resides at the northern extent of the Thacker Pass Project and bounds the Thacker Pass Project geologically as it juxtaposes claystone sediments against volcanic tuff (Tuff of Long Ridge).
- Radial vent faults which form the topographically high ridges that separate northern lake sediments in the pit vicinity from southern lake and ash sediment. Radial vent faults also form several N-S trending structures in Thacker itself and the ridgeline west.
- NE-SW trending faults which offset claystone and ash beds and create a corridor of elevated groundwater levels.

The HFB conductivity was adjusted during calibration to match observed water level conditions in these areas.

Surface water features

Steady-state drains were selected to simulate spring discharge at mapped locations (Figure 2.2 and Figure 3.11). Drain cells were assigned at the mapped spring survey elevation identified by seeps and springs reports (Piteau, 2019b).

Steady-state drains were also used to simulate groundwater discharge to surface streams for Crowley Creek, Rock Creek, Pole Creek, and Thacker Creek (Figure 3.11). Pole Creek was divided into three reaches to capture baseflow components in the Upper Pole (top of the catchment to major stream confluence), Middle Pole (stream confluence to canyon mouth), and Lower Pole (canyon mouth to Crowley Creek confluence). Simulated flow to drains represent the annual average baseflow component (groundwater discharge) of streamflow, surface water runoff and interflow components were not simulated in the groundwater model. Drains were used instead of the stream package because: (i) the streams are ephemeral and groundwater discharge is low; and (ii) drains are adequate for assessing the potential for connection to the bedrock system pumped in the project.

<u>Pumping wells</u>

The well package was utilized to simulate irrigation wells in the uppermost layer of alluvium (layer 21). Agricultural pumping was estimated for the calendar year 2018 as:

- Quinn River Valley: 37,725 afy across 34,780 acres,
- Kings River Valley: 6,000 afy across 9,940 acres,

Irrigation acreage was determined utilizing 2018 NDWR points of use for irrigation combined with 2017 NAIP imagery. Irrigation volumes were derived from 2018 NDWR basin crop inventories (NDWR, 2019). Attempts to incorporate historic pumping in the basins were not made because (i) the Proposed Action would be a localized incremental impact to the current basin-wide drawdown experienced by irrigation pumping; (ii) both basins are fully allocated, therefore pumping by LNC would require the transfer of water rights; (iii) the alluvial basins are separate hydrogeologic systems, not in hydraulic connection with the groundwater system at the Thacker Pass Project, such that only water supply pumping has the potential to impact Quinn River Valley. Pumping rates for each valley were equally distributed across the irrigation acreage (Figure 3.12).

Non-irrigation pumping wells were simulated using the CLN and Well packages in MODFLOW-USG. The transient calibration simulated three distinct aquifer tests from separate wells (locations shown on Figure 3.12) which are described as:

- PH-1: a 48-hour aquifer test in 2011;
- QRPW18-01: a 72-hour constant rate test in 2018;
- TW18-02: a 35-day constant rate test in 2018.

3.1.3 Model parameters

Model parameterization was derived from conceptual HGUs described in Section 2.4.3. Every active model cell was assigned values for hydraulic conductivity (K), specific yield (Sy), and specific storage (Ss). The numerical model zone distribution was the same for the hydraulic conductivity and storage parameters because the parameters are linked to the material properties of the hydrogeologic units.

Ranges for model K, Sy, and Ss used to represent in-situ rock and alluvium were compiled from packer testing, injection/recovery testing (Piteau, 2019a), literature values (Anderson and Woessner, 1992; Fetter, 2001), from aquifer tests performed at PH-1, QRPW18-01, and TW18-02, and transmissivity values reported in state reconnaissance reports (Huxel, 1966). Hydraulic conductivity is assumed to be horizontally isotropic for all units. Vertical anisotropy ratios in bedrock units varied between 1:1 and 1:10. Measured parameter values from baseline hydrogeologic characterization are compiled in Table 3.2.

Table 3.2: Summary of hydrogeologic testing

		Transmissivity (ft^2/d)			Hydraulic Conductivity (ft/d)			Storage Coefficient		
Geology	**# of tests**	**Max**	**Min**	**Mean[1]**	**Max**	**Min**	**Mean[1]**	**Max**	**Min**	**Mean[1]**
Alluvium	2	28107	26472	***26935***	52.5	51	***51.4***	1.67E-01	4.07E-04	***9.00E-03***
Basalt	2	2409	2	***69***	4.05	0.011	***0.61***	--	--	***--***
Claystone/ash	12	952	0.35	***62.5***	2.8	0.016	***0.35***	0.043	2.39E-02	***2.91E-02***
Basal ash	10	1900	1.11	***320.7***	3.90	0.22	***1.58***	4.60E-02	7.13E-06	***5.17E-04***
Tuff	6	2.23	0.81	***1.4***	0.068	0.012	***0.019***	--	--	***--***

[1] Geometric mean

Calibrated K and storage parameters for model layers 1 to 23 are shown in Figure 3.13 to Figure 3.35. The values and associated zones are also shown in cross section in Figure 3.36 to Figure 3.39. A total of 23 zones were used to represent hydrogeologic units in the groundwater model. Calibrated parameters for each zone are shown in Table 3.3.

Table 3.3: Calibrated groundwater model hydrogeologic zones

Zone	Description	Conceptual HGU	K_h (ft/d)	K_z (ft/d)	S_s (1/ft)	S_y
1	Basement Volcanic Tuff	Tuff	0.0035	0.00035	1.00×10^{-6}	0.0075
2	Basalt	Basalt	0.6	0.6	1.00×10^{-6}	0.01
3	Rhyolitic flows and younger intrusive rocks	Tuff	0.5	0.05	1.00×10^{-6}	0.01
4	Dacite	Tuff	0.001	0.001	1.00×10^{-6}	0.01
5	Jurassic Granite	Granodiorite	4.00×10^{-03}	4.00E-03	1.00×10^{-6}	0.01
6	Aphyric Rhyolite Lavas	Tuff	0.005	0.005	1.00×10^{-6}	0.0075
7	Winnemucca fmn: Shale, siltstone, sandstone and carbonate	Sedimentary bedrock	0.04	0.04	1.00×10^{-6}	0.01
8	Thacker Pass and KRV Qal alluvium	Alluvium	5	0.5	1.00×10^{-6}	0.01
9	Rhyolite West Kings River	Tuff	0.01	0.01	1.00×10^{-6}	0.01
11	Claystone	Claystone/ash	0.25	0.025	8.00×10^{-5}	0.015
12	Rock/Pole Creek Shear Zones	Tuff	0.5	0.5	1.00×10^{-6}	0.01
13	Silicified Claystone (East)	Claystone/ash	0.06	0.006	1.00×10^{-6}	0.01
14	Thacker Pass Ash	Claystone/ash	2.8	0.048	4.00×10^{-6}	0.02
15	Thacker Pass Tuff	Tuff	0.035	0.0035	1.00×10^{-6}	0.01
16	Thacker Pass Basalts	Basalt	0.08	0.008	1.00×10^{-6}	0.01
18	Older alluvium and alluvial fan deposits, KRV	Alluvium	0.5	0.05	5.00×10^{-6}	0.03
19	Valley Fill/Alluvium, KRV	Alluvium	8	0.8	5.00×10^{-6}	0.04
20	Younger Alluvium, KRV	Alluvium	15	1.5	1.00×10^{-5}	0.1
21	West Older Qal, Alluvial Fan, QRV	Alluvium	5	0.5	5.00×10^{-6}	0.03
22	East Older Qal, Alluvial Fan, QRV	Alluvium	5	0.5	5.00×10^{-6}	0.03
23	Moderate K Younger Qal alluvium Zones; QRV	Alluvium	23	2.3	5.00×10^{-6}	0.04
24	High K Gravel Zones; QRV	Alluvium	10	1	1.00×10^{-5}	0.1
29	Thacker Creek Shear Zone	Tuff	1	1	1.00×10^{-6}	0.01

3.2 MODEL CALIBRATION

3.2.1 Calibration Approach

Model calibration comprises three simulation periods:

- *Pre-mining (i.e. steady-state) calibration*: The pre-mining calibration matches current water level conditions (most recent water level available at each location through Q1 2019). The pre-mining calibration provides starting heads for the transient calibrations.

- *PH-1 transient calibration*: This simulation includes the constant rate aquifer test drawdown and recovery period at PH-1 from October 16, 2011 through November 16, 2011.
- *2018 pumping tests transient calibration*: This simulation includes the constant rate aquifer test drawdown and recovery periods at QRPW18-01 (72-hour pumping test) and TW18-02 (35-day pumping test) from October 2, 2018 through December 14, 2018.

The model calibration included three major groups of water levels, one set of flux targets for springs, and one set of reach flux targets for surface creeks:

- Kings River Valley water levels (Group 1)
- Quinn River Valley water levels (Group 2)
- Thacker Creek well water levels (Group 3)
- Spring fluxes – all springs within the model domain (Group 4)
- Creek fluxes – all creeks within the model domain (Group 4)

The calibration process was iterative. First, the steady-state calibration was modified until heads, spring fluxes, creek fluxes, and boundary flows were close to observed values. Then the transient calibration models were iteratively run, and parameters are adjusted until the model was calibrated to all three simulations. Calibration results are discussed in Sections 3.2.4 and 3.2.5.

3.2.2 Calibration Targets

Observed piezometric levels from monitoring and pumping wells were used as targets for calibration. All water levels were assigned equal weights of one.

The pre-mining calibration matched current observed heads in Q1 2019, or the nearest measurement to this date. This run provided initial heads for the transient calibrations. A total of 150 water level targets (Table 3.4) and 35 flux targets (Table 3.5) were selected for the pre-mining calibration (locations shown in Figure 3.40). Of the water level targets, 39 are from piezometers or wells within the Thacker Pass Project area and 111 consist of water levels from the NDWR database in Quinn River and Kings River Valleys. Springs are represented by individual flux targets except for springs contributing to Thacker Creek, which are considered apart of the Thacker Creek system. Surface creeks are represented by flux reach targets which consist of all creek drain cells and within the creek locations.

Table 3.4: Pre-mining calibration water level targets

Target	X (ft)[1]	Y (ft)[1]	Water Level Date	Layer	Group	Target (ft)
NDWR_03CBDD1	1327677	15136715	3/10/2011	21	1	4132
NDWR_05CBBB1	1316004	15155554	3/21/2002	21	1	4131
NDWR_05DABB1	1319081	15157335	2/23/2016	21	1	4104
NDWR_06ABBB1	1313719	15158615	3/13/2012	21	1	4111
NDWR_06BBBB1	1310966	15158558	3/20/2003	21	1	4127
NDWR_07BBBB1	1311022	15153483	2/23/2016	21	1	4092
NDWR_07CBBB1	1310965	15150755	3/14/2017	21	1	4096
NDWR_08AAAB1	1319909	15152768	3/25/2004	21	1	4130
NDWR_08ABB_1	1318614	15152380	3/20/2001	21	1	4132
NDWR_08BBCB1	1316213	15151986	3/14/2017	21	1	4102
NDWR_09AAA_1	1326551	15152615	3/14/2017	21	1	4104
NDWR_11ACAA1	1303144	15152395	3/24/2005	21	1	4109
NDWR_11BBBB1	1305644	15153661	3/10/2011	21	1	4097
NDWR_11BDBB1	1301813	15152051	3/14/2017	21	1	4083
NDWR_12CBBB1	1305658	15151001	3/14/2017	21	1	4087
NDWR_16AAAA1	1326599	15147237	3/15/2017	21	1	4103
NDWR_16BABB1	1322629	15147448	3/14/2017	21	1	4105
NDWR_16BBBB1	1321123	15147286	3/21/2003	21	1	4124
NDWR_17ABBB1	1318783	15147532	3/14/2017	21	1	4102
NDWR_17DBBB1	1318571	15144973	3/14/2017	21	1	4101
NDWR_18ABBB1	1313392	15147828	3/14/2017	21	1	4100
NDWR_19BCBC1	1311371	15173072	3/20/2002	21	1	4166
NDWR_19BDCA1	1312318	15172585	3/14/2017	21	1	4118
NDWR_20AAB_1	1319539	15142349	3/20/2001	21	1	4125
NDWR_23CACC1	1301942	15171213	3/13/2017	21	1	4063
NDWR_24BCCC1	1306145	15172721	3/19/2003	21	1	4149
NDWR_24BCCC2	1306007	15172641	3/14/2017	22	1	4109
NDWR_24BDDD1	1308634	15172637	3/14/2017	21	1	4113
NDWR_24CCCB1	1306045	15170090	3/14/2017	21	1	4070
NDWR_24CCCC1	1306802	15169648	3/22/2005	21	1	4106
NDWR_24DADB1	1310938	15171213	3/14/2017	21	1	4113
NDWR_25BCCB1	1305940	15167320	3/24/1995	21	1	4128
NDWR_25BDDA1	1308381	15167340	3/22/2005	21	1	4134
NDWR_25CBBC1	1305942	15166514	3/14/2017	21	1	4066
NDWR_26ABCC1	1303304	15168414	3/13/2017	21	1	4060
NDWR_26BBCC1	1300567	15168559	3/13/2017	21	1	4064

Target	X (ft)[1]	Y (ft)[1]	Water Level Date	Layer	Group	Target (ft)
NDWR_26CBCC1	1300544	15165841	3/13/2017	21	1	4064
NDWR_27BBA_1	1327429	15136677	3/22/2005	21	1	4118
NDWR_29ABBC1	1319420	15168534	3/11/2008	21	1	4124
NDWR_29ABBC2	1319223	15168689	3/14/2017	21	1	4111
NDWR_30BCCB1	1311185	15167249	3/14/2017	21	1	4104
NDWR_31ABCD1	1314069	15163933	3/14/2017	21	1	4104
NDWR_31BAAA1	1313791	15163977	3/8/2011	21	1	4122
NDWR_31BBBB1	1311232	15164177	3/14/2017	21	1	4098
NDWR_35DDA_1	1335173	15127250	3/12/2014	21	1	4105
NDWR_36BBBC1	1305659	15163896	3/24/2004	21	1	4107
PZ17-01-3805	1395500	15144963	10/5/2018	22	1	4165
QRPW18-01-3702	1395419	15144760	10/10/2018	22	1	4166
NDWR_02AAAA1	1430572	15157288	3/15/2005	21	2	4200
NDWR_02ABCD1	1428381	15156411	3/14/2018	21	2	4183
NDWR_02CCD_1	1424456	15120642	3/14/2001	21	2	4145
NDWR_02DBBD1	1397140	15123013	3/14/2018	21	2	4160
NDWR_02DBCC1	1427896	15153541	3/15/2005	22	2	4173
NDWR_03AAAA1	1425086	15157173	3/12/2002	21	2	4195
NDWR_03CBDD1	1420566	15122026	3/10/2011	21	2	4131
NDWR_03DCCD1	1422852	15152302	3/14/2018	21	2	4164
NDWR_03DDDD1	1425144	15152251	3/19/2007	22	2	4182
NDWR_04BADD1	1416192	15093118	3/11/2014	22	2	4122
NDWR_04BADD2	1416205	15093351	3/15/2018	22	2	4133
NDWR_04DCDC1	1418581	15152374	3/14/2018	21	2	4162
NDWR_04DDDC1	1419023	15152367	3/14/2018	21	2	4161
NDWR_04DDDD1	1387518	15120995	3/15/2018	21	2	4164
NDWR_05BDAB1	1411119	15156282	3/15/2005	22	2	4175
NDWR_06CAAC1	1405794	15122889	3/14/2018	21	2	4142
NDWR_06DAAC1	1408474	15154854	3/14/2006	22	2	4187
NDWR_08ADDD1	1413932	15118202	3/15/2018	22	2	4119
NDWR_08BCAA1	1409839	15119283	3/15/2018	21	2	4132
NDWR_08DDAA1	1413885	15116512	3/16/2005	21	2	4130
NDWR_09DADA1	1419162	15117157	3/15/2006	22	2	4130
NDWR_10ACAD1	1423713	15150403	3/15/2005	21	2	4172
NDWR_10AD_1	1424396	15118315	3/15/2018	22	2	4107
NDWR_10ADDD1	1425091	15149706	3/14/2018	21	2	4171
NDWR_11BCDD1	1426373	15149625	3/15/2005	21	2	4185

Target	X (ft)[1]	Y (ft)[1]	Water Level Date	Layer	Group	Target (ft)
NDWR_14BCBB1	1392797	15113857	3/13/2018	21	2	4159
NDWR_16AADA1	1419131	15114451	3/15/2018	21	2	4122
NDWR_16BDD_1	1416515	15113587	3/15/1993	21	2	4137
NDWR_16DAAA2	1419144	15112571	3/17/2004	22	2	4137
NDWR_17CAAA1	1411200	15112760	3/15/2018	22	2	4130
NDWR_17DAAA1	1413841	15112461	3/16/2005	22	2	4141
NDWR_18CCCA1	1403194	15110810	3/13/2018	21	2	4149
NDWR_20ACDA1	1412821	15139836	2/23/2016	21	2	4128
NDWR_20ADDD1	1413770	15107588	3/15/2018	21	2	4122
NDWR_20DAAA1	1414037	15139373	3/18/2004	21	2	4150
NDWR_21AAAA1	1419074	15109818	3/20/2007	22	2	4137
NDWR_21ACAA1	1418058	15140372	3/14/2018	21	2	4133
NDWR_21DCAA1	1418122	15137585	3/18/2004	22	2	4134
NDWR_22DCAA1	1391487	15137848	3/11/2018	22	2	4185
NDWR_24BCDC1	1431134	15171009	3/13/2018	21	2	4214
NDWR_26ACB_1	1396190	15135187	3/12/2019	21	2	4158
NDWR_26CCDA1	1425400	15099746	3/15/2006	21	2	4135
NDWR_27CCAB1	1420340	15132330	3/14/2018	21	2	4134
NDWR_28AADC1	1418927	15135213	3/14/2018	21	2	4120
NDWR_28ADDA1	1417478	15102664	3/14/1996	21	2	4120
NDWR_28ADDA2	1419029	15102722	3/17/2004	21	2	4121
NDWR_28DAAA1	1419333	15133661	3/16/2005	21	2	4140
NDWR_29ACDD2	1412333	15102382	3/15/2018	22	2	4109
NDWR_29ADAA1	1414077	15135041	3/14/2018	22	2	4125
NDWR_29BBDD1	1410085	15135480	3/14/2018	22	2	4135
NDWR_29CACC1	1410263	15132739	3/14/2018	22	2	4130
NDWR_30DACC1	1407775	15132771	3/14/2018	21	2	4125
NDWR_32CADC1	1378775	15096384	3/14/2018	21	2	4168
NDWR_33AAAA1	1419364	15131075	3/16/2005	22	2	4138
NDWR_33BAAA1	1416400	15131117	3/17/2005	21	2	4135
NDWR_33BCDA1	1383551	15129409	3/13/2018	21	2	4179
NDWR_33CAAD1	1416754	15128098	3/15/2018	21	2	4122
NDWR_33CADA2	1416294	15096118	3/15/2018	22	2	4113
NDWR_33DAAA2	1419366	15128095	3/14/2017	22	2	4120
NDWR_33DDDD1	1419458	15157710	3/14/2018	21	2	4173
NDWR_34AAAB1	1425061	15162824	3/15/2005	21	2	4196
NDWR_34ADBC1	1391524	15129425	3/14/2018	21	2	4172

Target	X (ft)[1]	Y (ft)[1]	Water Level Date	Layer	Group	Target (ft)
NDWR_34DAAD1	1425238	15159493	3/14/2006	21	2	4194
NDWR_34DCDD1	1423264	15157587	3/14/2018	21	2	4177
NDWR_35DAAA1	1430451	15159966	3/14/2018	21	2	4192
MW18-01-4763	1343859	15153360	2/15/2019	13	3	4822
MW18-02-4469	1366605	15145137	12/19/2018	19	3	4543
MW18-03-4718	1341940	15150304	11/30/2018	14	3	4750
MW18-04-4711	1349131	15154543	12/29/2018	14	3	4825
PH-1-4834	1349532	15152096	10/4/2018	12	3	5034
PZ18-01-4666	1343898	15151672	12/10/2018	15	3	4813
PZ18-01-4791	1343898	15151672	12/10/2018	13	3	4821
PZ18-02-4449	1362271	15156246	11/28/2018	19	3	4780
PZ18-02-4519	1362271	15156246	2/15/2019	18	3	4778
PZ18-02-4599	1362271	15156246	11/28/2018	17	3	4781
PZ18-03-4247	1366795	15152440	3/19/2019	21	3	4675
PZ18-03-4347	1366795	15152440	3/19/2019	20	3	4677
PZ18-03-4495	1366795	15152440	3/19/2019	19	3	4678
PZ18-04-4488	1357474	15153467	2/15/2019	19	3	4825
PZ18-04-4548	1357474	15153467	11/28/2018	18	3	4829
PZ18-04-4718	1357474	15153467	2/15/2019	14	3	4815
PZ18-04-4778	1357474	15153467	2/15/2019	13	3	4815
PZ18-05-4411	1339817	15149218	12/10/2018	19	3	4626
PZ18-05-4591	1339817	15149218	12/10/2018	17	3	4625
PZ18-06-4552	1344790	15147096	12/10/2018	17	3	4759
PZ18-06-4722	1344790	15147096	12/10/2018	14	3	4761
PZ18-07-4317	1341956	15150091	12/10/2018	20	3	4672
PZ18-07-4457	1341956	15150091	12/10/2018	19	3	4673
PZ18-07-4532	1341956	15150091	3/19/2019	18	3	4677
PZ18-07-4627	1341956	15150091	3/19/2019	16	3	4679
PZ18-08-4683	1343826	15153044	12/10/2018	15	3	4820
PZ18-08-4777	1343826	15153044	12/10/2018	13	3	4821
PZ18-09-4469	1343941	15149884	12/10/2018	19	3	4757
PZ18-09-4594	1343941	15149884	12/10/2018	17	3	4761
PZ18-09-4674	1343941	15149884	12/10/2018	15	3	4763
TW18-02	1341992	15150108	10/4/2018	20	3	4704
WSH-03-4339	1357534	15148277	12/10/2018	20	3	4751
WSH-07-4856	1349577	15155317	10/1/2011	11	3	5285
WSH-11-4705	1347075	15151669	12/11/2018	14	3	4817

Target	X (ft)[1]	Y (ft)[1]	Water Level Date	Layer	Group	Target (ft)
WSH-13-4580	1350838	15147888	12/19/2018	17	3	4813
WSH-14-4539	1352082	15149679	12/18/2018	18	3	4813
WSH-17-4716	1349227	15151450	12/18/2018	14	3	4861

[1]UTM NAD83 Zone 11 N coordinate system.

Table 3.5: Pre-mining calibration flux targets

Target	X (ft)[1]	Y (ft)[1]	Layer	Group	Target (gpm)[2]
BLM-01	1368340.44	15164149.46	10	4	0.0
BLM-02	1333327.39	15157108.79	9	4	0.0
BLM-03	1333278.17	15157620.6	9	4	0.0
BLM-04	1332861.51	15149156.05	20	4	0.0
BLM-05	1364265.64	15142341.76	16	4	0.0
BLM-06	1363684.94	15138453.98	13	4	0.0
SP-001	1350489.43	15151971.01	7	4	0.0
SP-002	1361557.2	15146211.65	16	4	-0.5
SP-003	1349086.68	15162150.25	4	4	0.0
SP-004	1335028.26	15166970.12	3	4	-1.2
SP-006	1336038.76	15169371.68	2	4	-0.5
SP-007	1338095.85	15168561.26	3	4	0.0
SP-008	1339785.48	15164693.11	3	4	0.0
SP-015	1347065.7	15139089.22	6	4	-0.5
SP-017	1352989.42	15135727.6	6	4	-0.5
SP-018	1364327.98	15142226.93	16	4	-0.5
SP-022	1363222.34	15136383.77	6	4	-1.5
SP-028	1367958.13	15155253.52	14	4	-4.4
SP-036	1360492.69	15161288.58	8	4	-1.1
SP-037	1353199.39	15133549.13	5	4	0.0
SP-038	1353501.23	15133942.83	5	4	-0.5
SP-039	1371496.6	15153864.05	16	4	-16.3
SP-044	1347001.9	15137686.26	6	4	-0.25
SP-045	1346493.74	15136699.86	5	4	-0.43
SP-046	1375093.11	15176519.77	7	4	-0.43
SP-047	1331369.43	15163921.04	11	4	-16.2
SP-048	1330915.97	15170232.13	11	4	-24.0
SP-049	1328041.04	15171589.18	16	4	-10.1
SP-050	1348344.19	15177321.53	4	4	-3.5
SP-051	1338889.85	15180111.06	3	4	-4.1
SP-052	1336307.82	15183677.61	3	4	-8.7
SP-054	1335719.23	15185893.49	2	4	-1.9
SP-055	1339750.86	15186510.63	3	4	-3.0
Thacker Creek (Reach 60)	-	-	-	4	-234.0
Lower Pole Creek (Reach 61)	-	-	-	4	0
Middle Pole Creek (Reach 65)				4	0
Upper Pole Creek (Reach 64)				4	0
Rock Creek (Reach 62)	-	-	-	4	0
Crowley Creek (Reach 63)	-	-	-	4	-492.0

[1]UTM NAD83 Zone 11 N coordinate system
[2]Negative fluxes indicate groundwater discharge

The PH-1 transient calibration matches water levels during the constant rate aquifer test drawdown and recovery period at PH-1 from October 16, 2011 through November 16, 2011. Table 3.6 lists the 10 transient calibration targets used in this model simulation. All 10 targets are included as water level targets. However, measurable drawdown only occurred at PH-1, the other targets serve to ensure to cone of depression is constrained and they are not included in calibration statistics. Locations are shown in Figure 3.41.

Table 3.6: PH-1 transient calibration targets

Name	X (ft)[1]	Y (ft)[1]	Layer
PH-1	1349520.76	15152092.44	11
WSH-3	1357533.6	15148277	20
WSH-4	1349251.3	15151937.05	10
WSH-5	1350240.5	15150021.2	9
WSH-6	1349871.4	15151442.95	9
WSH-7	1349580.1	15155319.3	6
WSH-11	1347075	15151668.7	14
WSH-13	1350838.4	15147887.62	14
WSH-14	1352082	15149678.8	18
WSH-17	1349218.95	15151435.06	13

[1]UTM NAD83 Zone 11 N coordinate system.

The 2018 transient calibration matches water levels during the constant rate aquifer test drawdown and recovery periods at both QRPW18-01 and TW18-02. The aquifer tests both took place in October 2018 with recovery for the 35-day aquifer test at TW18-02 extending into December 2018. Table 3.7 lists the 23 transient calibration targets used in this model simulation. Each target used observations for both water levels and drawdown in the calibration. Locations are shown in Figure 3.42

Table 3.7: 2018 pumping tests transient calibration targets

Name	X (ft)[1]	Y (ft)[1]	Layer
MW18-03-4718	1341939.57	15150304.34	14
PZ18-01-4791	1343898.23	15151672.45	13
PZ18-01-4666	1343898.23	15151672.45	15
PZ18-05-4591	1339816.87	15149218.39	17
PZ18-05-4411	1339816.87	15149218.39	19
PZ18-06-4722	1344789.63	15147095.69	14
PZ18-06-4552	1344789.63	15147095.69	17
PZ18-07-4627	1341955.98	15150091.09	16
PZ18-07-4532	1341955.98	15150091.09	18
PZ18-07-4457	1341955.98	15150091.09	19
PZ18-07-4317	1341955.98	15150091.09	20
PZ18-08-4777	1343826.05	15153043.84	13
PZ18-08-4683	1343826.05	15153043.84	15
PZ18-09-4674	1343940.88	15149884.4	15
PZ18-09-4594	1343940.88	15149884.4	17
PZ18-09-4469	1343940.88	15149884.4	19
PZ17-01-3805	1395500.36	15144963.15	22
WSH-11-4705	1347075	15151668.75	14
WSH-13-4580	1350838.37	15147887.62	17
WSH-14-4539	1352082.01	15149678.82	18
QRPW18-01	1395418.8	15144759.74	21
TW18-02	1341992.1	15150107.5	20
Windmill Well	1394214.08	15142028.11	21

[1]*UTM NAD83 Zone 11 N coordinate system.*

3.2.3 Pre-Mining Simulation

The pre-mining calibration simulates current steady-state conditions, utilizing most recent water levels available through Q1 2019. Target water levels from grouted-in piezometers were selected to represent equilibrium (or approximate) conditions. Figure 3.43 shows the calibration residuals for water level targets (i.e. observed minus simulated piezometric levels) for the pre-mining calibration.

The model-simulated solution provides an acceptable match to the observed values across much of the model area. This range in residuals is appropriate considering the high vertical relief in the groundwater system. On average, the water levels were within +/- 16.6 ft of the observed value (absolute residual mean) and the residual mean was -2.3 ft. In addition, the standard deviation over the head range was 1.8 percent which is an excellent metric of variation across observation.

Figure 3.44 shows the calibration residuals for the spring and creek flux targets for the pre-mining calibration. The model-simulated solution provides an acceptable match to the observed values across the model area. On average, spring and creek fluxes were within +/- 7.9 gpm of the observed value (absolute residual mean) and the residual mean was 3.1 gpm. In addition, the standard deviation over the flux range was 5.6 percent.

Table 3.8 compares the conceptual model water balance components with the simulated components in the pre-mining calibration. Major inflows and outflows to the groundwater system are well matched (recharge, ET, flow through constant head boundaries). On average, all model fluxes are within +/- 158.9 gpm (absolute residual mean) and the residual mean was -34.8 gpm. The standard deviation over the flux range was 1.1%. These results indicate the simulation is well aligned with the conceptual hydrogeologic system, given the uncertainty in conceptual model inputs and that the scale of the water budget is on the order of thousands of gallons per minute.

The groundwater model simulates perennial flow to the Upper and Middle reaches of Pole Creek of approximately . This supports the general belief that Pole Creek has perennial reaches, although not observed down-gradient of SP-36. Simulated flows to the lower reach of Pole Creek are believed to be overestimated by the model in the vicinity of the confluence with Crowley Creek. This is consistent with the noted overestimation of simulated Crowley Creek baseflow. This is over 2 miles east of the Thacker Pass Project.

Local springs within the creeks are generally underestimated (i.e. SP-039, SP-050, SP-51, etc.). These springs are ephemeral and located in a higher permeability drainage which is challenging to capture and calibrate in a porous media groundwater model, particularly in steady-state conditions.

Table 3.8: Conceptual model versus numerical model comparison

Component	Conceptual (gpm)	Model Calibration (gpm)	Residual (gpm)
Total Recharge	14,240[1]	14,287	47
Quinn River ET	2,350[1]	2,301	-49
Kings River ET	870[1]	905	35
Quinn River AG Wells[4]	16,170[1]	16,414	244
Kings River AG Wells[4]	2,790[1]	2,792	2
Kings River Basin CH in	0[1]	288	-288
Kings River Basin CH out	830[1]	672	-158
Quinn River Basin CH in	3,340[1]	3,240	-100
Quinn River Basin CH out	2,000[1]	814	1189
Springs	106	57	49.3
Thacker Creek	234	228	6
Upper Pole Creek	0[2]	65	-65
Middle Pole Creek	0[2]	32	-32
Lower Pole Creek	0	19	-19
Rock Creek	0	35	-35
Crowley Creek	492	650[3]	-158

[1]Rounded to nearest 10 gpm
[2]Inferred estimate from indirect measurement. Upper and Middle reaches of Pole Creek may support perennial flow as the stream is intermittent.
[3]Includes SP-035 (Indian Spring) simulated flow
[4]Net agricultural pumping after a 25% return flow is accounted

Key results determined from the pre-mining calibration include the following:

- The basal ash unit of rhyolitic ash in the southwest basin exploration area has a higher transmissivity than the surrounding claystone. The delineation of this HGU results in simulated steady-state water levels lower than observations at PZ18-06 and PZ18-09, but is critical to matching observed drawdown during the TW18-02 pumping test.
- Silicified or indurated claystone HGU located south of Pole Creek has a lower transmissivity than the surrounding claystone, which was necessary to match higher water levels observed at PZ18-02, PZ18-03, and PZ18-04.
- Shear zones beneath Rock Creek, Pole Creek, and Thacker Creek have higher transmissivity than the surrounding bedrock. These shear zones function as conduits to transmit recharge to lower elevations where groundwater is expressed as springs and are necessary to match spring discharge and water level distributions.

- Simulated pre-mining water levels in the area of the proposed pit range from 4,725 ft amsl in the southeast to 5,300 ft amsl at the northern end of the proposed pit.
- Steep groundwater gradients are simulated across the principal E-W fault north of the Thacker Pass Project, as indicated by water levels in WSH-07 and MW18-04.
- Alluvial sediments generally exhibit flat groundwater gradients. A slight cone of depression occurs in Kings River Valley due to irrigation pumping in the northern end of the model domain. Localized pumping variability by irrigation wells near the constant head boundary condition is the cause of a few high residuals in the northern portion of Kings River Valley (NDWR_26CBCC1 (-66 ft), NDWR_26BBCC1 (-59 ft), and NDWR19_BCBC1 (55 ft))
- Residuals in the proposed pit footprint are generally within +/- 20 ft, with good matches occurring at PH-1 (-16 ft), WSH-17 (-1 ft), MW18-01 (-10 ft), WSH-07 (7 ft) and PZ18-08 (0 ft). This region possesses several compartmentalized bedrock zones; thus the groundwater model adequately represents water levels near the pit. Water levels in the South Sub-pit are underestimated at WSH-14 (27 ft), which may be related to unmapped structures to the south east. The resulting effect is that the groundwater model may underpredict water levels, but overpredict the hydraulic connection (or transmissivity) in the South Sub-pit area.
- The groundwater model over predicts water levels in the vicinity of PZ18-07 (Southwest Basin) by 28 ft to 60 ft. Localized fractures and bedding contribute to a steep hydraulic gradient between TW18-02 (4,704 ft amsl) and PZ18-07 (~4,660 ft amsl). The model calibration was designed to simulate higher water levels observed at TW18-02. Overall, a maximum residual is -60 ft is relatively small compared to the variability in piezometric levels across the Thacker Pass Project area.
- The overall distribution of residuals is reasonable for a model that captures widely-varying piezometric levels and steep groundwater gradients. Negative and positive residuals are evenly distributed throughout both alluvial valleys. The negative and positive residuals are nearly evenly distributed in the Thacker Pass Project AOI (Figure 3.43).

Table 3.9 shows the key calibration changes made to the model through the calibration process and quantify how calibration statistics were affected.

Table 3.9: Statistical calibration history summary

Model Name	Model Changes	Residual Mean (ft)	Absolute Residual Mean (ft)	Residual Std. Deviation (ft)	RMS Error (ft)	Min. Residual (ft)	Max. Residual	Scaled Residual Std. Deviation	Scaled Absolute Residual Mean	Scaled RMS Error	Scaled Residual Mean
LNC19-ss-c	Starting model	-57.9	81.6	97.9	113.8	-294.6	613.6	0.0800	0.0666	0.0929	-0.0473
LNC19-SS-f	Modified basalt based on logs; Modified HFBs	-10.4	28.9	36.1	37.6	-126.2	136.9	0.0295	0.0236	0.0307	-0.0085
LNC19-SS-i	Incorporated PEST results for K values	-0.9	24.3	34.8	34.8	-52.7	127.6	0.0284	0.0198	0.0284	-0.0007
LNC19-SS-o	Discovered and repaired Modflow error in allocating wells. Fixed with developer, but reset calibration process.	-12.3	20.6	23.4	26.4	-63.5	62.6	0.0191	0.0168	0.0216	-0.0100
LNC19-SS-r	Added Basal Ash unit in Southwest Basin for transient calibration. Added in shear zones along creek drainages (Thacker Creek, Pole, Rock, and Crowley) to reduce head distribution in headwaters.	-5.6	18.3	23.7	24.4	-66.0	75.6	0.0194	0.0150	0.0199	-0.0046
LNC19-SS-s	Added silicified claystone unit NE of project area as delineated by surface geophysics	-2.2	16.6	21.8	21.9	-66.0	61.8	0.0178	0.0136	0.0179	-0.0018
LNC19_SS_t	Edited geometry of zone 11 near PH1 based on pit bottom (claystone). Increased zone 11 K from 0.15 ft/d to 0.25 ft/d.	1.7	17.7	23.7	23.8	-66.0	85.7	0.0194	0.0144	0.0194	0.0014
LNC19_SS_u	Reduced basalt K from 0.4 ft/d to 0.15 ft/d. Improved head match near WSH-14 and WSH-13 for better predictions on post mining recovery.	-2.3	16.6	21.8	21.9	-65.9	57.0	0.0178	0.0136	0.0179	-0.0018

The simulated groundwater budget for pre-mining conditions (Q1 2019) is shown in Table 3.10. The inflow components to the steady-state model water budget are groundwater recharge from precipitation, Quinn River inflow, and groundwater inflow (constant head boundaries). Discharge occurs to evapotranspiration, streams, seeps, springs, and groundwater outflow (constant head boundaries).

Table 3.10: Simulated pre-mining water budget

	Simulated Value (gpm)
Inflows	
Recharge	14,290[1]
Quinn River	7,750[1]
GW Inflow (Constant Head Boundary)	2,950[1]
Total	**24,990**[1]
Outflows	
Phreatophytes	3,200[1]
AG Pumping	19,210[1]
Springs	57
GW Outflow (Constant Head Boundary)	1,490[1]
Thacker Creek	228
Crowley Creek	650[2]
Rock Creek	35
Upper Pole Creek	65
Middle Pole Creek	32
Lower Pole Creek	24
Total	***24,990***[1]

[1] rounded to nearest 10 gpm

[2] Includes SP-035 (Indian Spring) simulated flow

3.2.4 Transient Model Simulations

PH-1 transient calibration

The PH-1 transient model simulates the groundwater system response to the constant rate aquifer test drawdown and recovery period at PH-1 from October 16, 2011 through November 16, 2011. PH-1 pumped at a rate of 85 gpm for approximately 24 hours before declining to 66 gpm. The pumping rate could not be increased cavitation and was terminated 56 hours into the test. The average pumping rate over the test period was 76.6 gpm, and this was the rate simulated in the model.

PH-1 was drilled and completed in claystone/ash beds in a compartmentalized fault block. WSH-17 is the nearest monitoring well (also screened in claystone/ash beds) but is separated from PH-1 by an east-west trending fault. Observed drawdown in WSH-17 is related to pre-pumping trends of water level re-equilibration which continued for several months after the test was terminated, thus there was no response to pumping PH-1. The other nearby monitoring locations (WSH-11, WSH-13, WSH-14) are all screened in claystone/ash beds, however none of them showed a drawdown response to PH-1 due to the low permeability nature of claystone and the presence of several minor compartmentalizing faults

Target locations are shown in Figure 3.41. Transient calibration hydrographs are shown in Figure 3.45a-3.45c, which compare the computed and observed water levels and drawdown over time. Drawdown at the end of the pumping test is shown in Figure 3.46. The transient model simulates the lack of response to pumping in WSH-3, WSH-11, WSH-13, WSH-14, and WSH-17. PH-1 drawdown occurs at the appropriate timing, though the magnitude of the drawdown is not as high as observed because the groundwater model does not simulate well bore losses from well inefficiency and turbulent flow. Water level recovery after pumping terminates is well matched by the groundwater model (Figure 3.45c) and supports aquifer parameters for the claystone/ash HGU.

Water level calibration statistics show that simulated piezometric levels were respectively within +/- 36.1 ft of the observed value (absolute residual mean) (Figure 3.47). The residual mean value was 31.2 ft. The standard deviation over the head range for the simulation was 5.9 percent. Drawdown statistics (Figure 3.48) show that simulated drawdowns in PH-1 were respectively within +/- 20.5 ft (absolute residual mean). The residual mean value was 16.39 ft. The standard deviation over the drawdown range for the simulation was 9.0 percent. These calibration statistics are considered acceptable given that the effects of turbulent well losses in PH-1 are not simulated by the groundwater model.

2018 pumping tests transient calibration

The 2018 transient model simulates the groundwater system response to the constant rate aquifer test and recovery periods at both QRPW18-01 and TW18-02. QRPW18-01 was pumped at a time-weighted average pumping rate of 2,516 gpm for 72 hours starting on October 3, 2018. TW18-02 was pumped at a time-weighted average pumping rate of 58 gpm for 35 days starting on October 5, 2018. The transient model simulates these time-weighted average pumping rates and recovery through December 14, 2018.

Target locations are shown in Figure 3.42. Transient calibration hydrographs are shown in Figure 3.49a-3.49h which compare the computed and observed water levels and drawdown over time. Drawdown at the end of the QRPW18-01 pumping test is shown in Figure 3.50. Water level and drawdown residuals are spatially plotted with their calibration hydrographs in Plan 3.1 and Plan 3.2, respectively.

The transient calibration accurately simulates the response to QRPW18-01 pumping in PZ17-01, the West Windmill Well, and water level recovery in the pumping well (QRPW18-01). PZ17-01 is located 24.3 ft from QRPW18-01 and the West Windmill Well is located 3,066 ft from QRPW18-01. Both wells are screened in basin fill alluvium. The model accurately simulates the near-field drawdown and recovery observed at PZ17-01, along with the far-field, delayed response observed in the West Windmill Well (Figure 3.49g). The alluvial aquifer parameterization in the model provides an acceptable simulation response in the observation wells.

Drawdown at the end of the TW18-02 pumping test is shown in Figure 3.51 and in Plan 3.2. The transient calibration also accurately simulates the response to TW18-02 pumping in MW18-03, PZ18-07, and PZ18-09; and accurately simulates the lack of response in PZ18-01, PZ18-05, PZ18-06, PZ18-08, WSH-11, WSH-13 and WSH-14. TW18-02 is partially screened across the basal ash unit, as well as PZ18-07, WSH-03, and PZ18-09. Drawdown response at PZ18-09 is well simulated well by the model in terms of timing and magnitude. PZ18-07 is closest to the pumping well and was the first to record drawdown, which the model represents. The magnitude of drawdown is overestimated by the simulation in the deeper sensors of PZ18-07. Most of the flow to TW18-02 is believed to come from a deep-seated ash bed, given the temperature response at PZ18-07 and pumping well drawdown (Piteau, 2019a). The model overpredicts drawdown at the nearby PZ18-07 because the scale of small discrete features are unsuited for porous media models. The integrated water level response at more distal monitoring locations, such as PZ18-09 and WSH-03, is much better represented by the numerical model.

MW18-03 is located in the broader claystone unit and experiences drawdown which is well simulated by the model. The drawdown response observed in MW18-03 represents bulk hydraulic parameters due to the distance and well screen interval relative to the pumping well TW18-02. Resulting model parameters for these hydrogeologic units provide an acceptable simulated response in the observation wells.

PZ18-01 has sensors located in volcanic tuff in the uplifted horst block of Silica Hill. PZ18-05 has sensors located in rheomorphic tuff, McDermitt tuff, and brecciated volcanic tuff west of a fault and serves as a proxy for Thacker Creek. PZ18-06 is southeast of TW18-02 with sensors in claystone/ash but is separated from the pumping test by a basalt hydrogeologic unit. PZ18-08 is located northeast of TW18-02, separated from the pumping well by two faults, and has sensors located in volcanic tuff, claystone/ash, and brecciated claystone/ash. WSH-11 is located northeast of TW18-02, screened across both claystone/ash beds and volcanic tuff, and is separated from TW18-02 by two faults. WSH-13 is screened across both basalt and claystone and WSH-14 is in claystone/ash beds, but both wells are located over 9,000 ft east of TW18-02. The model accurately simulated a lack of response in all these locations, which indicates a high level of confidence in the model parameterization of different hydrogeologic units, in the geometry of the hydrogeologic units, and in the location and parameterization of horizontal flow barriers.

The water level statistics (Figure 3.52) show that simulated piezometric levels were respectively within +/- 25.0 ft of the observed value (absolute residual mean). The residual mean value was 1.3 ft. The standard deviation over the head range for the simulation was 4.9 percent. The drawdown statistics (Figure 3.53) show that simulated drawdowns were respectively within +/- 1.30 ft (absolute residual mean). The residual mean value was -1.10 ft. The standard deviation over the drawdown range for the simulation was 24.8 percent, mainly due to small-scale effects at PZ18-07. These calibration statistics are considered acceptable.

Key results from transient simulations

Key results determined from the transient simulations are as follows:

- The model reasonably matches the drawdowns and recovery observed during aquifer testing.
- The model reasonably represents the compartmentalization at PH-1 with correct parameterization and geometry of hydrogeologic units and horizontal flow barriers.
- The model reasonably represents the alluvial aquifer in Quinn River Valley to the east of the proposed project area.
- The model reasonably represents the compartmentalization of the claystone/ash sediments in the southwest basin with correct parameterization and geometry of hydrogeologic units and horizontal flow barriers (Figure 3.51). Changes in permeability along silica hill are sufficiently represented as a low permeability unit between the southwest basin and open pit area. Likewise caldera ring faults and the deposition of volcanic tuff are hydraulic barriers between the southwest basin from Thacker Creek spring system (Figure 2.2 and Figure 3.51).

3.2.5 Sensitivity Analysis

A sensitivity analysis was performed to evaluate the sensitivity of the steady-state calibration to selected model parameters including hydraulic conductivity of key hydrogeologic units and HFBs in the model. For the purpose of the sensitivity analysis, mine area water levels were used as targets and the NDWR and groundwater flux targets were omitted. The model parameters evaluated in the sensitivity analysis are listed in Table 3.11.

Parameter Estimation (PEST) (Watermark Numerical Computing, 2010) was used to evaluate model sensitivity. PEST determines how changes in model parameters affect the fit between observed and modeled heads. PEST has the additional advantage of determining the relative sensitivity of the parameters with respect to one another. The relative parameter sensitivity is useful because it provides a ranking of the model parameter sensitivity from most sensitive (highest relative sensitivity value) to least sensitive (lowest relative sensitivity value).

After the PEST run was completed and the relative sensitivities were tallied, they were normalized and classed according to their relative sensitivity values. The selected parameter classes are high sensitivity, mid-range sensitivity, lower sensitivity, and lowest sensitivity.

The results of the parameter sensitivity analysis are listed in Table 3.11. The sensitivity analysis shows the model is most sensitive to the hydraulic conductivity of bedrock zones 13 and 29.

Key results from the sensitivity analysis are:

- The model is most sensitive to bedrock zones 13 (silicified claystone) and 29 (Thacker Creek drainage). Model sensitivity to the Thacker Creek shear (zone 29) validates the presence of drainage HGUs. Removal of drainage HGUs resulted in elevated water levels and overly steep hydraulic gradients. The Thacker Creek drainage was important to reduce groundwater levels in the Thacker Creek spring complex. PEST identified a value that was very similar to those identified during manual calibration.
- The PEST predicted values for volcanic tuff bedrock zones 1 and 15 were effectively identical to the manual calibration. Model calibration is sensitive to these units because they are thick and affect hydraulic gradients in Thacker Pass.
- Claystone / ash (zone 11) and basal ash (zone 13) were considered insensitive. Intuitively this is unlikely, and a result of steady-state water level gradients influenced more strongly by surrounding HGUs. Water level responses during transient calibration are sensitive to hydraulic conductivity values in these zones.

Table 3.11. Sensitivity analysis results

Parameter name	Description	PEST Value (ft/d)	Manual Calibration Value (ft/d)	Scaled Sensitivity
	Highest Sensitivity			
kpkx_z29	Thacker Creek Shear Zone	1.855	1.000	17.6
kpkx_z13	Silicified Claystone (East)	0.340	0.060	14.4
	Mid-range Sensitivity			
kpkx_z1	Basement Volcanic Tuff	0.004	0.0035	11.4
kpkx_z15	Thacker Pass Tuff	0.039	0.0350	10.0
	Low Sensitivity			
kpkx_z16	Thacker Pass Basalts	0.490	0.080	8.3
kpkx_z6	Aphyric Rhyolite Lavas	0.037	0.005	6.5
hf14	HFB	2.76E-06	2.00E-06	5.4
	Least Sensitive			
hf13	HFB	4.40E-06	1.00E-05	3.7
kpkx_z12	Rock & Pole Creek Shear Zones	0.157	0.500	3.6
kpkx_z11	Claystone	0.011	0.250	3.5
kpkx_z14	Thacker Pass Ash	0.028	2.800	2.4
hf12	HFB	1.14E-06	1.00E-06	1.8
kpkx_z3	Rhyolitic flows and younger intrusive rocks	0.084	23.000	1.7
hf16	HFB	9.29E-04	1.00E-06	1.4
hf15	HFB	5.52E-07	1.00E-05	0.3
hf3	HFB	2.20E-05	2.50E-07	0.3
hf1	HFB	1.00E-08	2.00E-07	0.3
hf11	HFB	1.24E-08	1.00E-05	0.2
hf4	HFB	1.00E-08	1.00E-07	0.1
hf9	HFB	1.87E-03	1.00E-05	0.1
hf6	HFB	7.63E-08	1.00E-07	0.0
hf5	HFB	1.00E-02	1.00E-03	0.0

4 WATER QUANTITY IMPACTS ASSESSMENT PREDICTIVE MODEL

4.1 PREDICTIVE SIMULATION OVERVIEW

The predictive runs were designed to estimate the potential for water quantity impacts within the study area that would result from the Thacker Pass Project. The key changes resulting from the Thacker Pass Project relevant to water quantity include the following:

- The open pit will be mined to its lowest elevation of 4,593 ft amsl (Figure 4.1). Measured groundwater elevations at the project area range from 4,810 ft to 5,270 ft, therefore the pit will intersect the water table. Some dewatering is anticipated to stabilize slopes and facilitate dry mining conditions.
- After approximately year 6, the open pit will be continuously backfilled with waste rock material, capped with growth media and revegetated during mining to minimize the footprint of open pits, reduce dewatering requirements, and eliminate the eventual formation of a permanent pit lake upon closure.
- Process and potable water for the project will be sourced from an alluvial groundwater wellfield in Quinn River Valley (Figure 1.2) and transported to the project site via pipeline. The projected water consumption demand is 2,605 afy (1,615 gpm) from 2024 through 2027 and 5,210 afy (3,230 gpm) from 2025 through the end of mining in 2065.

Based on discussion with state and federal agencies, potential closure alternatives have been narrowed down to the Proposed Action and two Alternatives which have been analyzed for water quantity and quality impacts and are summarized as:

1. **Backfilled Pit Proposed Action**: Predictive simulations include mining with continuous backfilling through 2065 and a closure simulation with a full backfill configuration. The fully backfilled pit would prevent the formation of a pit lake. Backfill material would be comprised of 65% waste rock and 35% gangue material. This is the Proposed Action.
2. **Open Pit Alternative**: Predictive simulation for mining through 2065 and closure simulation with an open pit configuration.
3. **Partially Backfilled South Sub-pit Alternative**: Predictive simulation for mining through 2065 and a closure simulation with a partially backfilled South Sub-pit (backfilled to an elevation of 4,709 ft). The North and West Sub-pits are fully backfilled to prevent pit lake formation. Small channels are cut into the North and West Sub-pits to convey drainage to the South Sub-pit for hydraulic capture. The South Sub-pit is partially backfilled to engineer a wetlands formation which will promote a permanent hydrologic sink.

Predictive simulations are configured to evaluate impacts from the following mining activities:

- Water supply pumping for Thacker Pass Project operations through end of mining in 2065;
- Reduced agricultural pumping in Quinn River Valley to offset the water supply pumping. This is a permanent reduction in production due to the transfer of water rights;
- Groundwater drawdown associated with mine development starting in 2024; and
- Permanent closure of the open pit under a backfill configuration, an open pit configuration, and a partially backfilled South Sub-pit configuration.

The following sections describe the predictive model set up and simulated water quantity impacts during mining and permanent closure.

4.1.1 Backfilled Pit Proposed Action

The Proposed Action was simulated utilizing ten individual models. Nine dewatering models were configured to simulate 5-year periods during mining and continuous backfilling from 2024 to 2065. One post-closure model was configured for 300 years of backfill recovery from 2065 to 2365. Stress period setup is presented in Appendix A.

Specific model changes incorporated to simulate mining and backfilling between 2024 to 2065 are as follows:

- QRPW18-01 was used to simulate water supply pumping of 2,605 afy (1,615 gpm) from 2024 through 2027 and 5,210 afy (3,230 gpm) from 2028 through end of mining in 2065.
- Irrigation pumping in Quinn River Valley was reduced by 5,250 afy (3,260 gpm) to represent the transfer of water rights for mining & milling at a transfer rate of 77.5%, minus the 25% re-infiltration to groundwater. Quinn River Valley pumping will be retired upon closure, thus less water will be pumped from the basin in the future than presently constituted.
- Drain boundary conditions were assigned to the pit bottom elevations to simulate sump pumping in five-year stages of mining based on the backfill footprints.
- Open pit and backfill cells were cut into the model grid to represent the continuously changing geometry of backfill and the pit through time based on five-year incremental mine plans.
- Backfill recharge was modified to a value of 3% MAP in the backfill footprint to represent infiltration through a vegetated cover. Backfill is anticipated to be closed with 12-inches of growth media seeded with a specific vegetation mixture suited to Nevada's climate. Sufficient growth media has been identified onsite (Cedar Creek, 2019). Cover and closure designs are further described in Section 7.

The post-closure Backfilled Pit Proposed Action model incorporated the following to simulate closure after mining ends in 2065:

- The model runs for 300 years from 2065 through 2365 (stress period setup listed in Appendix A).
- Water supply pumping from QRPW18-01 has ended.
- Agricultural pumping in Quinn River Valley remained at the reduced rates due to water rights transfer.
- The ultimate pit configuration with backfill is used to simulate recovery.

Backfilled Pit Proposed Action setup

As shown in Figure 4.1, the Thacker Pass Project proposed pit includes three sub-pits:

- West sub-pit with a bottom elevation of 4,774 ft amsl;
- North sub-pit with a bottom elevation of 4,757 ft amsl;
- South sub-pit with a bottom elevation of 4,593 ft amsl.

The properties of the backfill cells were modified because backfill has higher hydraulic conductivity and storage than bedrock. Characterization of backfill hydrogeologic properties has occurred through two testing programs described as:

1. Claystone waste rock dump. Three samples were collected from this waste dump facility associated with hectorite clay mining in 2013. The dump has been exposed to weathering and settling, particularly along exposed slopes from where samples were collected. These samples are interpreted to represent the fine-grained endmember of backfill materials. Laboratory testing and description of these samples are further described in Section 7.
2. Bulk samples: A bulk ore sample collection program was undertaken to supply LNC's pilot plant with test material for metallurgical purposes. As part of the investigation over 50,000 lbs of material was collected and dry sieved to assess rock properties. Rock materials possessed a very coarse-grained fraction, with over 80% of the material retained on #18 mesh (1 mm diameter). These samples are interpreted to represent the coarse-grained endmember of backfill materials which occur with minimal handling and exposure.

The emplacement of backfill is anticipated to produce materials somewhere within the continuum of waste rock samples collected. Bedrock claystone will be excavated using more aggressive ripping and conveyance methods than the large diameter auger drilling used for collection. Additionally, the samples will be exposed to weathering during intermediate stages of backfilling, compacted and compressed, and mobilized several times before final emplacement. For these reasons the bulk backfill hydrogeologic parameters are believed to reside within the endmembers of these two sample suites. A weighted geometric mean of bulk hydrologic properties for the average “claystone waste dump” and “bulk samples” was used to estimate hydraulic conductivity is summarized in Table 4.1. Claystone dump hydraulic conductivity was developed from laboratory testing as described in Section 7. Hydrogeologic conductivity for bulk testing samples were estimated using the Hazen method (Fetter, 2001). Hydraulic conductivity for the backfill is ultimately estimated using a weighted log average of composited waste rock (65% of backfill) and gangue (35% of backfill), which is summarized in Table 4.1.

Table 4.1: Backfill hydraulic conductivity calculation

Material	% of Backfill	D10 (mm)	Hydraulic Conductivity (ft/d)	Source
Claystone Waste Dump (Waste Rock)	32.5%	0.002	0.05	Laboratory Testing. (DBS&A, 2019)
Bulk Sample (Waste Rock)	32.5%	0.2	76.4	LNC, 2020 / Hazen Method
Waste Rock Composite	**65%**	**-**	**1.96**	
Gangue	35%	0.0001	1.44	Laboratory Testing. (DBS&A, 2019)
Backfill Composite	**100%**	**-**	**1.76**	

Storage parameters are estimated to be as follows based on similar experience in Nevada:

- Specific yield (Sy) = 0.15;
- Compressible storage of $1x10^{-5}$ 1/ft.

The backfilled pit configuration is shown in cross section in Figure 4.2. Layer by layer pit-area hydraulic conductivity zone distribution for the backfilled pit configuration is shown in Figure 4.3.

Drain boundary conditions which represent sump pumping of groundwater were applied to the projected backfill area in the predictive model representing the 5-year period before backfilling was completed. For example, drain boundary conditions in the footprint of the 2035 backfill were applied from 2030 through the end of 2034. Then in the next model (2035-2039), the drained model cells corresponding to backfill or open air were assigned their respective properties and the drain cells were removed from that footprint. New drain cells were activated in 2035 corresponding to the 2040 backfill footprint to represent sump pumping. This method was utilized to represent continuous backfilling while mining progressed. Five-year backfill footprints are shown in Figure 4.1. Simulated drain cells do not account for surface water via (precipitation and runoff) which would also require management.

The recharge zone representing groundwater recharge to the backfill was modified in the footprint of the backfill to be 3% of MAP. A 12-inch thick vegetated cover will be placed on reclaimed backfill, which will intercept infiltration during the growing season. Infiltration through backfill was conservatively estimated using HYDRUS modeling (Section 7) to be 3% of Mean Annual Precipitation (MAP). This infiltration rate was confirmed through empirical estimates from two additional sources:

1. Long-term drain down investigation of closed and covered heap leaches in Nevada identify a logarithmic relationship between infiltration rate and precipitation can be derived from equilibrated seepage measurements reported by Kampf et. al (Kampf, 2002). Figure 4.4 shows the relationship graphically and indicates that a 3% MAP infiltration rate is reasonable given the annual site precipitation (12.22 in/yr).
2. The Maxey-Eakin method for natural recharge in Nevada utilizes a precipitation zones from the Hardman map to delineate the percentage of precipitation which reports to the groundwater system as reach (Maxey-Eakin, 1949). The Thacker Pass project resides within the 3% MAP infiltration rate of the Hardman Map.

The 3% MAP infiltration rate was applied to all covered and vegetated facilities including backfill, waste rock facilities, and gangue stockpiles. Although testing and simulations suggest that a thinner cover would produces similar results, utilizing a 12-inch cover provides a buffer against erosion and material settling.

Backfilled Pit Proposed Action Predictive Dewatering Results

Figure 4.5 shows the simulated groundwater production rates as mining progresses as 5-year averages. Mining is anticipated to intersect the water table in 2035 at very shallow saturated thickness. Simulated sump pumping rates are <8 gpm in 2035, increasing to approximately 55 gpm by the end of mining. The highest simulated pumping rates (~55 gpm) occurred between 2060 to 2065 when mining in the South Sub-pit encounters thicker saturated sections of claystone/ash beds.

The simulated dewatering rates are achievable through in-pit sump pumping and water management. However, actual dewatering requirements will depend upon geotechnical analysis to determine the magnitude of slope depressurizing to maintain wall stability. Dewatering could include a combination of vertical drains, horizontal drains, sump pumping, and dewatering wells if necessary, based on the results of the geotechnical analysis and modestly increase dewatering rates above simulated values.

The contoured piezometric surface at the end of mining in 2065 is shown in Figure 4.6. Simulated drawdown at the end of mining (2065) is shown in Figure 4.7. Two 10-foot isopleth drawdowns are present corresponding to pumping from Quinn River Valley and mining at Thacker Pass. Drawdown in Quinn River Valley is constrained to an approximately 1-mile radius around QRPW18-01. The 10-foot isopleth at Thacker Pass is approximately a 2-mile radius centered around the South Sub-pit, where groundwater discharge is anticipated to be greatest. The end of mining drawdown isopleth does not extend to the Thacker Creek spring system. Continuous placement of backfill during mining buffers drawdown to the west because it is more conducive to groundwater recharge than maintaining an open pit. The maximum amount of drawdown (200 ft) occurs along the northeastern wall of the pit where the principal E-W fault has been mined out during years 2030 to 2055. Approximately 25 ft of drawdown is simulated in the West Sub-pit footprint whereas 150 ft of drawdown is simulated in the South Sub-pit where mining recently finished.

Figure 4.8 shows the simulated groundwater flow (baseflow) at Crowley Creek, Thacker Creek, and Pole Creek reaches during the dewatering simulation. Baseflow at Crowley and Thacker Creeks have a maximum decline of ~16 gpm and 8 gpm respectively. Groundwater flow to both creeks recover during mine closure. The simulated declines in groundwater flow are small relative to baseflows (<4%), and even smaller when the components of interflow and surface runoff are considered in the overall streamflow. Crowley Creek in particular flows at very high rates, in excess of 3,000 gpm, during spring freshet. Simulated potential impacts to baseflow will not affect the surface water related flow components in the creek which are several times greater than baseflow. Therefore, seasonal peaks and declines of streamflow will remain effectively unchanged.

Upper Pole and Middle Pole reaches are minimally affected with simulated groundwater baseflow declines of <1 gpm (Figure 4.8), beyond the ability to effectively quantify with field measurements. Groundwater flow to the Lower Pole Creek reach was simulated to decline by 14 gpm with recovery post mining. Observed groundwater flow in Lower Pole Creek occurs at several ephemeral springs, the largest of which is SP-039 which flows seasonally at rates greater than 150 gpm (depending on winter snowfall and climatic conditions). The potential reduction in groundwater flow to Lower Pole Creek should be interpreted as i) potential reduction in peak flows and/or ii) the duration of spring discharge is slightly shortened. The magnitude of seasonal spring flow (> 150gpm) is much greater than simulated groundwater flow declines (14 gpm). Additionally, surface water flow components are unaffected. Thus the occasional continuous streamflow linking Pole Creek to Crowley Creek would not be measurably impacted, but rather is dependent on the same climatic variables which are the principal control on stream flow.

Simulated hydrographs for mine piezometers for the dewatering simulation are shown in Figure 4.9a to 4.9d.

The water budget for the end of the predictive period is listed in Table 4.2.

Table 4.2: Simulated water budget at end of mining in 2065 (Proposed Action)

	Simulated Value (gpm)
Inflows	
Recharge	14,265
Quinn River	7,749
GW Inflow (Constant Head Boundary)	2,330
GW Inflow (Storage)	106
Total	**24,451**
Outflows	
Phreatophytes	3,206
AG Pumping	15,960
Springs	57
GW Outflow (Constant Head Boundary)	943
GW Outflow (Storage)	7
Thacker Creek	221
Crowley Creek	634
Upper Pole Creek	65
Middle Pole Creek	31
Lower Pole Creek	10
Rock Creek (simulated)	35
Water Supply Pumping	3,230
Dewatering Wells	15
Pit Sump Pumping	41
Total	**24,455**

Backfilled Pit Proposed Action post-closure results

Water level recovery hydrographs for sub-pits are shown in Figure 4.10. Water levels at the end of the 300-year post-closure period are shown in Figure 4.11 The recovery may be summarized as follows:

- At 300 years post-closure the groundwater system has reached equilibrium, the water levels within the backfill are:
  - North sub-pit: 4,833 ft amsl'
  - West sub-pit: 4,817 ft amsl'
  - South sub-pit: 4,753 ft amsl.
- A temporary decline in groundwater discharge is simulated at Crowley and Thacker Creeks of 16 gpm and 8 gpm respectively (Figure 4.8). This decline is minor relative to baseflow to the creeks, and even smaller when considering surface runoff and interflow

components to the creeks, which are very high seasonally. This impact is less than the uncertainty of field measurements, and therefore undiscernible from seasonal and natural variation.

- No measurable impacts to the Upper and Middle reaches of Pole Creek are predicted, where simulated groundwater flow reductions are <1gpm. No impacts to surface runoff and interflow are anticipated.
- Groundwater flow to Lower Pole Creek, near the confluence with Crowley Creek, were simulated to decline during mining, but fully recover during mine closure. This is an ephemeral reach which is naturally dry during summer, fall, and winter months. Thus any potential groundwater flow reductions, if realized, would potentially shorten or reduce peak flows, but episodes of continual flow resulting from surface runoff and interflow in the reach would occur. Surface runoff and interflow components of streamflow would be unaffected, thus occasional continuous streamflow linking Pole Creek to Crowley Creek would continue unaffected.
- The propagation of drawdown through time is presented in Appendix D. The southern extent of drawdown shrinks during mine closure, whereas the northern extent expands primarily during the first 100 years post-closure.
- Figure 4.12 shows drawdown at the end of the 300-year recovery simulation. At the end of recovery, the 10-foot isopleth extends north from the pit area into volcanic tuff (McDermitt Tuff) of Thacker Pass. Mining out the principal E-W fault, which acts as a strong hydraulic barrier, is the primary reason for drawdown north of the backfilled pit. The removal of faults coupled with the backfill location causes long-term drawdown to occur mainly north of the pit area. The 10-foot drawdown isopleth does not reach Thacker Creek.
- Three springs (SP-001, SP-003, and SP-058) are estimated to have 10 or more feet of drawdown at the end of the recovery simulation. SP-001 is located within the pit footprint and will be directly affected, but this location is a man-made stock pond and is dry. SP-003 is also dry no flow had been observed during baseline surveys. SP-058 is a developed stock pond with water piped in from a remote location. Additional simulated results to springs are discussed in Section 4.2.
- The maximum extent of drawdown due to water supply pumping at QRPW18-01 in Quinn River Valley occurs at the end of mining. QRPW18-01 recovers completely following pumping (Figure 4.9d). Additional recovery above the pre-mining water level is due to the retirement of mining and milling water rights in Quinn River after mining ends.

4.1.2 Open Pit Alternative

The Open Pit Alternative was simulated utilizing two models: one for dewatering through the end of mining, and one for post-closure pit lake recovery.

The calibrated groundwater model was configured for a predictive model which simulated open pit dewatering from 2024 through 2065 (stress period setup listed in Appendix A) by incorporating the following:

- Five hypothetical dewatering wells were simulated starting in 2035.
- Drain boundary conditions were assigned to as pit bottom elevations to simulate sump pumping. Drains were activated on the same 5-year schedule as the Backfilled Pit Proposed Action simulation.
- QRPW18-01 was utilized to simulate required water supply pumping of 2,605 afy (1,615 gpm) from 2024 through 2027 and 5,210 afy (3,230 gpm) from 2028 through end of mining in 2065.
- Pumping in Quinn River Valley was reduced by 5,250 afy (3,260 gpm) to offset the water supply pumping.

The Open Pit Alternative post-closure model incorporated the following to simulate conditions after mining ends in 2065:

- The model runs for 300 years from 2065 through 2365 (stress period setup listed in Appendix A).
- Water supply pumping from QRPW18-01 has ended.
- Pumping in Quinn River Valley was left at the reduced rate used in the dewatering model representing the retirement of mining and milling water rights.
- Open pit cells were modified to represent the open pit and the water balance in the open pit was simulated utilizing CLNs as described in the next section.

Open Pit Alternative model: pit lake setup

The model required minor reconfiguration to simulate pit lakes which may form post-closure. The Open Pit Alternative configuration is shown in plan view in Figure 4.13 and in cross section in Figure 4.14.

Pit lake recovery was simulated using a high K, high storage approach which leverages MODFLOW-USG's ability to internal calculate groundwater flow and storage by adjusting model cells and simulating surface water components with the CLN package (Rupp, 2019).

Open pit cell properties differ from groundwater cells in that they represent the characteristics of the open void occupied by a pit lake or air. The open pit void does not contain porous media. The drainable (i.e., "fillable") storage parameter for the pit lake cells (Sy) was increased from typical values for porous media of 1 to 15 percent to the value of an open void of 100 percent. This means that the pit lake cell volumes below the lake surface are completely occupied by water in the groundwater model.

Compressible storage of the pit lake cells was decreased from typical values for a groundwater system of 1×10^{-6} to a value of 1×10^{-9} since water in a pit lake is substantially less compressible than the combined water/aquifer skeleton of the groundwater cells. In addition, the open void occupied by a pit lake does not resist flow as do groundwater model cells. Therefore, the hydraulic conductivity values of the open pit lake cells were modified to a high value of 100 ft/d which allows the specified lake cells to replicate the open void of the pit lake. This approach is valid so long as the simulated hydraulic gradient across the high K, high storage pit lake cells is small.

Simulating pit lake recovery is based on a simple mass-balance approach, as follows:

$$\text{Pit inflows–Pit outflows = change in storage} \qquad (1)$$

The mass balance approach takes advantage of built-in features of MODFLOW-USG. The MODFLOW-USG numerical formulation already accounts for inflows, outflows, and changes in storage, as specified in the mass-balance formulation of the groundwater model.

The first step of the mass balance approach was to modify the properties of pit cells. The pit-area hydraulic conductivity zone distribution for the open pit configuration is shown in Figure 4.15. Once the properties of the pit lake cells were modified as appropriate, the sources and sinks associated with the pit lake water balance were incorporated and include the following:

- Potential inflows include groundwater inflow, direct precipitation, and pit-wall runoff;
- Potential outflows include evapotranspiration, transpiration, and groundwater outflow (if the pit lake is not a hydraulic sink).

Water budget terms change as a function of stage. The individual components were calculated for each sub-pit on 5-m (16.4-ft) increments from the stage/volume/area curve listed in Appendix B. Groundwater seepage was automatically calculated in the model simulation by MODFLOW-USG. The other inflows and outflows were specified independently with a combined source/sink connected linear network (CLN) boundary that represents the cumulative surface water balance. Given that the values of the pit lake water budget are additive, surface water components were summed and included as combined source-sink wells in the model. A new source/sink boundary was specified in the model for every elevation increment. CLN boundaries were developed at 2 ft increments by linearly interpolating the surface water balance between pit stages. Calculated surface water balances for the assign CLN flows are provided in Appendix C.

Direct precipitation

The mean annual precipitation (MAP) of 12.22 in/yr recorded at the Thacker Pass Station using data from 2011 through 2018 was used for the precipitation input data to the pit lake.

Pit wall runoff

Pit wall runoff occurs from precipitation falling on the exposed pit walls above the pit lake. The majority of precipitation falling directly onto exposed pit wall areas will evaporate. However, some of the runoff will eventually report to the pit lake, either from overland flow or, more frequently, from subsurface interflow. A runoff coefficient of 10% MAP was utilized in this model. Runoff from areas outside the open pit was assumed to be zero due to surface water diversions.

The total volume of pit wall runoff is dependent on the exposed pit wall area. This area was calculated as a function of stage from the stage/area relationships in Appendix B. Appendix B also contains the stage/volume relationships and a comparison of the observed vs. simulated cumulative pit volume.

Evaporation

The open-water ET rate was 41.7 in/yr. This rate was calculated utilizing the average annual PET rate of 59.6 in/yr. The PET is converted to shallow lake evaporation of 41.7 in/yr by applying the standard pan conversion coefficient of 0.7.

Open Pit Alternative predictive dewatering results

Figure 4.16 shows the simulated groundwater pumping rates as mining progresses. Hypothetical dewatering wells began operation in 2035, when mining begins to encounter the water table, and sump pumping was simulated in tandem with mining. Total dewatering rates began at approximately 10 gpm during 2035 when mining initially intersects small amounts of groundwater. Dewatering rates gradually increases until 2060 when mining in the South sub-pit begins. Pumping rates reach ~95 gpm through the end of mining in 2065.

Dewatering wells provided little benefit to reducing the overall sump pumping requirements, which were greater than the Backfilled Pit Proposed Action to keep the open pits dry.

The contoured piezometric surface at the end of mining in 2065 is shown in Figure 4.17. All three sub-pits have been dewatered below the following elevations:

- West Sub-pit: 4774 ft amsl;
- North Sub-pit: 4757 ft amsl;
- South Sub-pit: 4593 ft amsl.

Simulated drawdown at the end of mining is shown in Figure 4.18. The 10-foot isopleth of drawdown in Quinn River Valley caused by water supply pumping is equal to the Backfilled Pit Proposed Action (i.e. approximately a 1-mile radius adjacent to QRPW18-01). The 10-foot isopleth in Thacker Pass extends north, east, and south from the pit area in Thacker Pass, but does not extend to Thacker Creek. The maximum amount of drawdown (300 ft) occurs along the northern wall of the pit, with 200 ft of drawdown in the bottom of the North Sub-pit, 75 ft of drawdown in the bottom of the West Sub-pit, and 150 ft of drawdown at the bottom of the South Sub-pit.

Figure 4.19 shows the simulated groundwater flow (baseflow) at Crowley Creek, Thacker Creek, and Pole Creek reaches during the dewatering simulation. The Open Pit Alternative presents greater long-term flow reductions over the Proposed Action, although the impacts are still low. Baseflow at Crowley and Thacker Creeks have a maximum decline of ~14 gpm and 19 gpm respectively. Groundwater flow at Crowley Creek is predicted to recover post mining. As with the Proposed Action scenario, the predicted reductions in groundwater flow to the creeks is small relative to the total streamflow (baseflow and surface runoff/interflow). Seasonal peaks and declines in streamflow of will remain effectively unchanged.

Upper Pole and Middle Pole reaches are minimally affected with simulated groundwater flow declines of <1 gpm and 1 gpm respectively (Figure 4.19), which are beyond the ability effectively quantify with field measurements. Groundwater flow to the Lower Pole Creek reach was simulated to decline by 13 gpm with recovery post mining. As in the Proposed Action scenario, the magnitude of the predicted groundwater flow decline is much less than seasonal spring flows (>150gpm) within Lower Pole Creek, therefore the formation of continuous streamflow linking Pole Creek to Crowley Creek would continue, dependent on climate conditions.

Simulated hydrographs for mine piezometers for the dewatering simulation are shown in Figure 4.20a to 4.20d.

The simulated water budget at the end of mining is presented in Table 4.3

Table 4.3: Simulated water budget at end of mining in 2065 (Open Pit Alternative)

	Simulated Value (gpm)
Inflows	
Recharge	14,287
Quinn River	7,749
GW Inflow (Constant Head Boundary)	2,338
GW Inflow (Storage)	103
Total	**24,477**
Outflows	
Phreatophytes	3,206
AG Pumping	15,960
Springs	57
GW Outflow (Constant Head Boundary)	935
GW Outflow (Storage)	2
Thacker Creek	225
Crowley Creek	635
Upper Pole Creek	65
Middle Pole Creek	32
Lower Pole Creek	12
Rock Creek (simulated)	35
Water Supply Pumping	3,230
Dewatering Wells	15
Pit Sump Pumping	70
Total	**24,479**

Open Pit Alternative post-closure results

Recovery hydrographs for the Open Pit Alternative are shown in Figure 4.21. Water levels at the end of the 300-year recovery period are shown in Figure 4.22. The recovery may be summarized as follows:

- At 300 years of post-closure, at which time the change in storage have stabilized, the open pit lake stages are:
  - North Sub-pit: 4,779 ft amsl, forming a shallow lake 25 ft deep.
  - West Sub-pit: 4,827 ft amsl, forming a shallow lake 53 ft deep.
  - South Sub-pit: 4,677 ft amsl, form a pit lake 81 ft deep.

  All pit lakes reach equilibrium by approximately 80 years post-closure. The maximum head change across the recovered pit lake is 0.9 ft across a distance of 1250 ft, yielding a gradient of 0.000072 ft/ft. This is 3 orders of magnitude lower than the post-mining bedrock gradient of 0.02 ft/ft which exists from the northern extent of the open pit to the south east extent, thus indicating the high K, high storage approach is suitable.

- Equilibrated open pit lake areas and corresponding annual average evaporation rates are:
  - North Sub-pit: 13 acres / 29.6 gpm evaporation
  - West Sub-pit: 12 acres / 37.8 gpm evaporation
  - South Sub-pit: 25 acres / 56.7 gpm evaporation

  The cumulative evaporation rate from pit lakes is 124.1 gpm. Evaporative demand is met primarily from precipitation and surface water runoff, which are the biggest components of pit lake inflows.
- The North and West Sub-pits result in a flow-through to the South Sub-pit, while the South Sub-pit is a hydrologic sink (Figure 4.22).
- A temporary decline in groundwater discharge is simulated at Crowley Creek of 14 gpm (Figure 4.19). This decline is minor relative to baseflow to the creeks, and even smaller when considering surface runoff and interflow components to the creeks, which are very high seasonally. This impact is less than the uncertainty of field measurements, and therefore undiscernible from seasonal and natural variation.
- Groundwater flow to Thacker Creek is predicted to decline by 19 gpm due to pit lake formation (Figure 4.19). This decline is still minor relative to baseflow to the creek, and less when considering surface runoff and interflow components.
- No measurable impacts to the Upper and Middle reaches of Pole Creek were simulated, where simulated groundwater flow reductions are ~1gpm. No impacts to surface runoff and interflow are anticipated.
- Groundwater flow to Lower Pole Creek, near the confluence with Crowley Creek, were simulated to decline during mining, but fully recover during mine closure. This is an ephemeral reach which is naturally dry during summer, fall, and winter months. The predicted impacts are very similar as the Proposed Action closure scenario.
- The propagation of drawdown through time is presented in Appendix D. Drawdown propagates primarily to the south in the Open Pit Alternative.
- Figure 4.23 shows drawdown at the end of the 300-year post-closure simulation. The 10-foot drawdown isopleth grows larger through time due to the evaporative losses from pit lake formation. Maximum drawdown extent at the end of the post-closure simulation reaches a 2.5-mile radius across Thacker Pass centered on the open pit. However the 10-foot isopleth does not reach Thacker Creek.

- No water rights are predicted to fall within the maximum extent of the 10-ft drawdown isopleth. The nearest water right (permits 79742 and 87006) corresponding to SP-028 reside approximately 3/4 mile east of the 10-ft drawdown isopleth (Figure 4.23).
- Nine springs (SP-001, SP-002, SP-003, SP-015, SP-033, SP-058, SP-059, SP-060, SP-061) are located within the estimated 10-foot drawdown isopleth at the end of the recovery simulation. Only SP-033 has perennial flow. SP-060 and SP-061 have been observed to flow seasonally during wet years, but still go dry during summer, fall, and winter. SP-003, SP-015, SP-058, SP-059 are characterized as man-made features having no observed discharge or having water piped in from remote locations, thus will not be affected by mining operations.
- The maximum extent of drawdown due to water supply pumping at QRPW18-01 in Quinn River Valley occurs at the end of mining. QRPW18-01 recovers completely following mine operations.

4.1.3 Partially Backfilled South Sub-pit Alternative

The Partially Backfilled South Sub-pit Alternative is a closure configuration which places backfill up to the 4,709 ft amsl elevation in the South Sub-pit to promote the creation of a wetlands which will function as a hydraulic sink. At the 4,709 ft amsl elevation the potential evaporative demand is ~115 gpm, nearly double the evaporation required to maintain a hydrologic sink in the Open Pit Alternative.

Water levels at the end of the Backfilled Pit Proposed Action dewatering run (Section 4.1.1) were utilized as the starting conditions for the Partial Backfilled South Sub-pit Alternative, which simulated post-closure with the partial backfill configuration. Impacts during active mining (2024 to 2065) are captured by the Backfilled Pit Proposed Action and Open Pit Alternative simulations.

The Partial Backfilled South Sub-pit Alternative post-closure model incorporated the following to simulate closure after mining ends in 2065:

- The model runs for 300 years from 2065 through 2365 (stress period setup listed in Appendix A).
- Water supply pumping from QRPW18-01 has ended.
- Pumping in Quinn River Valley was left at the reduced rate used in the dewatering model.
- The ultimate pit configuration with partial backfill, backfilled to 4,709 ft in the south pit is used to simulate recovery.

- Wetlands vegetation in the partial backfill is estimated to produce an annual transpiration rate of 1 ft / yr and an extinction depth of 10 ft. The North and West sub-pits retain the full backfill configuration.
- Drainage channels are cut through the saddle between the North and West Sub-pits to promote drainage and flow to the South Sub-pit.

<u>Backfill setup</u>

The Partial Backfilled South Sub-pit Alternative configuration is shown in Figure 4.24 and in cross section view in Figure 4.25. The properties of open pit and backfill cells were modified as described in Section 4.1.1 and Section 4.1.2. The pit-area hydraulic conductivity zone distribution for the backfilled pit configuration is shown in Figure 4.26.

The recharge zone representing groundwater recharge to the backfill was modified in the footprint of the backfill to be 3% of MAP as described in Section 4.1.1.

Partially Backfilled South Sub-pit Alternative post-closure results

Water level hydrographs for the Partially Backfilled South Sub-pit Alternative are shown in Figure 4.27. Water levels at the end of the 300-year recovery period are shown in Figure 4.28. The recovery may be summarized as follows:

- Water levels recover rapidly, reaching equilibrium approximately 30 years post-closure. water levels within the backfill are:
    - North sub-pit: 4,809 ft amsl;
    - West sub-pit: 4,788 ft amsl;
    - South sub-pit: 4,708 ft amsl.
- The ephemeral wetlands form a permanent hydraulic sink. An ephemeral pond will develop on the backfill surface during winter and spring when evaporative demands are low. During summer months the water levels will decline below the backfill surface. Seasonal variation is anticipated to be <1 ft of the backfill surface. This phenomenon is commonly observed in wetlands. Annual average evapotranspiration from the wetlands is approximately 56.2 gpm, well below the estimate evaporative capacity at the partial backfill elevation (115 gpm).
- A temporary decline in groundwater discharge is simulated at Crowley Creek of 16 gpm (Figure 4.29). This decline is minor relative to baseflow to the creeks, and even smaller when considering surface runoff and interflow components to the creeks, which are very high seasonally. This impact is similar in result as the Proposed Action and Open Pit Alternative.

- Groundwater flow to Thacker Creek is predicted to decline by 11 gpm due to wetlands formation (Figure 4.29). This decline is still minor relative to baseflow, and less when considering surface runoff and interflow components.
- No measurable impacts to the Upper and Middle reaches of Pole Creek are predicted, simulated groundwater flow reductions are <1gpm. No impacts to surface runoff and interflow are anticipated.
- Groundwater flow to Lower Pole Creek, near the confluence with Crowley Creek, were simulated to decline during mining, but fully recover during mine closure. The predicted impacts are very similar as the Backfilled Pit Proposed Action and Open Pit Alternative closure scenarios in that ephemeral streamflow would continue in response to climatic conditions.
- Simulated hydrographs for mine piezometers for the recovery simulation are shown in Figures 4.30a-4.30e.
- The propagation of drawdown through time is presented in Appendix D. Drawdown propagates primarily to the south in the Partially Backfilled Sub-pit Alternative, but not as far as with an open pit.
- Figure 4.31 shows drawdown at the end of the 300-year recovery simulation. The maximum extent of the 10-foot drawdown isopleth north and south from the pit area, centered around the South Sub-pit wetlands. Faults in the pit area which act as barriers to flow were removed during mining. The removal of faults coupled with the backfill location causes the drawdown to occur north of the pit area. The southern extent of drawdown is related to the permanent hydraulic sink formed by the wetlands. The 10-foot drawdown isopleth does not reach Thacker Creek.
- Five springs (SP-001, SP-003, SP-058, SP-059, and SP-061) are estimated to have 10 or more feet of drawdown at the end of the recovery simulation. All of these springs are ephemeral (SP-001, SP-061) or are man-made features (SP-003, SP-058, SP-059).
- The maximum extent of drawdown due to water supply pumping at QRPW18-01 in Quinn River Valley occurs at the end of mining. QRPW18-01 recovers completely following cessation of pumping.

4.2 ALTERNATIVE COMPARISON

A comparison analysis between alternatives is made to compare and contrast simulated groundwater quantity impacts. Figure 4.32 compares the simulated maximum drawdown extent of the 10-foot isopleths between the Proposed Action and closure alternatives. The maximum drawdown extent is calculated across all simulated time steps, thus representing a comprehensive drawdown footprint related to mining. Implicit to this representation is that the shape of the maximum extent never physically occurs at a single time. Time series results of drawdown propagation is provided in Appendix D.

The Open Pit Alternative results in the largest extent of 10-foot drawdown with a diameter of ~5.5 miles, while the Backfilled Pit Proposed Action results in the smallest extent. The Partially Backfilled South Pit Alternative develops a drawdown isopleth smaller in size, but most similar to the Open Pit Alternative.

Hydrographs for spring locations in the mine area and in the Montana Mountains are presented in Appendix E. These hydrographs present a comparison analysis of the effects of mining and dewatering from the model on springs. The hydrographs indicate the following key results:

- SP-023, SP-042, SP-043, SP-046 all recover to pre-mining groundwater elevations. These springs are not predicted to have permanent impacts with regard to mining.
- SP-035, SP-047, SP-048, SP-049, SP-050, SP-051, SP-052, SP-054, SP-055, SP-056 exhibit drawdown of <1 ft at the end of the 300-year recovery period. Based on modeling results, seasonal variability, and conservative nature of the approach, these springs are unlikely to be impacted by mining.
- BLM-02, BLM-03, SP-004, SP-006, SP-007, SP-036, SP-039, SP-040 exhibit 2 to 4 feet of drawdown at the end of the 300-year recovery period. These springs may experience some impact, however given the locations of SP-006, SP-004, BLM-02 and BLM-03 with respect to faults, they will likely be compartmentalized and isolated from mine related drawdown.

Although these small-scale drawdowns can be computed from the model, the 10 foot drawdown isopleth is generally accepted to delineate drawdown impacts because is at a scale large enough to exclude: seasonal variability in groundwater levels, small scale heterogeneity in the geology beyond the heterogeneity reasonably represented by a regional model, and numerical model error. In particular, seasonal water level variation of <1ft is observed at Thacker Pass and likely to be exacerbated in the higher elevation recharge catchments of the Montanas.

Table 4.4 compares the simulated drawdown for all three closure configurations for water rights locations that fall within the 10-foot drawdown isopleths of the Proposed Action or Alternatives.

Table 4.4: Affected water rights and springs with greater than ten feet of drawdown at the end of 300-year recovery

Water Right ID or Spring Name	Type	Backfilled Pit Proposed Action Drawdown (ft)	Open Pit Alternative Drawdown (ft)	Partial Backfill Alternative Drawdown (ft)	Description
82384	LNC Well (PH-1)	205.3	245.4	245.0	Mine owned well
82385	LNC Well (PH-1)	205.3	245.4	245.0	Mine owned well
SP-001	Spring	12.7	50.0	37.7	Trough area, not natural spring; average flow 0 gpm
SP-002	Spring	4.4	13.3	9.5	Ephemeral flow
SP-003	Spring	14.8	18.6	16.0	Average flow 0 gpm
SP-015	Spring	4.8	15.1	9.7	Average flow 0 gpm
SP-033	Spring	2.1	3.9	6.4	Perennial flow 0.95 gpm
SP-058	Spring	17.8	42.0	31.8	Man-made depression, water piped in
SP-059	Spring	6.9	14.1	11.0	Man-made trough,
SP-060	Spring	5.4	9.0	7.3	Ephemeral flow
SP-061	Spring	7.4	15.4	12.0	Ephemeral flow

The streamflow hydrographs and simulated changes of groundwater flow to Crowley and Thacker Creeks are compared for all three model scenarios in Figures 4.33 and Figure 4.34. Stream flow rates from Crowley and Lower Thacker gaging stations were averaged for every day of the year (13 months of baseline data). Baseflow rates for each stream are estimated as 492 gpm (Crowley) and 234 gpm (Thacker). The simulated maximum decline in groundwater flow for the Proposed Action and Alternatives was subtracted from baseflow stream rates to compare how impacts potentially affect total streamflow rates during the maximum extent of drawdown. Results are discussed as follows:

- Declines in baseflow at Crowley Creek between all three closure scenarios have minimal impact to overall total stream flow (Figure 4.33). Surface runoff and interflow in the spring are orders of magnitude greater than baseflow and dominate flow during this period. The channel goes dry during summer and fall. The timing of the dry period is essentially unaffected by simulated changes in groundwater flow.
- Baseflow declines in Thacker Creek are only discernible during drier summer and fall months amounting to 8 gpm to 19 gpm decline in flows depending on the closure scenario. Storm and spring runoff events show no discernible changes from baseflow declines. The creek continues to flow perennially. Changes in baseflow between closure scenarios is much less than the seasonal variation in flow rates, indicating risks of seasonally losing streamflow is very low.

4.3 RECOVERY MODEL SENSITIVITY ANALYSIS

A sensitivity analysis on pit lake or backfill 300-year post-closure simulations was performed on key model parameters to evaluate the potential variation in predictions. Two suites of sensitives were performed:

- **ET +/- 15% Sensitivity**: This sensitivity evaluates the predicted recovery of pit lakes by adjusting the simulated PET by +/- 15%. Two sensitivities (increased ET and decreased ET) were run for predictive scenarios for a total of 4 new models (only the Open Pit and Partially Backfilled South Sub-pit Alternatives are considered because no surface water bodies form in the Backfilled Pit Proposed Action). Surface water balance changes are made to CLN wells in each of the sub-pits, and models were run for the 300-year post-closure period. PET is the largest surface water component and, thus, by analyzing sensitivity to PET the sensitivity of other surface water components to the pit lake (precipitation, pit wall runoff) were also assessed.
- **K +/- 25% Sensitivity:** Hydraulic conductivity was varied by +/- 25% of calibrated log K values for key HGUs adjacent to the sub-pits (Table 4.5). HGUs representing claystone/ash (11), basal ash (14), silicified claystone (13), and basalt (16) are modified in the sensitivity simulation. Additionally, two HFBs representing minor fault structures are included (HFB 13 and HFB 14) to assess sensitivity to structural controls. All three predictive scenarios are simulated with an upper and lower sensitivity run. Inputs are described in Table 4.4.

Table 4.5: Sensitivity analysis input parameters

Parameter	**Base value (in/yr)**	**+ 15% PET (in/y**	**-15% PET (in/yr)**
PET	59.60	68.5	50.7
HGU Zone	**Base value (ft/d)**	**+25% Log K (ft/d)**	**-25% Log K (ft/d)**
11	0.25	0.5	0.13
13	0.06	0.25	0.015
14	2.8	4.7	1.7
16	0.08	0.28	0.02
HFB 13	1.0e-5	1.78e-4	5.62e-7
HFB 14	2.0e-6	5.32e-5	7.52e-8

Water level recovery hydrographs for the sensitivity analysis are shown Figure 4.35 to Figure 4.37. Key results from the sensitivity analysis are as follows:

- Modifying hydraulic conductivity provides the greatest variation in equilibrium water levels. The recovery of the West and South Sub-pits varies approximately 80 ft to 100 ft. Increasing hydraulic conductivity values has a greater effect than reducing values.

In two instances a pit lake or wetlands did not develop under the increased hydraulic conductivity scenario (West Sub-pit and South Partially Backfilled Sub-pit).

- Pit lake water levels varied by approximately 5 ft to 20 ft in response to modifying hydraulic conductivity values. Greater changes occurred by increasing hydraulic conductivity, suggesting the system is already somewhat constrained by low permeability materials and increased evaporation as lake levels rise.
- Pit lake water levels are less sensitive to changes in PET, suggesting climatic variations will have a small effect on predictions. Changes in pit lake elevations due to PET were approximately 3 ft to 8 ft in the ultimate recovery stage.
- Although the model demonstrates sensitivity to hydraulic conductivity, the likelihood of encountering wide-spread bulk variation from calibrated hydraulic conductivity in Thacker Pass is low. This is because the model is calibrated to multiple monitoring locations in the proposed open pit footprint. Thus, the sensitivity analysis is a useful tool to guide future monitoring and bound potential results.

Water balances for the sensitivity analysis are used in the geochemical modeling sensitivity analysis in Section 5.

4.4 PREDICTIVE GROUNDWATER MODEL UNCERTAINTY

The groundwater model incorporates an area with relatively complex hydrogeology. Calibration efforts indicate that the model reasonably reproduces the observed water levels, water level changes, and spring discharge rates. The predictions made with the calibrated model are expected to be representative of future conditions. However, as with any numerical groundwater model, there are uncertainties involved in the model itself and its corresponding predictions. This section describes some of the uncertainties and how they may affect the model results and predictions.

Conceptual model

The conceptual model provides the basis for constructing the numerical groundwater model. Although there is some uncertainty in the specific conceptual model detail, including parameter values discussed below, the current conceptual model fits the geologic framework of the Thacker Pass Project. Alternative conceptual models were considered during the calibration process but failed to match observed water level and flows as accurately (Table 3.9). Therefore, the uncertainty associated with the conceptual model is considered low.

Water balance

The estimated water balance represented in the model is based on available data and model results. The greatest uncertainty is associated with the distribution of irrigation pumping in Quinn River and Kings River Basins. However the predicted groundwater impacts are relatively insensitive to the distribution of irrigation pumping because (i) Thacker Pass activities are in a low permeability bedrock hydrogeologic setting, (ii) basin alluvial aquifers have high transmissivities, thus generate wide cones of depression, and (iii) the allocation of water rights to the Quinn River pumping well will effectively mitigate the amount of water currently pumped from the basin because of the 77.5% exchange rate on water rights transfers.

Individual water balance components in Thacker Pass (i.e., recharge, ET, groundwater outflow) could vary beyond the ranges assumed in the simulations. However their effects on predicted pit lake and backfill recovery is small, as indicated by the sensitivity analysis. Therefore, there is little uncertainty in the water balance with respect to potential water quantity impacts.

Bedrock groundwater system

The model incorporates the bedrock groundwater system in a manner that accounts for overall bedrock recharge and flux rates. The most practical approach for a model of this scale is to include the key high-level details of bedrock stratigraphy and structure. The groundwater flow in the bedrock occurs in a manner that is appropriately represented in the model as porous media.

The model incorporates various mapped geologic features such as known faults, abundances of ash or clay beds, and lithologic changes that represent low permeability zones. Testing and/or monitoring indicated that these features result in variations within the bedrock groundwater flow system. However, there are other features that may exist in the model area that could result in localized compartmentalization or flow conduits along bedding planes. The result of more compartmentalization would be that impacts to the bedrock groundwater system from dewatering are more localized than simulated in the model.

Backfill infiltration

Realistic infiltration rates are assumed for a backfill with vegetated cover, supported by Nevada based data. However soil covers can be compromised by poor grading, subsidence and fissuring, and poor growth media. Such defects would increase infiltration rates to backfill resulting in higher water level recoveries and greater outflow to groundwater. Uncertainty associated with vegetated cover performance is low, but inspections during reclamation can reduce uncertainties further. Additional infiltration cover modeling described in Section 7, indicates the assumed rates for backfill (3% MAP) are conservative, being higher than simulated rates.

Springs, seeps, and stream flow in Montana Mountains

The groundwater model deliberately omitted compartmentalized geologic structures in the Montana Mountains. Omitting structures in the Montana Mountains was done for the following reasons:

- Attempts to calibrate the model to spring flow by adjusting the hydraulic conductivity and anisotropy of McDermitt Tuff bedrock alone yielded groundwater levels in the Thacker Pass Project which were on the order of 100s of feet higher than observed measurements.
- Water levels and flows in Pole and Rock Creeks do not align with the hydraulic gradient of the spring elevations. More weight was given to matching Pole and Rock Creek conditions in the model rather than the springs.
- There was concern that implementing several faults in the Montana Mountains without directly measured piezometric information would over constrain drawdown predictions.
- Predictive simulations are conservative with respect to drawdown extent in the Montana Mountains without the presence of faults. Even under the simulated conditions the predicted impacts to springs and flow in Pole Creek are minor and less than measurement error as discussed in the following section.
- The majority of groundwater data was focused on the Thacker Pass Project area and neighbouring vicinity as developing the groundwater model to accurately represent this area is paramount.

The exclusion of the structures in the Montana Mountains, which compartmentalize the springs, was a more conservative approach to modeling. In reality, there are faults which create hydrogeologic compartments between Thacker Pass and the mapped springs and streams.

Parameter values

Parameter values used in the model were estimated from multiple hydraulic tests performed on insitu rock units across the site. Test values were used as guidelines for initial model values, which were subsequently adjusted within reasonable ranges during the model calibration process. As discussed in Section 3.2, the calibration statistics indicate a reasonable fit between observed and calibrated conditions. Although there are other possible parameter combinations that could produce a similarly good fit, the sensitivity analysis presented in Section 3.2.5 shows that it is unlikely that the parameters and results of these alternative parameters would vary substantially from those used in the current model.

5 WATER QUALITY AND IMPACTS ASSESSMENT MODELING

Potential water quality impacts from the Thacker Pass Project are related to pore water quality in backfilled sub-pits or the formation and chemogenesis of pit lakes. Characterization of the future geochemical conditions meets the following objectives:

- Quantify the post-closure water balance consisting of dynamic pit inflow and outflow rates, water level recovery, equilibrium water level to backfilled sub-pits.
- Characterize the geochemical nature of inflows to the closed facility and geochemical reactions likely to occur given the mineralogical (source minerals, solid state solution) and environmental (redox potential, lake turnover) setting.
- Predict future water chemistry with a geochemical mass loading model of natural waters and site appropriate geochemical reactions.
- Evaluate constituents which exceed NDEP Profile I standards (for backfill pore water) or NDEP Profile III standards (for pit lakes). Profile III exceedances will require further analysis of predicted concentrations and exposure times in an ecological risk assessment (ERA) (NDEP, 2014). LNC is currently preparing an ERA to address any predicted exceedances to Profile III to be issued separately.
- Develop a sensitivity analysis of input assumptions to assess the potential range of pore water and pit lake chemistries in the Proposed Action and Alternatives.

Geochemical characterization of rock materials indicates the geologic units host abundant acid neutralizing material, therefore acid generation is not a concern from backfilled pits, potential pit lakes, nor waste rock facilities (WRFs) (SRK, 2019). The primary environmental risks with respect to mine water quality is the potential to leach hydrothermally enriched elements (antimony, arsenic, fluoride, molybdenum) which are attendant elements associated with the lithium ore emplacement mechanism and alteration of moat sediments in the caldera. Claystone and ash sediments have been shown to release elevated concentrations of such elements under circum-neutral conditions in both humidity cell (HCT) and Meteoric Water Mobility (MWMP) tests. The chemical release of these elements is likely through the process of ion-exchange and the mechanical increase of reactive areas through milling and mining. Traditional sulfide oxidation reactions do not play a meaningful role in the release of metals from waste rock.

Water quality impacts are analyzed for the Proposed Action and two Alternatives which are summarized in Section 4.1. Detailed geochemical description of each configuration is provided in Section 5.4.

5.1 METHODOLOGY

5.1.1 Modeling Approach

The pit lake geochemical modeling process couples individual water balance components with geochemical profiles assigned to each component and simulates their resulting chemistry through a dynamic solute mass loading model, chemical reactions, and mineral surface adsorption. A conceptual schematic of mass inputs to the geochemical backfill / pit lake model for the pit is shown in Figure 5.1. Key steps during the geochemical model are briefly summarized with additional discussion provided in latter sections:

1. Develop a dynamic water balance from the groundwater flow model simulating the inflows, outflows, and storage of water in each sub-pit. As water levels rise, inflows, and outflows dynamically change until equilibrium is reached. Groundwater outflow between sub-pits, if any, is dynamically calculated as a separate water balance component.
2. Assign individual, charge-balanced water chemistries to inflow components. Charge balance is achieved by adjusting chloride/sodium concentrations because sodium and chloride do not impact resulting geochemistry. Charge balancing required minimal modification, such that solution ionic strengths were not significantly altered.
3. Scale the laboratory test data from humidity cell tests (HCTs) to represent field parameters of pit wall rock and backfill. Laboratory humidity cell tests (HCTs) accelerate the weathering process of rock. Scaling factors reduce the loading rate of constituents to represent realistic field loading rates.
4. Select appropriate time steps that represent different stages of water-level rise within the post-closure backfill or pit lake, including a time step that represented equilibrium conditions, or at least 95 percent pit lake recovery.
5. Assign appropriate atmospheric and redox conditions to the geochemical model.
6. Multiply the individual inflow components from the water balance by their proxy geochemical profile and mix proportionately to develop the mass balance model.
7. Add solute mass representing pit wall submergence, in proportion to the material types exposed in the pit wall and from any submerged backfill (if applicable).
8. Remove pure water from the open pit lake to account for evaporation and/or transpiration in quantities estimated from the water balance.
9. Remove outflow water balance components from the mass balance according to the mixed concentration at the specified time step.
10. Equilibrate pore water/pit lake water with likely mineral phases available for reaction. Mineral phases were assumed to saturation indices (SI) of 0 except for barite and calcite (SI = 0.5) which is often shown to be super-saturated (Eary, 1999).

11. Carbon dioxide partial pressure is set to slight oversaturation ($pCO_2 = 10^{-2.5}$ atm), based on elevation and observations at existing pit lakes (Eary, 1999).
12. Simulate adsorption of specific species (antimony, arsenic, barium, lead, cadmium, copper, nickel, calcium, phosphate, zinc, beryllium, and sulfate) onto ferrihydrite according to Dzombak and Morel (1990). The mass of available ferrihydrite is limited to that precipitated by the geochemical model (i.e., no additional ferrihydrite from pit walls or aerosols is included). Additional adsorption onto other oxides or mineral phases (manganese oxides, aluminium oxides, calcite, organic carbon, backfill substrate) are not included in the adsorption model, adding conservatism in the geochemical model.

A predictive geochemical model was developed for each sub-pit by developing individual water balance and mass balance inputs. Adjustments to the chemistry of the mechanically mixed waters are then made to account for potential chemical reactions in the lake water column and atmosphere, using the aqueous-speciation code PHREEQC with the MINTEQ-4F thermodynamic database (Parkhurst and Appelo 1999).

The geochemical model is constructed to represent lake/pore water conditions during filling and under equilibrium elevation conditions. Time steps to evaluate pit lake chemistry were selected to capture early pit filling and throughout an approximately 300-year post-closure period (2365). A summary of geochemical model time steps is presented in Table 5.1

Table 5.1: Geochemical model time step assignments.

Closure Alternative	Time Steps (Years Post-Closure)
Fully Backfilled Pit	1, 2, 3, 5, 10, 20, 30, 50, 75, 150, 175, 200, 250, 300
Open Pit	1, 2, 3, 5, 10, 20, 30, 50, 75, 150, 175, 200, 250, 300
Partially Backfilled South Sub-pit	1, 2, 3, 5, 10, 20, 30, 50, 75, 150, 175, 200, 250, 300

The effects of evapoconcentration, mineral precipitation, and sorption are simulated as instantaneous reactions following mixing at the conclusion of each time step. Mineral precipitation was applied using a universal set of minerals and equilibrium SIs at all the simulated pits (Table 5.2). Minerals that could precipitate were determined from two sources.

1. A list of common minerals with reactions controlling pit lake chemistry was summarized by Eary and Nordstrom and Alpers (Eary, 1999 & Nordstrom and Alpers, 1999), and used to include appropriate minerals for an acidic to circumneutral pit lake.
2. Minerals which are likely to precipitate based on geologic experience and identified by positive saturation indices in the MineteqV4 database. This only applies to the inclusion of magnesite ($MgCO_3$) as a potential precipitation mineral.

Saturation indices were derived from literature values (Eary, 1999) or set to 0. The processes to remove mass were limited to select mineral precipitation, adsorption onto precipitated ferrihydrite, groundwater outflow, and pit lake pumping. Additional processes that are known pathways for mass to be removed from solution (i.e. solid solutions, chemisorption, adsorption to suspended colloids or backfill, and adsorption onto calcite) were not simulated because i) they require site specific laboratory testing and ii) retain a conservative geochemical model. Once mass is removed via precipitation or adsorption onto ferrihydrite, it has conceptually been removed from the water column. A sensitivity analysis was performed which inhibited mineral precipitation to evaluate the effect of mineral precipitation on water chemistry.

Table 5.2: Mineral precipitation phases

Mineral Phase	Chemical Formula	Saturation Index (SI)	Source
Barite	$BaSO_4$	0.5	Eary, 1999
Calcite	$CaCO_3$	0.5	Eary, 1999
CO2(g)	CO_2	-2.49	Eary, 1999
Malachite	$Cu_2CO_3(OH)_2$	0	Eary, 1999
Ferrihydrite	FeOOH	0	Eary, 1999
Fluorite	CaF_2	0	Eary, 1999
Gibbsite	$Al(OH)_3$	0	Eary, 1999
Gypsum	$CaSO_4$	0	Eary, 1999
Rhodochrosite	$MnCO_3$	0	Eary, 1999
Magnesite	$MgCO_3$	0	Mineteq V4 Database

Redox conditions are evaluated for each pit lake or backfilled sub-pit during filling and upon reaching equilibrium. Backfill conditions are anticipated to be less oxygenated, although not strongly reducing, owing to the partial saturation of pore water in the backfill, barometric pumping, and low quantities of organic matter found in waste rock. The geochemical models assign redox conditions as a as follows:

- Pit lakes are assigned redox values of pE = 4 (mildly oxygenated);
- Backfill is assigned a redox value of pE = -4 (mildly reducing).

Oxygen gas was the oxidizing agent used to modify redox conditions.

Shallow lakes undergo seasonal mixing and oxygenation due differential temperature variation in the lake profile and wind driven currents. As a result they are typically fully mixed and in equilibrium with atmospheric gasses (Drever, 2002). All the potential pit lakes which may form in sub-pits are anticipated to be fully mixed due to:

- Relatively shallow nature of most sub-pits (< 100 ft deep).

- Strong wind-driven currents and seasonal changes in temperatures that occur in northern Nevada.
- Existing lake water and inflows, such as precipitation and pit wall runoff, are completely mixed resulting in oxygenated conditions throughout the entire water column.

5.1.2 Laboratory Test Data Scaling

HCT results require scaling prior to assignment as proxies for pit wall runoff and pit wall submergence to account for the change in physical properties between laboratory and field. Scaling mass release from laboratory setting to field conditions accounts for several physical differences between laboratory and field environments such as: water to rock ratio or grain size distribution; rock surface area; water content and flushing rates; temperature; oxidation conditions; and chemistry of the rinsing solution (Kempton, 2012). This study conservatively assumes two scaling factors, sample specific surface area and water to rock ratio (or grain size distribution), to bring laboratory results to the field scale. HCT samples consist of ground or crushed waste rock that have higher porosity, specific surface area, and are rinsed more rigorously than in-situ pit wall rocks. This approach is conservative because HCT samples in a controlled laboratory environment are subjected to higher relative humidity, moisture content and average temperatures than in the field environment thus accelerating most chemical reactions. These effects were not corrected for in this study.

Field scale mass loading rates were calculated by multiplying laboratory HCT water chemistry results by specific surface and water to rock scaling factors (SF), shown in Equation 2.

$$Field\ chemistry\left[\frac{mg}{l}\right] = Lab\ chemistry\left[\frac{mg}{l}\right] * SF_{sp.\ surface\ area} * SF_{water:rock} \tag{2}$$

Scaling for specific surface HCT results was performed by calculating the ratio between field and laboratory conditions using Equation 3.

$$SF_{sp.\ surface\ area} = \left[\frac{(Field\ sp.\ surface\ area)}{(Lab\ specific\ surface\ area)}\right] \tag{3}$$

Laboratory samples are estimated to have a specific surface area of 43.8 m^2/kg based specific surface area calculations for platelet shaped particles and soil particle size distributions which are summarized in Equation 4 (Santamarina, 2002).

$$\sum SSA = \frac{(2+\beta)(C_u+7)}{4\rho_s d_{50}} \tag{4}$$

Where SSA is the specific surface area of a soil, β is the slenderness of the particle (assumed to be 2.5:1), C_u is the uniformity coefficient of a particle size distribution (a value of 55.6 obtained from waste rock samples), ρ_s is the dry density (1850 kg / m^3), and d_{50} is the median particle size (0.87 mm determined from waste rock samples). The laboratory specific surface value was confirmed to be conservative by using the MDAG specific surface area calculator which estimated values exceeding 100 m^2/kg for waste samples (MDAG Grain 3.0, 2008).

Backfill is estimated to have a specific surface area of 17.7 m^2/kg. The backfill SSA of 17.7 m^2/kg was based on particle size distributions of coarse gangue at LNC and is comparable with backfill at other sites in Nevada. The program MDAG Grain 3.0 was used to determine specific surface area of backfill based on grain size distribution from coarse gangue and run of mine waste rock.

Field samples of insitu wall rock were estimated to have a specific surface area of 2.94 m^2/kg. Wall rock specific surface area is estimated from literature and based on experience at other Nevada sites. Transport estimate from tracer experiments in fractured granite estimated values ranging from 0.0006 m^2/kg to 0.004 m^2/kg (Abelin et. al., 1991). MEND reviewed four closure cases which utilized MINEWALL 2.0 to calibrate to pit lake chemistry. Wall rock surface area ratios (reactive surface area per unit of wall rock surface area) ranged from 27:1 m^2/m^2 to 736:1 m^2/m^2 (MEND, 1995). Assuming a 1 m thick rind (a conservative estimate from the MEND report) and a rock density of 2400 kg/m^3, this translates to specific surface areas ranging from 0.01 m^2/kg to 0.35 m^2/kg. Such literature values are less than that utilized for the Thacker Pass Project primarily on the basis that material sloughing will collect on benches. The value of 2.94 m^2/kg was selected based on Piteau's experience calibrating pit lake chemistry at other Nevada sites. Additionally, the total scaling factor produced (0.57) aligns well with a literature review by Morin, which suggests a comprehensive scaling factor between 0.05 to 0.6 is typical for mine site applications (Morin, 2013).

An average fractured rock porosity of 5% for wall rock is applied based on numerical model calibration and experience.

Scaling for the water to rock ratio was performed by dividing the volume of water used to rinse the sample by the number of lab pore volumes as shown in Equation 5. This produces a mass per pore volume of concentration constituents. Laboratory samples were estimated to have an average porosity of 30 percent and bulk density of 1.85 kg/L. Normalized HCT results were then scaled to field parameters using measured bulk density and porosity values of 2.48 kg/L and 5% porosity for wall rock (LNC, 2019b). Backfill was scaled using a bulk density of 2.1 kg/L and 30% porosity. The volume of pore flushes which is rinsed by runoff was calculated in the water balance and used in geochemical mixing of inflow components. Therefore, the scaling factor uses a nominal one-liter volume of rinse water and one-kilogram sample of wall rock.

$$SF_{water:rock} = \left[\frac{(\rho_{b\,rock})*(Mass_{Lab})*(\emptyset_{HCT})*1\,L}{(Vol\,Effluent_{Lab})*(\emptyset_{rock})*(\rho_{b\,HCT})*1\,kg}\right] \quad (5)$$

The aforementioned parameter values for laboratory samples and insitu rock were identified through a combination of:

- Laboratory reports (SRK, 2019)
- Waste rock and gangue particle size distributions (LNC, 2019b)
- Literature values for wall rock bulk density and porosity from work performed by Siskind and Fumanti (Siskind and Fumanti, 1974) and Kempton (Kempton, 2012); and
- Groundwater model calibration for bedrock material of approximately one percent specific yield (i.e. porosity). Therefore, rock in the blasted damaged rock zone (DRZ) of the pit wall is anticipated to range between two to five percent porosity.

Scale Factors and inputs used in the geochemical model for wall rock and backfill material were developed in Table 5.3.

Table 5.3: HCT scaling

Parameter	Units	Wall Rock	Backfill
Lab Sample Mass	kg	1.5	1.5
Lab porosity	-	0.30	0.30
Applied fluid	liter	0.7	0.7
Lab bulk density	kg/L	1.85	1.85
Field porosity	-	0.05	0.30
Field bulk density	kg/L	2.485	2.1
Water-Rock Scaling Factor[1]		**9.94**	**1.4**
Lab specific surface area	m^2/kg	43.8	43.8
Field specific surface area	m^2/kg	2.94	17.7
Specific Surface Area Scaling Factor[1]		**0.067**	**0.40**
Overall Scaling Factor[1]		**0.67**	**0.57**

[1] Indicates calculated scaling factor

5.1.3 Conceptual Model

Generalized water and mass balance components of backfill recovery and pit lake chemogenesis are shown in Figure 5.1. Groundwater inflow is anticipated to be the most important component to backfilled pore water chemistry because surface water management practices will prevent the collection of meteoric water on the backfill. The surface water management plan includes i) positive drainage of the backfill above grade to promote drainage and shed precipitation, ii) surface water diversions surrounding the open pit, iii) reclamation of the backfill with a vegetated cover to inhibit infiltration. Thus, pore water chemistry will mainly reflect the inflow components of groundwater, minor fluxes of infiltration, and flushing of backfill material; and the outflow component of discharge to bedrock groundwater.

The North Sub-pit will be mined to and elevation of 4,757 ft amsl, which is approximately 277 ft below the pre-mining water level at PH-1 (5,034 ft amsl). Groundwater is compartmentalized by northeast to southwest trending minor faults, that will be removed by mining (Figure 2.7). Thus, the post-closure backfilled water level recovery of 4,845 ft amsl in the North Sub-pit reflects water levels outside the fault compartment (4,750 ft amsl to 4,850 ft amsl).

The West Sub-pit will be mined to the 4,774 ft amsl elevation and recover to 4,817 ft amsl. The majority of the sub-pit resides above 4,850 ft amsl, and only a small sector in the southwest corner of the West Sub-pit will intersect the water table.

The South Sub-pit will have a pit floor of ~4,593 ft amsl and recover to 4,753 ft amsl. Saturated thickness in the South Sub-pit will be greatest of the three sub-pits, and thus have the largest component of groundwater inflow entering the pit.

5.2 WATER BALANCE INPUTS

A water balance was prepared for each of the three sub-pits that follows the conservation of mass continuity equation:

$$P + R_{pit\ wall} + R_{overland} + Pit_{inflow} + GW_{inflow} + Q - GW_{outflow} - Pit_{outflow} - E = \frac{\Delta V_{pit\ lake}}{\Delta t} \tag{6}$$

Where:

P	= Direct precipitation
$R_{pit\ wall}$	= Pit wall run-off
$R_{overland}$	= Overland run-off
Pit_{inflow}	= Inflows from adjacent sub-pit
GW_{inflow}	= Groundwater inflow
E	= Pit lake evaporation
Q	= Pumping into or from the pit lake

$Pit_{outflow}$ = Outflow to adjacent sub-pit
$GW_{outflow}$ = Groundwater outflow
$\frac{\Delta V_{pit\ lake}}{\Delta t}$ = Change in pit lake volume

Equation 6 accounts for all inflows and outflows to the sub-pit where the difference results in a change of storage. It is anticipated that not all of the sub-pits will necessarily have values for every component in Equation 6, for example overland runoff is not applicable for the Proposed Action because of surface water diversions and backfilling above grade.

Water balances and their corresponding mass balances were performed using the dynamic system model (DSM) GoldSim (GoldSim, 2016). GoldSim software simulates transient system fluxes and reservoir storage in dynamically changing systems, i.e. pit lakes. GoldSim models were designed for a 300-year simulation period using daily time steps. A summary of water balance input sources is provided in Table 5.4. Geochemical profiles assigned to the mass balance are discussed in Section 5.3.

Table 5.4: Water balance inputs

Water Balance Component	Units	Value	Source
Precipitation	in/yr	12.22	LNC Meteorological Station (Piteau, 2019a)
Pit Wall Runoff	%	10%	Coefficient assumed
Bedrock Inflow	gpm	n/a	Intrinsically calculated by numerical flow model
Bedrock Outflow	gpm	n/a	Intrinsically calculated by numerical flow model
Evaporation	in/yr	41.72	LNC Meteorological Station with a 0.7 PET to lake coefficient. (Piteau, 2019a)
Inter pit flow	gpm	n/a	Intrinsically calculated by numerical flow model

Water balance components for groundwater inflows/outflow and inter-pit flows were calculated from the Modflow groundwater model using the high K, high storage methodology described in Section 4.1.2. The Modflow model simulates pit lake/backfill recovery. Surface water balance components of precipitation, pit wall runoff, and evaporation are implemented as prescribed fluxes and the flux of water between pit lakes and the groundwater system is intrinsically calculated. Output filling curves and recovery water from the Modflow model serve as a second check for predicted lake/backfill recovery results simulated by GoldSim.

5.3 GEOCHEMICAL INPUT DATA

Water balance components were assigned a geochemical profile derived from groundwater monitoring, pit lake monitoring, waste rock kinetic tests, or assigned a value based on literature. A charge balance was performed on each geochemical profile to verify electric neutrality. Sodium and chloride were adjusted to balance charges if there is a greater than 5 percent difference between cation and anion milliequivalents. A summary of methodology for assigning geochemical profiles is provided in Table 5.5 and described in the following sections

Table 5.5: Geochemical profile assignments

Water Balance Component	Source	Comments
Precipitation	NADP, 2017	Representative rainwater chemistry data from Smith Valley
Pit Wall Runoff	WRMP HCT Program	HCT data is selected as surrogate geochemical source terms for exposed lithology in final pit wall. Data is scaled from laboratory to pit wall setting. (SRK, 2019)
Pit Wall Submergence	WRMP HCT Program	Early term HCT data is scaled for mass loading terms to the pit lake. 3 pore volumes are used to simulated pit wall flushing
Bedrock Groundwater	MW18-01, MW18-04, WSH-11, WSH-17, WSH-14, WSH-13	Bedrock groundwater chemistry from LNC monitoring program. Unique for each sub-pit.
Evaporation	n/a	Evaporation is assigned geochemical profile of pure water
Backfill outflow	Geochemical model	
Pit lake inflow/outflow	Geochemical model	

5.3.1 Direct Precipitation

Precipitation was assigned a geochemical profile derived from the National Atmospheric Depositional Program (NADP) station located in Smith Valley Nevada (NADP, 2017). Precipitation rates were derived from LNC's meteorological station, whose average monthly precipitation rates are shown in Table 2.1.

5.3.2 Evaporation

Evaporation was assigned a geochemical profile of pure water.

5.3.3 Groundwater Inflows

Groundwater inflow volumes were calculated for each individual sub-pit. Groundwater fluxes were lumped into a single hydrogeologic unit, representing bedrock, although the wall rock may be comprised of claystone/ash, ash, basalt, or tuff. A unique geochemical groundwater profile was developed from adjacent monitoring wells in LNC's groundwater monitoring network. Non-detects from the water quality dataset were assigned values in two ways:

1. If the element was detected at any time during the well's monitoring period, then all non-detect values were assigned to equal 50 percent of the detection limit.

2. If the element was never detected during the monitoring history, then a value of zero was assigned to geochemical profile.

A composite water chemistry is developed for each sub-pit using weighted water chemistry profiles from nearby monitoring wells. Well selection for proxy groundwater chemistry is described as follows with well locations and corresponding sub-pit assignments shown in Figure 5.2. Weights are assigned to water chemistry profiles by proximity to the sub-perimeter, thus wells exposed to more of the sub-pit perimeter will have higher weights. Composite water chemistries and input geochemical water chemistry profiles are shown in Tables 5.6 through 5.8. Raw time series data for groundwater wells are provided in the Thacker Pass Project Hydrologic Baseline and Data Collection Report (Piteau, 2019a). A brief summary of groundwater chemistry conditions for each sub-pit is discussed as follows:

- Groundwater is Ca/Na – HCO_3 to Ca/Na – SO_4 types and circum-neutral pH. TDS increases in claystone / ash beds in wells near the South Sub-pit (WSH-11, WSH-13, WSH-14, and WSH-17) which also corresponds to higher natural concentrations of fluoride (Piteau, 2019a). Arsenic concentrations in groundwater are elevated above NRVs ubiquitously across the site, including the footprints of LNC's sub-pits.
- North Sub-pit composite chemistry is shown in Table 5.6, which is comprised of wells MW18-04, WSH-11, and WSH-17. Arsenic concentrations are elevated in this composite. A zone of elevated fluoride concentrations is found in WSH-11 and WSH-17, however composited concentrations are below NRVs because of the low weighted contribution from MW18-04. MW18-04 is screened across volcanic tuff, whereas all other wells are completed in the claystone/ash unit. Utilizing MW18-04 for the study is considered reasonable because the West and North Sub-pits excavate the bounding E-W control structure and will receive upgradient groundwater from the volcanic tuff unit.
- West Sub-pit composite chemistry is shown in Table 5.7. Arsenic concentrations for 3 nearby monitoring wells exceed NRVs, with MW18-04 being the only well with arsenic concentrations below 0.010 mg/l. Fluoride exceeds NRVs at WSH-11 and WSH-17, but do not carry over into the composite geochemical profile due to sample weighting.
- South Sub-pit composite chemistry is shown in Table 5.8, which is comprised of wells WSH-13, WSH-14, and WSH-17. Once again arsenic concentrations are elevated above NRVs and WSH-13 and WSH-17 possess elevated fluoride concentrations.

Table 5.6: North sub-pit groundwater geochemical profile

Parameter	Units	MW18-04	WSH-11	WSH-17	*Composite*
Percent of Composite		**48%**	**15%**	**37%**	
Number of samples		5	5	16	
pH	s.u.	7.17	7.92	8.01	*7.59*
Alkalinity, Total	mg/L	65.18	224.94	176.42	*130.09*
Aluminum	mg/L	0.115	0.005	0.0	*0.064*
Antimony	mg/L	0.000	0.000	0.001	*0.001*
Arsenic	mg/L	0.004	0.027[1]	0.027[1]	*0.016*[1]
Barium	mg/L	0.04	0.06	0.06	*0.03*
Beryllium	mg/L	0.000	0.000	0.001	*0.000*
Bismuth	mg/L	0.010	0.010	0.010	*0.010*
Boron	mg/L	0.01	0.22	0.35	*0.17*
Cadmium	mg/L	0.000	0.000	0.001	*0.000*
Calcium	mg/L	16	26	21	*19*
Chloride	mg/L	14	43	32	*25*
Chromium	mg/L	0.003	0.001	0.003	*0.002*
Cobalt	mg/L	0.001	0.001	0.001	*0.001*
Copper	mg/L	0.004	0.005	0.024	*0.012*
Fluoride	mg/L	0.2	4.3[1]	4.0[1]	*2.2*
Gallium	mg/L	0.010	---	---	*0.010*
Iron	mg/L	0.095	0.016	0.02	*0.056*
Lead	mg/L	0.0017	0.0003	0.001	*0.0013*
Lithium	mg/L	0.01	0.34	0.21	*0.138*
Magnesium	mg/L	4	21	12	*10*
Manganese	mg/L	0.02	0.05	0.05	*0.04*
Mercury	mg/L	0.00015	0.00001	0.0001	*0.00010*
Molybdenum	mg/L	0.002	0.008	0.019	*0.010*
Nickel	mg/L	0.003	0.001	0.009	*0.012*
Total Nitrogen	mg/L	0.33	0.11	0.11	*0.22*
Phosphorus	mg/L	0.05	0.05	0.05	*0.05*
Potassium	mg/L	2.58	1.22	1.07	*1.82*
Selenium	mg/L	0.001	0.001	0.003	*0.001*
Silver	mg/L	0.001	0.001	0.003	*0.001*
Sodium	mg/L	19	62	72	*45*
Strontium	mg/L	0.09	0.61	0.41	*0.287*
Sulfate	mg/L	16	41	37	*27*
Thallium	mg/L	0.0001	0.0001	0.001	*0.0002*
Tin	mg/L	0.01	0.01	0.01	*0.00*
TDS	mg/L	138	425	357	*262*
Uranium	mg/L	0.0005	0.0006	0.003	*0.001*
Vanadium	mg/L	0.001	0.010	0.007	*0.005*
Zinc	mg/L	0.027	0.001	0.01	*0.017*

[1] Exceeds Profile 1 NRVs

Table 5.7: West sub-pit groundwater geochemical profile

Parameter	Units	MW18-01	MW18-04	WSH-11	WSH-17	*Composite*
Percent of Composite		**41%**	**13%**	**25%**	**20%**	
Number of samples		5	5	5	16	
pH	s.u.	7.58	7.17	7.92	8.01	*7.70*
Alkalinity, Total	mg/L	111.93	65.18	224.94	176.42	*147.46*
Aluminum	mg/L	0.033	0.115	0.005	0.0	*0.0*
Antimony	mg/L	0.000	0.000	0.000	0.001	*0.000*
Arsenic	mg/L	0.011[1]	0.004	0.027[1]	0.027[1]	*0.017[1]*
Barium	mg/L	0.02	0.04	0.06	0.06	*0.04*
Beryllium	mg/L	0.000	0.000	0.000	0.001	*0.000*
Bismuth	mg/L	0.010	0.010	0.010	0.010	*0.010*
Boron	mg/L	0.01	0.01	0.22	0.35	*0.13*
Cadmium	mg/L	0.000	0.000	0.000	0.001	*0.000*
Calcium	mg/L	32	16	26	21	*26*
Chloride	mg/L	22	14	43	32	*28*
Chromium	mg/L	0.001	0.003	0.001	0.003	*0.001*
Cobalt	mg/L	0.001	0.001	0.001	0.001	*0.001*
Copper	mg/L	0.004	0.004	0.005	0.024	*0.008*
Fluoride	mg/L	0.3	0.2	4.3[1]	4.0[1]	*2.0*
Gallium	mg/L	0.010	0.010	0.010	0.0	*0.01*
Iron	mg/L	0.033	0.095	0.016	0.0	*0.03*
Lead	mg/L	0.0003	0.0017	0.0003	0.001	*0.001*
Lithium	mg/L	0.01	0.01	0.34	0.21	*0.14*
Magnesium	mg/L	11	4	21	12	*13*
Manganese	mg/L	0.01	0.02	0.05	0.05	*0.03*
Mercury	mg/L	0.00002	0.00015	0.00001	0.0001	*0.0000*
Molybdenum	mg/L	0.002	0.002	0.008	0.019	*0.007*
Nickel	mg/L	0.003	0.003	0.001	0.009	*0.004*
Total Nitrogen	mg/L	1.15	0.33	0.11	0.11	*0.56*
Phosphorus	mg/L	0.05	0.05	0.05	0.05	*0.05*
Potassium	mg/L	1.50	2.58	1.22	1.07	*1.48*
Selenium	mg/L	0.001	0.001	0.001	0.003	*0.001*
Silver	mg/L	0.001	0.001	0.001	0.003	*0.001*
Sodium	mg/L	17	19	62	72	*40*
Strontium	mg/L	0.14	0.09	0.61	0.41	*0.310*
Sulfate	mg/L	23	16	41	37	*29*
Thallium	mg/L	0.0001	0.0001	0.0001	0.001	*0.000*
Tin	mg/L	0.01	0.01	0.01	0.01	*0.01*
TDS	mg/L	221	138	425	357	*289*
Uranium	mg/L	0.0005	0.0005	0.0006	0.003	*0.001*
Vanadium	mg/L	0.001	0.001	0.010	0.007	*0.005*
Zinc	mg/L	0.015	0.027	0.001	0.01	*0.01*

[1] Exceeds Profile 1 NRVs

Table 5.8: South sub-pit groundwater geochemical profile

Parameter	Units	WSH-13	WSH-14	WSH-17	*Composite*
Percent of Composite		**27%**	**37%**	**35%**	
Number of samples		17	5	16	
pH	s.u.	8.26	7.92	8.01	*8.00*
Alkalinity, Total	mg/L	208.2	207.4	176.4	196.6
Aluminum	mg/L	0.028	0.005	0.023	0.017
Antimony	mg/L	0.002	0.002	0.001	0.0013
Arsenic	mg/L	0.003	0.018[1]	0.027[1]	0.017[1]
Barium	mg/L	0.000	0.000	0.001	0.0002
Beryllium	mg/L	0.000	0.000	0.001	0.0003
Bismuth	mg/L	---	---	---	0
Boron	mg/L	0.87	0.25	0.35	0.45
Cadmium	mg/L	0.000	0.000	0.001	0.0002
Calcium	mg/L	12	54	21	31
Chloride	mg/L	27	130	32	67
Chromium	mg/L	0.001	0.001	0.003	0.001
Cobalt	mg/L	---	---	---	*0*
Copper	mg/L	0.006	0.005	0.024	0.012
Fluoride	mg/L	5.1[1]	1.3	4.0[1]	3.3
Gallium	mg/L	---	---	---	0.00
Iron	mg/L	0.019	0.016	0.02	0.017
Lead	mg/L	0.0003	0.0003	0.0013	0.0006
Lithium	mg/L	0.216	0.256	0.219	0.232
Magnesium	mg/L	8	31	12	18.2
Manganese	mg/L	0.03	0.00	0.05	0.025
Mercury	mg/L	0.00008	0.00001	0.00008	0.00005
Molybdenum	mg/L	0.084	0.031	0.019	0.041
Nickel	mg/L	0.0003	0.0003	0.0013	0.0006
Total Nitrogen	mg/L	0.33	0.11	0.11	*0.17*
Phosphorus	mg/L	0.05	0.05	0.05	0.05
Potassium	mg/L	1.32	3.27	1.07	1.96
Selenium	mg/L	0.001	0.001	0.003	0.001
Silver	mg/L	0.001	0.001	0.003	0.001
Sodium	mg/L	111	65	72	79.9
Strontium	mg/L	0.33	0.82	0.41	0.54
Sulfate	mg/L	44	61	37	48
Thallium	mg/L	0.0001	0.0001	0.0005	0.0002
Tin	mg/L	0.01	0.01	0.01	0.01
TDS	mg/L	419	555	357	448
Uranium	mg/L	0.006	0.0006	0.003	0.0013
Vanadium	mg/L	0.007	0.022	0.007	0.012
Zinc	mg/L	0.0030	0.001	0.01	0.0051

[1] Exceeds Profile 1 NRVs

5.3.4 Pit Wall Runoff

Precipitation which accumulates and is in contact with the sub-pit's wall rock react with minerals and can potentially mobilize constituents. Pit wall runoff is defined as the unsaturated portion of flow that occurs surficially or as interflow along the rind of the open pit to the lake (MEND, 1995). The geochemical composition of run-off depends on the exposure of rock in contact with water and the number of rinses that have leached the rock exposure.

The geochemical modeling approach develops mass loading via runoff chemistry in a three-step process described as follows:

1. An analysis of the geochemical units (lithology and respective PAG/non-PAG classification) for existing and future pit walls was made to determine the relative percentage of each particular exposed geochemical unit. Exposed wall rock lithology is shown in Figure 5.3. Percentages of exposed geochemical unit were used to partition runoff water balance components between the several geochemical units exposed above the water table at each pit. The exposure of geochemical units is dynamically re-calculated as water levels rise in order to reflect the remaining exposure of geochemical units. Tables of exposed lithologies at particular pit stages are provided in Appendix F and shown graphically in Figure 5.4 to Figure 5.6. Key trends in the distribution of materials in sub-pits are:
   - The overwhelming majority of exposed pit wall material is Non-PAG Claystone / Ash and Non-PAG Ash geochemical units. These units comprise 60% to 80% of the exposed wall area. Remaining in wall claystone is below ore grade (2,000 ppm Li).
   - HPZ/Tuff materials are found mainly at lower elevations of the North and West sub-pits.
   - Basalt is not exposed in the West Sub-pit but is present at higher elevations in the South and North Sub-pits.
2. Develop unique geochemical profiles for each geochemical unit found in the pit wall. Geochemical profiles for pit wall runoff and submergence components of the model are developed from HCTs. HCTs have been performed on 20 samples summarized in Table 5.9. Twelve of the samples were a part of prior geochemical investigation performed in 2011 - 2012 (SRK, 2012), while the remaining 8 were performed in 2018 - 2020. Recently, samples for unoxidized gangue and PAG Ash reached sufficient testing to be included in the study. Three HCT samples were omitted from the pit lake study as follows:
   - WLC-199 202-221.8 is comprised of ore rock with lithium and associated elements above the cut-off grade and will not be exposed in the ultimate pit shell nor in WRFs.
   - 4-NFILTCAKE-E09B-308 and 4-LFILTCAKE-E05B-314 represent tailings salts and tailings which will be stored on containment in the Tailing Facility and therefore not pertinent to this study.

- HCT sample locations relative to the pit configuration are shown in Figure 5.3. A discussion of Geochemical units and HCT selection is provided in the subsequent section.

3. Develop chemical release functions (CRFs) for mass loading from weekly HCT leachates and linked to the geochemical model using pore volume flushes. Each week of HCT rinsing is equivalent to approximately 1.55 pore volumes. The number of pore volumes that rinse the pit wall was dynamically calculated in the pit lake water balance and correlated to individual weeks of HCT testing. The geochemical model then composites the chemical release function based on the pore volumes which have been rinsed between geochemical time steps. An example of the calculation is provided in Table 5.10 and in Figure 5.7.

Table 5.9: HCT sample summary

Sample ID	Material	Used in Study	Max Week	Min pH	Total Sulfur (%)	AGP (T $CaCO_3$/KT)	ANP (T $CaCO_3$/KT)	ANP/ AGP	Source
WLC-026 (125.8-166.1)	Basalt	Y	47	7.2	1.01	21.9	168	7.67	SRK, 2012
WLC-65 (332-346.1)	HPZ	Y	74	6.6	0.17	2.2	5.9	2.68	SRK, 2012
WLC-85 (168.6-176.9)	Claystone/ Ash	Y	47	7.03	2.34	60.9	157	2.58	SRK, 2012
WLC-87 (143.6-163.9)	Ash	Y	47	7.62	0.29	3.4	176	51.76	SRK, 2012
WLC-88 (80.3-89.4)	Claystone/ Ash	Y	47	7.79	0.43	6.3	216	34.29	SRK, 2012
WLC-90 (113.5-125.8)	Claystone/ Ash	Y	47	7.65	1.87	44.7	98	2.19	SRK, 2012
WLC-92 (26.9-46)	Claystone/ Ash	Y	47	7.62	0.08	1.6	191	119.38	SRK, 2012
WLC-96 (206.4-230.2)	Ash	Y	47	6.53	1.91	45.9	61.2	1.33	SRK, 2012
WLC-117 (76.5-85.5)	Claystone/ Ash	Y	74	6.82	1.54	37.2	39.2	1.05	SRK, 2012
WLC-199 (132.2-162.2)	Claystone/ Ash	Y	47	7.66	1.29	33.1	424	12.81	SRK, 2012
WLC-199 (202-221.8)	Claystone/ Ash	N	47	6.12	1.19	26.9	195	7.25	SRK, 2012
WLC-204 (75-82)	Claystone/ Ash	Y	47	7.81	0.14	4.1	133	32.44	SRK, 2012
7&56-CG30M-L19A-4	Oxidized Gangue	Y	44	6.59	0.01	0.3	18.8	62.67	SRK, 2020
LNC-079 (0-7.6)	Alluvium	Y	40	7.15	0.03	0.9	24.9	27.67	SRK, 2020
WLC-050 (337.1-357.2)	Ash - PAG	Y	44	6.97	1.7	53.1	28.2	0.53	SRK, 2020
4-NFILTCAKE-E09B-308	Neutralization Solids	N	44	7.55	1.03	360	36.3	0.10	SRK, 2020
4-LFILTCAKE-E05B-314	Clay Tailings	N	40	1.59	0.85	120	0.2	0.00	SRK, 2020
9-CYCUFCOMP-E23B-356	Oxidized Gangue	Y	32	6.11	2.54	21.9	168	7.67	SRK, 2020
SAMPLE GROUP #2 (+) 75UM	Unoxidized Gangue	Y	20	6.65	-	63	168	2.66	SRK, 2020
SAMPLE GROUP #9 (+) 75UM	Unoxidized Gangue	Y	20	7.03	-	65	214	3.29	SRK, 2020

Table 5.10: Chemical release function algorithm for HCT weeks

Pit Lake step (yr)	Calculated Pore Volumes	Min PV	Max PV	HCT Week (Pore Volume)					
				0 (1.55)	1 (3.1)	2 (4.65)	4 (6.2)	8 (12.4)	12 (18.6)
1	0.5	0	1.55	100%	-	-	-	-	-
5	2.3	0	3.1	50%	50%	-	-	-	-
10	5.7	3.1	6.2	-	33%	33%	33%	-	-
50	27	13	18.6	-	-	-	33%	33%	33%

The runoff term of mass loading was calculated by multiplying composited geochemical HCT profiles by the flux of runoff for every time step according to Equation 7.

$$M_i = SF * C_i^{pv} \left[\frac{SA_i}{SA_t}\right] * q_{runoff} \tag{7}$$

Where:

M_i= Runoff mass loading rate of an individual geochemical unit in units of (mass / time).

SF= Total scaling factor, unitless.

C_i^{pv}= Composite geochemical profile concentration of an individual geochemical unit (i) in units of (mass / length^3). The composite geochemical profile is a vector of individual elements for Profile I or Profile II. The values of composite geochemical profile concentration are varied through time according to proxy HCT data.

SA_i= Surface area of geochemical unit (i) of rock materials located above the current pit lake water level in units of (length^2).

SA_t= Total surface area above the current pit lake water level in units of (length^2).

q_{runoff}= Runoff flux in units of (length^3 / time).

Mass loading via runoff to the simulated pit lake is then is multiplied by the time step size to generate a cumulative mass term for solutes derived from runoff to the pit lake. GoldSim was employed as the dynamic simulator using a time step length of 1 day. The cumulative mass from all source terms (runoff, groundwater, precipitation, submerged pit walls, etc.) was divided by the pit lake's volume at each time step to generate a unequilibrated concentration of mass through time. Select time steps are chosen and geochemically equilibrated in using PHREEQC.

The composite geochemical profile concentrations are functionalized by pore volumes flushed to relate real world runoff with laboratory weeks, as demonstrated in Table 5.10 and Figure 5.7. Pore volumes are tracked in the dynamic model by dividing the volume of runoff by the DRZ volume above the pit lake at each time step (Equation 8). In this way the instantaneous concentrations of runoff mass are dynamically calculated through time to match observed trends in HCT data.

$$PV_i = PV_{i-1} + \frac{(q_{runoff} * \Delta t)}{DRZ} \quad (8)$$

Where acid-generating material is located in the pit wall, the composite geochemical profiles are conservatively adjusted to reflect the period when HCT acid-generation begins and thus eliminate a potential time delay before acidity is added to the pit lake model. HCTs for the Thacker Pass Project did not produce acid leachate, therefore this was not included in the geochemical model.

Geochemical unit descriptions

Geochemical characterization for the Waste Rock Management Plan (WRMP) has identified nine unique geochemical materials present in the ultimate pit wall (SRK, 2019).

- Alluvium
- Claystone / Ash Non-PAG (<70% ash content)
- Claystone / Ash PAG
- Ash Non-PAG (>70% ash content)
- Ash PAG
- Basalt
- HPZ / Volcanic tuff
- Gangue
- Waste Rock

A tenth geochemical unit (backfill) is derived from compositing waste rock and gangue geochemical units at a 65% waste rock / 35% gangue ratio, corresponding to the Proposed Action Plan of Operations (LNC, 2019c). Specific HCTs used to develop geochemical profiles are summarized in Table 5.11.

The principal ore bearing unit is claystone/ash or ash material with a lithium cutoff grade of 2,000 mg/kg. All of the geochemical units are classified as Non-PAG materials, with the exception of very minor fraction of claystone/ash which possesses elevated quantities of sulfide minerals. Claystone / ash PAG and Ash PAG materials comprise ~0.25% of waste rock material and 1% of the ultimate pit wall.

Graphical summaries of HCT leachate concentrations as well as the composite geochemical values used in the model are graphically shown in Appendix G. Tabular week by week results from HCT tests are provided in Appendix H. Key trends pertinent to the LNC geochemical characterization are described as follows:

- **Claystone / Ash / Waste Rock material**: Claystone and ash materials comprise the majority of waste material and pit wall exposure in all three sub-pits. For purposes of the study the Claystone / ash unit is defined as zones with < 70% ash and Ash geochemical units as zones composed of > 70% ash. However, claystone and ash materials are deposited as a continuum of interbeds in varying abundances which comprise the water lain, volcanoclastic moat sediments of the deposit. The deposition and associated hydrothermal mineralization have left claystone / ash units significantly enriched in lithium, antimony, arsenic, molybdenum, selenium, and cesium (Table 5.11). However, not all elevated elements are kinetically mobile. HCTs identified that selenium and lithium were not released at particularly high rates.

  Kinetic release of elements through HCTs is primarily related to geochemical processes of desorption, ion exchange, and dissolution of soluble minerals (i.e. salts) upon initial flushes. None of the claystone/ash samples produced acid leachate (Figure 5.8a); thus sulfide oxidation is not determined to be a controlling reaction to the release of ions. This is also confirmed by the low release of sulfate and iron in late weeks (Figure 5.8a to Figure 5.8h). Two distinct release patterns were observed for constituents which exceeded NRVs.

  Elevated concentrations during initial flushing (weeks 0 – 4). Several elements including fluoride, molybdenum, sulfate, uranium, were observed to produce elevated concentrations during initial weeks of flushing, and then asymptotically decline to below NRVs during latter weeks (Figure 5.8d to Figure 5.8g, and Appendix G). This behavior suggests the dissolution of soluble minerals and/or mobilization through ion exchange.

  Steady release of mass through testing. This behavior is predominantly exhibited by the metalloid complexes of arsenic and antimony. Both ions form oxygen complexes in solution and follow similar behaviors, although arsenic is typically more actively sorbed/desorbed onto colloid surfaces. The steady release of arsenic and antimony from claystone materials suggests desorption is occurring along colloid surfaces, and the available mass in colloids is large owing to the fine-grained nature of claystone /ash matrix material. The process of sample preparation, and by analogy mine excavation, mechanically liberates colloids from their compacted state to a broken, disturbed matrix. Such mechanical mixing exposes a greater fraction of the rock matrix to water, thus allowing a greater reactive surface area than in native rocks. Arsenic and antimony are release above NRVs consistently through the HCT testing program (Figure 5.8b and Figure 5.8c). As such, waste rock is anticipated to have the potential to release these elements in backfill or WRFs.

- **Ash**: Ash units follow similar trends as claystone, owing to their very similar geochemical composition, depositional environments, and physical properties. Two out of the three Ash HCTs release antimony and arsenic at lower rates than the average claystone sample. Two hypotheses explain this observation. 1) Larger grain sizes in the ash lapilli intrinsically possess lower specific surface areas, and thus less reactive capacity, and/or 2) groundwater flow occurring primarily through ash beds has removed most of the arsenic and antimony mass through geologic time.
- **Basalt**: The basalt sample released high first flushes of sulfate, calcium, iron and magnesium. Basalt also steadily released arsenic and antimony, confirming the volcanic source of these elements. Uranium concentrations were highest in basalt, equilibrating to ~0.018 mg/l, whereas for other samples uranium concentrations fell below detection limits.
- **HPZ / Tuff**: HPZ/ tuff materials released low concentrations of all constituents, suggesting the rock units are relatively inert. Antimony concentrations were below NRVs.
- **Alluvium:** Alluvium material behaved similarly to claystone/ash material, which is to be expected because claystone/ash is the parent unit to overlying regolith. Alluvium did release the lowest amount of protons (higher pH), and greater alkalinity than other samples, suggesting near surface enrichment is occurs with carbonate coating and deposition.
- **Gangue:** Gangue undergoes a process of mechanical scrubbing and rinsing with freshwater prior to being put through a classification process (hydro-cycloning) and removed from the ore feed. Thus, the gangue is mechanically broken down into smaller particle sizes and is rinsed prior to emplacement. Gangue material is envisioned to comprise ~35% of the backfilled pit and will be stockpiled at surface. Gangue is divided into two types based on source rock, oxidized gangue and unoxidized gangue. HCTs from both types were composited to create a geochemical profile for gangue material.

  HCT leachate from oxidized gangue samples were elevated with respect to aluminum and iron metals which were not observed in other samples. The ion balance in gangue samples was generally poor (>30%), which suggests a portion of clay particles are passing through the 45 µm laboratory filter and releasing iron and aluminum when acidified for preservation. Elevated metal concentrations are retained for the pit lake and WRF analysis for conservatism.

  Unoxidized rock samples generated circum-neutral leachate and were elevated in antimony, arsenic, molybdenum, and sulfate. Unoxidized gangue is closer in geochemical character to claystone waste rock and leaches a similar suite of solutes and concentrations.

Further descriptions of the mineralogy, static geochemical testing program, and interpretation of geochemical units are fully described in the WRMP (SRK, 2019).

Table 5.11: Geochemical Abundance Index (GAI) enrichment values for HCT samples

Sample ID	Material	GAI Values[1]								
		Li	Sb	Cs	Se	As	Mo	S	U	Fe
WLC-026 (125.8-166.1)	Basalt	5	6	6	6	5	3	4	2	0
WLC-65 (332-346.1)	HPZ	3	5	1	5	7	4	0	2	0
WLC-85 (168.6-176.9)	Claystone / Ash	7	4	4	5	6	6	6	1	0
WLC-87 (143.6-163.9)	Ash	4	5	4	5	2	2	3	0	0
WLC-88 (80.3-89.4)	Claystone / Ash	5	6	4	5	3	4	2	0	0
WLC-90 (113.5-125.8)	Claystone / Ash	5	4	4	4	3	4	5	0	0
WLC-92 (26.9-46)	Claystone / Ash	6	2	6	3	0	0	0	0	0
WLC-96 (206.4-230.2)	Ash	6	6	5	4	7	6	5	0	0
WLC-117 (76.5-85.5)	Claystone / Ash	6	6	4	4	5	6	5	0	0
WLC-199 (132.2-162.2)	Claystone / Ash	6	4	4	4	4	4	5	0	0
WLC-199 (202-221.8)	Claystone / Ash	7	6	6	4	6	6	5	1	0
WLC-204 (75-82)	Claystone / Ash	6	4	6	4	1	0	0	0	0
Average		**6**	**5**	**5**	**4**	**4**	**4**	**3**	**1**	**0**

GAI explanation (GARD, 2014)
GAI=0 represents <3 times median soil content
GAI=1 represents 3 to 6 times median soil content
GAI=2 represents 6 to 12 times median soil content
GAI=3 represents 12 to 24 times median soil content
GAI=4 represents 24 to 48 times median soil content
GAI=5 represents 48 to 96 times median soil content
GAI=6 represents more than 96 times median soil content

HCT datasets were composited using geometric averages to develop a representative geochemical profile, with pH calculated using the geometric mean of hydrogen proton concentrations. The methodology for assigning non-detects values in the HCT dataset varied slightly from that used for groundwater chemistry to account for geometric averaging. Non-detect values were assigned in two ways:

1. If the element was detected at any time during the monitoring period, then all non-detect values were assigned to equal 50 percent of the detection limit.
2. If the element was never detected during the monitoring history, then a value 10 percent of the detection limit was assigned to geochemical profile.

HCTs used to composite proxy geochemical profiles are shown in Table 5.12. Waste rock is assumed to be comprised of both Claystone / Ash and Ash geochemical units; thus it is comprised of all the HCTs for this material.

Table 5.12: Composite geochemical profile HCT summary

Geochemical Unit	HCT Sample	Runoff HCT weeks	Submergence HCT week
Ash (Non-PAG)	WLC-87 (143.6-163.9)	0-40	2
	WLC-96 (206.4-230.2)	0-40	2
Ash (PAG), Claystone (PAG)	WLC-050 (337.1-357.2)	0-40	2
Basalt	WLC-026 (125.8-166.1)	0-40	2
Claystone (Non-PAG)	WLC-85 (168.6-176.9)	0-40	2
	WLC-88 (80.3-89.4)	0-40	2
	WLC-90 (113.5-125.8)	0-40	2
	WLC-92 (26.9-46)	0-40	2
	WLC-199 (132.2-162.2)	0-40	2
	WLC-204 (75-82)	0-40	2
HPZ, Tuff	WLC-65 (332-346.1)	0-40	2
Alluvium	LNC-079 (0-7.6)	0-40	2
Gangue	7&56-CG30M-L19A-4	0-40	0
	9-CYCUFCOMP-E23B-356	0-40	0
	Sample Group #2 (+) 75um	0-20	0
	Sample Group #2 (+) 75um	0-20	0
Waste Rock	WLC-85 (168.6-176.9)	0-40	0
	WLC-88 (80.3-89.4)	0-40	0
	WLC-90 (113.5-125.8)	0-40	0
	WLC-92 (26.9-46)	0-40	0
	WLC-199 (132.2-162.2)	0-40	0
	WLC-204 (75-82)	0-40	0
	WLC-87 (143.6-163.9)	0-40	0
	WLC-96 (206.4-230.2)	0-40	0

Tabulated values for composited geochemical profiles used in the geochemical model are presented in Appendix I

5.3.5 Submerged Pit Wall / Backfill Flushing

Composited HCT results were assigned to wall rock lithologies of the sub-pit to account for mass loading attributed to the submergence and flushing of pit wall rock. Pit wall deformation is known to be capable of extending deep into the rock mass at distances greater than 50 ft; however, oxidation is restricted to the shallow 15 ft to 50 ft rind immediately behind the pit wall. This geochemically reactive zone is adjacent the atmosphere and runoff which oxidize insitu minerals along fracture planes and in accumulated debris. However, the mass release by material comprising the LNC pit wall is related to the increased surface area and deformation in the DRZ rather than oxidation of sulfides behind the pit wall. Thus, a narrow rind surrounding the pit is the appropriate representation of mass loading from submerged wall rock.

Three flushed pore volumes and a DRZ thickness of 15 ft is appropriate to account for the accumulation of solutes from flushing the rind around an open pit based the conceptual model and experience. This corresponds to approximately 2 weeks of HCT testing, being the first flushes of chemical production. Flushed pore volumes were multiplied by the relative percentages of submerged lithologies and the corresponding lithologic geochemical composition. Mass loading from pit wall flushing is considered to occur only once upon initial inundation.

5.4 PREDICTIVE SIMULATIONS

Unique geochemical models were prepared for the North, West, and South sub-pits for the Proposed Action and two Alternative closure configurations described in Section 4.1. The geochemical model configuration and results are described in the following sub-sections.

5.4.1 Backfilled Pit Proposed Action

Backfilled Pit Proposed Action configuration

The Backfilled Pit Proposed Action and would preclude the formation of a pit lake in any of the sub pits. Backfill comprised of 65% waste rock (claystone/ash and ash geochemical units) and 35% gangue would be placed in the open pit as shown in Figures 4.1 and Figure 4.2. Backfill elevation is least 50 ft above post-closure water levels in each sub-pit, summarized in Table 5.13.

Table 5.13: Backfill elevation summary

Sub-pit	Maximum Backfill Elevation (ft, amsl	Minimum Backfill Elevation (ft, amsl)	Simulated Post-Closure Water Level (ft, amsl)
North	5,143	4,968	4,833
West	5,343	5,143	4,817
South	5,143	4,843	4,753

Backfill will not contain any amendments at the present time, future geochemical testing may evaluate several amendments with the objective of attenuating arsenic and antimony complexes potentially released by waste rock.

Additional mass loading terms are incorporated into the geochemical model to account for infiltration through backfill and rinsing submerged backfill. Week 0 chemistry for the Backfill geochemical profile was used to represent infiltration and backfill submergence (Appendix I). Week 0 chemistry releases the greatest mass of major and minor ions solutes, and is therefore a conservative representation of mass loading. Scaling factors for backfill material are described in Table 5.3.

Geochemical modeling follows the methodology outlined in section 5.1.1. and geochemical profiles in section 5.3.

Backfilled Pit Proposed Action water balance results

Water balance results are presented in Table 5.14 and Appendix J. Equilibrium water levels in the backfilled sub-pits recover to the following elevations as discussed in Section 4 (Figure 4.11).

The single largest contribution to the backfilled pit is groundwater inflow, followed by infiltration (Table 5.14). There is no contribution from pit wall runoff or precipitation owing to the backfill placement final elevation being above pit wall grade. Equilibrium groundwater outflow ranges from 8.0 gpm to 14.7 gpm and is the only discharge from backfilled pits. Groundwater outflow will possess pore water geochemistry which will mix with background groundwater along its flow path.

Table 5.14: Backfilled Pit Proposed Action: water balance summary

West Sub-pit									
Stage (ft, amsl)	**4779**	**4785**	**4788**	**4792**	**4807**	**4813**	**4817**	**4817**	**4817**
Time (yr)	**1**	**3**	**5**	**10**	**30**	**55**	**100**	**200**	**300**
Infiltration (gpm)	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
Pit Wall Runoff (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bedrock Groundwater (gpm)	8.2	6.9	6.5	6.2	5.8	5.6	5.5	5.4	5.4
ET (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Groundwater Outflow (gpm)	16.8	15.8	15.6	15.3	14.8	14.7	14.7	14.7	14.7
North Sub-pit									
Stage (ft, amsl)	**4771**	**4786**	**4795**	**4807**	**4820**	**4828**	**4832**	**4833**	**4833**
Time (yr)	**1**	**3**	**5**	**10**	**30**	**55**	**100**	**200**	**300**
Infiltration (gpm)	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
Pit Wall Runoff (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bedrock Groundwater (gpm)	5.5	11.0	9.6	8.5	7.0	5.8	4.9	4.9	4.9
ET (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Groundwater Outflow (gpm)	2.0	2.6	3.7	5.0	6.9	7.9	8.0	8.0	8.0
South Sub-pit									
Stage (ft, amsl)	**4608**	**4656**	**4684**	**4706**	**4735**	**4748**	**4751**	**4753**	**4753**
Time (yr)	**1**	**3**	**5**	**10**	**30**	**55**	**100**	**200**	**300**
Infiltration (gpm)	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Pit Wall Runoff (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
East WRF Inflow (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bedrock Groundwater (gpm)	41.4	32.9	24.2	17.9	9.3	6.0	5.3	5.1	5.1
North Sub-pit Inflow (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West Sub-pit Inflow (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ET (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Groundwater Outflow (gpm)	13.8	8.7	6.8	6.1	6.1	8.9	10.3	11.0	11.0

Backfilled Pit Proposed Action geochemical results

Simulated pore water chemistry in sub-pits are shown in Table 5.15 to Table 5.17 and graphically in Figures 5.9a through 5.9c. The PHREEQ-C input for the Backfilled Pit Proposed Action is provided in Appendix K. Key results of the geochemical model are:

- Pore water chemistry is predicted to be circum-neutral and meet most Profile I standards. Water chemistry improves through time as the initial mass released during filling is mixed with groundwater. This is observed in all backfilled sub-pits.

- There is no risk of acid-generation given the alkalinity available in backfill materials and groundwater. Predicted alkalinity concentrations range from 130 mg/l to 250 mg/l, which are aligned with observed groundwater concentrations.
- Sulfate is predicted to exceed NRVs during for 75 years post-closure and TDS for 100 years post-closure (South Sub-pit). Concentration of both constituents gradually declines as the backfill is subsequently rinsed by groundwater.
- Manganese Profile I NRVs are exceeded for 3-years post-closure only in the North Sub-pit.
- Magnesium Profile I NRVs are exceeded for 30-years post-closure in the North Sub-pit and South Sub-pits, but decline with time.
- Chloride Profile I NRVs are slightly exceeded in the North and South Sub-pits for a maximum of 10 years, and then decline.
- Backfill pore water chemistry is predicted to have elevated concentrations of arsenic and antimony after 300 years of closure in each sub-pit (Figure 5.9b). The source of arsenic and antimony is waste rock (claystone/ash and ash) placed in the backfill. This result is anticipated based on the consistently elevated concentrations of these elements generated during HCT testing. The risk associated to downgradient groundwater by arsenic and antimony is analyzed in the following sub-section and in Section 6.

Table 5.15: Backfilled Pit Proposed Action: simulated North Sub-pit chemistry

Concentration (mg/L)	*Profile I*	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**
Year		**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
pH	*6.5-8.5*	7.71	7.71	7.71	7.72	7.73	7.75	7.76	7.66	7.58	7.55	7.54	7.54	7.54	7.54	7.54
pe	*-----*	4.00	4.00	2.00	1.00	0.00	-1.00	-2.00	-3.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00
Alkalinity Total	*-----*	232	233	233	235	238	244	248	188	152	144	138	138	137	137	137
Aluminum	*0.2*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	*0.006*	**0.099**	**0.090**	**0.086**	**0.077**	**0.066**	**0.048**	**0.040**	**0.024**	**0.015**	**0.012**	**0.011**	**0.011**	**0.011**	**0.011**	**0.011**
Arsenic	*0.01*	**0.185**	**0.125**	**0.109**	**0.089**	**0.077**	**0.056**	**0.048**	**0.031**	**0.021**	**0.019**	**0.017**	**0.017**	**0.017**	**0.017**	**0.017**
Barium	*2*	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03
Beryllium	*0.004*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Boron	*-----*	1.112	0.971	0.916	0.817	0.708	0.543	0.466	0.315	0.229	0.209	0.193	0.193	0.191	0.191	0.192
Bismuth	*----*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	*0.005*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Calcium	*-----*	248	243	238	225	205	171	152	97	64	57	51	51	50	50	51
Chloride	*400*	**427**	**413**	399	366	319	241	199	122	80	70	63	63	62	62	62
Chromium	*0.1*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	*1*	0.018	0.016	0.018	0.018	0.016	0.014	0.013	0.010	0.009	0.009	0.008	0.008	0.008	0.008	0.008
Fluoride	*4*	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.76	2.88	2.63	2.45	2.45	2.42	2.42	2.43
Iron	*0.6*	0.00	0.00	0.00	0.01	0.10	0.09	0.08	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Lead	*0.015*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Lithium	*-----*	3.09	2.96	2.85	2.60	2.26	1.71	1.41	0.87	0.57	0.50	0.45	0.45	0.44	0.44	0.44
Magnesium	*150*	**190**	**187**	**181**	**167**	146	111	92	57	38	33	30	30	29	29	30
Manganese	*0.1*	**0.2**	**0.1**	**0.1**	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mercury	*0.002*	0.0011	0.0006	0.0005	0.0004	0.0003	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Molybdenum	*-----*	7.35	6.96	6.69	6.07	5.23	3.88	3.19	1.88	1.17	1.00	0.87	0.87	0.85	0.85	0.86
Nickel	*0.1*	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total Nitrogen	*10*	1.68	1.62	1.56	1.43	1.26	0.97	0.82	0.54	0.38	0.34	0.32	0.32	0.31	0.31	0.31
Phosphorus	*-----*	0.52	0.45	0.43	0.39	0.34	0.27	0.24	0.18	0.14	0.13	0.13	0.13	0.13	0.13	0.13
Potassium	*-----*	32.2	29.5	28.1	25.4	22.0	16.5	13.8	8.5	5.7	5.0	4.5	4.5	4.4	4.4	4.4
Selenium	*0.05*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	*0.1*	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Sodium	*-----*	215	204	197	181	160	126	108	75	56	52	48	48	48	48	48
Strontium	*-----*	3.985	3.880	3.762	3.464	3.033	2.313	1.926	1.210	0.817	0.726	0.656	0.657	0.647	0.647	0.652
Sulfate	*500*	**1,087**	**1,055**	**1,023**	**941**	**820**	**618**	**509**	308	197	171	151	152	149	149	150
Thallium	*0.002*	0.0005	0.0005	0.0005	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Tin	*-----*	0.037	0.033	0.031	0.028	0.025	0.020	0.017	0.013	0.010	0.009	0.009	0.009	0.009	0.009	0.009
TDS	*1000*	**2,453**	**2,385**	**2,320**	**2,159**	**1,927**	**1,541**	**1,335**	864	600	538	491	491	485	485	488
TSS	*-----*															
Uranium	*0.03*	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vanadium	*-----*	0.058	0.053	0.051	0.046	0.039	0.030	0.025	0.016	0.011	0.009	0.008	0.009	0.008	0.008	0.008
Zinc	*5*	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

0.00	Profile I Exceedance

Table 5.16: Backfilled Pit Proposed Action: simulated West Sub-pit chemistry

Concentration (mg/L)	*Profile I*	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit
Year		**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
pH	*6.5-8.5*	7.66	7.64	7.63	7.63	7.63	7.64	7.63	7.63	7.62	7.62	7.62	7.62	7.62	7.62	7.62
pe	-----	4.00	4.00	2.00	0.00	-1.00	-2.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00
Alkalinity Total	-----	193	183	180	179	180	184	181	178	176	175	174	174	174	174	174
Aluminum	*0.2*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	*0.006*	**0.032**	**0.031**	**0.030**	**0.030**	**0.031**	**0.033**	**0.032**	**0.031**	**0.031**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**
Arsenic	*0.01*	**0.031**	**0.029**	**0.027**	**0.029**	**0.030**	**0.032**	**0.030**	**0.029**	**0.029**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**
Barium	*2*	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Beryllium	*0.004*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Boron	-----	0.336	0.318	0.311	0.313	0.317	0.331	0.322	0.315	0.309	0.308	0.305	0.305	0.305	0.305	0.305
Bismuth	----	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	*0.005*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Calcium	-----	125	122	120	122	123	128	127	125	123	123	122	122	122	122	122
Chloride	*400*	157	153	151	153	155	162	161	159	157	156	155	155	155	155	155
Chromium	*0.1*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	*1*	0.006	0.006	0.006	0.007	0.007	0.007	0.007	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Fluoride	*4*	3.55	3.57	3.58	3.57	3.57	3.54	3.54	3.56	3.56	3.57	3.57	3.57	3.57	3.57	3.57
Iron	*0.6*	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Lead	*0.015*	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lithium	-----	1.11	1.08	1.06	1.08	1.09	1.14	1.13	1.11	1.10	1.10	1.09	1.09	1.09	1.09	1.09
Magnesium	*150*	74	72	72	72	73	76	76	75	74	74	73	73	73	73	73
Manganese	*0.1*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mercury	*0.002*	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Molybdenum	-----	2.59	2.49	2.45	2.49	2.53	2.66	2.61	2.56	2.52	2.51	2.49	2.49	2.49	2.49	2.49
Nickel	*0.1*	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total Nitrogen	*10*	0.79	0.76	0.75	0.75	0.75	0.77	0.76	0.75	0.74	0.74	0.73	0.73	0.73	0.73	0.73
Phosphorus	-----	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15
Potassium	-----	10.6	10.2	10.0	10.1	10.3	10.8	10.6	10.4	10.3	10.3	10.2	10.2	10.2	10.2	10.2
Selenium	*0.05*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	*0.1*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Sodium	-----	79	76	75	75	76	78	77	76	75	75	74	74	74	74	74
Strontium	-----	1.528	1.483	1.465	1.482	1.499	1.560	1.549	1.523	1.504	1.500	1.490	1.490	1.490	1.490	1.490
Sulfate	*500*	407	397	393	398	404	421	418	411	406	405	402	402	402	402	402
Thallium	*0.002*	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Tin	-----	0.013	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.011	0.011	0.011	0.011	0.011	0.011
TDS	*1000*	**1,057**	**1,023**	**1,010**	**1,020**	**1,031**	**1,070**	**1,061**	**1,044**	**1,031**	**1,028**	**1,021**	**1,021**	**1,021**	**1,021**	**1,021**
TSS	-----															
Uranium	*0.03*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Vanadium	-----	0.019	0.018	0.018	0.018	0.018	0.019	0.019	0.019	0.018	0.018	0.018	0.018	0.018	0.018	0.018
Zinc	*5*	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

0.00 Profile I Exceedance

Table 5.17: Backfilled Pit Proposed Action: simulated South Sub-pit chemistry

Concentration (mg/L)	*Profile I*	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**
Year		**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
pH	*6.5-8.5*	7.74	7.74	7.73	7.73	7.73	7.73	7.73	7.75	7.76	7.77	7.69	7.66	7.64	7.63	7.62
pe	-----	4.00	4.00	-2.00	0.00	-2.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00
Alkalinity Total	-----	248	245	244	243	242	241	241	245	250	251	205	190	180	174	172
Aluminum	*0.2*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	*0.006*	**0.073**	**0.077**	**0.079**	**0.081**	**0.079**	**0.076**	**0.071**	**0.055**	**0.042**	**0.036**	**0.025**	**0.022**	**0.019**	**0.018**	**0.017**
Arsenic	*0.01*	**0.065**	**0.068**	**0.072**	**0.074**	**0.071**	**0.067**	**0.062**	**0.050**	**0.039**	**0.034**	**0.026**	**0.023**	**0.021**	**0.020**	**0.019**
Barium	*2*	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.02
Beryllium	*0.004*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Boron	-----	1.017	1.038	1.053	1.061	1.030	0.970	0.900	0.732	0.599	0.535	0.428	0.391	0.367	0.354	0.348
Bismuth	----	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	*0.005*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Calcium	-----	199	208	211	215	215	215	207	180	156	143	106	94	85	80	78
Chloride	*400*	378	394	**401**	**407**	**401**	387	362	289	228	198	146	129	117	111	108
Chromium	*0.1*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	*1*	0.016	0.016	0.018	0.018	0.018	0.017	0.015	0.013	0.011	0.010	0.008	0.008	0.008	0.007	0.007
Fluoride	*4*	3.64	3.62	3.61	3.60	3.58	3.55	3.53	3.51	3.50	3.49	3.71	3.74	3.45	3.30	3.24
Iron	*0.6*	0.00	0.00	0.08	0.08	0.08	0.07	0.07	0.06	0.04	0.04	0.03	0.02	0.02	0.02	0.02
Lead	*0.015*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Lithium	-----	2.54	2.65	2.71	2.76	2.72	2.63	2.45	1.95	1.52	1.31	0.95	0.83	0.75	0.71	0.69
Magnesium	*150*	**166**	**173**	**176**	**179**	**177**	**171**	**161**	128	101	87	64	56	51	48	47
Manganese	*0.1*	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mercury	*0.002*	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Molybdenum	-----	5.74	6.05	6.21	6.36	6.25	6.04	5.63	4.43	3.42	2.92	2.06	1.77	1.57	1.46	1.42
Nickel	*0.1*	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Total Nitrogen	*10*	1.25	1.31	1.34	1.36	1.34	1.30	1.21	0.96	0.75	0.64	0.46	0.40	0.36	0.34	0.33
Phosphorus	-----	0.37	0.37	0.38	0.38	0.37	0.35	0.33	0.27	0.22	0.19	0.15	0.14	0.13	0.13	0.12
Potassium	-----	23.7	24.8	25.4	25.9	25.4	24.5	22.8	18.1	14.1	12.1	8.7	7.6	6.8	6.4	6.2
Selenium	*0.05*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	*0.1*	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Sodium	-----	207	212	215	216	211	201	187	152	124	111	88	80	75	72	71
Strontium	-----	3.522	3.661	3.724	3.775	3.726	3.604	3.372	2.699	2.136	1.857	1.382	1.221	1.110	1.053	1.029
Sulfate	*500*	**898**	**940**	**958**	**973**	**965**	**940**	**881**	**700**	**547**	470	340	295	265	249	242
Thallium	*0.002*	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001
Tin	-----	0.027	0.027	0.028	0.028	0.027	0.026	0.024	0.020	0.016	0.014	0.011	0.010	0.009	0.009	0.009
TDS	*1000*	**2,139**	**2,216**	**2,250**	**2,279**	**2,256**	**2,199**	**2,080**	**1,728**	**1,432**	**1,283**	967	860	786	747	731
TSS	-----															
Uranium	*0.03*	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000
Vanadium	-----	0.051	0.053	0.055	0.056	0.054	0.051	0.048	0.038	0.030	0.026	0.020	0.018	0.016	0.015	0.015
Zinc	*5*	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00

0.00 Profile I Exceedance

Backfilled Pit Proposed Action groundwater screening level assessment

The objective of the groundwater screening level assessment is to determine which constituents require more rigorous evaluation using a fate and transport numerical model. The screening level assessment conservatively estimates the concentration of solutes at specific intervals down-gradient of the backfill. Discharged pore water from the backfill will migrate and mix with background groundwater along flow vectors. The concentration of constituents down-gradient is a function of the velocity field (advective dispersion) as well as diffusion across a concentration gradient. Mixing between pore water and background groundwater will occur according to the background velocity field.

To conservatively assess groundwater chemistry down-gradient of backfilled sub-pits, a simple mass mixing analysis was performed for various groundwater footprints surrounding the backfill. The analysis mixed the flux of backfill discharge with the background groundwater flux surrounding the backfill. Resulting groundwater chemistry represent the mixed geochemical profiles of groundwater and pore water at a specified time and distance from the backfill. This analysis is considered conservative because it omits additional processes which could potentially retard or dilute pore water chemistry such as:

- No dilution due to mixing with insitu storage (rock porosity) was incorporated into the calculation to produce a conservative steady-state estimate.
- No dispersion of the velocity field (i.e. dispersivity), and thus spreading of pore water concentrations was not considered.
- Diffusion across concentration gradients is omitted. This is typically a minor effect relative to advection.
- No attenuation onto the aquifer skeleton is considered because the receiving down-gradient host rock is composed of the same claystone/ash units which release arsenic and antimony. This is a conservative estimate as some volcanic tuff and HPZ materials are found along the flow paths of backfill discharge.
- Discharge across the entire backfill footprint was assumed which is much broader than the footprint of saturated backfill in the sub-pits.

The mass mixing model was performed using the following steps:

1. Identify the mixing footprint beneath backfill for each sub-pit at specified times. Each cell which was intersected by a particle trace was assigned a time value corresponding to the mean particle travel time. In this sense the mixing footprint beneath the backfill is delineated through time. Time values lumped into the following groups:

- 0-50 yr
- 50-100 yr
- 100-150 yr
- 150-200 yr
- 200-250 yr
- 250-300yr

2. Mixing footprints were delineated using a forward particle track analysis inform the average distance travelled for each time period. to map the Modpath 3DU. The Modpath 3DU simulator was used to generate particle tracks using the equilibrium velocity field at 300 years post-closure (S.S. Papadopulos, 2019). Initial particle locations were placed at pit shell / backfill contact, however where backfill was unsaturated particle locations were automatically placed at the underlying water table. Forward particle traces were calculated using the Runge-Kutta numerical scheme and omitting the effects of retardation and dispersion. Porosity values were the same as specific yield values presented in Table 3.3.
3. The foregoing time group footprints are shown in Figure 5.10 to Figure 5.12 for each backfilled sub-pit.
4. Calculate the fluxes of groundwater and backfill outflow for each time group. Each unique footprint is assigned a unique Hydrostratigraphic Zone in the Backfilled Pit post-closure numerical groundwater model. A water balance is performed for each zone using the cell-by-cell output file from Modflow-USG to calculate the flux of background groundwater entering the mixing footprint. Backfill discharge was previously accounted for in the sub-pit water balance. Groundwater flow and backfill discharge fluxes are tabulated in Table 5.18.
5. Assign geochemical profiles for groundwater and pore water. Geochemical values for arsenic, antimony, and sulfate are assigned for groundwater (via background chemistry shown in Tables 5.6 to 5.8). Discharging pore water chemistry is assigned a time-weighted average from concentrations shown in Tables 5.15 to 5.17. Only arsenic, antimony, sulfate, and magnesium are considered in the risk assessment because their concentrations exceed NRVs for more than 10 years. Chloride and manganese exceedances are short and only slightly above NRVs, therefore analysis of other constituents is a suitable analogue for these elements. Input geochemical mixing values are provided in Table 5.18.
6. Proportionately mix groundwater with backfill discharge. Resulting mixed concentrations are shown in Table 5.18.

Table 5.18: Backfilled Pit Proposed Action: screening level assessment

Backfilled North Sub-pit						
			As (mg/l)	**Sb (mg/l)**	**SO4 (mg/l)**	**Mg (mg/l)**
Background Groundwater Chemistry			0.016[1]	0.0006	27	10
Backfill Discharge Chemistry			0.024[1]	0.016[1]	388	42
Time Group	Groundwater (gpm)	Discharge (gpm)	**As (mg/l)**	**Sb (mg/l)**	**SO4 (mg/l)**	**Mg (mg/l)**
0 – 50 yr	13.5	4.7	0.018[1]	0.005	77	18
50 – 100 yr	40.8	8.0	0.017[1]	0.003	59	15
100 – 150 yr	31.0	8.0	0.018[1]	0.004	67	17
150 – 200 yr	37.1	8.0	0.017[1]	0.003	62	16
200 – 250 yr	46.6	8.0	0.017[1]	0.003	56	15
250 – 300 yr	62.5	8.0	0.017[1]	0.002	49	14
Backfilled West Sub-pit						
			As (mg/l)	**Sb (mg/l)**	**SO4 (mg/l)**	**Mg (mg/l)**
Background Groundwater Chemistry			0.017[1]	0.0003	29	13
Backfill Discharge Chemistry			0.028[1]	0.030[1]	405	74
Time Group	Groundwater (gpm)	Discharge (gpm)	**As (mg/l)**	**Sb (mg/l)**	**SO4 (mg/l)**	**Mg (mg/l)**
0 – 50 yr	3.7	13.9	0.026[1]	0.024[1]	326	61
50 – 100 yr	8.0	14.5	0.024[1]	0.020[1]	272	52
100 – 150 yr	8.0	14.7	0.024[1]	0.020[1]	273	52
150 – 200 yr	11.1	14.7	0.025[1]	0.017[1]	243	47
200 – 250 yr	16.9	14.7	0.022[1]	0.014[1]	204	41
250 – 300 yr	258.6	14.7	0.018[1]	0.002	49	16
Backfilled South Sub-pit						
			As (mg/l)	**Sb (mg/l)**	**SO4 (mg/l)**	**Mg (mg/l)**
Background Groundwater Chemistry			0.017[1]	0.0013	48	18
Backfill Discharge Chemistry			0.031[1]	0.031[1]	409	76
Time Group	Groundwater (gpm)	Discharge (gpm)	**As (mg/l)**	**Sb (mg/l)**	**SO4 (mg/l)**	**Mg (mg/l)**
0 – 50 yr	4.0	8.4	0.026[1]	0.022[1]	293	58
50 – 100 yr	12.4	11.0	0.023[1]	0.015[1]	217	46
100 – 150 yr	14.0	11.0	0.023[1]	0.014[1]	207	44
150 – 200 yr	23.5	11.0	0.022[1]	0.011[1]	163	37
200 – 250 yr	32.5	11.0	0.021[1]	0.009[1]	139	33
250 – 300 yr	57.8	11.0	0.019[1]	0.006[1]	105	28

[1] Exceeds Profile 1 NRVs

Results for the screening level assessment are discussed as follows:

- Arsenic and antimony are the only elements which exceed NRVs beyond the pit footprints (0-50 years).
- Sulfate and manganese concentrations are predicted to be lower than NRVs at all time intervals. Risk associated with sulfate and manganese impacting groundwater is low because i) the composite pore water chemistry is below NRVs for all three sub-pits (Table 5.18), and ii) groundwater mixing attenuates sulfate and manganese concentrations within a short distance of the backfill. For these reasons sulfate and manganese were not further evaluated using fate and transport modeling.
- Arsenic concentrations are slightly higher than background chemistry as a result of backfilling. Arsenic concentrations will always exceed NRVs because background concentrations are higher than Profile I standards. Predicted arsenic concentrations range from 0.017 mg/l to 0.026 mg/l, which are within the range of observed chemistries onsite (WSH-11, WSH-17, MW18-03). Because of the prevailing background concentrations, arsenic is not considered to degrade groundwater and was not evaluated in the fate and transport modeling.
- Antimony concentrations exceed NRVs in mixed groundwater zones for the West and South Sub-pits. Exceedances remain above or near Profile I standards for most of the post-closure period. Therefore antimony was evaluated using the fate and transport model which is described in Section 6.

5.4.2 Open Pit Alternative

Open Pit Alternative configuration

Open Pit Alternative is an alternative closure configuration evaluated for the EIS. Closure of the three sub-pits would occur after mining is completed with no backfill placement or buttressing. Overland runoff would be diverted along the pit crests. Three separate pit lakes are anticipated to form under this closure Alternative, as discussed in Section 4.1.

Open Pit Alternative water balance results

Three separate pit lakes form in the open sub-pits (Figure 4.17). Water balance results are presented in Table 5.19 and Appendix J. Key results from the pit lake water balance is as follows:

- North Sub-pit: The North Sub-pit recovers to an elevation of 4,779 ft amsl at approximately 30 years post-closure. The pit lake is mostly comprised of pit wall runoff and precipitation (~75% of inflow components). The pit lake is a flow through, with all of its discharge being captured by the South Sub-pit pit lake.

- West Sub-pit: The West Sub-pit recovers to an elevation of 4,827 ft amsl at approximately 30 years post-closure. The pit lake is mostly comprised of pit wall runoff and precipitation (~90% of inflow components). This is a result of the large open pit catchment above the water table. The pit lake is a flow through with most of its discharge being captured by the South Sub-pit pit lake, however some discharge along the western margin of the pit lake may escape containment and discharge towards Kings River Valley.
- South Sub-pit: The South Sub-pit recovers to an elevation of 4,677 ft amsl at approximately 100 years post-closure. The South pit lake has a greater fraction of the lake comprised of groundwater (~42% of inflow components) than the other two sub-pits due to mining deeper below the water table. The South sub-pit pit lake is a hydraulic sink, capturing components of discharge from the North sub-pit, West sub-pit, and from below the East WRF. These inflow components comprise ~15 gpm of the pit inflow at equilibrium and are assigned geochemical profiles from their respective sources in the geochemical model.

Table 5.19: Open Pit Alternative: water balance summary

North sub-pit									
Stage (ft, amsl)	**4762**	**4773**	**4775**	**4777**	**4779**	**4779**	**4779**	**4779**	**4779**
Time (yr)	**1**	**3**	**5**	**10**	**30**	**55**	**100**	**200**	**300**
Precipitation (gpm)	1.5	4.3	6.4	7.4	8.3	8.4	8.4	8.4	8.4
Pit Wall Runoff (gpm)	17.3	17.0	16.8	16.7	16.6	16.6	16.6	16.6	16.6
Bedrock Groundwater (gpm)	7.5	11.4	8.9	8.6	8.6	8.6	8.6	8.6	8.6
ET (gpm)	5.4	15.2	22.6	26.0	29.1	29.6	29.6	29.6	29.6
Groundwater Outflow (gpm)	2.9	1.4	1.4	2.2	3.7	3.9	3.9	3.9	3.9
West sub-pit									
Stage (ft, amsl)	**4797**	**4810**	**4816**	**4824**	**4827**	**4827**	**4827**	**4827**	**4827**
Time (yr)	**1**	**3**	**5**	**10**	**30**	**55**	**100**	**200**	**300**
Precipitation (gpm)	1.4	3.4	5.7	8.1	10.2	10.7	10.7	10.7	10.7
Pit Wall Runoff (gpm)	32.5	32.3	32.1	31.9	31.6	31.6	31.6	31.6	31.6
Bedrock Groundwater (gpm)	7.6	5.6	4.8	4.7	4.6	4.4	4.4	4.4	4.4
ET (gpm)	5.3	12.2	20.0	28.5	36.0	37.8	37.8	37.8	37.8
Groundwater Outflow (gpm)	6.9	6.5	6.1	7.1	8.3	9.0	9.0	9.0	9.0
South sub-pit									
Stage (ft, amsl)	**4611**	**4626**	**4636**	**4652**	**4677**	**4677**	**4677**	**4677**	**4677**
Time (yr)	**1**	**3**	**5**	**10**	**30**	**55**	**100**	**200**	**300**
Precipitation (gpm)	3.3	7.0	8.3	10.1	14.2	16.6	17.1	17.1	17.1
Pit Wall Runoff (gpm)	19.8	19.4	19.3	19.1	18.7	18.4	18.4	18.4	18.4
Bedrock Groundwater (gpm)	36.8	41.3	36.8	28.7	16.6	9.4	8.0	8.0	8.0
East WRF Inflow (gpm)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
North Sub-pit Inflow (gpm)	2.1	1.4	1.2	1.4	3.2	4.3	4.4	4.4	4.4
West Sub-pit Inflow (gpm)	6.2	7.0	6.3	7.5	8.8	10.2	10.3	10.3	10.3
ET (gpm)	11.7	23.4	28.5	34.9	48.7	55.2	56.7	56.7	56.7
Groundwater Outflow (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Open Pit Alternative geochemical results

Simulated water chemistry in TPP sub-pits are shown in Tables 5.20 and 5.22 and graphically in Figures 5.13a through 5.13c. PHREEQC input files are presented in Appendix K. Key results of the geochemical model are:

- The North and West Sub-pits, which are flow through pits, share similar trends chemogenesis namely i) initial filling and inundation which releases first flushes of constituents from pit rinsing and runoff during years 0 - 10, ii) slower solute concentration characterized by evapoconcentration of constituents, and iii) late-term equilibrium where lake concentrations decline due to discharge from pit lakes and reduced solute loading from pit wall runoff terms.

- The North Sub-pit pit lake chemistry is predicted to be circum-neutral with increasing solute concentrations during the first 150 years of filling. Pit lake chemistry is predicted to exceed NRVs with respect to Profile I for several constituents (Sb, As, F, Mn, SO4, and TDS) however outflow from the pit lake will be captured by the South sub-pit pit lake. Several constituents are predicted to exceed Profile III standards (As, F, Mo, V) and thus require an ecological risk assessment (ERA) to evaluate toxicity thresholds to wildlife if this alternative is pursued.
- The West Sub-pit pit lake chemistry is predicted to be circum-neutral with increasing solute concentrations during the first 80 years of filling. Pit lake chemistry is predicted to exceed NRVs with respect to Profile I for several constituents (Sb, As, F, Mn, SO4, and TDS). West Sub-pit outflow is anticipated to be captured by the South Sub-pit pit lake. Several solutes are predicted to exceed Profile III standards (As, F, Mo, V), although only fluoride is anticipated to remain above Profile III standards during the entire 300-year simulation. Arsenic, molybdenum, and vanadium concentrations decline below Profile III after year 200.
- The South Sub-pit pit lake chemistry is predicted to be circum-neutral with increasing solute concentrations throughout its formation due to the process of evapoconcentration of a hydraulic sink. Pit lake chemistry is predicted to exceed Profile III standards (As, Sb, B, F, Mo, V). Outflow from other mine facilities is captured by the South sub-pit pit lake, however sensitivity analyses indicate this is a minor component to pit lake chemistry, overshadowed by the effect of evapoconcentration.
- Major ion chemistry of the pit lake is controlled by equilibrium mineral precipitation of Barite, Calcite, Ferrihydrite, Fluorite, Gibbsite, Rhodochrosite, and Magnesite. These are common minerals anticipated to precipitate under the given thermodynamic conditions. Sensitivity analyses are performed to evaluate lake chemistry without the process of mineral precipitation.

Table 5.20: Open Pit Alternative: simulated North Sub-pit chemistry

Concentration (mg/L)	*Profile III*	*Profile I*	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**	**N Sub-pit**
Year			**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
pH	*6.5-8.5*	*6.5-8.5*	7.74	7.77	7.77	7.76	7.74	7.79	7.85	7.96	8.02	8.04	8.05	8.02	8.03	8.02	7.99
pe	*-----*	*-----*	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Alkalinity Total	*-----*	*-----*	233	251	254	252	248	277	308	392	438	454	466	428	437	424	402
Aluminum	*4.47*	*0.2*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Antimony	*0.29*	*0.006*	**0.036**	**0.038**	**0.042**	**0.046**	**0.059**	**0.085**	**0.091**	**0.109**	**0.099**	**0.094**	**0.075**	**0.061**	**0.060**	**0.057**	**0.053**
Arsenic	*0.2*	*0.01*	**0.108**	**0.110**	**0.115**	**0.113**	**0.134**	**0.179**	**0.204**	**0.263**	**0.265**	**0.259**	**0.205**	**0.171**	**0.165**	**0.150**	**0.124**
Barium	*23.1*	*2*	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.07	0.08	0.08	0.08
Beryllium	*2.83*	*0.004*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Boron	*5*	*-----*	0.708	0.730	0.803	0.911	1.224	1.785	1.738	1.646	1.249	1.101	0.656	0.507	0.494	0.458	0.429
Bismuth	*----*	*----*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	*0.05*	*0.005*	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Calcium	*----*	*-----*	156	156	164	181	220	174	124	67	46	40	33	37	36	37	41
Chloride	*----*	*400*	124	122	137	171	249	205	143	97	72	64	59	53	58	57	56
Chromium	*1*	*0.1*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Copper	*0.5*	*1*	0.010	0.011	0.012	0.013	0.017	0.023	0.025	0.027	0.027	0.027	0.027	0.026	0.026	0.026	0.026
Fluoride	*2*	*4*	**3.44**	**3.45**	**3.47**	**3.48**	**3.52**	**3.91**	**4.26**	**5.34**	**5.83**	**6.00**	**6.12**	**5.61**	**5.75**	**5.58**	**5.29**
Iron	*----*	*0.6*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead	*0.1*	*0.015*	0.001	0.001	0.001	0.001	0.001	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.004	0.004	0.004
Lithium	*40.3*	*-----*	1.20	1.23	1.36	1.57	2.14	2.27	1.89	1.62	1.30	1.17	0.67	0.49	0.44	0.38	0.34
Magnesium	*----*	*150*	77	78	86	103	145	140	110	86	60	53	44	40	42	41	41
Manganese	*377*	*0.1*	**0.3**	**0.2**	**0.3**	**0.3**	**0.4**	**0.4**	**0.3**	**0.2**	**0.1**	**0.1**	0.1	0.1	0.1	0.1	0.1
Mercury	*0.10*	*0.002*	0.0008	0.0008	0.0008	0.0008	0.0009	0.0009	0.0007	0.0006	0.0007	0.0007	0.0007	0.0007	0.0008	0.0007	0.0005
Molybdenum	*0.60*	*-----*	**2.69**	**2.78**	**3.08**	**3.52**	**4.73**	**5.67**	**4.95**	**4.06**	**2.55**	**2.04**	**0.93**	0.54	0.37	0.27	0.21
Nickel	*171*	*0.1*	0.02	0.02	0.02	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.03
Total Nitrogen	*100*	*10*	0.78	0.86	1.00	1.26	1.85	2.47	2.56	3.26	3.47	3.46	3.58	3.15	3.40	3.36	3.26
Phosphorus	*----*	*-----*	0.34	0.35	0.39	0.44	0.59	0.81	0.93	1.39	1.59	1.62	1.70	1.46	1.43	1.14	0.82
Potassium	*----*	*-----*	14.6	14.9	16.4	18.6	24.9	27.5	24.5	24.3	22.3	21.2	16.6	14.1	14.2	13.3	12.8
Selenium	*0.05*	*0.05*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	*----*	*0.1*	0.001	0.001	0.001	0.001	0.002	0.003	0.003	0.004	0.004	0.004	0.004	0.006	0.007	0.006	0.005
Sodium	*2000*	*-----*	156	159	177	211	295	318	274	257	224	209	164	136	136	126	116
Strontium	*1127*	*-----*	1.782	1.793	1.990	2.366	3.296	3.279	2.639	2.128	1.542	1.340	1.082	0.975	1.054	1.043	1.011
Sulfate	*----*	*500*	**674**	**670**	**741**	**880**	**1,223**	**1,185**	**906**	**634**	404	328	171	138	131	120	128
Thallium	*0.032*	*0.002*	0.0003	0.0003	0.0003	0.0004	0.0005	0.0006	0.0006	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008
Tin	*29.2*	*-----*	0.017	0.018	0.020	0.022	0.028	0.036	0.037	0.047	0.050	0.050	0.052	0.048	0.053	0.052	0.051
TDS	*7000*	*1000*	**1,447**	**1,462**	**1,588**	**1,831**	**2,422**	**2,348**	**1,908**	**1,577**	**1,285**	**1,187**	970	860	868	831	809
TSS	*-----*	*-----*															
Uranium	*6.995*	*0.03*	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Vanadium	*0.1*	*-----*	0.030	0.031	0.035	0.039	0.053	0.082	**0.113**	**0.223**	**0.294**	**0.308**	**0.283**	**0.185**	**0.162**	**0.122**	0.092
Zinc	*25*	*5*	0.02	0.02	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

0.00	Profile I and Profile III exceedance
0.00	Profile III exceedance
0.00	Profile I exceedance

Table 5.21: Open Pit Alternative: simulated West Sub-pit chemistry

Concentration (mg/L)	*Profile III*	*Profile I*	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit	W Sub-pit
Year			**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
pH	*6.5-8.5*	*6.5-8.5*	7.76	7.75	7.74	7.74	7.73	7.76	7.80	7.86	7.90	7.91	7.88	7.83	7.83	7.82	7.80
pe	-----	-----	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Alkalinity Total	-----	-----	248	242	241	243	238	254	271	304	325	330	305	268	267	262	251
Aluminum	*4.47*	*0.2*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	*0.29*	*0.006*	**0.059**	**0.057**	**0.055**	**0.055**	**0.062**	**0.080**	**0.086**	**0.091**	**0.077**	**0.072**	**0.055**	**0.047**	**0.043**	**0.042**	**0.040**
Arsenic	*0.2*	*0.01*	**0.086**	**0.088**	**0.086**	**0.087**	**0.099**	**0.141**	**0.169**	**0.206**	**0.203**	**0.198**	**0.152**	**0.134**	**0.123**	**0.112**	**0.091**
Barium	*23.1*	*2*	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.09	0.10	0.11	0.11	0.11
Beryllium	*2.83*	*0.004*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Boron	*5*	-----	0.767	0.763	0.763	0.799	0.969	1.288	1.236	0.995	0.647	0.548	0.219	0.158	0.118	0.106	0.099
Bismuth	----	----	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	*0.05*	*0.005*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Calcium	----	-----	170	173	179	192	225	185	143	94	70	64	55	52	53	54	58
Chloride	----	*400*	103	108	116	133	177	121	76	37	22	18	15	14	15	15	14
Chromium	*1*	*0.1*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	*0.5*	*1*	0.008	0.007	0.007	0.008	0.009	0.011	0.012	0.014	0.014	0.014	0.013	0.014	0.014	0.015	0.016
Fluoride	*2*	*4*	**3.40**	**3.40**	**3.38**	**3.36**	**3.36**	**3.53**	**3.69**	**4.04**	**4.25**	**4.29**	**4.20**	**4.23**	**4.14**	**4.06**	**3.79**
Iron	----	*0.6*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead	*0.1*	*0.015*	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
Lithium	*40.3*	-----	1.38	1.40	1.44	1.56	1.96	1.85	1.50	1.09	0.80	0.72	0.30	0.21	0.13	0.10	0.08
Magnesium	----	*150*	89	91	95	104	132	113	86	57	39	35	23	22	21	21	22
Manganese	*377*	*0.1*	**0.4**	**0.5**	**0.5**	**0.6**	**0.8**	**0.6**	**0.4**	**0.2**	**0.1**	0.1	0.0	0.0	0.0	0.0	0.0
Mercury	*0.10*	*0.002*	0.0006	0.0006	0.0006	0.0007	0.0008	0.0008	0.0006	0.0004	0.0006	0.0006	0.0005	0.0006	0.0006	0.0005	0.0003
Molybdenum	*0.60*	-----	**4.00**	**3.93**	**3.90**	**4.05**	**4.85**	**5.23**	**4.54**	**3.23**	**1.87**	**1.51**	**0.61**	0.39	0.16	0.11	0.11
Nickel	*171*	*0.1*	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.01	0.01	0.01	0.01
Total Nitrogen	*100*	*10*	0.95	0.96	1.00	1.11	1.47	1.76	1.83	2.17	2.27	2.26	2.30	2.05	2.13	2.12	2.07
Phosphorus	----	-----	0.30	0.30	0.30	0.32	0.40	0.51	0.59	0.84	0.94	0.95	0.98	0.85	0.81	0.64	0.46
Potassium	----	-----	15.7	15.9	16.2	17.4	21.5	21.7	19.3	17.0	15.0	14.3	10.3	8.9	8.2	7.6	7.5
Selenium	*0.05*	*0.05*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	----	*0.1*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.002
Sodium	*2000*	-----	143	146	152	167	214	203	169	134	106	97	60	47	39	34	30
Strontium	*1127*	-----	2.031	2.059	2.130	2.324	2.947	2.606	2.038	1.371	0.852	0.713	0.490	0.463	0.460	0.467	0.462
Sulfate	----	*500*	**747**	**765**	**797**	**876**	**1,117**	**985**	**749**	464	278	227	100	88	70	65	78
Thallium	*0.032*	*0.002*	0.0002	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Tin	*29.2*	-----	0.016	0.016	0.016	0.017	0.020	0.024	0.024	0.028	0.029	0.029	0.030	0.028	0.030	0.030	0.029
TDS	*7000*	*1000*	**1,530**	**1,555**	**1,610**	**1,747**	**2,141**	**1,901**	**1,529**	**1,122**	868	797	579	508	482	467	469
TSS	-----	-----															
Uranium	*6.995*	*0.03*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vanadium	*0.1*	-----	0.033	0.033	0.033	0.035	0.043	0.061	0.084	**0.153**	**0.197**	**0.205**	**0.178**	**0.117**	**0.102**	0.079	0.061
Zinc	*25*	*5*	0.03	0.03	0.04	0.04	0.06	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01

0.00	Profile I and Profile III exceedance
0.00	Profile III exceedance
0.00	Profile I exceedance

Table 5.22: Open Pit Alternative: simulated South Sub-pit chemistry

Concentration (mg/L)	*Profile III*	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit	S Sub-pit
Year		**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**80**	**100**	**150**	**175**	**200**	**250**	**300**
pH	*6.5-8.5*	7.81	7.81	7.81	7.81	7.80	7.81	7.82	7.87	7.88	7.89	7.92	7.94	7.95	7.98	7.99
pe	*-----*	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Alkalinity Total	*-----*	274	273	274	273	271	278	288	333	347	357	387	403	424	448	471
Aluminum	*4.47*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	*0.29*	0.030	0.026	0.026	0.027	0.033	0.053	0.071	0.130	0.187	0.222	**0.298**	**0.333**	**0.389**	**0.442**	**0.500**
Arsenic	*0.2*	0.044	0.041	0.041	0.044	0.052	0.087	0.123	**0.250**	**0.390**	**0.479**	**0.670**	**0.762**	**0.898**	**1.025**	**1.145**
Barium	*23.1*	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Beryllium	*2.83*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Boron	*5*	0.648	0.624	0.638	0.675	0.788	1.158	1.426	2.165	2.768	3.117	3.683	3.912	4.347	4.723	**5.129**
Bismuth	*----*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	*0.05*	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.004	0.004
Calcium	*----*	117	116	116	120	134	142	140	121	122	122	111	105	100	93	87
Chloride	*----*	93	95	99	106	129	148	158	196	233	255	314	345	398	451	511
Chromium	*1*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Copper	*0.5*	0.012	0.011	0.012	0.012	0.014	0.018	0.022	0.027	0.027	0.028	0.028	0.029	0.029	0.030	0.030
Fluoride	*2*	**3.68**	**3.66**	**3.68**	**3.69**	**3.71**	**3.86**	**4.03**	**4.75**	**4.89**	**4.99**	**5.27**	**5.43**	**5.63**	**5.87**	**6.09**
Iron	*----*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead	*0.1*	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.003	0.004	0.005	0.006	0.008	0.010	0.012	0.015
Lithium	*40.3*	0.97	0.92	0.93	1.00	1.22	1.59	1.83	2.56	3.25	3.65	4.25	4.45	4.84	5.12	5.40
Magnesium	*----*	63	62	63	68	83	103	115	153	156	154	141	133	126	117	111
Manganese	*377*	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
Mercury	*0.10*	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0005	0.0007	0.0010	0.0012	0.0018	0.0021	0.0027	0.0033	0.0036
Molybdenum	*0.60*	**2.06**	**1.88**	**1.86**	**1.99**	**2.44**	**3.58**	**4.34**	**6.28**	**7.64**	**8.37**	**9.35**	**9.56**	**10.06**	**10.30**	**10.52**
Nickel	*171*	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.08	0.09	0.13	0.14	0.16	0.18	0.20
Total Nitrogen	*100*	0.56	0.57	0.59	0.67	0.86	1.38	1.85	3.57	5.59	6.91	10.57	12.49	15.45	18.59	22.16
Phosphorus	*----*	0.33	0.33	0.33	0.35	0.45	0.79	1.14	2.66	4.56	5.83	9.40	11.20	13.79	15.95	17.73
Potassium	*----*	10.0	9.5	9.5	10.2	12.5	17.1	20.5	31.7	43.4	50.7	65.8	73.0	84.5	95.3	107.2
Selenium	*0.05*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	*----*	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.004	0.007	0.008	0.011	0.014	0.018	0.023	0.026
Sodium	*2000*	125	123	126	135	161	209	242	349	453	517	651	710	810	899	995
Strontium	*1127*	1.561	1.530	1.561	1.683	2.043	2.552	2.867	3.855	4.686	5.167	6.223	6.736	7.673	8.577	9.600
Sulfate	*----*	460	445	451	491	614	790	886	1,150	1,346	1,449	1,577	1,617	1,722	1,789	1,880
Thallium	*0.032*	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004	0.0005	0.0008	0.0011	0.0013	0.0019	0.0022	0.0027	0.0032	0.0038
Tin	*29.2*	0.015	0.014	0.014	0.015	0.018	0.024	0.030	0.051	0.076	0.092	0.137	0.162	0.201	0.242	0.289
TDS	*7000*	1,152	1,134	1,148	1,215	1,417	1,702	1,867	2,360	2,736	2,945	3,298	3,442	3,730	3,965	4,243
TSS	*-----*															
Uranium	*6.995*	0.009	0.009	0.009	0.010	0.011	0.012	0.012	0.014	0.016	0.018	0.020	0.021	0.023	0.025	0.028
Vanadium	*0.1*	0.028	0.026	0.026	0.028	0.033	0.051	0.073	**0.181**	**0.332**	**0.433**	**0.671**	**0.759**	**0.888**	**0.988**	**1.076**
Zinc	*25*	0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.08	0.09	0.10	0.12	0.13	0.15	0.16	0.18

0.00 Indicates Profile III exceedance

Open Pit Alternative risk assessment

Risk assessment to groundwater for the Open Pit Alternative evaluates the fate and capture of pit lake outflows from the North and West Sub-pits to the South Sub-pit. The Modpath 3DU simulator was used to generate reverse particle tracks using the equilibrium velocity field at 300 years post-closure (S.S. Papadopulos, 2019). Initial particle locations were placed along the saturated perimeter of the South Sub-pit pit lake and allowed to travel backwards in time. The capture zone analysis and resulting particle trace analysis is shown in Figure 5.14.

The South Sub-pit capture zone extends into the North and West pit lake footprints. Particle tracks fully encompass the North Sub-pit, thus ensuring full capture of discharge at equilibrium. All particles originating in the West Sub-pit are captured by the South Sub-pit pit lake, however the capture zone terminates near the Sub-pits western margin leaving a small potential for some outflow to escape capture.

The fate and transport of pit lake outflow is rigorously evaluated using a fate and transport, described in Section 6. Antimony is simulated as proxy for pit lake outflow, however if pit lake outflow is not fully captured by the South Sub-pit, then including additional species maybe warranted.

An ecological risk assessment is required to evaluate impacts to wildlife and presented as a standalone report.

5.4.3 Partially Backfilled South Sub-pit Alternative

Partially Backfilled South Sub-pit configuration

The Partially Backfilled South Sub-pit Alternative places backfill up to the 4,708 ft amsl elevation in the South Sub-pit to promote the creation of a wetlands which will function as a hydraulic sink. At the 4,708 ft amsl elevation the potential evaporative demand is ~115 gpm, nearly double the evaporation required to maintain a hydrologic sink in the Open Pit Alternative. The configuration design is shown in Figures 4.24 and Figure 4.25.

Partially Backfilled South Sub-pit water balance results

Water levels recover to the backfill elevation (4,708 ft amsl) approximately 10 years post-closure in the South Sub-pit (Figure 4.27). Water levels in the backfill recover to lower elevations than in the fully backfilled configuration because of the wetlands expressed in the Partially backfilled South Sub-pit.

The evaporative demand exceeds inflows to the pit, thus reaching an annual equilibrium just below the backfill surface. Water balance results are presented in Table 5.23.

An ephemeral pond will develop on the backfill surface during winter and spring when evaporative demands are low. During summer months the water levels will decline below the backfill surface. Seasonal variation is anticipated to be within 1 ft of the backfill surface. This phenomenon is commonly observed in wetlands. The headwaters at Thacker Creek follow this trend with increasing spring discharge during winter and spring months which is mostly consumed by phreatophytes during the summer (Piteau, 2019a).

Table 5.23: Partially Backfilled South Sub-pit Alternative: water balance summary

Partially Backfilled South Sub-pit									
Stage (ft, amsl)	**4654**	**4688**	**4704**	**4707**	**4708**	**4708**	**4708**	**4708**	**4708**
Time (yr)	**1**	**3**	**5**	**10**	**30**	**55**	**100**	**200**	**300**
Infiltration (gpm)	8.3	8.3	8.3	8.0	7.8	7.8	7.8	7.8	7.8
Precipitation (gpm)	0.0	0.0	0.0	8.1	17.0	17.2	17.2	17.0	17.0
Pit Wall Runoff (gpm)	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Bedrock Groundwater (gpm)	17.9	11.7	3.5	11.3	14.4	14.4	14.4	14.4	14.4
East WRF Inflow (gpm)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
North Sub-pit Inflow (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West Sub-pit Inflow (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ET (gpm)	0.0	0.0	0.0	10.8	23.6	23.9	23.9	23.7	23.7
Transpiration (gpm	0.0	0.0	0.0	23.2	32.6	32.6	32.6	32.5	32.5
Groundwater Outflow (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Backfilled North Sub-pit									
Stage (ft, amsl)	**4774**	**4768**	**4780**	**4785**	**4793**	**4799**	**4799**	**4799**	**4799**
Time (yr)	**1**	**3**	**5**	**10**	**30**	**55**	**100**	**200**	**300**
Infiltration (gpm)	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
Pit Wall Runoff (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bedrock Groundwater (gpm)	5.4	6.1	6.3	6.6	6.4	6.1	6.1	6.1	6.1
ET (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Groundwater Outflow (gpm)	3.1	3.7	5.5	6.9	8.6	9.2	9.2	9.2	9.2
Backfilled West Sub-pit									
Stage (ft, amsl)	**4775**	**4777**	**4781**	**4781**	**4781**	**4781**	**4781**	**4781**	**4781**
Time (yr)	**1**	**3**	**5**	**10**	**30**	**55**	**100**	**200**	**300**
Infiltration (gpm)	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Precipitation (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pit Wall Runoff (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bedrock Groundwater (gpm)	6.5	6.3	6.0	5.3	5.3	5.3	5.3	5.3	5.3
ET (gpm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Groundwater Outflow (gpm)	15.5	15.4	14.9	14.5	14.5	14.5	14.5	14.5	14.5

Partially Backfilled South Sub-pit geochemical results

Simulated water chemistry in the Partially Backfilled South Sub-pit are shown in Table 5.24 and graphically in Figures 5.15a through 5.15c. PHREEQC input files are presented in Appendix K. Key results of the geochemical model are:

- Partially Backfilled South Sub-pit chemistry is predicted to be circum-neutral with increasing solute concentrations through evapoconcentration. Solute concentrations are higher than those in the Open Pit Alternative due to the additional mass loading from submerged backfill and increased evaporative demand. As a result several Profile III exceedances are predicted (Sb, As, B, F, Mo, Na, TDS, V). The partially backfilled pit is an effective hydraulic sink, therefore no Profile I exceedances occur.

- Pit chemistry is controlled by the equilibrium of barite, calcite, ferrihydrite, gibbsite, rhodochrosite, and magnesite. The geochemical setting is particularly conducive to magnesite precipitation owing to the abundant releases of magnesium from backfill material. Without Magnesite mineral precipitation, alkalinity concentrations would remain unrealistically elevated (> 1,000 mg/l) because of the lack of alternative divalent cations to form minerals.
- The North backfilled chemistry is similar to the Backfilled Pit Proposed Action. North Sub-pit chemistry is elevated in the same overall solutes (Sb, As, Mg, Mn, SO4, TDS), but concentrations decline more quickly because the backfill reaches equilibrium more quickly and at a lower elevation.
- West Sub-pit backfill chemistry is also elevated in the same solutes (Sb, As, TDS). Because the backfill is only slightly saturated, the mass flux equilibrium occurs rapidly and there is little change to pore water chemistry.

Table 5.24: Partially Backfill South Sub-pit Alternative: simulated North Sub-pit chemistry

Concentration (mg/L)	*Profile III*	*Profile I*	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit	N Sub-pit
Year			**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
pH	*6.5-8.5*	*6.5-8.5*	7.72	7.72	7.73	7.74	7.76	7.65	7.57	7.54	7.54	7.55	7.54	7.55	7.54	7.54	7.55
pe	-----	-----	4.00	4.00	2.00	1.00	0.00	-1.00	-2.00	-3.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00
Alkalinity Total	-----	-----	237	235	238	242	247	186	149	137	139	139	139	140	139	139	140
Aluminum	*4.47*	*0.2*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	*0.29*	*0.006*	**0.079**	**0.079**	**0.069**	**0.055**	**0.039**	**0.022**	**0.013**	**0.009**	**0.009**	**0.009**	**0.009**	**0.010**	**0.009**	**0.009**	**0.009**
Arsenic	*0.2*	*0.01*	**0.143**	**0.116**	**0.091**	**0.066**	**0.049**	**0.030**	**0.020**	**0.017**	**0.017**	**0.017**	**0.017**	**0.017**	**0.017**	**0.017**	**0.017**
Barium	*23.1*	*2*	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Beryllium	*2.83*	*0.004*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Boron	*5*	-----	0.894	0.860	0.746	0.605	0.458	0.304	0.216	0.186	0.186	0.188	0.186	0.191	0.186	0.186	0.189
Bismuth	----	----	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	*0.05*	*0.005*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Calcium	----	-----	213	220	205	180	149	92	58	45	45	46	45	48	45	45	47
Chloride	----	*400*	344	356	319	261	192	116	71	55	55	56	55	58	55	55	57
Chromium	*1*	*0.1*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	*0.5*	*1*	0.015	0.015	0.015	0.014	0.012	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
Fluoride	*2*	*4*	3.45	3.44	3.43	3.44	3.45	3.80	2.74	2.38	2.37	2.40	2.37	2.43	2.37	2.37	2.41
Iron	----	*0.6*	0.00	0.00	0.00	0.01	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Lead	*0.1*	*0.015*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Lithium	*40.3*	-----	2.49	2.56	2.28	1.86	1.37	0.82	0.51	0.39	0.39	0.40	0.39	0.41	0.39	0.39	0.40
Magnesium	----	*150*	**153**	**160**	145	119	89	54	34	26	26	27	26	28	26	26	27
Manganese	*377*	*0.1*	**0.2**	**0.1**	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mercury	*0.10*	*0.002*	0.0009	0.0006	0.0004	0.0003	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Molybdenum	*0.60*	-----	5.86	6.05	5.33	4.30	3.09	1.77	1.00	0.72	0.72	0.75	0.72	0.78	0.72	0.72	0.75
Nickel	*171*	*0.1*	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total Nitrogen	*100*	*10*	1.37	1.40	1.26	1.04	0.79	0.52	0.35	0.30	0.30	0.30	0.30	0.31	0.30	0.30	0.30
Phosphorus	----	-----	0.43	0.40	0.35	0.29	0.24	0.18	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Potassium	----	-----	25.8	25.8	22.6	18.3	13.4	8.1	5.1	4.0	4.0	4.1	4.0	4.2	4.0	4.0	4.1
Selenium	*0.05*	*0.05*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	----	*0.1*	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Sodium	*2000*	-----	176	178	160	134	105	73	54	47	47	48	47	48	47	47	48
Strontium	*1127*	-----	3.225	3.343	3.006	2.483	1.857	1.157	0.739	0.589	0.587	0.601	0.588	0.617	0.589	0.589	0.604
Sulfate	----	*500*	**874**	**907**	**814**	**667**	490	292	174	132	129	133	130	138	130	130	134
Thallium	*0.032*	*0.002*	0.0004	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Tin	*29.2*	-----	0.030	0.029	0.026	0.021	0.017	0.012	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
TDS	*7000*	*1000*	**2,042**	**2,102**	**1,918**	**1,636**	**1,296**	830	550	451	450	459	451	469	451	451	461
TSS	-----	-----															
Uranium	*6.995*	*0.03*	0.002	0.002	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vanadium	*0.1*	-----	0.046	0.047	0.041	0.033	0.024	0.015	0.010	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Zinc	*25*	*5*	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

0.0 Profile I exceedance

Table 5.25: Partially Backfill South Sub-pit Alternative: simulated West Sub-pit chemistry

Concentration (mg/L)	*Profile III*	*Profile I*	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**	**W Sub-pit**
Year			**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
pH	*6.5-8.5*	*6.5-8.5*	7.62	7.62	7.63	7.62	7.61	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62	7.62
pe	-----	-----	4.00	4.00	2.00	0.00	-1.00	-2.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00
Alkalinity Total	-----	-----	176	176	178	173	173	173	174	174	174	174	174	174	174	174	174
Aluminum	*4.47*	*0.2*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	*0.29*	*0.006*	**0.029**	**0.029**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**	**0.030**
Arsenic	*0.2*	*0.01*	**0.027**	**0.026**	**0.027**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**
Barium	*23.1*	*2*	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Beryllium	*2.83*	*0.004*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Boron	*5*	-----	0.302	0.302	0.308	0.306	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305
Bismuth	----	----	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	*0.05*	*0.005*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Calcium	----	-----	119	119	121	123	123	123	123	123	123	123	123	123	123	123	123
Chloride	----	*400*	150	150	153	156	156	156	156	156	156	156	156	156	156	156	156
Chromium	*1*	*0.1*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	*0.5*	*1*	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Fluoride	*2*	*4*	3.59	3.59	3.58	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57	3.57
Iron	----	*0.6*	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Lead	*0.1*	*0.015*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lithium	*40.3*	-----	1.05	1.05	1.07	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Magnesium	----	*150*	71	71	72	73	73	73	73	73	73	73	73	73	73	73	73
Manganese	*377*	*0.1*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mercury	*0.10*	*0.002*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Molybdenum	*0.60*	-----	2.40	2.40	2.46	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Nickel	*171*	*0.1*	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total Nitrogen	*100*	*10*	0.73	0.73	0.74	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Phosphorus	----	-----	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Potassium	----	-----	9.9	9.9	10.1	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
Selenium	*0.05*	*0.05*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	----	*0.1*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Sodium	*2000*	-----	73	73	74	74	74	74	74	74	74	74	74	74	74	74	74
Strontium	*1127*	-----	1.445	1.447	1.472	1.495	1.494	1.494	1.494	1.494	1.494	1.494	1.494	1.494	1.494	1.494	1.494
Sulfate	----	*500*	388	389	395	405	404	404	404	404	404	404	404	404	404	404	404
Thallium	*0.032*	*0.002*	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Tin	*29.2*	-----	0.011	0.011	0.012	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
TDS	*7000*	*1000*	996	997	**1,013**	**1,024**	**1,023**	**1,023**	**1,024**	**1,024**	**1,024**	**1,024**	**1,024**	**1,024**	**1,024**	**1,024**	**1,024**
TSS	-----	-----															
Uranium	*6.995*	*0.03*	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Vanadium	*0.1*	-----	0.017	0.017	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
Zinc	*25*	*5*	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

0.0	Profile I exceedance

Table 5.26: Partially Backfill South Sub-pit Alternative: simulated South Sub-pit chemistry

Concentration (mg/L)	*Profile III*	*Profile I*	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**	**S Sub-pit**
Year			**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
pH	*6.5-8.5*	*6.5-8.5*	7.67	7.67	7.67	7.66	7.67	7.68	7.69	7.71	7.69	7.69	7.67	7.66	7.65	7.66	7.66
pe	-----	-----	4.00	4.00	2.00	0.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Alkalinity Total	-----	-----	220	219	218	216	219	229	238	252	251	250	247	245	246	251	255
Aluminum	*4.47*	*0.2*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antimony	*0.29*	*0.006*	0.107	0.108	0.111	0.113	0.123	0.154	0.180	0.233	0.286	**0.320**	**0.389**	**0.431**	**0.476**	**0.525**	**0.573**
Arsenic	*0.2*	*0.01*	0.104	0.105	0.101	0.109	0.122	0.176	**0.223**	**0.309**	**0.393**	**0.446**	**0.567**	**0.646**	**0.737**	**0.839**	**0.942**
Barium	*23.1*	*2*	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Beryllium	*2.83*	*0.004*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Boron	*5*	-----	1.141	1.145	1.150	1.142	1.326	1.878	2.308	3.223	4.176	4.804	**6.376**	**7.374**	**8.583**	**9.934**	**11.307**
Bismuth	----	----	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	*0.05*	*0.005*	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.004	0.005	0.006	0.006
Calcium	----	-----	312	317	324	326	328	329	326	328	370	399	469	514	541	542	542
Chloride	----	*400*	576	582	592	582	609	725	820	1,035	1,258	1,409	1,778	2,016	2,300	2,615	2,933
Chromium	*1*	*0.1*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Copper	*0.5*	*1*	0.006	0.006	0.014	0.015	0.007	0.014	0.020	0.036	0.040	0.043	0.054	0.063	0.073	0.085	0.097
Fluoride	*2*	*4*	**3.36**	**3.35**	**3.33**	**3.31**	**3.36**	**3.59**	**3.79**	**4.14**	**4.15**	**4.16**	**4.17**	**4.18**	**4.20**	**4.23**	**4.26**
Iron	----	*0.6*	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead	*0.1*	*0.015*	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.004	0.004	0.006	0.007	0.007	0.008	0.008
Lithium	*40.3*	-----	4.28	4.32	4.37	4.35	4.54	5.26	5.84	7.09	8.35	9.18	11.23	12.55	14.24	16.12	18.00
Magnesium	----	*150*	240	242	246	243	255	302	341	418	470	506	592	648	681	682	682
Manganese	*377*	*0.1*	0.7	0.7	0.8	0.7	0.7	0.8	0.8	0.9	1.0	1.0	1.2	1.2	1.3	1.4	1.4
Mercury	*0.10*	*0.002*	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0003	0.0004	0.0005	0.0007	0.0008	0.0010	0.0011	0.0013
Molybdenum	*0.60*	-----	**8.63**	**8.74**	**8.91**	**8.98**	**9.48**	**10.94**	**12.03**	**14.30**	**16.55**	**18.03**	**21.65**	**23.96**	**26.59**	**29.48**	**32.31**
Nickel	*171*	*0.1*	0.05	0.05	0.05	0.05	0.05	0.07	0.08	0.11	0.14	0.16	0.21	0.24	0.27	0.31	0.35
Total Nitrogen	*100*	*10*	1.93	1.95	1.98	1.97	2.22	3.42	4.50	6.95	9.51	11.25	15.54	18.30	21.40	24.90	28.47
Phosphorus	----	-----	0.43	0.44	0.44	0.44	0.51	0.80	1.07	1.68	2.27	2.60	3.43	3.96	4.57	5.24	5.92
Potassium	----	-----	36.0	36.4	37.1	37.0	39.1	47.1	53.7	67.8	82.2	91.5	113.9	127.9	144.8	163.6	182.3
Selenium	*0.05*	*0.05*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Silver	----	*0.1*	0.002	0.002	0.002	0.002	0.002	0.003	0.005	0.007	0.010	0.012	0.016	0.019	0.022	0.025	0.028
Sodium	*2000*	-----	259	261	262	255	280	376	456	636	820	941	1,240	1,430	1,651	1,898	**2,147**
Strontium	*1127*	-----	5.089	5.139	5.212	5.148	5.449	6.589	7.519	9.620	11.808	13.263	16.926	19.299	22.032	25.065	28.118
Sulfate	----	*500*	1,354	1,370	1,394	1,387	1,455	1,698	1,891	2,308	2,734	3,013	3,703	4,144	4,460	4,598	4,735
Thallium	*0.032*	*0.002*	0.0005	0.0005	0.0005	0.0005	0.0005	0.0007	0.0009	0.0014	0.0019	0.0023	0.0031	0.0036	0.0042	0.0049	0.0057
Tin	*29.2*	-----	0.032	0.032	0.033	0.032	0.036	0.051	0.065	0.097	0.130	0.153	0.209	0.246	0.287	0.334	0.382
TDS	*7000*	*1000*	3,022	3,054	3,099	3,074	3,213	3,739	4,165	5,095	6,044	6,674	**8,225**	**9,218**	**10,131**	**10,868**	**11,610**
TSS	-----	-----															
Uranium	*6.995*	*0.03*	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.005	0.005	0.007	0.008	0.008	0.009	0.011
Vanadium	*0.1*	-----	0.071	0.071	0.077	0.080	0.083	**0.131**	**0.175**	**0.261**	**0.332**	**0.371**	**0.470**	**0.523**	**0.588**	**0.660**	**0.732**
Zinc	*25*	*5*	0.07	0.07	0.08	0.07	0.07	0.07	0.08	0.09	0.10	0.11	0.13	0.15	0.17	0.19	0.22

0.00 Profile III exceedance

Partially Backfilled South Sub-pit risk assessment

Particle track analysis confirm the Partially Backfilled South Sub-pit is a hydraulic sink (Figure 5.16). This configuration removes backfill outflow from the North and South Sub-pits, outflow from the West Sub-pit will continue. The outflow risk assessment for the West Sub-pit unchanged from the Open Pit Alternative.

An ecological risk assessment is required to evaluate impacts to wildlife and is presented as a standalone report.

5.5 SENSITIVITY ANALYSIS

Sensitivity analyses were performed for predicted pit lakes and backfill geochemistry to understand the influence model parameters have on chemistry. Multiple sensitivity scenarios were performed for each closure alternative to identify trends in the geochemical model controlling predictions and understand the robustness of results. Sensitivity scenarios were selected to evaluate increasing solute mass loading or concentrations and thus were biased towards higher concentrations. For example, a sensitivity scenario considering additional pore flushes adds greater solute mass to the solution, but a reciprocal sensitivity to evaluate fewer pore flushes was not performed.

5.5.1 Backfilled Pit Proposed Action

Sensitivity parameters selected for the Backfilled Pit Proposed Action are summarized as follows:

- **Five (5) backfill pore flushes:** This sensitivity increases the number of backfill pore flushes from 3 to 5 to evaluate resulting higher mass loading to backfill pore water.
- **Reducing pE environment:** This sensitivity reduces the available oxygen in the backfill to a pE value of -4, mildly reducing. The precipitation of metal oxides is restricted in this sensitivity.
- **Increased backfill scale factor:** This sensitivity increases backfill scaling factor from 0.57 to 1.4. Scaling terms of HCTs were modified (Table 5.3) by increasing the specific surface area of backfill to laboratory estimates (43.8 m^2/kg). This results in greater mass released from backfill flushing and infiltration.
- **Week 1 HCT Flushing:** This sensitivity utilizes week 1 HCT results in lieu of week 0 for backfill flushing. Solute mass loading reduces significantly between week 0 and week 1 for many constituents, this sensitivity evaluates how the geochemical model may be overpredicting mass loading.

- **Infiltration + 25%:** This sensitivity increases the infiltration rate by 25%.
- **No mineral precipitation:** This sensitivity restricts mineral precipitation, thus evaluates the bulk pore water chemistry from mass loading.
- **Increased claystone / ash K 25%**: This sensitivity evaluates pore water chemistry when the log of hydraulic conductivity for claystone/ash and basalt units is raised 25%. This is the same sensitivity evaluated in Section 4.3.
- **Reduced claystone / ash K 25%:** This sensitivity evaluates pore water chemistry when the log of hydraulic conductivity for claystone/ash and basalt units is raised 25%. This is the same sensitivity evaluated in Section 4.3.

Raw chemistry results comparing sensitivity scenarios are provided in Appendix L. Key results identified from the sensitivity analysis are as follows:

- In general, backfilled pore water sensitivities converge towards central values through simulation time. Greater variability is simulated during early backfill filling by adjusting model inputs. Greater confidence is observed during late time pore water chemistries which strengthens confidence in model predictions, the screening level assessment, and provides guidance for monitoring.
- The West Sub-pit backfill was least sensitive to varying model inputs, followed by the North Sub-pit and the South Sub-pit. The number of additional late-time exceedances are relatively few and do not occur for each sensitivity. New late-time exceedances include:
    - South Sub-pit: 2 new exceedances (Sulfate, TDS),
    - West Sub-pit: 0 new exceedance,
    - North Sub-pit: 0 new exceedances
- The sensitivity with greatest impact is the “Increased backfill scale factor”. This simulation increases concentrations of all constituents in backfill pore water through time. The “Five backfill pore flushes” and ”No mineral precipitation” sensitivities also had moderate effects on simulated chemistry. Removing mineral precipitation was limited to aluminum, fluoride, calcium, and alkalinity ions because the precipitation pathways to gibbsite, fluorite, and calcite were removed. Beyond these elements mineral precipitation has little effect on the backfill pore water chemistry because the discharge of mass keeps pore water concentrations below precipitation thresholds.
- Sensitivities with low effect to backfill concentrations include:
    - “Reducing pE environment”,
    - “No Ferrihydrite precipitation”,

Insensitivity to ferrihydrite is expected, given that simulated redox conditions keep iron in solution during later geochemical simulation years.

- Antimony sensitivity follows the trend of greater variability during early backfill filling and converges to concentrations ranging between 0.01 mg/l to 0.03 mg/l (Figure 5.17). Sensitivities which trended towards higher concentrations of antimony were the “Increased backfill scale factor”, “Five backfill pore flushes”, and ”Infiltration + 25%”. Each of these scenarios increased mass loading from the backfill in some fashion. The effect from the “Five backfill pore flushes” sensitivity was observed only during early filling, by the end of the simulation antimony concentrations had converged to the normal. Concentrations of antimony in the South Sub-pit backfill were least affected by the sensitivity analyses owing to the higher influxes of groundwater to the backfill than the other sub-pits which provides greater control on antimony concentrations.

5.5.2 Open Pit Alternative

- **50 ft DRZ:** This sensitivity extends the open pit DRZ zone from 15 ft to 50 ft behind the pit wall, adding more mass loading from submerged wall rock.
- **Increased scale factor:** Scaling factor for wall rock is increased by a factor of 3 (a value of 2.0) to evaluate additional mass loading.
- **No mineral precipitation**: This sensitivity restricts mineral precipitation, thus evaluates the bulk pore water chemistry from mass loading.
- **No ferrihydrite precipitation** This sensitivity restricts ferrihydrite precipitation and thus adsorption onto ferrihydrite colloids.
- **Increased claystone / ash K 25%:** This sensitivity increases the log of hydraulic conductivity for claystone/ash and basalt units is raised 25%. This is the same sensitivity evaluated in Section 4.3.
- **Reduced claystone / ash K 25%:** This sensitivity reduces the log of hydraulic conductivity for claystone/ash and basalt units is raised 25%. This is the same sensitivity evaluated in Section 4.3.
- **Increased ET 15%:** This sensitivity increases PET by 15% (68.5 in/yr), leading to lower lake levels and greater evapoconcentration. This is the same sensitivity evaluated in Section 4.3.
- **Reduced ET 15%:** This sensitivity reduces PET by 15% (50.7 in/yr), leading to higher lake levels and less evapoconcentration. This is the same sensitivity evaluated in Section 4.3.

Raw chemistry results comparing sensitivity scenarios are provided in Appendix L. Key results identified from the sensitivity analysis are as follows:

- Open pit chemistry indicates greater variability than the Backfilled Pit Proposed Action. The variability within the North and West Sub-pits is fundamentally different from the

South Sub-pit owing to the hydraulic nature of a flow through pit versus a sink. North and West Sub-pits generally have greater variability between years 30 to 100. This corresponds to the period after the pit lakes have mostly filled, but prior to groundwater outflow from the lakes reaching equilibrium. Solute mass leaving the North and West Sub-pit lakes becomes a controlling process after approximately 100 years post-closure.

- The South Sub-pit shows greater variability after approximately 50 years post-closure. This is because the South Sub-pit is a hydraulic sink, and is somewhat sensitive to solute mass loading which becomes evapoconcentrated during late time. Sensitivities which increase the mass loading or evaporation rate exacerbate the effects of evapoconcentration.
- The number of additional late-time Profile III exceedances are relatively few and do not occur for each sensitivity. New late-time exceedances include:
  - South Sub-pit: 3 new Profile III exceedances (TDS, SO4, pH),
  - West Sub-pit: 3 new Profile III exceedances (As, Mo, V),
  - North Sub-pit: 3 new Profile III exceedances (As, Mo, V)

  The South Sub-pits exceedances to pH only occur in a single sensitivity run and are unlikely. Likewise the exceedance to Mo only occurs in a few sensitivities in the North and West Sub-pits.
- The sensitivity with greatest variation is the “Increased scale factor” across all sub-pits, however the South sub-pit also shows a similar magnitude of response in the “50 ft DRZ” and “No mineral precipitation” sensitivities. These sensitivities were responsible for new Profile III exceedances sub-pits. The additional mass loading from these sensitivities are instructive to understand the geochemical model behavior, but should be considered overly conservative.
- Eliminating mineral precipitation produced several unrealistic results in the South sub-pit such as extremely high concentrations of alkalinity, fluoride, calcium, and magnesium. In typical aqueous environments carbonates and fluorite would form, which would also exert pH control on the solution as a by-product. Although these particular constituents do not constitute a new exceedance, the unlikelihood of their magnitudes should be acknowledged.
- Sensitivities with low effect to pit lake concentrations include:
  - “No Ferrihydrite precipitation”,
  - “Reduced ET 15%”,
  - “Reduced claystone / ash K 25%”
- Adjustments to the surrounding hydraulic conductivity, particularly reducing hydraulic conductivity, had small effects on pit lake chemistry relative to other parameters, which is attributed to the control exerted by evaporation and groundwater on pit lake chemistry.

- Sulfate sensitivity is a good surrogate for major ion chemistry trends in the pit lakes because gypsum is undersaturated in the pit lakes. Chemical trends diverge in the North and West Sub-pits before converging to between 100 mg/l to 400 mg/l (Figure 5.18). The South Sub-pit chemistry diverges during late-time, ranging to between 500 mg/l to 850 mg/l (Figure 5.18).

5.5.3 Partially Backfilled South Sub-pit Alternative

Sensitivity analysis for the Partially Backfilled South Sub-pit Alternative utilized a subset of sensitivity runs previously described in the Backfill and Open Pit sensitivity analysis including:

- Five (5) backfill pore flushes
- Increased backfill scale factor
- Week 1 HCT flushing for backfill
- No mineral precipitation
- Increased claystone / ash K 25%
- Reduced claystone / ash K 25%
- Increased ET 15%
- Reduced ET 15%:

Raw chemistry results comparing sensitivity scenarios are provided in Appendix L. Key results identified from the sensitivity analysis are as follows:

- Variability in the Partially Backfilled South Pit follows similar trends as the Open Pit South Sub-pit, namely increased variability during late time when lake chemistry is controlled evapoconcentration. A key difference is that the Partially Backfilled South Pit accumulates more solute mass from the backfill material.
- Two new Profile III exceedance occurs during late-time (pH, Li) in the “No mineral precipitation” and “Increased backfill scale factor” sensitivities.
- Unrealistic concentrations are simulated in the “No mineral precipitation” sensitivity, with alkalinity exceeding 6,000 mg/l. Although this sensitivity generated high variation, such conditions are not anticipated to occur in this setting.
- Again the sensitivities with greatest variation were the “Increased scale factor” and “Five backfill pore flushes”.
- Concentrations are reduced for most ions in the “Week 1 HCT flushing for backfill” sensitivity. In practice this suggests that the rinsing of waste rock by precipitation while exposed during mining or temporary storage can reduce solute concentrations in pore water and the pit lake.

- A wetland does not form in the “Increased claystone / ash K 25%” sensitivity as water levels only recover to 4,703 ft amsl. Therefore, the sensitivity results reflect pore water chemistry through time.

5.6 PREDICTIVE GEOCHEMICAL MODEL UNCERTAINTY

The geochemical model is based on mixing solutes in proportion to the water balance and chemical release function and using equilibrium reactions from the Mineteq4 thermodynamic database to simulate a final solution. There are inherent degrees of uncertainty associated with elements of the geochemical model, varying by site location and geochemical setting. Therefore, the geochemical modeler must employ professional judgement and reasonable conservatism to ensure realistic suite of final pit lake or pore water chemistry. A discussion of model uncertainties and how they may affect predicted pore water / pit lake chemistry is discussed in the following sections.

Geochemical processes

The geochemical model omits more variable, site specific geochemical process such as co-precipitation, solid state substitution, and adsorption onto manganese oxides, (MnOOH), aluminum oxides ($Al(OH)_3$), or clay colloids. Doherty, Tighe, and Wilson identified iron substrates (i.e. ferrihydrite, zero valence iron, and ferric chloride) applied at a 3% weight ratio was effective in reducing antimony and arsenic concentrations in pore water, so long as a pH above 6 s.u. was maintained (Doherty, 2017). The presence of ferric iron (Fe^{3+}) in solution is particularly valuable as it co-precipitates with arsenic and antimony metalloids in oxidizing conditions. Work by Thanabalasingam and Pickering (Thanabalasingam, 1990) indicate the sorption capacity of antimony decreases from Mn-oxides to Al-oxides and then Fe-oxides. Furthermore, literature review of partition coefficients by Allison and Allison identify antimony as a little studied cation (Allison, 1990).

The geochemical model only considers ferrihydrite which precipitates from solution as a possible sorption site, omitting existing iron-oxide sorption sites found in backfill, wall rock, or aerosols. The additional processes present alternate pathways for trace ions, such as antimony (V) and antimony (III), to be removed from solution. Additional site-specific work and engineering may improve the understanding of antimony mobility.

Scaling

Uncertainties surrounding scaling laboratory results to field scale simulations are discussed in Section 5.1.2. Scaling factors may directly affect the quantity of solute mass added to the system. Geochemical sensitivity analyses identified scaling as a control on predicted chemistry. However sensitivity analyses did not evaluate lower scaling factors which are plausible given the conservative selection of laboratory surface area and the unconsidered environmental conditions which would reduce field reactivity such as lower air temperatures and relative humidity. These considerations would reduce simulated concentrations.

Chemical release functions

Geochemical release functions are derived from HCT testing and applied at several temporal timesteps in the model for pit wall runoff. Model uncertainty is associated with the rate of pore volume flushing and reactive rock area. The sensitivity analysis evaluates cases where more mass is released through these processes, but preferred flow pathways could also reduce the reactive areas and solute mass loading.

First flush (week 0) mass loading rates were conservatively selected for infiltration and backfill rinsing components. However, infiltration along discrete macropores would flush solute mass more quickly and resemble longer term HCT results, thus reducing pore water concentrations. Likewise, two backfill pore flushes (of week 0 constituents) simulated submerged materials to account for mass loading from the assumed drainable porosity (15%) and total porosity (30%) of the backfill (i.e. Total porosity / drainable porosity = number of pore flushes). However if the backfill is well graded and possesses dead end pore space, then the number of flushes should be reduced and thus result in lower pore water concentrations.

Geochemical characterization

Groundwater chemistry has been monitored in claystone/ash rock units at several locations near the proposed pit. Temporal variations to water chemistry are low and the spatial variation between locations is also relatively low. Therefore, uncertainty regarding groundwater inflow components is considered low.

Geochemical profiles for rock units predominantly focus on the claystone/ash and ash materials, which is appropriate given its abundance. Solute releases among claystone/ash samples are generally consistent and exhibit similar trends, with some noted potential variation between larger grain sizes in ash samples from claystone. At least one HCT has been collected to evaluate each geochemical unit, thus completing a sample dataset. Samples meet the distribution of sulfide, ANP, and AGP observed within the exploration dataset (SRK, 2019).

Continued, strategic geochemical testing as mining encounters deeper rock and as ore processing becomes refined should be continued particularly gangue materials to improve characterization.

6 FATE AND TRANSPORT ANALYSIS

A fate and transport simulation of outflow from the Proposed Action and Alternatives was completed to more precisely quantify the post-closure concentrations of antimony in the groundwater system. Screening level assessment modeling of elevated constituents predicted that antimony was the only element which could potentially have concentrations above Nevada Reference Values (NRVs). Arsenic concentrations were determined to be elevated primarily due to pre-existing background concentrations in groundwater. Sulfate and magnesium were predicted to meet NRVs after mixing with ground water during the first 50 years (Section 5.4.1). Fate and transport modeling was performed to understand the risks associated with the migration of antimony in the bedrock groundwater system and develop an appropriate monitoring and mitigation plan.

The fate and transport analysis is a more rigorous evaluation of solute transport than that used in the screening level assessment because the advection-dispersion governing equation incorporates additional physical processes such as dispersion, diffusion, advection at local velocity fields, and retardation of mass for each cell in the groundwater model. The approach used for the screening level assessment was deliberately designed to provide a conservative evaluation of solute transport. The fate and transport approach differs from the screening level assessment analysis in the following key aspects:

- The fate and transport model considers mixing with in-situ storage (effective porosity). The volume of stored groundwater was omitted from the screening level assessment.
- The fate and transport model implements dispersion of the velocity field (i.e. dispersivity) in the calculations.
- The fate and transport model implements diffusion across concentration gradients. This is typically a minor effect relative to advection.
- The fate and transport model simulates outflow from all three sub-pits simultaneously, providing a comprehensive evaluation of groundwater concentrations through time.
- The fate and transport model more rigorously simulates backfill discharge from saturated backfill, whereas the screening level assessment assumed the entire backfill footprint (including the unsaturated portion) would discharge to groundwater. The footprints of saturated pore water where discharge occurs is a fraction of the area than that used in the risk assessment, and thus the discharge to groundwater is constrained to a smaller volume of the bedrock aquifer that resides almost entirely east of the groundwater divide in Thacker Pass. This effect is particularly important in the West sub-pit which is almost entirely unsaturated. The risk assessment deliberately

overpredicts the footprint of mass loading from backfill as a part of its screening level approach.

6.1 MODEL CONFIGURATION

The existing MODFLOW-USG groundwater model was reconfigured to run fate and transport for the previously simulated post-closure period (2065-2365) for the Proposed Action and Alternative closure configurations. The Block Centered Transport (BCT) package was used to simulate the fate and transport of antimony (Panday, 2017). No other solute was simulated in the model. The BCT package is the only transport package currently compatible with MODFLOW-USG.

The BCT package utilizes an implicit TVD (total variation diminishing) solution scheme to solve the advective-dispersion equation (Equation 9) for solute concentrations at a given model time step. An implicit TVD scheme is used to minimize numerical dispersion. The BCT package is fully compatible with the groundwater flow model, thus simulating wet/dry cells associated with upstream weighting scheme or the full Richards equation solution for unsaturated cells.

$$\frac{\partial M}{\partial t} = \frac{\partial}{\partial x_i}\left[D_{ij}\frac{\partial c}{\partial x_j}\right] - \frac{\partial}{\partial x_i}[v_i c] - [\tau_w \theta_w c + \tau_s \rho_b c_s] - [u_w \theta_w + u_s(1-\theta_e)] + R \quad \text{(9) (Panday, 2017)}$$

Where:

$\frac{\partial M}{\partial t}$ = the total mass per unit volume of a component species

t= time

x_i=the principal coordinate directions

D_{ij}=the apparent hydrodynamic dispersion tensor

c= the concentration of a component species in water

v_i=the Darcy velocity in direction x_i

θ_e=the effective porosity

ρ_b=bulk density of porous medium

c_s=adsorbed concentration of component

τ_w= first order decay coefficient in water

τ_s= first order decay coefficient on soil

u_w=the zero-order decay coefficient in water

u_s=the zero-order decay coefficient on soil

R=the source / sink term for the component species

The transport model used milligrams for mass units and feet for length units, thus solute concentrations were mg/ft^3 and later converted to mg/L. Fifteen (15) stress periods were used corresponding to pore water concentrations derived from the geochemical model for the Proposed Action and Alternatives (Tables 6.1 to Table 6.3). Model configuration for fate and transport are described in the following sub-sections.

Table 6.1: Transport model stress periods: Proposed Action

Stress Period	Start Date	End Date	Elapse Time (days)	South Sub-Pit Sb Concentration (mg/l)	North Sub-Pit Sb Concentration (mg/l)	West Sub-Pit Sb Concentration (mg/l)
1	1/1/2065	12/31/2065	365	0.073	0.099	0.032
2	1/1/2066	12/31/2066	365	0.077	0.090	0.031
3	1/1/2067	12/31/2067	365	0.079	0.086	0.030
4	1/1/2068	12/31/2069	731	0.081	0.077	0.030
5	1/1/2070	12/31/2074	1826	0.079	0.066	0.031
6	1/1/2075	12/31/2084	3653	0.076	0.048	0.033
7	1/1/2085	12/31/2094	3653	0.071	0.040	0.032
8	1/1/2095	12/31/2114	7304	0.055	0.024	0.031
9	1/1/2115	12/31/2139	9131	0.042	0.015	0.031
10	1/1/2140	12/31/2164	9131	0.036	0.012	0.030
11	1/1/2165	12/31/2214	18262	0.025	0.011	0.030
12	1/1/2215	12/31/2239	9131	0.022	0.011	0.030
13	1/1/2240	12/31/2264	9131	0.019	0.011	0.030
14	1/1/2265	12/31/2314	18262	0.018	0.011	0.030
15	1/1/2315	12/31/2364	18263	0.017	0.011	0.030

Table 6.2: Transport model stress periods: Open Pit Alternative

Stress Period	Start Date	End Date	Elapse Time (days)	South Sub-Pit Sb Concentration (mg/l)	North Sub-Pit Sb Concentration (mg/l)	West Sub-Pit Sb Concentration (mg/l)
1	1/1/2065	12/31/2065	365	0.030	0.036	0.059
2	1/1/2066	12/31/2066	365	0.026	0.038	0.057
3	1/1/2067	12/31/2067	365	0.026	0.042	0.055
4	1/1/2068	12/31/2069	731	0.027	0.046	0.055
5	1/1/2070	12/31/2074	1826	0.033	0.059	0.062
6	1/1/2075	12/31/2084	3653	0.053	0.085	0.080
7	1/1/2085	12/31/2094	3653	0.071	0.091	0.086

Stress Period	Start Date	End Date	Elapse Time (days)	South Sub-Pit Sb Concentration (mg/l)	North Sub-Pit Sb Concentration (mg/l)	West Sub-Pit Sb Concentration (mg/l)
8	1/1/2095	12/31/2114	7304	0.130	0.109	0.091
9	1/1/2115	12/31/2139	9131	0.187	0.099	0.077
10	1/1/2140	12/31/2164	9131	0.222	0.094	0.072
11	1/1/2165	12/31/2214	18262	0.298	0.075	0.055
12	1/1/2215	12/31/2239	9131	0.333	0.061	0.047
13	1/1/2240	12/31/2264	9131	0.389	0.060	0.043
14	1/1/2265	12/31/2314	18262	0.442	0.057	0.042
15	1/1/2315	12/31/2364	18263	0.500	0.053	0.040

Table 6.3: Transport model stress periods: Partially Backfilled South Sub-pit Alternative

Stress Period	Start Date	End Date	Elapse Time (days)	South Sub-Pit Sb Concentration (mg/l)	North Sub-Pit Sb Concentration (mg/l)	West Sub-Pit Sb Concentration (mg/l)
1	1/1/2065	12/31/2065	365	0.107	0.079	0.029
2	1/1/2066	12/31/2066	365	0.108	0.079	0.029
3	1/1/2067	12/31/2067	365	0.111	0.069	0.030
4	1/1/2068	12/31/2069	731	0.113	0.055	0.030
5	1/1/2070	12/31/2074	1826	0.123	0.039	0.030
6	1/1/2075	12/31/2084	3653	0.154	0.022	0.030
7	1/1/2085	12/31/2094	3653	0.180	0.013	0.030
8	1/1/2095	12/31/2114	7304	0.233	0.009	0.030
9	1/1/2115	12/31/2139	9131	0.286	0.009	0.030
10	1/1/2140	12/31/2164	9131	0.320	0.009	0.030
11	1/1/2165	12/31/2214	18262	0.389	0.009	0.030
12	1/1/2215	12/31/2239	9131	0.431	0.010	0.030
13	1/1/2240	12/31/2264	9131	0.476	0.009	0.030
14	1/1/2265	12/31/2314	18262	0.525	0.009	0.030
15	1/1/2315	12/31/2364	18263	0.573	0.009	0.030

Specified Concentration Cells

Saturated backfill was simulated using constant concentration cells which were assigned antimony concentrations corresponding to pore water chemistry from the geochemical model. The geochemical model previously estimated pore water chemistry based on mass loading from water balance components (infiltration, groundwater inflow/outflow) and geochemical reactions as described in Section 5. The geochemical model assumes that all infiltration applied to backfill reports to the saturated backfill. However, considering there is potential for a component of infiltration to percolate through the backfill directly to the underlying groundwater system, this end member scenario is presented later as a sensitivity analysis scenario.

Specified antimony concentrations through time are presented in Figure 6.1 as well as Table 6.1 to Table 6.3. The location specified concentration cells are shown in Figure 6.2. Constant head cells at Kings River and Quinn River basin boundaries were assigned a constant concentration of 0.00025 mg/l representing one-tenth the typical laboratory detection limit, consistent with the approach used in the Water Quantity and Quality Impacts Report.

6.1.1 Adsorption

No adsorption was simulated in the fate and transport model. Implementing adsorption would be contingent upon site specific field testing to identify a suitable material and sorption capacity.

6.1.2 Dispersivity and diffusion

Hydrodynamic dispersion occurs because of velocity variation through porous media caused by heterogeneity. Dispersion is a function of scale. At the macro scale, dispersion is controlled by the heterogeneity of pore spaces and permeability along flow paths. At the micro scale, the heterogeneity between void spaces and colloid surfaces causes microscopic velocity variation within pore spaces. The fate and transport model applied the common assumption that longitudinal dispersivity is approximately 10% of the distance traveled, or 10% of the largest cell dimension (Bear and Cheng, 2010). Values for the dispersivity tensor were applied as follows:

- Longitudinal dispersivity: 10% of the longest cell dimension;
- Transverse dispersivity: 1% of the longest cell dimension;
- Vertical transverse dispersivity: 1% of the cell thickness.

Dispersivity zones are shown in Figure 6.3. Fickian diffusion was estimated to be 0.000651 mg^2/ft, however diffusion is a much smaller component of the transport equation and is not critical to the transport process in this setting. The sensitivity analysis includes two scenarios evaluating the effects of dispersion.

6.1.3 Initial concentrations

Initial antimony concentrations were developed for the entire model domain to represent the snapshot of antimony distribution in groundwater prior to closure. Initial antimony concentrations were interpolated from water quality sampling at Thacker Pass monitoring wells and spring locations. In samples where antimony concentrations were below detection, a value of one-tenth the detection limit (0.00025 mg/l) was used. Antimony concentrations at Quinn and King River basins were also assumed to be 0.00025 mg/l but are not relevant to the focus of the fate and transport model. A kriged distribution of antimony was developed to populate the model with initial concentration (Figure 6.4).

The majority of the model domain possessed antimony concentrations less than detection limits (assigned 0.00025 mg/l). Antimony was measured at Lyle's Spring (Sp-051, 0.0037 mg/l) located at the headwaters of Rock Creek. In the Thacker Pass Project area, measurable antimony concentrations were observed at PH-1 (0.005 mg/l), WSH-13 (0.001 mg/l), and WSH-14 (0.002 mg/l). These concentrations are incorporated into the initial concentration distribution.

The distribution of initial concentrations was applied to recharge values to ensure continued addition of mass through simulation time.

6.1.4 Effective porosity

Effective porosity (θ_{eff}) refers to the fraction of porosity in a rock or sediment which is available to contribute to fluid flow. Effective porosity is commonly less than total porosity (θ) and greater than specific yield (S_y). The BCT package requires that effective porosity be greater than specific yield for numerical convergence, they cannot be equal.

Effective porosity values were estimated from literature, laboratory testing, and from the calibrated numerical model. Assigned values are tabulated in Table 6.4 and described as follows:

- Bedrock units were assigned effective porosity values ranging from 0.015 to 0.03. Values are approximately double the estimated specific yield values.
- Alluvial units were assigned values ranging from 0.15 to 0.25 based on literature values and calibrated model values.
- Backfill material was assigned a value of 0.28 as determined by material testing.
- Open pit or "air" cells were assigned a value of 0.99 so that the transport model could run.

A sensitivity analysis was performed on effective porosity to evaluate its effect on solute transport.

Table 6.4: Transport parameters for hydrogeologic zones

Zone	Description	Conceptual HGU	K_h (ft/d)	K_z (ft/d)	S_y	θ_{eff}
1	Basement Volcanic Tuff	Tuff	0.0035	0.00035	0.0075	0.015
2	Basalt	Basalt	0.6	0.6	0.01	0.02
3	Rhyolitic flows and younger intrusive rocks	Tuff	0.5	0.05	0.01	0.02
4	Dacite	Tuff	0.001	0.001	0.01	0.02
5	Jurassic Granite	Granodiorite	4.00×10^{-03}	4.00E-03	0.01	0.02
6	Aphyric Rhyolite Lavas	Tuff	0.005	0.005	0.0075	0.015
7	Winnemucca fmn: Shale, siltstone, sandstone and carbonate	Sedimentary bedrock	0.04	0.04	0.01	0.02
8	Thacker Pass and KRV Qal alluvium	Alluvium	5	0.5	0.01	0.02
9	Rhyolite West Kings River	Tuff	0.01	0.01	0.01	0.02
11	Claystone	Claystone/ash	0.25	0.025	0.013	0.03
12	Rock/Pole Creek Shear Zones	Tuff	0.5	0.5	0.01	0.02
13	Silicified Claystone (East)	Claystone/ash	0.06	0.006	0.01	0.02
14	Thacker Pass Ash	Claystone/ash	2.8	0.048	0.015	0.03
15	Thacker Pass Tuff	Tuff	0.035	0.0035	0.0075	0.015
16	Thacker Pass Basalts	Basalt	0.08	0.008	0.01	0.03
18	Older alluvium and alluvial fan deposits, KRV	Alluvium	0.5	0.05	0.03	0.15
19	Valley Fill/Alluvium, KRV	Alluvium	8	0.8	0.04	0.15
20	Younger Alluvium, KRV	Alluvium	15	1.5	0.1	0.25
21	West Older Qal, Alluvial Fan, QRV	Alluvium	5	0.5	0.03	0.15
22	East Older Qal, Alluvial Fan, QRV	Alluvium	5	0.5	0.03	0.15
23	Moderate K Younger Qal alluvium Zones; QRV	Alluvium	23	2.3	0.04	0.15
24	High K Gravel Zones; QRV	Alluvium	10	1	0.1	0.25
29	Thacker Creek Shear Zone	Tuff	1	1	0.01	0.02
31	Open Air Cells	Air	100	100	0.99	1.0
34	Backfill	Backfill	1.76	1.76	0.15	0.28

6.2 MODEL RESULTS

Antimony transportation for all three closure scenarios was simulated beginning upon project closure in year 2065 through 2365. The distribution of antimony in groundwater is discussed for the Proposed Action and Alternatives in the following sub-sections

6.2.1 Backfilled Pit Proposed Action Results

Antimony concentrations at 20-yr, 50-yr, 100-yr, 200-yr, and 300-yr post-closure are presented in Figure 6.5 to Figure 6.9. A composite image showing the 0.006 mg/l isopleth at each time period is shown in Figure 6.10. Cross-sections showing the 0.006 mg/l isopleth are provided in Figure 6.11 (cross-section traces shown in Figure 6.10). A discussion of transport results are as follows:

- The overall distribution of antimony after 300 years remains within the Thacker Pass Project's permit boundary. Antimony concentrations migrate towards the south east according to the post-mining groundwater gradient.
- Discharge from the West sub-pit was towards the south. After 300 years, the 0.006 mg/l isopleth migrated approximately 0.5 miles southward. Notably, concentrations below the unsaturated portion of the West Sub-pit backfill (i.e. WSH-11) are below NRVs and do not approach Thacker Creek. Because groundwater discharge occurs from saturated backfill, the fate and transport model represented the spatial footprint of the backfilled pit which will discharge to groundwater. The fate and transport model assumed that all infiltration to the backfill preferentially flows to the saturated backfill and does not percolate into the underlying bedrock.
- Groundwater outflow from the North Sub-pit discharged in a south to south east vector and was aligned with the South Sub-pit. The footprints of antimony concentrations from the North and South sub-pits coalesce across the backfill footprint (Figure 2.5 to Figure 2.9).
- Discharge from the South Sub-pit migrated to the southeast. After 300 years, the 0.006 mg/l travelled approximately 1 mile to the south east, reaching monitoring well WSH-03, but still over 1 mile away from MW18-02.
- The lateral extent of antimony migrated approximately 0.5 to 1 mile east of the backfill. Antimony did not migrate west of the backfill.
- The vertical extent of antimony migrated approximately 600 ft downward through the claystone and into underlying volcanic tuff (Figure 6.11). Vectors along cross-section I-I' are vertically downward and perpendicular to the section trace are downward and towards the south east. The outflow between the South and North sub-pits can be discerned through fate and transport modeling. A key result regarding the vertical distribution of antimony is that down-gradient monitoring wells should be screened at depth, across claystone and volcanic tuff units to monitor water quality. Screening wells only across the water table may not capture the dispersion of antimony in deep groundwater.
- The magnitude of antimony concentrations decreases with time. This is partially related to the declining concentrations of antimony in specified concentrations heads (i.e. the geochemical model) and also due to dispersion of maximum concentrations during transport. For example, the footprint of peak antimony concentration of 0.03 mg/l at 100

years post closure (Figure 6.7) migrates and declines to <0.02 mg/l at 300 years post closure (Figure 6.9).

- Potential water quality impacts to Thacker Creek are not anticipated. Infiltration through the unsaturated backfill which percolates directly to groundwater, if any, was predicted to meet NRVs outside the backfill footprint (described in Section 6.3). This is analogous to conditions below the WRFs and Gangue Stockpile which were also not predicted to exceed NRVs beyond the facility's footprint. Outflow from saturated backfill was predicted to migrate eastward away from Thacker Creek.
- Potential impacts to other water stakeholders in Quinn River Basin are not predicted by the fate and transport model. The extent of elevated antimony concentrations remain within the Thacker Pass Project's permit boundary.

6.2.2 Open Pit Alternative Results

Antimony concentrations at 20-yr, 50-yr, 100-yr, 200-yr, and 300-yr post-closure are presented in Figure 6.12 to Figure 6.16. A composite image showing the 0.006 mg/l isopleth at each time period is shown in Figure 6.17. Cross-sections showing the 0.006 mg/l isopleth are provided in Figure 6.18 (cross-section traces shown in Figure 6.18). A discussion of transport results for the Open Pit Alternative are as follows:

- The South Sub-pit functions as a hydraulic sink to capture antimony. Discharge from the North and West Sub-pits ultimately migrate towards the South Pit. The maximum extent of the 0.006 mg/l isopleth remains within the pit footprint (Figure 6.17).
- Transport of antimony from the West Sub-pit initially moves radially because the pit lake is supported by surface water inflows. After the initial migration radially, the wider groundwater gradient transports discharge towards the South Sub-pit, which ultimately captures antimony.
- Groundwater outflow from the North Sub-pit discharged in a south to south east vector and was captured in the South Sub-pit. The footprints of antimony concentrations from the North and South sub-pits coalesce in the open pit.
- The extent of antimony migrated is approximately 1 mile long by 0.75 miles wide contained within the eastern footprint of the open pit.
- Potential water quality impacts to Thacker Creek are not anticipated. Potential impacts to other water stakeholders in Quinn River Basin are not predicted by the fate and transport model.

6.2.3 Partially Backfilled South Sub-Pit Alternative Results

Antimony concentrations at 20-yr, 50-yr, 100-yr, 200-yr, and 300-yr post-closure are presented in Figure 6.19 to Figure 6.23. A composite image showing the 0.006 mg/l isopleth at each time period is shown in Figure 6.24. Cross-sections showing the 0.006 mg/l isopleth are provided in Figure 6.25 (cross-section traces shown in Figure 6.24). A discussion of transport results for the Open Pit Alternative are as follows:

- The partially backfilled South Sub-pit functions as a hydraulic sink to capture antimony. Discharge from the North and West Sub-pits ultimately migrate towards the South Pit. The maximum extent of the 0.006 mg/l isopleth remains within the pit footprint (Figure 6.23).
- Transport of antimony from the West Sub-pit initially moves directly down-gradient towards the South Sub-pit. This is due to less surface water inflow to the West Sub-pit when it is backfilled which creates a groundwater gradient to the south east. The wetlands in the South Sub-pit ultimately captures antimony.
- Groundwater outflow from the North Sub-pit discharged in a south to south east vector and was captured by the wetlands South Sub-pit.
- The extent of elevated antimony concentrations is contained within the eastern footprint of the open pit. The 300-yr extent is very similar to that of the Open Pit Alternative.
- Potential water quality impacts to Thacker Creek are not anticipated. Potential impacts to other water stakeholders in Quinn River Basin are not predicted by the fate and transport model.

6.3 SENSITIVITY ANALYSIS

Sensitivity analyses were performed on transport parameters to evaluate the potential to impact groundwater stakeholders and environmental receptors under a range of conditions. The sensitivity analysis includes the following simulations:

- **No dispersion**: This sensitivity evaluates transport where no dispersion is simulated, thus advection is the critical transport mechanism.
- **Isotropic dispersion**: This sensitivity simulates isotropic dispersion by applying longitudinal dispersivity to transverse and vertical transverse dispersivity terms.
- **High effective porosity**: This sensitivity evaluates transport where the effective porosity of bedrock units is doubled. This sensitivity should decrease the extent of antimony transport because pore velocities will be lower.
- **Low effective porosity**: This sensitivity evaluates transport where the effective porosity of bedrock units is reduced to 0.5% above the specific yield value. This sensitivity should increase the extent of antimony transport because pore velocities will be greater.
- **High hydraulic conductivity**: This sensitivity increases the hydraulic conductivity by 25% of calibrated log K values as described in Table 4.5.
- **Low hydraulic conductivity**: This sensitivity reduces the hydraulic conductivity by 25% of calibrated log K values as described in Table 4.5.

- **Infiltration through backfill**: This sensitivity evaluates conditions if infiltration through backfill percolates directly to the groundwater system and does not report to saturated backfill. In this scenario, recharge to the backfill is assigned an antimony concentration of 0.044 mg/l, which corresponds to the concentration assigned to infiltration in the geochemical model (Piteau, 2019). Constant concentration cells were left unchanged. This sensitivity double counts mass loading via infiltration because the geochemical model assumes infiltration reports to saturated backfill. Therefore the results are anticipated to be conservative.

6.3.1 Sensitivity Analysis Results

Comparisons of the 0.006 mg/l isopleths at 300-years post mining (maximum extent) are shown for the sensitivity analyses in Figure 6.26 to 6.28. Individual maps of the 0.006 mg/l isopleth for each sensitivity model are shown in Appendix M. Key results from the sensitivity analysis are as follows:

- Generally, all the sensitivity simulations produced a similar suite of results as their base case configurations.
- Backfilled Pit Proposed Action sensitivities continued to show a south east gradient. Sensitivities highlighted different transport times related to groundwater velocity (Figure 6.26).
- Open Pit Alternative sensitivities indicated capture by the South Sub-pit would continue under a variety of conditions. A component of antimony was diverted towards the south, owing to a change in groundwater gradients from higher fault conductance of a vent fault near Silica Hill. This was the only sensitivity which had uncaptured antimony by the South Sub-pit (Figure 6.27).
- Partially Backfilled South Sub-pit Alternative sensitivities supported capture by the wetlands. A wetlands did not form in the higher hydraulic conductivity sensitivity, thus this was the only sensitivity in which antimony was not captured (Figure 6.28).
- The fate and transport model was most sensitive to variations in hydraulic conductivity and porosity. Hydraulic conductivity affects the water level gradient and transmissivity of rock units, and thus can influence the direction of groundwater flow. Porosity directly affects the Darcy velocity and thus the advective flux of solutes, but the direction of groundwater flow remains unchanged. Increased hydraulic conductivity and lower effective porosity had very similar effects on increasing the travel distance of antimony in groundwater (Figure 6.26). Of the two scenarios, a lower porosity has a greater likelihood because variation to calibrated hydraulic conductivity values produced poor matches to observed water levels.
- The lower hydraulic conductivity scenario resulted in groundwater gradients becoming more southerly for the Proposed Action. This is the only sensitivity scenario where antimony from the South sub-pit migrates south towards WSH-13 (Figure 6.26).

- Antimony transport is insensitive to varying the dispersion tensors between isotropic dispersion, anisotropic dispersion (base case), and no dispersion.
- Antimony concentrations in the "Infiltration through backfill" sensitivity match the footprint of unsaturated backfill. Mass loading from infiltration was diluted by a much greater flux of underlying groundwater residing below the unsaturated backfill. A small component of antimony migrates south below the West WRF. Antimony mass loading is "double counted" in this sensitivity and is considered conservative. This sensitivity simulation validates that solute transport is controlled by discharge from the saturated backfill.
- Under every sensitivity scenario, the simulated antimony migration did not reach the Thacker Pass Project's permit boundary. This provides confidence that the closure approaches are conceptually robust and potential impacts to stakeholders are unlikely under a reasonable range of natural variation in the groundwater system.

Results from the fate and transport model and sensitivity analyses are used to identify future compliance monitoring well locations discussed in Section 8.

7 WASTE ROCK FACILITY AND STOCKPILE WATER QUALITY IMPACTS ANALYSIS

This section analyzes the potential of infiltration from waste rock and gangue stockpile facilities to impact groundwater quality. The Thacker Pass Project will construct three (3) facilities (West WRF, East WRF, Gangue Stockpile) which will be constructed directly on native soils and can potentially discharge infiltrate to the groundwater system. Facility locations are shown in Figure 7.1 and summarized in Table 7.1.

Table 7.1: WRF and Gangue Stockpile summary

Facility ID	Material	Infiltration Footprint (ft^2)	Average height (ft)	Maximum height (ft)	Base elevation (ft, amsl)	Average Groundwater Elevation (ft, amsl)	Cover Description
West WRF	Waste Rock	$6.98 \times 10^{+6}$	270	540	4,710	4,750[1]	12 inches of growth media with custom seed mixture
East WRF	Waste Rock	$6.01 \times 10^{+6}$	118	185	5,015	4,800	12 inches of growth media with custom seed mixture
Gangue Stockpile	Gangue	$1.15 \times 10^{+7}$	210	290	4,760	4,750	12 inches of growth media with custom seed mixture

[1] Groundwater level at base elevation of West WRF is ~4,700 ft amsl. The West WRF is situated on a slope and built to an angle of repose.

Each facility will be closed with a 12-inch thick growth media and climate specific vegetated cover for the Thacker Pass Project (Table 7.2). Growth media will be derived from overburden alluvium that is approximately 1 ft to 10 ft thick across the open pit footprint (Cedar Creek, 2019). Application of a growth media is important because the chemistry of waste rock materials does not promote vegetation growth. Cover vegetation will be comprised primarily of grasses and sagebrush that optimize a composite root distribution designed to capture water and reduce infiltration in the facility. Grasses are anticipated to possess root zones of 12 inches or less, and sagebrush/saltbush have been documented to have much deeper root systems of up to 30 ft (Anderson and Woessner, 1992). This design is advantageous to i) primarily capture meteoric water in the growth media cover by grasses and ii) secondarily capture seasonal wetting fronts migrating through the cover by sagebrush/saltbush. A one-dimensional conceptual design of the cover and capture system is presented in Figure 7.2.

Table 7.2: Proposed seed mixture for vegetated cover[1]

Variety	Species	Pure Live Seed (lbs / acre)	% mix	Assumed root depth (in)
Wyoming Big Sagebrush	*Artemisia tridentate spp. Wyomingensis*	1	8%	48
Fourwing Saltbush	*Atriplex canescens*	0.5	4%	48
Squirreltail	*Elymus elymoides*	2.75	23%	12
Sandberg's Bluegrass	*Poa secunda*	1	8%	12
Crested Wheatgrass	*Agropyron cristatum*	6	50%	12
Blue Flax	*Linum lewisii*	0.5	4%	8
Scarlet globemallow	*Sphaeralcea coccinea*	0.25	2%	12
Western Yarrow	*Achillia millifolium*	0.1	1%	12

[1] Vegetated cover seed mixture Thacker Pass Project Proposed Plan of Operations (LNC, 2019c).

7.1 MATERIALS CHARACTERIZATION DATA COLLECTION

Soil material samples were collected and submitted for unsaturated hydraulic parameter testing to characterize the materials anticipated to be at each of the three facilities. Samples representing growth media were collected from three locations, with the fourth sample developed from a composite of alluvial samples collected across site. Three samples representing waste rock were collected from LNC's hectorite clay waste rock material, located in the eastern portion of the proposed pit (Figure 7.1). A second suite of waste rock material consisting of over 50,000 lbs of "bulk sample" was collected for the purposes of mining, however particle size distributions of the material was available to compliment the waste rock characterization. Samples representing the gangue (2 samples) and tailings material (2 samples) were collected from LNC's pilot plant and they represent the material to be placed at the gangue and tailings facility locations shown in Figure 7.1. The samples are summarized in Table 7.3. Photos of the different types of soil materials sampled are shown in Figure 7.3.

Table 7.3: Unsaturated testing sample summary

Sample ID	Material	Source	Target Dry Density (kg/m^3)
49-SWECO+1.0-D25B-138	Gangue	McClelland Labs	1300
9-SWECO+1.0-E22B-348	Gangue	McClelland Labs	1300
4-LFILTCAKE-E05B-315	Tailings	McClelland Labs	1700
4381-Blend	Tailings	McClelland Labs	1700
WD19-01	Waste Rock	LNC	1600
WD19-02	Waste Rock	LNC	1600
WD19-03	Waste Rock	LNC	1600
Growth 19-01	Growth Media	LNC	As found
Growth 19-02	Growth Media	LNC	As found
Growth 19-03	Growth Media	LNC	As found

Sample ID	Material	Source	Target Dry Density (kg/m^3)
Growth 19-04	Growth Media	Cedar Creek Consultants	As found

Soil samples were sent to Daniel B. Stephens & Associates, Inc (DBS&A) to be analyzed for material characteristics that could be used for infiltration modeling. The growth media characteristics were implemented into the top 12 inches of the 1D cover and capture model, while the waste rock (East and West WRF) or gangue (Gangue Stockpile) material characteristics were implemented into the material that made up the rest of the 1D cover and capture model as shown in Figure 7.2. The tailings characteristics were analyzed, but they were not utilized in infiltration modeling. Particle size distributions for "bulk sample" of waste rock material were analyzed at LNC's pilot plant.

7.1.1 Laboratory Results

Samples were analyzed by DBS&A for initial soil properties, saturated hydraulic conductivity, soil moisture characteristics, particle size, and Atterberg limits (DBS&A, 2019). Table 7.4 contains a summary of key soil characteristics determined in the lab. Figures 7.4a to 7.4e show the particle size distribution charts for the growth media, waste rock, tailings, and gangue sample groups. Figures 7.5a to 7.5d show the soil water retention curves for the growth media, waste rock, tailings, and gangue sample groups. The full laboratory report is presented in Appendix N. Key results from laboratory testing are summarized as follows:

- Growth media and waste rock materials are classified as either a sandy silt or silty sand with lean clay, emphasizing that silt sized particles are abundant. Bulk Sample waste rock materials are classified as a poorly sorted sand or gravel.
- Saturated hydraulic conductivities of growth media and waste rock are on the order of 5×10^{-6} cm/s to 8×10^{-5} cm/s, indicating lower permeability materials as would be expected in a soil composed primarily of silt. Gangue material is approximately an order of magnitude higher. Bulk sample waste rock hydraulic conductivity is estimated to have hydraulic conductivity values of 2.65×10^{-2} cm/s based on the average D10 particle size and using a Hazen method coefficient of 60.
- Soil water retention curves for all materials reflect the influence of fine-grained particles which produce a more linear curve (semi-log plot) and higher saturated moisture content than sand and gravel material.

Table 7.4: Unsaturated testing laboratory results

Sample ID	Material	D_{10} (mm)	D_{60} (mm)	ASTM Classification	alpha (1/cm)	N	θ_r	θ_{sat}	K_{sat} (cm/s)
49-SWECO+1.0-D25B-138	Gangue	2.2×10^{-4}	0.065	Sandy lean clay (CL)	0.0224	1.176	0.00	0.51	5.6×10^{-4}
9-SWECO+1.0-E22B-348	Gangue	6.6×10^{-5}	0.15	Sandy fat clay (CH)	0.0097	1.224	0.00	0.53	3.7×10^{-4}
4-LFILTCAKE-E05B-315	Tailings	6.5×10^{-9}	0.82	Silty sand (SM)	0.0017	1.256	0.00	0.629	8.3×10^{-7}
4381-Blend	Tailings	5.7×10^{-52} [1]	0.26	Silty sand (SM)	0.0295	1.142	0.00	0.595	4.8×10^{-6}
WD19-01	Waste Rock	3.7×10^{-3}	0.13	Silty sand with gravel (SM)	0.0033	1.341	0.034	0.437	1.6×10^{-5}
WD19-02	Waste Rock	2.2×10^{-3}	0.17	Silty sand with gravel (SM)	0.0030	1.443	0.057	0.439	7.1×10^{-6}
WD19-03	Waste Rock	6.3×10^{-4}	0.11	Sandy elastic silt (MH)	0.0048	1.224	0.006	0.502	3.7×10^{-5}
Growth 19-01	Growth Media	1.5×10^{-3}	0.063	Silt with sand (ML)	0.0094	1.224	0.00	0.425	3.8×10^{-5}
Growth 19-02	Growth Media	6.5×10^{-3}	0.14	Silty sand with gravel (SM)	0.0060	1.549	0.024	0.422	6.7×10^{-5}
Growth 19-03	Growth Media	1.2×10^{-3}	0.05	Silt with sand (ML)	0.0084	1.287	0.024	0.454	8.4×10^{-5}
Growth 19-04	Growth Media	2.7×10^{-3}	0.056	Silt with sand (ML)	0.0063	1.330	0.038	0.457	5.5×10^{-5}
Bulk Sample Waste Rock[2]	Waste Rock	2.1×10^{-1}	0.78	Poorly graded sand (SP)	0.075	1.58	0.044	0.41	2.1×10^{-2}

[1] Estimated by laboratory

[2] Only particle size data available, Ksat estimated using Hazen Method. Unsaturated parameters estimated using Rosetta database in HYDRUS (Simunek, 2013)

7.2 INFILTRATION MODELING

7.2.1 Approach

Infiltration rates through backfill, WRFs and the Gangue Stockpile were simulated utilizing a 1D HYDRUS model which was conceptually configured as shown in Figure 7.2. The HYDRUS simulation used on-site daily precipitation and potential evapotranspiration (PET) data from 2012-2018, which repeated every 7 years for a 300-year simulation to assess the equilibrium infiltration rate. Precipitation data was developed from the onsite meteorological station (Thacker Pass Station). PET rates were calculated from hourly meteorological data from the Thacker Pass Station using the Penman-Monteith equation validated by the American Society of Civil Engineers standards (ASCE-EWRI, 2004). Figure 7.6 shows the precipitation data and Figure 7.7 shows the PET data.

Transpiration and evaporation were partitioned from PET using the relationship between leaf area index (LAI) and surface cover fraction (SCF) using Equation 10 as detailed in the HYDRUS 1D user manual (Simunek, 2013):

$$SCF = 1 - \exp\left(-0.463 * LAI\right) \tag{10}$$

Grasses and grass-like species make up 88% of the seed mix, and referenced LAI values for grasses and grassland range from 0.7 to 2.8 (He et al., 2007 and Scurlock, et al, 2001). For this model, a LAI value of 2 was used, which results in a SCF of 0.6, meaning that 60% of PET is allocated to transpiration in the HYDRUS model and 40% is allocated to evaporation. PET was partitioned into transpiration and evaporation outside of the HYDRUS model and incorporated into the 7-year data set used for model input of meteorological parameters.

The upper HYDRUS model boundary condition was set as an atmospheric boundary condition with surface layer. The lower boundary condition was set to a seepage face boundary to represent underdrain conditions along a compacted soil or bedrock foundation. Initial water content conditions were set to be slightly lower than field capacity (0.27) to represent drying occurring during stacking, detailed in Table 7.5. The van Genuchten – Mualem model with no hysteresis was utilized as the unsaturated hydraulic conductivity model. Unsaturated hydraulic properties were assigned using mean values for each material group as displayed in Table 7.5. Backfill parameters were developed using a weighted log mean of 35% gangue and 65% waste rock.

Table 7.5: Model input: unsaturated hydraulic properties

Material	alpha (1/m)	N	θ_r	θ_{sat}	K_{sat} (m/d)[1]	Initial Water Content (% cm^3/cm^3)
Gangue	1.47	1.199	0.02	0.502	0.44	28.0
Waste Rock	1.67	1.336	0.03	0.435	0.59	27.2
Growth Media	0.740	1.342	0.021	0.424	0.05	27.2
Backfill[2]	1.5	1.324	0.024	0.47	0.53	27.2

[1] Geometric mean

[2] Backfill properties determined through 35% gangue / 65% waste rock weighted log mean.

Root water uptake was simulated using the Feddes water uptake reduction model (Simunek, 2013). Feddes' parameters were set as detailed in Table 7.6. Vegetation root densities were designed based on the proposed vegetative cover seed mix:

- 88% of the root density was placed in the upper 12 inches, representing shallow root systems of grasses.
- 12% of the root density was placed between 12 in to 48 in depths, representing deeper roots of sagebrush/saltbush.
- No transpiration was permitted below 48 in.

Table 7.6: Model input: Feddes' parameters

Parameter	Value (m)
P0	-0.1
P0pt	-0.25
P2H	-2
P2L	-8
P3	-15
r2H	0.005[1]
r2L	0.001[1]

[1] units in (m/d)

In the Feddes model, the P3 pressure represents the root wilting point beyond which no further water can be extracted by vegetation. Literature values for wilting points range from -80 m to -160 m corresponding to pasture land and agricultural plants (Wesseling, 1991 & Simunek, 2013). A value of -15 m was conservatively selected with respect to infiltration. Alternative P3 pressures are evaluated in the sensitivity analysis.

Discharge from mine facilities was simulated by using a HYDRUS 1D model representing the thickest section of the facility to estimate infiltration through the cover. Then the infiltration rate through the cover was applied across to the footprint of the facility to obtain an equilibrium discharge rate. Evaluating impacts using equilibrium rates is conservative because it considers the maximum, long-term loading of infiltration post-closure and ignores the temporary period when the wetting front is propagating through the dump facility.

7.3 SENSITIVITY ANALYSIS

Sensitivity analysis on 300-year infiltration simulations was performed on key model parameters to evaluate the potential variation in infiltration rates and to identify a conservative infiltration rate to be applied for predictive groundwater impacts simulations. The percentage of MAP that infiltrates at equilibrium is compared between sensitivity scenarios for the following parameters:

- Wilting point (P3 HYDRUS parameter)
- K_{sat}
- Van Genuchten parameters:
- Precipitation +/- 15%
- PET +/- 15%
- Root zone:

Infiltration sensitivity analysis indicates that a 3% MAP (0.37 in/yr) base case infiltration rate through covers is suitable and slightly conservative. The variability of infiltration to parameters tend to reduce the overall infiltration, thus selecting a slightly higher infiltration rate for impacts modeling can accommodate the presence of macropores and heterogeneity in the cover materials. Key results from the sensitivity analysis are shown in Figure 7.8 and summarized as follows:

- Nearly all sensitivity simulations generated an infiltration rate slightly less than 3% MAP. Thus groundwater impacts simulations for backfill and waste rock facilities are conservatively formulated with respect to water quality impacts.
- The root wilting point had the greatest sensitivity among parameters. Adjusting the root wilting point to literature values (-50m) captured most meteoric waters and reduced infiltration <1% MAP. Higher wilting points increased infiltration rates, but are unlikely given the soil will be relatively well saturated at these pressures. Corresponding water contents at -15 m for growth media and waste rock materials are 0.23 and 0.26 respectively based on their soil water retention curves (Figure 7.5). Such water contents are slightly drier than the observed field water content (0.23 for growth media and 0.31 for waste rock).

- Growth media soil parameters had little effect on infiltration. Waste rock hydraulic conductivity values had a larger effect.
- Modifying van Genutchen parameters had a large effect on gangue materials. This sensitivity should be considered theoretical because variations to the soil water retention curve would also have implications to saturated hydraulic conductivity. Both properties are related to material characterization, but in this exercise were evaluated independently.
- Climatic variation had the smallest impact to simulated infiltration. Increasing precipitation or decreasing PET had effectively no change on infiltration, suggesting the cover's capacity to transmit water is soil moisture controlled rather than atmospherically controlled.
- Removing the root zone for sage brush increased infiltration, suggesting that some component (~ 1%) of meteoric water is removed by sagebrush/salt bush plants.

7.3.1 Results

Facility discharge rates are presented in Table 7.7 for a 3% MAP infiltration rate through the facilities.

Table 7.7: HYDRUS equilibrium infiltration model results

Facility	% MAP	Infiltration (in/yr)	Area (ft^2)	Infiltration (gpm)
West WRF	3	0.37	$6.98 \times 10^{+6}$	3.1
East WRF	3	0.37	$6.01 \times 10^{+6}$	2.6
Gangue Stockpile	3	0.37	$1.15 \times 10^{+7}$	5.0

Simulated infiltration rates are in line with other measured vegetated cover performance. Vegetated covers on lysimeters have measured infiltration rates of <1 mm/yr (Scanlon, 2005) under natural and irrigated conditions. Field observation of vegetated covers indicate that under abundant water conditions, vegetation opportunistically grows to consume available water. This feedback mechanism between climate and vegetation growth adds built-in capacity to maintain cover performance, but is not captured by numerical models which prescribe transpiration fluxes and root distributions a priori. Given measured performance at other sites and the growth capability of vegetation, the numerical simulations are conservative (likely overestimates) with respect to infiltration.

7.4 GEOCHEMICAL MODELING AND RISK ASSESSMENT

The geochemical modeling objective is to evaluate equilibrium groundwater quality beneath unlined mine facilities. An equilibrium assessment is most conservative with respect to groundwater chemistry because it accounts for long term infiltration through WRFs, which increase through time, and omits the mixing of groundwater storage.

7.4.1 Modeling approach

Geochemical impacts to groundwater quality were simulated using a mass mixing approach that was utilized in the Backfilled Pit Proposed Action screening level assessment. The primary difference is that infiltration discharge and groundwater mixing is only evaluated across each facility's footprint.

This approach is described in the following steps:

1. Perform a forward particle tracking analysis. The Modpath 3DU simulator was used to generate particle tracks using the equilibrium velocity field at 300 years post-closure (S.S. Papadopulos, 2019). Initial particle locations were placed at the water table beneath the facilities footprint. Resulting particle traces are shown in plan view in Figure 7.9 and in Cross-section in Figures 7.10 to 7.11.
2. Identify the mixing depth beneath the facility. Particle traces were used to evaluate mixing depths of infiltration discharge with underlying groundwater flow.
3. Calculate the groundwater fluxes below each facility. A water balance is performed for the mixing depth below the footprint of each facility using the cell-by-cell output file from Modflow-USG.
4. Assign geochemical profiles for groundwater and infiltration. A review of HCT data from waste rock and gangue materials indicated aluminium, arsenic, antimony, iron, and sulfate were constituents which exceeded Profile I NRVs, and are therefore the elements selected for risk analysis in the geochemical mixing model. Geochemical concentrations for these elements in the groundwater and infiltration chemistries are provided in Table 7.8. All other elements have concentrations below NRVs and are therefore not included in the analysis. Note infiltration chemistries for waste rock and gangue are derived from their respective Week 0 HCT geochemical profiles presented in Appendix I.
5. Proportionately mix the equilibrium groundwater and infiltration fluxes using PHREEQC. The groundwater and infiltration geochemical profiles are proportionately mixed in PHREEQC and allowed to chemically equilibrate. This mixing calculation is considered conservative because it omits groundwater stored in pore spaces.

Table 7.8: Input geochemical concentrations for facilities

		Groundwater Concentrations			Infiltration Concentrations	
Facility Location		**West WRF**	**East WRF**	**Gangue**	**West WRF/ East WRF**	**Gangue**
Parameter	Units	MW18-03	Composite (WSH-17 / WSH-14)	Composite (WSH-03 / WSH-14)	Waste Rock (Week 0 HCT)	Gangue (Week 0 HCT)
pH	s.u.	7.74	7.87	8.23	7.83	7.13
Antimony	mg/L	0.002	0.002	0.0009	0.063[1]	0.018[1]
Arsenic	mg/L	0.043[1]	0.021[1]	0.007	0.024[1]	0.05[1]
Sulfate	mg/L	26	53	24	906[1]	91

[1] Exceeds Profile 1 NRVs

7.4.2 Geochemical model results

Particle trace results indicate the down-gradient flow paths from the West WRF are towards the Thacker Creek channel, which is the natural western drainage. Vertical mixing through claystone / ash and volcanic tuff units is approximately 122 ft thick (37 m) (Figure 7.10). The post-mining steady-state flux of groundwater flow through this mixing zone is approximately 37.2 gpm. Geochemical mixing indicates that no new exceedances will occur outside the facility footprint (Table 7.9). Arsenic concentrations are above NRVs, but are elevated in background groundwater (0.43 mg/l, Table 7.8).

Groundwater flow paths below East WRF and Gangue Stockpile trend along the same vector towards the eastern drainage in the Thacker Pass Project. The proximity of facilities and alignment of groundwater flow vectors are conducive to evaluating both facilities together. Vertical mixing depth below both facilities is approximately 345 ft (105 m) in claystone/ash units (Figure 7.11). The combined steady-state groundwater flux through this mixing zone is approximately 134 gpm. Delineating the groundwater flux between the East WRF and Gangue Stockpile yields 45.5 gpm and 88.7 gpm for each facility respectively.

Geochemical mixing of infiltration with underlying groundwater flow indicates that no new exceedances to groundwater quality will occur below either the East WRF or Gangue Stockpile. The only exceedance NRV below mine facilities is arsenic and it is a result of elevated background concentrations rather than infiltration from the facility (0.021 mg/l, Table 7.8).

Table 7.9: Simulated groundwater geochemical concentrations

	Fluxes			Mixed Concentrations		
Facility	Groundwater (gpm)	Facility Infiltration (gpm)	Combined Flow (gpm)	**As (mg/l)**	**Sb (mg/l)**	**SO_4 (mg/l)**
West WRF	37.2	3.1	40.3	0.041[1]	0.004	76
East WRF	45.5	2.6	48.1	0.020[1]	0.004	78
Gangue Stockpile	88.7	5.0	93.7	0.007	0.001	25

[1] Exceeds Profile 1 NRVs

7.4.1 Geochemical model sensitivity analysis

A sensitivity analysis for geochemical modeling was performed on the infiltration component to evaluate potential exceedances if input parameters to the analysis change. Although infiltration was the only variable evaluated in the sensitivity analysis, because the mixing model is a simple scalar function, the sensitivity results apply to other inputs (i.e. background groundwater flow, mixing zone depth) when changed by the same proportion (i.e. +/- 50% change).

Infiltration rates of 5% MAP, 8% MAP, and 12% MAP were utilized to capture a range of values. The highest sensitivity value, 12% MAP, is an approximate estimate for infiltration through an uncovered facility. Geochemical sensitivity results are summarized in Table 7.10 and discussed as follows:

- Two new exceedances occur in the sensitivity analysis at infiltration rates more than double the anticipated fluxes. Antimony concentrations rise above NRVs below the West WRF and East WRF when infiltration rates reach 8% MAP. This corresponds to a magnitude of change of between 2 to 3 times more infiltration, or less groundwater flux / mixing depth below the facilities. The likelihood of sustaining this level of change beyond simulated values is low, and the sensitivity results provides strong confidence that the predicted groundwater chemistry will not develop unpredicted exceedances.
- NRVs for arsenic are exceeded at the West and East WRFs by the background groundwater chemistry. Increased contribution of infiltration lower arsenic concentrations below the WRFs.

Table 7.10: Mine facility geochemical sensitivity analysis

Facility	Sensitivity	3% MAP[2]	5% MAP	8% MAP	12% MAP
West WRF	Infiltration Flux (gpm)	3.1	5.1	8.2	12.2
	As (mg/l)	0.041[1]	0.039[1]	0.038[1]	0.036[1]
	Sb (mg/l)	0.004	0.006	0.008[1]	0.010[1]
	SO_4 (mg/l)	76	107	147	193
East WRF	**Sensitivity**	**3% MAP[2]**	**5% MAP**	**8% MAP**	**12% MAP**
	Infiltration Flux (gpm)	2.6	4.3	6.9	10.4
	As (mg/l)	0.020[1]	0.021[1]	0.021[1]	0.020[1]
	Sb (mg/l)	0.004	0.005	0.006[1]	0.008[1]
	SO4 (mg/l)	78	93	114	138
Gangue Stockpile	**Sensitivity**	**3% MAP[2]**	**5% MAP**	**8% MAP**	**12% MAP**
	Infiltration Flux (gpm)	5.0	8.4	13.4	20.1
	As (mg/l)	0.007	0.007	0.009	0.010
	Sb (mg/l)	0.001	0.002	0.002	0.002
	SO4 (mg/l)	25	26	26	27

[1] Exceeds Profile 1 NRVs

[2] Base Case simulation value

8 MONITORING AND MITIGATION PLAN

A groundwater monitoring and mitigation plan has been developed to address potential impacts to surface and groundwater resources from the Thacker Pass Project operation. The objectives of the monitoring and mitigation plan are:

- Monitor groundwater levels between the Thacker Pass open pit and water resources in the Montana Mountains (springs and Pole Creek) during and after mining operations. Groundwater monitoring will serve as a warning system to trigger potential supplemental water mitigation to affected surface water features.
- Monitor groundwater quality down-gradient of the Proposed Action backfilled pit and mine facilities.
- Monitor groundwater levels in Quinn River valley and restore potential well productivity losses to stock water users.
- Provide additional characterization data regarding groundwater compartmentalization and water quality to refine model predictions for permit renewals of the Water Pollution Control Permit (WPCP).

The proposed monitoring infrastructure is comprised of the following elements and shown in Figure 8.1 to Figure 8.3:

- Piezometer locations in the Montana mountains positioned between springs locations and the simulated 10-ft drawdown contour. Piezometer locations target geologic structures surrounding the springs to evaluate bedrock compartmentalization. Piezometer locations are summarized in Table 8.1.
- Monitoring well locations within and surrounding the Backfilled Pit Proposed Action. Monitoring well locations are summarized in Table 8.2.
- Drive-point monitoring well at Pole Creek.
- Monitoring locations in Quinn River Valley utilizing existing stock wells and new piezometers.

Monitoring wells MW18-04, MW18-01, and MW18-03 will be lost during mining operations. Only MW18-04 is should be replaced at a future time to re-establish up-gradient groundwater monitoring of the open pit. Replacing MW18-04 will occur towards the end of the proposed mine life. A suitable location will be identified after mining impacts this well. The other monitoring wells will be superseded by the proposed monitoring plan.

Additional piezometers will be installed after mining commences to support geotechnical and dewatering (if necessary) programs. Piezometer locations will be developed in concert with mining and will provide near pit water level monitoring through the project's duration.

8.1.1 Piezometers

Piezometers are proposed to be located upgradient of the open pit to monitor water levels in the Montana Mountains in bedrock (McDermitt Tuff) groundwater blocks between springs and the Thacker Pass Project. Hydraulic data in Thacker Pass has identified that fault structures functioning as hydraulic barriers are an important control for the groundwater system. Given that the geology of the Montana Mountains is composed of similar caldera materials (claystone deposits, volcanic tuff, and basalt flows), mapped and unmapped geologic structures north of the Thacker Pass Project are anticipated to compartmentalize the groundwater system. Most spring locations in the Montanas are associated with faults (SP-007, SP-004, SP-008, SP-051, SP-052, SP-055), further illustrating the role of geologic structures as hydraulic barriers. Piezometer locations target the hanging wall mapped structures (where possible) to monitor water levels and characterize compartmentalization. For example, Montanas PZ-02 is targeted between two mapped faults, one associated with SP-007 and another to the south.

One new piezometer is proposed for Quinn River Valley, located approximately 2 miles north of QRPW18-01 for the purpose of monitoring drawdown in the alluvial aquifer. The piezometer will be drilled to approximately 100 ft depth to accommodate long term monitoring. Additional monitoring in Quinn River Valley is proposed through using a network of 4 stock water wells from the Home Ranch, discussed in Section 8.1.3.

Two new piezometers are proposed adjacent to Crowley Creek. The first is up-gradient from the confluence with Rock Creek and LNC's stream gaging station with the objective of measuring piezometric levels adjacent to the gaining reach of Crowley Creek. This piezometer is proposed to be a dual completion to monitor i) base flow conditions adjacent to the creek which are expected to vary seasonally with the freshet and stream load, and ii) lower groundwater conditions which are anticipated to show less seasonal variation. The second is down-gradient of the Pole Creek confluence with Crowley Creek and is designed to monitor water levels to the south.

Piezometers should be completed with 2-inch steel pipe to allow for permanent access to sensors for replacement. All piezometer locations require field verification to ensure accessibility. A summary of proposed piezometer locations is provided in Table 8.1.

Table 8.1: Proposed piezometer monitoring locations

Name	X-Collar (UTM)[1]	Y-Collar (UTM[1]	Z-Collar (ft, amsl)	Depth (ft)	Comment
Montanas PZ-01	408019	4623243	6623	400	Monitor water levels outside of predicted 10 ft isopleth. Test for compartmentalization and serve as regional monitoring point
Montanas PZ-02	408596.3	4623746	6074	800	Serve as sentinel monitoring location in Montanas at headwaters of Pole and Rock Creeks. Serve as regional monitoring point. Evaluate fault compartmentalization for modeling.
Montanas PZ-03	409171.4	4618790	5312	650	Monitor water levels west of backfill
Montanas PZ-04	409834.4	4620624	6201	500	Monitor water levels in Montanas within 10 ft isopleth
Montanas PZ-05	411341	4619424	5381	500	Monitor water levels directly upgradient of pit and E-W fault
QR PZ-06	425778	4619470	4233	100	Monitor North of Quinn River Production Wells.
Crowley PZ-07	421028	4619980	4523	80	Monitor Crowley Creek water levels
Crowley PZ-08	419962	4617347	4456	30	Monitor Crowley Creek and Lower Pole Creek water levels

[1] Approximate location pending field confirmation and accessibility

8.1.2 Monitoring wells

The results of the fate and transport model indicate that the migration of elevated antimony is not expected to migrate beyond the Thacker Pass Project permit boundary after 300-years post-closure. Therefore, the proposed monitoring well locations are strategically designed with the following criteria:

- Surround the potential footprint of elevated antimony groundwater within the permit boundary.
- Place monitoring wells where groundwater is predicted to meet NRVs for antimony, thus if an exceedance occurs it will trigger a mitigation action.
- Positioned between mine facilities and the Thacker Pass Project permit boundary.
- Select monitoring wells to measure pore water conditions in the backfill post-closure. This refers to future wells South Sub-pit MW-05 and West Sub-pit MW-06. These would not be compliance points.

Monitoring wells will be completed as 4-inch diameter wells and meet Nevada Division of Environmental Protection (NDEP) standards. Based on results from the fate and transport model, the wells should be completed with 140 ft to 240 ft of screen and intercept claystone and volcanic tuff units. Under this design monitoring wells could be converted to pump back wells using small 3-inch submersible pump should antimony concentrations exceed NRVs.

Two existing wells (WSH-03 and WSH-13) are suitably located down-gradient of the South Sub-pit to serve as compliance points. Background antimony concentrations at these wells are <0.0025 mg/l and 0.002 mg/l respectively. Because mining is not anticipated to encounter meaningful groundwater until 2060, LNC would install bedrock monitoring wells prior to mining below the water table.

Table 8.2: Proposed monitoring well locations

Name	X-Collar (UTM)	Y-Collar (UTM)	Z-Collar (ft, amsl)	Depth (ft)	Comment
West Sub-Pit MW-01	410722.8	4617501	5026	160	Down-gradient of West Sub-Pit
West Sub-Pit MW-02	408607	4617515	4683	60	Down-gradient of West WRF
South Sub-Pit MW-03	412587.9	4616675	4809	120	Down-gradient of South Sub-Pit
South Sub-Pit MW-04	413690.2	4616664	4758	100	Located adjacent to future road
South Sub-Pit MW-05	412476.1	4617598	4855	250	Drilled in Backfill after closure
West Sub-pit MW-06	411159.3	4618116	5135	360	Drilled in Backfill after closure
WSH-13[1]	411736.4	4617085.4	4944.7	500	Existing well, located south of South Sub-Pit
WSH-03[1]	413777.1	4617204.0	4799.9	500	Existing well located east of South Sub-Pit.

[1] Existing monitoring well

8.1.3 Pumping wells

Several production and stock wells in Quinn River valley as listed in Table 8.3 are proposed to be instrumented with transducers to monitor groundwater levels across the valley (Figure 8.3). These are intended to serve as background monitoring locations as well as trigger mitigation in the case that stock water production is affected by drawdown related to mine operations. The wells will be monitored with a pressure transducer, after LNC has secured permission from the well owner. Several of the stock wells are solar powered, such that static water levels can be measured at night when pumps are not operating.

Modeling indicates that drawdown associated with water production in Quinn River Valley will occur within an approximate 1-mile radius of the production well during mining operations. An additional backup well will be drilled some distance from QRPW18-01. The proposed monitoring locations (Table 8.3) would envelope the simulated 10-ft isopleth and thus provide excellent coverage to verify model impacts. Both the pumping well and back-up well would also be instrumented with pressure transducers to monitor water levels through time.

Table 8.3: Proposed pumping well monitoring locations

Name	X-Collar (UTM)	Y-Collar (UTM)	Z-Collar (ft, amsl)	Depth (ft)	Comment
QRPW18-01	425330	4616161	4204	560	This includes all LNC production wells located in Quinn River
Windmill Well	424957	4615300	4204	100	
Home Ranch East Well	425664	4614820	4191		
Home Ranch Stock Well #5	425560	4613210	4184		
Home Ranch Stock Well #6	424198	4611460	4184		

8.1.4 Proposed Monitoring Schedule

The proposed schedule for installing monitoring is synchronized with the mine plan and timing of potential impacts. Accessibility to some locations, such as Montanas PZ-03 and backfill monitoring wells, will not be available until after mining has reached that area. In general, the proposed monitoring schedule is as follows:

- Piezometer installation would be completed prior to the beginning of mining to monitor water levels in the Montanas. Although mining is not anticipated to intersect saturated materials below the E-W structure until ~2035, early installation will aid in building additional baseline data.
- Transducer placement in the Windmill Well would occur prior to the commencement of mining or operating the production well.
- A replacement monitoring well for MW18-03, located down-gradient of the West WRF, would be drilled approximately 1 year before mining commences to allow data to be collected from both the proposed West Sub-Pit MW-02 and MW18-03 prior to abandonment and allow for comparison.
- Down-gradient bedrock monitoring wells would be drilled by 2050, which is approximately 5-years prior to intersecting thicker sections of groundwater in the North and South Sub-Pits.
- Backfill monitoring wells would be drilled upon mine closure.

A proposed monitoring schedule is provided in Table 8.4.

Table 8.4: Proposed Monitoring Schedule

Element	Year	Comments
Drill and Install Drive Point Piezometers	2020 - 2021	Complete installations and begin monitoring prior to mining.
Install Transducers in Quinn River Stock Wells	2021	
Drill and Install Piezometers: Montanas PZ-01, Montanas PZ-02, Montanas PZ-04, Montanas PZ-05, QR PZ-06, and Crowley PZ-07 & PZ-08	2021	Complete installations and begin monitoring prior to mining.
Initiate Mine Construction	2021	
Install Monitoring Well West Sub-Pit MW-02	2023	Replacement well for MW18-03 drilled 1-year prior to mining and West WRF construction.
Commence Mining	2024	
Install Piezometers Montanas PZ-03	2024	Location is accessible after mining begins
Install Monitoring Wells (West Sub-pit MW-01, South Sub-pit MW-03, South Sub-pit MW-04)	2050	Install down-gradient monitoring wells 5-years prior to encountering more saturated groundwater and backfilling in 2055.
End Mining and Begin Mine Closure	2065	
Install Backfill Monitoring Wells (West Sub-pit MW-06 and South Sub-pit MW-05)	2066	Backfill monitoring well installation at closure

8.2 PROPOSED MITIGATION

Mitigation options are presented in the event that impacts occur beyond predicted conditions. Because the projected timeline is long, it is anticipated that any mitigation action, if necessary, would not occur for years to decades after closure. Several mitigation options are developed to address water quality and quantity impacts described as follows:

- Antimony groundwater contamination mitigation: Three proposed mitigation options (Options 1-3 below) are designed to directly mitigate the affected groundwater area or provide source control during backfilling. Each of these options is expected to be an effective control to counter contaminant migration, if required.
- Surface water mitigation: Option 4 is proposed to mitigate potential impacts to surface water features in the Montana Mountains.
- Quinn River Valley stock water mitigation: Option 5 mitigation plan is to mitigate potential impacts to stock water users in Quinn River.
- Two other mitigation options are studies to be administered during operations to better understand potential source control options that may be included during the placement of backfill. Their objective is to evaluate options to reduce or attenuate antimony mass prior to discharge from the backfill. The proposed monitoring and mitigation set forth below does not consider the possibility of a regulatory exemption under NAC 445A.424, which may be addressed in more detail as part of the pending Water Pollution Control Permit application.

8.2.1 Pump back system (Option 1)

Pump back wells would be completed in the claystone and volcanic tuff units adjacent to the monitoring location where antimony concentrations are exceeded. Monitoring wells themselves are designed to be converted to pump back wells if necessary. Pump back wells would be designed to operate in perpetuity using solar panels. Model predictions and onsite experience indicates that the expected depth to water would be within 25 ft to 75 ft of ground surface, which is within the range of solar pump systems. Pumping rates are expected to range between 10 gpm to 40 gpm depending on local hydrogeologic conditions and well design. Given that the long-term predicted outflow from backfill is approximately 34 gpm and antimony concentrations are predicted to decline to <0.02 mg/l, the quantity of water to manage from the pump back system is anticipated to be less than 80 gpm.

Discharge produced from the pump back system would be managed by one of four options depending on the volume of water produced and project economics.

1. Discharge and enhanced evaporation to backfill: The volume of contaminated water would be routed to and applied to the backfill surface where the majority of fluid would be consumed via evaporation and transpiration by plants. Cover evaluation indicated that transpiration by plants will have additional capacity to remove water and prevent infiltration. If needed, misters and evaporators can be used to enhance evaporation during application. The remaining fluid would report back to the backfill as infiltration to eventually be re-captured by the pump back system. This system creates a capture loop between backfill and pump back wells where evaporation is used to reduce fluid volumes.
2. Passive treatment of antimony by sequestration onto metal oxides: Contaminated water from pump back wells would be discharged through a series of oxidizing ripples and aerobic wetlands amended with an adsorption agent (ferrihydrite, zero valence iron, ferric chloride, or Mn-oxides) to facilitate sequestration of metals. The passive treatment system would consist of redundant ponds to allow for periodic rehabilitation and reamendment of adsorption agents. Treated water would return to groundwater through infiltration basins. Additional proof of concept studies are required to test and trial the passive treatment concept, however similar systems have proven effective for arsenic treatment at closed mine sites. These studies are discussed in section 8.3.5.
3. Blending and surface water discharge: Volumes of contaminated water which exceed the capacity of the tailings facility would be blended with fresh groundwater and discharged to surface where it will re-infiltrate. At a potential pump back concentration of 0.012 mg/l

antimony, the blending ratio would be approximately 1:1 to bring contaminated water into compliance with NRVs (assuming background chemistry is near non-detect).

4. Active treatment: Contaminated water would be treated through a small reverse osmosis plant and returned to groundwater through infiltration basins.

8.2.2 Backfill hydrogeologic control pumping (Option 2)

An alternative mitigation approach would be to pump pore water from the backfill. This approach is considered a preventative measure because once antimony is detected above NRVs in monitoring wells, the initial flush of antimony has transported through the groundwater system. Therefore, pumping would begin upon closure and positive confirmation of pore water chemistry. Backfill design can be engineered to encourage drainage to a centralized location, in the South Sub-pit, by intermittently placing finger drains of gravel every 3 to 4 lifts throughout the backfill.

Several challenges exist with source control pumping including:

- This mitigation is most effective when designed to prevent water level recovery in the backfill and thus function as a permanent dewatering system. In this sense, the costs to maintain pumping the backfill in perpetuity are high.
- Backfill production wells are expensive and challenging to maintain because of subsidence in backfill materials over time. These wells would have high construction and maintenance costs. Multiple wells would be required to supress water levels in the backfill.
- Managing discharge from backfill wells will be more challenging than the pump back system because more fresh water would be required to blend discharge water of higher antimony concentration and potentially greater flow rates.

Maintaining an unsaturated backfill is unlikely under the given conditions, however pumping from the backfill will aid in managing the quantity of discharge into the groundwater system.

8.2.3 Partial backfill closure (Option 3)

Selecting the Partially Backfilled South Sub-pit Alternative closure design would engineer a wetlands in the South Sub-pit which would function as a hydraulic sink. At the 4,708 ft amsl elevation, the potential evaporative demand is ~115 gpm, approximately double the evaporation required to maintain a hydrologic sink in the Open Pit Alternative. Results from the impacts analysis indicate the following:

- An ephemeral pond will develop on the backfill surface during winter and spring when evaporative demands are low. During summer months, the water levels will decline below the backfill surface. Seasonal variation is anticipated to be within 1 ft of the backfill surface.
- The wetlands function as a hydraulic sink for backfilled pits whose capture zone extends into the saturated portions of the North and West sub-pits. Fate and transport modeling demonstrate capture of groundwater outflow by the South Sub-pit wetlands.
- Simulated water levels in the West Sub-pit backfill will be suppressed, leaving only 7 ft of saturated thickness. The design of the West-Sub-pit can be modified to eliminate any saturated thickness and thus discharge.

8.2.4 Mitigation options for surface water (Option 4)

This mitigation option will respond to drawdown propagating towards surface water features in the Montana Mountains, if required. Additional water will be delivered to surface water features through small diameter water wells equipped with a solar pump to augment flow. The riparian footprints for the springs are quite small, on the order of 30 ft x 30 ft. Therefore, the flow rates will be small (<1 gpm) and applied to the riparian zone. Alternatively, guzzlers can be installed at spring locations to provide shelter and water for Sage Grouse Habitat.

For Pole Creek, additional water will be sourced near the headwaters and discharged to the creek bed. Because potential drawdown to springs is not anticipated for several decades after closure (if at all), mitigation to springs would not occur unless a meaningful drawdown attributable to mine operations is measured in the piezometer network. Model predictions do not indicated discernible changes to baseflow conditions to potentially perennial reaches of Pole Creek.

It should be noted the LNC expects to fund Sage Grouse habitat restoration through the State's credit system; these restoration projects would compensate for potential habitat degradation of springs in the Montana Mountains, should it occur.

8.2.5 Quinn River stock water mitigation (Option 5)

The nearest stock well which could be impacted is the Windmill Well. The well is 100 ft deep with a static depth to water of approximately 14 ft bgs. Drawdown may potentially lower the water table by 15 additional feet (29 ft bgs). However, the Windmill Well will still have approximately 71 ft of saturated alluvium to supply stock water on the order of 10 gpm during maximum pumping. Lowering water levels may affect the pump performance, although under these conditions it is unlikely. Thus, the Windmill Well has a low probability of being impacted by operations. A transducer installed in the well, with owner's permission, will allow stakeholders to monitor for impacts.

In an abundance of caution, LNC proposes to work with the owner of the Windmill Well to install a small pipeline from the discharge line of the Quinn River production well to serve as a stock water source. In the unlikely event that other wells be adversely impacted, water trucks supplied by the Quinn River production well can temporarily haul water to stock ponds while a new well is drilled.

8.2.6 Adsorption amendment (Study 1)

The sequestration of antimony through adsorption onto iron, manganese, and aluminum oxides may be the geochemical foundation for passive treatment or soil amendment to the backfill to mitigate antimony mobilization. Doherty, Tighe, and Wilson identified iron substrates (i.e. ferrihydrite, zero valence iron, and ferric chloride) applied at a 3% weight ratio was effective in reducing antimony and arsenic concentrations in pore water, so long as a pH above 6 s.u. was maintained (Doherty, 2017). The presence of ferric iron (Fe^{3+}) in solution is particularly valuable as it co-precipitates with arsenic and antimony metalloids in oxidizing conditions. Alternative amendment options include manganese oxides that have demonstrated high sorption capacities (Thanabalasingam, 1990). Furthermore, literature review of partition coefficients by Allison and Allison identify antimony as a little-studied cation (Allison, 1990).

Several challenges exist to applying a soil amendment including:

- Experimental amendment studies have reduced antimony from initial concentrations of approximately 0.2 mg/l to concentrations between 0.02 mg/l to 0.09 mg/l, which is still above NRVs and anticipated backfill porewater concentrations (Doherty, 2017). The amendments were effective in removing antimony at high concentrations but were inconclusive if antimony concentrations could be lowered to meet NRVs. Site specific testing is needed to evaluate the potential attenuation through amendments.
  - Sources of amendment to backfill may be scarce, therefore depositing an amendment during backfill emplacement is likely not feasible. Alternative approaches are:
  - Use smaller volumes of amendment in the passive treatment of contaminated groundwater.
- Constrain the amendment application only to backfill which will reside with 50 ft of recovered water levels, thus omitting the unsaturated portions of backfill from amendment. Even at this application the volume of amendment will likely be vast,

economically prohibitive, and in the case of ferrihydrite may not be commercially available.

- Maintaining suitable pH conditions. Some potential amendments such as ferric chloride (FeCl) will lower pH unless mitigated with lime or another pH buffering agent. Acidification of waters will ultimately negate the intended sorption effect of the amendment, as antimony sorption occurs most readily between pH 7 s.u. to 8.5 s.u. On-site groundwater and backfill pore water is anticipated to naturally reside in the 7.5 s.u. to 8.5 s.u. pH range, which should not require lime for most amendment options.
- Demonstrating that the aforementioned amendments are suitable under geochemical conditions found in Thacker Pass backfill. The native waste rock will be relatively low in iron oxides, thus an amendment to backfill will be a competitive sorption site for all ions in solution. The effectiveness of the amendment at sequestering antimony specifically among other metal ions needs to be field demonstrated.

LNC intends to execute a geochemical investigation during operations to quantify the feasibility of antimony sequestration by an amendment. The results of the investigation will form the basis for pre-feasibility level engineering of site-specific passive treatment or potential amendment to backfill. The investigation workplan will be shared with regulatory agencies prior to commencement for comment, as will the findings.

8.2.7 Ongoing geochemical attenuation studies (Study 2)

LNC will undertake additional geochemical testing to evaluate the sorption capacity of antimony onto volcanic tuff. Fate and transport modeling indicate that outflow from backfill will flow through the underlying volcanic tuff unit, comprised of rhyolitic to lithic welded tuffs. The attenuation capacity of this material with regard to antimony is currently unknown. Batch and bottle roll testing combined with additional MWMP testing would be used to develop a site-specific partition coefficient of antimony.

Ongoing geochemical testing and study results are anticipated to be included in LNC's WPCP permit. The attenuation study will be a component of these studies. Results from the attenuation study will be included in the WPCP renewal and in future impacts analyses.

9 CONCLUSIONS

9.1 WATER QUANTITY IMPACTS ANALYSIS

Key findings from the water quantity impacts analysis in Section 4 include:

- Dewatering requirements for open pit mining are predicted to be low and manageable by in-pit sump pumping during operation unless geotechnical analysis indicates more extensive depressurization is required. Simulated dewatering rates range from 55 gpm to 95 gpm.
- The end of mining 10-ft drawdown isopleth for the Thacker Pass Project is constrained to less than a 2.5-mile radius centered at the open pit. Drawdown is greatest in the North and South Sub-pits where mining encounters the thickest saturated materials.
- The 300-year 10-ft drawdown isopleth in Thacker Pass expands in the Open Pit and Partially Backfilled South Sub-pit Alternatives as a result of evaporative losses to pit lakes or wetlands. The Open Pit Alternative produces the largest drawdown footprint.
- The 300-year 10-ft drawdown isopleth for the Partially Backfilled South Sub-pit Alternative has a smaller footprint across Thacker Pass than the Open Pit Alternative owing to the engineered higher water level recovery (4,708 ft amsl) in the South Sub-pit.
- The Backfilled Pit Proposed Action produces the smallest drawdown footprint. After 300-years post mining, the southern extent of drawdown is much less than the other closure scenarios due to backfilling. The northern extent of drawdown is also smaller.
- The reduction of simulated groundwater flow to Thacker Creek is small, falling within the measurement error of the stream gauges, and are significantly less than seasonal variation (~94 gpm). The greatest reduction to groundwater baseflow to the creek is associated with the Open Pit Alternative (~19 gpm) and the least reduction is from the Backfilled Pit Proposed Action (8 gpm). Such flow reductions will not affect the streamflow components related to surface water runoff and interflow, which can be 2 to 3 times the flow rate of groundwater baseflow. Most of the simulated flow losses are predicted to occur near the headwaters of Thacker Creek (SP-010 and SP-011) which are closer to the Thacker Pass Project. Flow contributions to Thacker Creek further downstream are not anticipated to be impacted.
- No measurable impacts to the Upper and Middle reaches of Pole Creek were simulated, where simulated groundwater flow reductions are < 1gpm. No impacts to surface runoff and interflow are anticipated.
- A temporary decline in groundwater discharge is simulated at Crowley Creek of 16 gpm. This decline is minor relative to baseflow to the creeks, and even smaller when

considering surface runoff and interflow components to the creeks, which are several orders of magnitude higher than baseflow seasonally. This impact is less than the uncertainty of field measurements, and therefore undiscernible from seasonal and natural variation.

- Groundwater flow to Lower Pole Creek, near the confluence with Crowley Creek, were simulated to decline during mining, but fully recover during mine closure. This is an ephemeral reach which is naturally dry during summer, fall, and winter months. Surface runoff and interflow components of streamflow would be unaffected.
- Nine (9) spring locations fall within the maximum 10-ft drawdown isopleths (Open Pit Alternative), but only SP-033 has had any perennial discharge (0.95 gpm) with all other springs either being ephemeral (SP-001, SP-002, SP-060, SP-061) or man-made stock ponds (SP-003, SP-015, SP-058, SP-059). The Backfilled Pit Proposed Action would only potentially impact SP-001 (which will be mined through), SP-003, and SP-058.
- Water rights sourced at SP-028 (permit numbers 79742 and 87006) are outside the 10-ft drawdown isopleth in all the simulated alternatives.
- Drawdown related to water supply pumping in Quinn River basin is predicted to be constrained to a 1-mile radius in the alluvial aquifer. The cone of depression does not intercept any mapped water rights. Transferring irrigation water rights to the Quinn River well will cumulatively restore water to the basin because of the 77.5% transfer allotment rate to mining and milling use. In addition, the water rights are being transferred from nearby wells currently used for irrigation, further mitigating potential localized impacts. Upon mine closure, the water rights are anticipated to be retired, thus resulting in a net positive recovery of water levels in Quinn River Valley with regard to the Proposed Action.
- The South Sub-pit will form a hydraulic sink in both the Open Pit and Partially Backfilled South Sub-pit Alternatives. All groundwater outflow from the North Sub-pit pit lake and the West Sub-pit pit lake will be captured in the South Sub-pit lake.
- Equilibrium evaporative losses are approximately 124.1 gpm in the Open Pit Alternative and 56.2 gpm in the Partially Backfilled South Sub-pit Alternative. Inflows to the lakes are primarily derived from surface water sources (precipitation and runoff). The Backfilled Pit Proposed Action has no evaporative losses because pit lake(s) do not form.
- Infiltration through reclaimed WRF and Gangue Stockpile facilities was simulated to range from 2.6 gpm to 5.0 gpm at equilibrium. Vegetated covers are anticipated to have more capacity to capture and transpire water to the atmosphere owing to the conservative wilting point parameters selected and the opportunistic population increase in vegetation if wetter conditions are available.

9.2 WATER QUALITY IMPACTS ANALYSIS

Key findings from the groundwater quality impacts analysis in Sections 5 and 7 include:

- None of the geochemical units are classified as acid-generating, nevertheless PAG and non-PAG materials are delineated in the geochemical model. The only PAG HCT sample did not produce acid leachate through 44 weeks of HCT testing.
- Claystone/ash and ash geochemical units comprise the majority of the pit wall and backfill material. As a result, the resulting pore water chemistry and pit lake will reflect the chemical release functions of these source materials. Claystone/ash materials were characterized as releasing elevated concentrations of fluoride, molybdenum, sulfate, and uranium during initial flushing. Arsenic and antimony complexes were steadily released throughout testing.
- Oxidized gangue material generates lower antimony, arsenic, and sulfate mass than unoxidized gangue. Unoxidized gangue leachate is similar to that of claystone / ash waste rock.
- The Backfilled Pit Proposed Action produced the fewest number of Profile I exceedances which were primarily arsenic, antimony, and sulfate (Table 9.1). Pore water chemistry is anticipated to improve through time. In this configuration, only 34 gpm will cumulatively discharge from backfill.
- A screening level assessment provided a mass conservative evaluation of solute concentrations down gradient of the backfilled pit. The risk assessment indicates:
- Sulfate and magnesium concentrations will be below NRVs immediately when mixed with groundwater.
- Background groundwater concentrations of arsenic are elevated above NRVs, and thus the contribution of arsenic from backfill is not an impact with regard to arsenic.
- Antimony is the only element with the potential to affect down gradient groundwater stakeholders. These potential impacts were evaluated in a series of fate and transport simulations.
- Predicted pit lake chemistry in the Open Pit Alternative generated several NRV Profile I exceedances (discharge from North and West Sub-pits) and Profile III (Table 9.1). The South Sub-pit will be a hydrologic sink and capture outflow from the North and West Sub-pits. Profile III exceedances will require an ERA to assess impacts to biologic receptors.
- Predicted ephemeral wetlands chemistry in the Partially Backfilled South Sub-pit Alternatives also predicts several exceedances to Profile III NRVs. Constituent concentrations are higher than the Open Pit Alternative due to the additional mass

loading from backfill rinsing and continued evapoconcentration. The wetlands will be a hydrologic sink and capture outflow from the North and West Sub-pits.

- Pit lake and backfill chemistry is anticipated to be in equilibrium with several mineral phases. Calcite, gibbsite and magnesite have the greatest effect on controlling major ion chemistry and generating realistic chemical profiles.
- Several important geochemical reactions for trace ions are not included in the geochemical model such as co-precipitation, adsorption onto manganese oxides, (MnOOH), aluminum oxides ($Al(OH)_3$), or clay colloids, and solid-state substitution. Because these processes vary widely from location to location, site specific testing after mining has commenced will refine the geochemical model and predicted concentrations. Additional laboratory testing should be conducted during operations to evaluate the attenuation potential of alluvium and volcanic tuff materials (claystone/ash units leach antimony not considered to have attenuation potential). Likewise, alternative backfill compositions such as including additional gangue and/or tailings, storing waste rock above the water table, or amending the backfill with a strong sorption substrate is warranted after mining has begun and these materials become more accessible.
- Infiltration from WRFs and the Gangue Stockpile is not anticipated to have any impacts to groundwater quality. The sensitivity analysis confirms that no groundwater impacts are anticipated in the event groundwater flow is reduced or infiltration is increased by a factor of 2 to 3. This is unlikely because infiltration through vegetated covers on mine facilities is anticipated to be less than simulated.

9.2.1 Fate and transport analysis

Key findings regarding groundwater quality impacts from the fate and transport analysis discussed in Section 6 include:

- For all closure scenarios, the overall distribution of antimony after 300 years remains within the Thacker Pass Project's permit boundary.
- Potential impacts to other water stakeholders in Quinn River Basin are not predicted by the fate and transport model. The extent of elevated antimony concentrations remain within the Thacker Pass Project's permit boundary.
- For the Backfilled Pit Proposed Action, antimony concentrations migrate approximately 1 mile towards the south east according to the post-mining groundwater gradient. After 300 years maximum antimony concentrations are declining to <0.2 mg/l. WSH-03 is well positioned to monitor down-gradient outflow from a fully backfilled pit.
- For both the Open Pit and Partially Backfilled South Sub-pit closure alternatives, antimony is captured in the South Sub-pit. A hydraulic sink forms and prevents the migration of antimony beyond the open pit footprint.

- Generally all the sensitivity simulations produced a similar suite of results, namely capture of antimony in the South Sub-pit, or the migration of antimony towards WSH-3 (Backfilled Pit Proposed Action). Antimony travels faster and along different vectors under the high hydraulic conductivity sensitivity. The probability of encountering these conditions are low because model calibration with higher conductivity parameters does not produce a good match to groundwater levels, however the sensitivity is informative to understand key controls.

Table 9.1: Summary of predicted Profile I and Profile III constituent exceedances

Backfilled Pit Proposed Action (Profile I NRVs)														
Year	**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
North Sub-pit	Sb, As, Cl, Mg, Mn, SO4, TDS	Sb, As, Cl, Mg, Mn, SO4, TDS	Sb, As, Mg, Mn, SO4, TDS	Sb, As, Mg, SO4, TDS	Sb, As, SO4, TDS	Sb, As, SO4, TDS	Sb, As, SO4, TDS	Sb, As	Sb, As	Sb, As	Sb, As	Sb, As	Sb, As	Sb, As	Sb, As
West Sub-pit	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS	Sb, As, TDS
South Sub-pit	Sb, As, Mg, SO4, TDS	Sb, As, Mg, SO4, TDS	Sb, As, Cl, Mg, SO4, TDS	Sb, As, Cl, Mg, SO4, TDS	Sb, As, Cl, Mg, SO4, TDS	Sb, As, Mg, SO4, TDS	Sb, As, Mg, SO4, TDS	Sb, As, SO4, TDS	Sb, As, SO4, TDS	Sb, As, TDS	Sb, As	Sb, As	Sb, As	Sb, As	Sb, As
Open Pit Alternative (Profile I and Profile III NRVs)															
Year	**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
North Sub-pit	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS, V	Sb, As, F, Mn, Mo, SO4, TDS, V	Sb, As, F, Mn, Mo, TDS, V	Sb, As, F, Mn, Mo, TDS, V	Sb, As, F, Mn, Mo, SO4, TDS, V	Sb, As, F, Mo, V	Sb, As, F, V	Sb, As, F, V	Sb, As, F
West Sub-pit	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, SO4, TDS	Sb, As, F, Mn, Mo, TDS, V	Sb, As, F, Mn, Mo, V	Sb, As, F, Mo, V	Sb, As, F, Mo, V	Sb, As, F, V	Sb, As, F, V	Sb, As, F	Sb, As, F
South Sub-pit (Profile III)	F, Mo	F, Mo	F, Mo	F, Mo	F, Mo	F, Mo	F, Mo	As, F, Mo, V	As, F, Mo, V	As, F, Mo, V	Sb, As, F, Mo, V	Sb, As, F, Mo, V	As, Sb, F, Mo, v	Sb, As, F, Mo, V	As, Sb, B, F, Mo, V
Partially Backfilled South Sub-pit Alternative (Profile III NRVs)															
Year	**1**	**2**	**3**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**	**175**	**200**	**250**	**300**
South Sub-pit	F, Mo	F, Mo	F, Mo	F, Mo	F, Mo	F, Mo, V	As, F, Mo, V	As, F, Mo, V	As, F, Mo, V	Sb, As, F, Mo, V	Sb, As, B, F, Mo, TDS, V	Sb, As, B, F, Mo, TDS, V	Sb, As, B, F, Mo, TDS, V	Sb, As, B, F, Mo, TDS, V	Sb, As, B, F, Mo, Na, TDS, V

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11 REPORT LIMITATIONS

This report has been prepared for the specific purpose identified herein at the request of and for the use of the Client. Observations, conclusions, and recommendations contained herein are opinions based upon the scope of services, information obtained through observations and measurements taken by Piteau Associates at certain points and certain times, and interpretation and extrapolation of secondary information from published and unpublished material. The report may infer the configuration of strata, ground and groundwater conditions both between data points and below the maximum depth of investigation. The report also may deduce temporal trends and averages for climatic, hydrological and water quality parameters. Such interpretations and extrapolations are only indicative and no liability is accepted for variations between the opinions expressed herein and conditions which may be identified at a later date through direct measurement and observation.

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Respectfully submitted,

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