HydroGeoLogica TECHNICAL MEMORANDUM

To: Taylor Taipale, FGMI
Company: Fairbanks Gold Mining, Inc.
From: Liane George, Pam Rohal
Date: May 7, 2019
Subject: **Fort Knox Pit Lake Evaluation, 2019 Update**

Introduction

This technical memorandum presents a summary of the 2019 update to the pit lake closure evaluation, completed in support of current reclamation and closure planning efforts for the Fort Knox Mine (the Mine). The Mine site is located near Fairbanks, Alaska and is owned and operated by Fairbanks Gold Mining, Inc. (FGMI), a subsidiary of Kinross Gold Corporation. FGMI is currently updating their Reclamation and Closure Plan for the Mine, to be submitted later this year. This pit lake evaluation update reflects the reclamation/closure concepts to date, utilizing the open pit for storage and mixing of natural and process waters during the post-closure period, as well as for storage of approximately 18 million tons (Mtons) of waste rock in an in-pit dump. The existing closure water balance and chemistry model has been updated with: operational data estimates through closure; post-closure flow/volume forecasts; and updated site water chemistry data. The results from the modeling have been used to complete this evaluation. This memo also includes an evaluation of the potential for stratification of the pit lake during the post-closure period, which may affect discharge water quality in the future.

The objectives of this update are to:

- present updated water flow/volume data for input to the pit lake water balance;
- present updated input water chemistry data;
- develop estimates of post-closure, pit lake water quality compared to Alaska reference standards;
- evaluate the potential for stratification in the post-closure pit lake; and
- determine the effectiveness of the current reclamation approach from a water quality perspective.

Project Background

The Mine is located approximately 15 miles northeast of Fairbanks, Alaska in T2N, R2E and T2N, R3E, Fairbanks Meridian near the headwaters of the Fish Creek drainage. The land is owned by the State of Alaska, the Alaska Mental Health Trust, and private parties. WMC (2006) provides a description of the site climate, topography, hydrology, hydrogeology, and geology and therefore this information is not replicated in the current document.

Fort Knox Mine Updated Reclamation and Closure Plan

FGMI is currently updating their Reclamation and Closure Plan for submittal to Alaska Department of Natural Resources (ADNR). The following sections describe the elements of the operation and closure plan (to date) that are relevant to the pit lake evaluation.

Current Operations through Mill Closure (2019 – 2021). The mine will continue to operate under current conditions through 2021, with active mining in the current pit, leaching operations at Walter Creek/Barnes Creek heap leach facilities, and milling/tailings deposition in the tailings storage facility (TSF). The September 2018 bathymetric survey estimated the operational volume of the TSF decant ponds (combined) at 14,118 acre-feet. Water treatment systems are operating to discharge water off-site and reduce water inventory prior to closure. Production water from pit dewatering wells was being treated by a reverse osmosis (RO) system through February 2019; currently, dewatering water is being discharged off-site after blending with other discharge waters to meet discharge permit standards. An interception system collects TSF seepage water (and some groundwater) downgradient of the TSF; a portion of this water is being treated by a second RO system as of February 2019 for off-site discharge, while excess seepage water is recycled directly back to the TSF decant ponds. This RO system will cease operation at the end of 2027. Another RO system will be implemented in June 2019 to treat decant pond water directly for off-site discharge. The brine (concentrate) from the individual RO systems is being/will be directed to the TSF decant ponds.

Pit Expansion and Mill Closure (2022). During 2022, mining in the eastern half of the current (Fort Knox) pit will continue; however, the milling operations will shut down. Planned reclamation of the north TSF decant pond will be completed, and surface water diversion will be initiated. Post 2022, mining of the open pit will continue and extend to the west into the Gilmore expansion area. There will be a ridge of unmined material between the completed (eastern) pit bottom and the development of a western pit bottom in the Gilmore expansion. Ore from the Gilmore expansion will be placed in the Barnes Creek heap leach facility for leaching. A portion of the waste rock from the Gilmore expansion will be placed in an in-pit dump within the completed, eastern pit bottom. The configuration of the open pit at mine closure is illustrated in Figure 1.

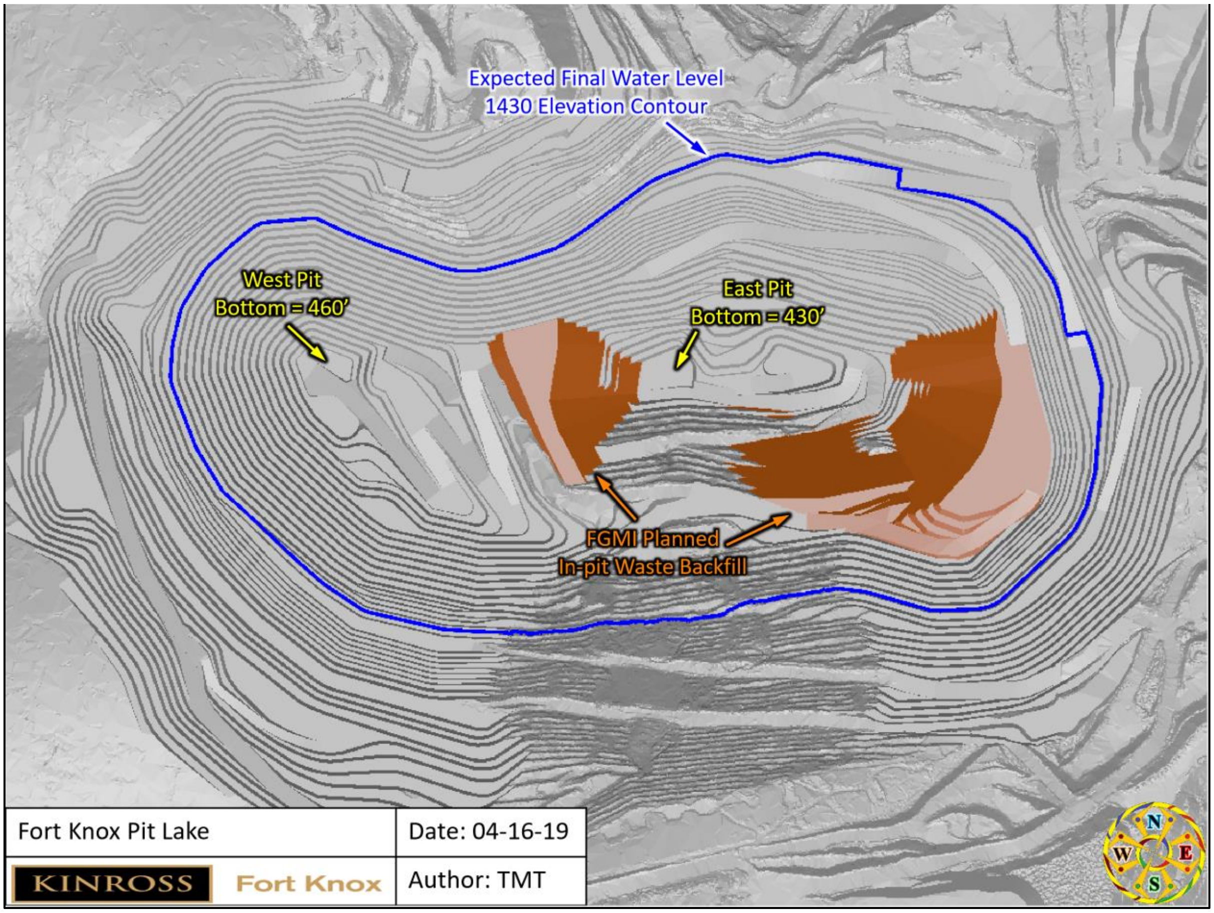

Figure 1 – Final Pit Configuration

East Pit Lake (initial filling period; 2022-2027). During 2022, water from the TSF north decant pond will be transferred to the inactive, eastern Fort Knox pit bottom creating an initial 'east' pit lake. Runoff to the north TSF area will be diverted and reclamation (growth media cover/revegetation) of this area will continue. Pit dewatering will continue throughout this period as needed to provide slope stability and continued mining in the Gilmore area. However, some natural groundwater inflow, direct precipitation, and pit wall runoff water will accumulate in the east pit lake. In 2027, the remaining water in the TSF south decant pond will be transferred to the east pit lake so that reclamation activities at the TSF may be completed. Runoff to all areas of the TSF will be diverted, allowing for a dry closure of the TSF. TSF seepage from the interception system will be pumped to the east pit lake at this time; pumpback to the pit will continue as long as necessary, until water quality standards are met. Mining will be completed in the Gilmore pit in 2027. The east pit lake will continue to fill up to the elevation of the ridge separating the Gilmore west pit bottom, at which point the pit lake will overflow into the west pit area, eventually combining to create a single pit lake.

Active Heap Leaching (ongoing – 2030). Heap leaching at Walter and Barnes Creek facilities will continue through approximately 2030. After the end of economic leaching, an initial draindown from the heap leach pads will be pumped to the pit lake for a period of 2 to 3 months. After the initial transfer, residual draindown from the heap leach facilities will gravity-flow to the pit throughout the post-closure period.

Closure (2032 – post-closure period). After the end of mining and active transfers to the pit lake, the pit lake will continue to fill with water from natural discharges including: pit-area groundwater inflow, direct precipitation to the pit lake, pit wall runoff, and runoff from disturbed/undisturbed areas above the pit rim that have not been diverted. The pit lake is expected to fill over several decades up to the contact with the Fish Creek alluvium, at which point the pit lake water is predicted to flow into the downgradient groundwater. The final pit lake elevation will be controlled by contact with the alluvium, estimated at an elevation of 1,430 feet above mean sea level (ft amsl) (Figure 1).

Closure Water Balance Modeling – Updated Input Data

The existing, site-wide closure water balance model was initially developed in 2011 using Goldsim modeling software (www.goldsim.com) to incorporate operational flows from facilities outside the pit area (SWS, 2011). The pit lake portion of the site-wide model was based on the original pit lake modeling from 2006 (WMC, 2006). The model has been updated based on the current closure strategy, described above. Updated site information, including pit geometry, and water flows/volume data and forecasts are described in the sections below. Water chemistry data were also updated and are described in a subsequent section.

Closure Pit Geometry. The final pit geometry data (elevation, volume, and surface area) is based on the Phase 10 mine plan expansion. The spill point elevation for the pit lake is estimated to be 1,430 feet above mean sea level (ft amsl). This spill point elevation was selected to represent a conservative estimate at which discharge may occur to the environment via the Fish Creek alluvium.

In-Pit Backfill Quantity. Between 2022 and 2027, approximately 18 Mtons of waste rock will be placed within the lower elevations of the east pit bottom; the backfill geometry (shape) was provided by FGMI in order to calculate volumes by elevation in the pit for use in the water model. It was assumed that the pit backfill would have an in-place porosity of 23 percent (pers. comm. with FGMI, February 2019).

Pit Water Balance Inflows/Outflows. The closure water balance model tracks the magnitude and relative proportions of flows into and out of the pit during the recovery period. The flows are outlined below and summarized in Table 1:

Inflows:

- TSF decant pond transfers
- Interception system pumping
- Draindown from heap leach facilities
- Direct precipitation
- Undisturbed catchment area runoff
- Disturbed catchment area runoff
- Pit wall runoff
- Groundwater inflow

Outflows:

- Evaporation
- Overflow to alluvium

Table 1 – Fort Knox Closure Pit Lake Water Balance Summary

Closure Pit Lake Modeling Period	Timestep Period	Pit Lake Elevation at end of Timestep (ft amsl)	Pit Lake Volume at end of Timestep (acre-feet)	Closure Pit Lake Water Balance Modeling Component, Cumulative Flows (acre-feet)								
				Inflows							Outflows	
	Dates			Direct precipitation	Undisturbed catchment runoff	Pit wall runoff (includes disturbed catchment runoff)	Groundwater inflow	TSF Decant Pond transfers	Interception System pumping	Heap Leach Facilitiy transfers	Lake evaporation	Overflow to alluvium
North Decant Pond to East Pit Lake	2022	659	2,839	26	4	378	416	2,032	0	0	17	0
East Pit Lake	2023- 2026	781	8,730	265	18	1,483	2,658	4,491	0	0	185	0
East/West Pit Lake, prior to Heap Leach Draindown	2027- 2030	826	21,073	788	33	2,714	10,180	5,491	2,421	0	553	0
Heap Leach Pads initial draindown period	2031	865	27,059	977	38	3,036	12,047	5,491	3,228	2,929	687	0
15 years of filling	2032- 2036	923	46,323	2,096	60	4,589	21,216	5,491	7,268	7,082	1,479	0
40 years of filling	2037- 2061	1,177	118,228	10,484	170	11,376	62,208	5,491	8,079	27,842	7,423	0
Pit Lake up to Alluvium Spill Point	2062- 2086	1,430	179,393	21,661	277	17,076	93,948	5,491	8,079	48,251	15,391	0
Pit Lake ~20 Years after Spill to Alluvium	2087- 2106	1,430	179,393	32,673	368	21,109	113,766	5,491	8,079	65,209	23,152	44,151

Climate Data. The model uses average monthly precipitation and pan evaporation as shown in Table 2. Average precipitation was derived from the Fort Knox Mine operational water balance model (Knight Piésold, received January 2019).

Table 2 – Precipitation and Evaporation Data

Month	Average Precipitation (inches)	Average Pan Evaporation (inches)
January	0.92	0.0
February	0.61	0.0
March	0.63	0.0
April	0.27	0.0
May	1.1	1.5
June	1.9	4.5
July	3.2	4.3
August	3.4	2.8
September	2.2	0.80
October	1.3	0.25
November	1.0	0.0
December	0.87	0.0
TOTAL	**17.5**	**14.1**

Catchment area runoff. An area of undisturbed catchment and waste rock dumps exists above the pit rim that will provide runoff to the pit. The runoff calculations were based on the calibrated operational water balance from Q4, 2014 (SWS, 2014).

Pit wall runoff. Pit wall runoff was calculated based on the precipitation rate onto the pit footprint area minus the pit lake area. A pit wall runoff coefficient of 35 percent (i.e., 35 percent of precipitation reaches the lake) was applied to account for evaporation from the pit wall/benches and infiltration that will not readily reach the lake.

Groundwater inflow. Groundwater inflow to the pit was estimated based on the forecasted dewatering requirements during the phased-closure period. Long-term, groundwater inflow to the pit was based on estimates, updated in 2017 to reflect the input from the calibrated, dewatering prediction water balance model used for the Status of Dewatering 2015 report by SWS (SWS, 2016). The predicted groundwater inflow rate varies from approximately 1,200 gallons per minute (gpm) during initial pit lake filling to approximately 500 gpm at steady-state when the pit lake reaches the spill point elevation.

TSF decant ponds. The closure water balance model tracks water flows/volumes at the TSF during the forecasted period prior to TSF closure (2019 through 2027) in order to estimate the volume of water that will need to be transferred to the pit at closure. The calibrated, Fort Knox Mine operational model (Knight Piésold, 2019) was reviewed to confirm consistency between models. Inflows to the TSF during this time include mill process water, direct precipitation, surface runoff, consolidation water, seepage/groundwater from the interception system, and RO system brines. Outflows include evaporation, seepage, entrainment, make-up to the heap leach facilities, and discharge via the RO system. Based on the operational information and updated modeling, approximately 2,000 acre-feet of water will be transferred from the TSF north decant pond to the pit during 2022, plus an additional ~3,500 acre-feet from the TSF south decant pond during 2025 through 2027.

Pumping from the Interception System. The interception system collects a mixture of seepage from the TSF and groundwater. The volume/rate of pumping to the pit during the closure/post-closure period was calculated as the sum of seepage from the TSF and the groundwater. The seepage rate from the TSF varies in the modeling between 100 and 1,500 gpm as a function of the decant pond elevation; these estimates are based on modified results from the 2011 SEEP/W 2-dimensional (2-D) modeling (SWS, 2011). These results were adjusted to align with the new tailings deposition plan and the updated seepage modeling completed in 2018 (Knight Piésold, 2018). The groundwater inflow rate to the interception system is assumed to stay constant at 400 gpm while the system is operational (MWH 2016). This approach is consistent with previous model updates. The data used in modeling are presented in Table 3.

Table 3 – TSF Seepage and Groundwater Inflow

Pond elev (ft)	Toe seepage (gpm)	Groundwater inflow (gpm)
1495	100	400
1500	151	400
1522	361	400
1524	369	400
1525.5	394	400
1527	841	400
1532	906	400
1539	926	400
1542	942	400
1552	1493	400

Barnes Creek and Walter Creek Heap Leach. Once processing of the leach solution is no longer economic, draindown from the pads will be pumped to the pit, as well as the volume of solution stored in the in-heap ponds (358 acre-feet and 409 acre-feet stored in the Walter Creek and Barnes Creek heap leach ponds, respectively). The process solution draindown rates are based on the Walter Creek heap leach draindown analyses developed in 2013 (Knight Piésold, 2013). The draindown rates were increased by a factor of 1.66 to estimate the draindown from Barnes Creek heap leach, based on its larger pad footprint. The majority of the process water will drain in the first few months, and residual process water will gravity-drain and be routed to the pit through the post-closure period; this flow rate is estimated to decrease over time to approximately 4 gpm. Infiltration of direct precipitation and snowmelt through the pads will also be collected in the heap leach ponds and will be transferred to the pit throughout closure/post-closure, at an average annual rate of approximately 510 gpm. This flow rate is estimated based on direct precipitation/snowmelt rate onto the pad footprints, less effective evaporation (estimated as 25% of monthly pan evaporation rates). Long-term process flow rates and net flow from precipitation are presented in Table 4. Monthly flow rates from the combined heap leach pads to the pit are presented for the entirety of the model run in Figure 2.

Table 4 – Precipitation and Residual Process Flow Through the Heap Leach Pads

Month	Precipitation Through the Pads (gpm)	Residual Process Flow (gpm)
Jan	396	4
Feb	290	4
Mar	271	3
Apr	118	5
May	325	11
Jun	353	3
Jul	914	3
Aug	1152	4
Sep	911	5
Oct	535	4
Nov	449	4
Dec	376	3
Average	510	4

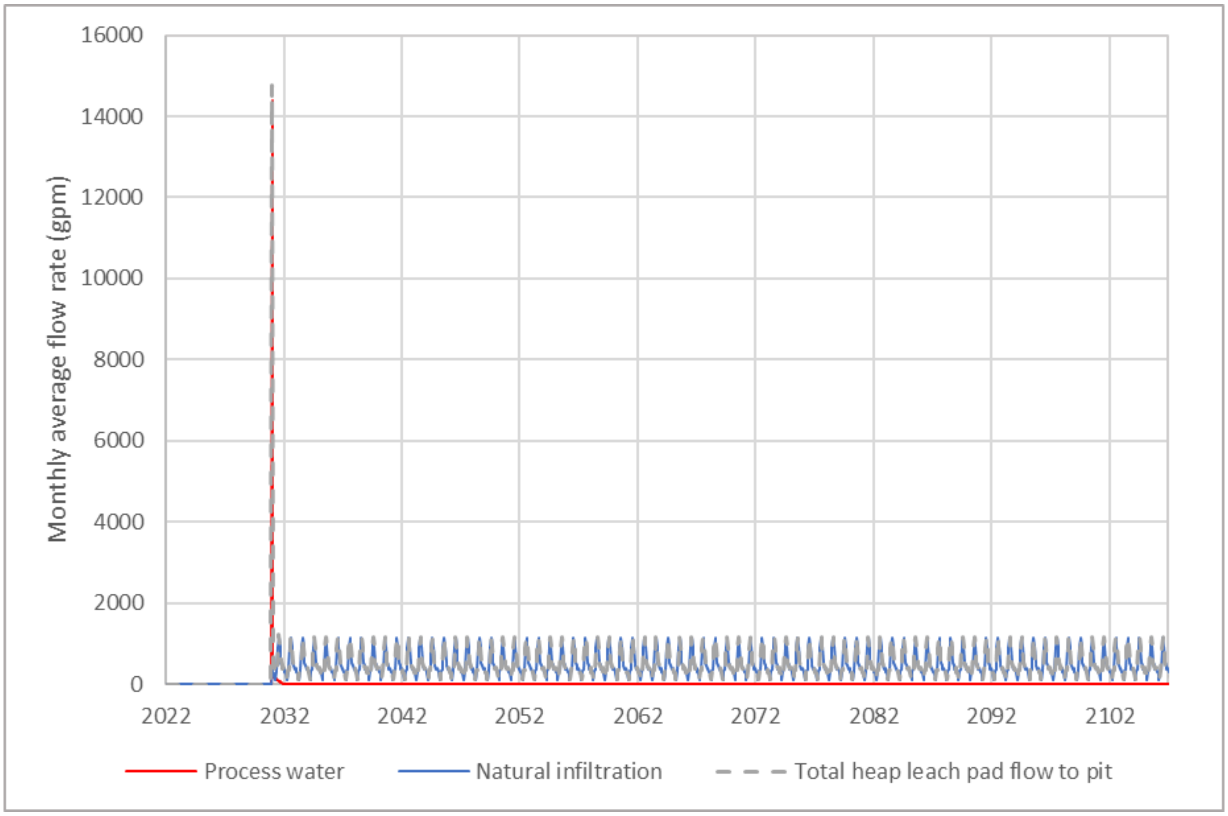

Figure 2 – Estimated, Post-Closure Flow from Walter Creek and Barnes Creek Heap Leach Pads to the Pit

Closure Water Quality Modeling – Updated Input Data

The closure water balance model includes water chemistry data which are linked to the individual flow components to calculate chemical mass loading and concentrations over time at the following locations:

- TSF decant pond
- Seepage interception system
- Pit lake

The water chemistry input data were updated in the model with recent site data/information as described in this section and summarized in Table 5. When calculating averages for water quality data, if all analyses for a constituent were below the analytical detection limit, the concentration for that constituent was set to zero in the water chemistry model. If only some analyses were below detection, the average concentration for that location was calculated by substituting all non-detect values with one-half of the method detection limit for the analysis. Derivation of representative water quality data are described in the sections below.

These data are compared to Alaska reference standards in the subsequent tables. The Alaska reference standards were developed based on water quality standards cited in ADEC 18 AAC 70 (amended as of April 6, 2018) and by selecting the lowest of drinking water, aquatic, irrigation, and human health standards for inorganic constituents listed in the Alaska Water Quality Criteria Manual for Toxic and other Deleterious Organic and Inorganic Substances (ADEC, 2008). Aquatic standards for cadmium, copper, lead, nickel, and zinc are hardness-based; the estimated calcium and magnesium concentrations in the pit lake at the spill point elevation were used to calculate a hardness value of 98 mg/L as $CaCO_3$. The ammonia standard was calculated based on the estimated pH of the pit lake (8.2 standard units (s.u.), and the range of surface water temperatures measured at the Fresh Water Reservoir (0 to 22 degrees C).

Direct precipitation. Precipitation chemistry was calculated based on the average concentration in samples collected between 2015 and 2017 at station 'AK01 Poker Creek, Fairbanks North Star Borough, AK' as part of the National Atmospheric Deposition Program (NADP, 2019).

Surface water/undisturbed catchment area runoff. Background surface water quality data for upper Barnes Creek were used to represent the undisturbed catchment runoff. These data were used in previous pit lake model updates and were based on average data from Upper Barnes Creek (MWH, 2004).

Disturbed catchment area runoff. Much of the disturbed catchment area is in contact with waste rock from the pit. Therefore, the average rinse testing data (by Meteoric Water Mobility Procedure

(MWMP)) from annual waste rock samples collected from the site between 2007 and 2017 were used to estimate the water quality of runoff in contact with the disturbed catchment area.

Pit wall runoff and waste rock backfill. Pit wall runoff chemistry and waste rock backfill rinsing chemistry were also estimated based on the average MWMP rinse chemistry from the waste rock samples, as described above. This is a conservative estimate for the wall rock chemistry compared to previous updates which used scaled laboratory chemistry data to represent field conditions. The estimated manganese concentration (0.053 mg/L) was slightly above the Alaska reference standard (0.050 mg/L); all other water quality parameters were below the standards.

Groundwater inflow. Water quality data from dewatering well samples, collected between 2016 and 2018, were geometrically averaged (i.e., geomeans) for each well location and by pit dewatering sector. The calculated water chemistry data for each sector were then weighted based on the sector dewatering pumping rates measured in 2018 (Piteau, 2018). The flow-weighted average data are presented in Table 5. The flow-weighted average arsenic concentration (0.016 mg/L) used in the model to represent groundwater inflow to the pit was slightly above the reference standard (0.010 mg/L), and the estimated, groundwater antimony level (0.006 mg/L) is at the reference standard. These input pit groundwater chemistry data (Table 5) were consistent with water quality data from samples of mixed, pit groundwater directed to the RO system (RO Feed). For comparison, these data are presented, with the averaged groundwater chemistry data by pit sector in Attachment A.

TSF Decant Pond transfers. Water chemistry of the TSF decant pond during the operational period through TSF closure was predicted based on results of the mass balance mixing calculations at that location. The water balance for the TSF is described in the previous section. The initial water quality in the TSF was derived from empirically measured values for 2017-2018; the estimated, initial water chemistry for the TSF decant pond contained elevated aluminum, arsenic, antimony, copper, manganese, weak-acid dissociable (WAD) cyanide, ammonia, and nitrate compared to the Alaska reference standards (Table 5). An estimate of the RO system(s) brine water chemistry is based on 2016-2017 sample analyses from the existing RO plant; this water chemistry indicates elevated antimony, arsenic, manganese, and nitrate (Table 5). The TSF Pond water quality is also affected by untreated flow from the seepage interception system, calculated in the model as described below.

Consistent with previous submittals, degradation of WAD-cyanide was approximated by applying of a half-life of 80 days for the first 2.5 years, and 3.4 years thereafter (Schafer and Associates, 1990). The cyanide half-life starts once cyanide is no longer being added to the leach circuit (at the end of 2030). Other than cyanide, all other constituent concentrations were calculated based on conservative, mass-balance mixing calculations. The predicted water quality in the north and south decant ponds at selected dates during transfer to the pit lake, is presented in Table 6 and compared to the Alaska reference standards. Based on the model calculations the decant ponds will contain elevated antimony, arsenic, copper, manganese, nickel, sulfate, total dissolved solids (TDS), WAD-cyanide, ammonia, and nitrate at the time of transfer to the pit lake.

Interception system pumping. The interception system collects a mixture of seepage from the TSF and downgradient groundwater. Water quality of the seepage component is assumed to be equivalent to that calculated in the decant pond over time. An estimate of downgradient groundwater chemistry was calculated based on samples collected from wells MW-5, MW-6, and MW-7 during 2017 through early 2019. Water chemistry data were averaged by well, and then averaged for the area to develop a 'representative' water chemistry for input to the model (Table 5). Concentrations of iron and manganese were estimated to be above the Alaska reference standards.

Heap Leach Facilities draindown. The water chemistry of the process water portion of heap leach transferred to the pit lake was estimated for the modeling based on water quality analyses of pregnant leach solution (PLS) from 2017 through early 2019. This water chemistry indicates elevated concentrations of antimony, arsenic, cadmium, copper, iron, mercury, nickel, selenium, silver, zinc, TDS, WAD-cyanide, ammonia, nitrate, and nitrite compared with the reference standards (Table 5). It is likely that the actual heap process water will have lower metals and nitrogen compound concentrations as it enters the pit because the water will be first run through the CIC plant prior to discharge. As a conservative assumption, this water chemistry estimate is applied to the process water throughout the post-closure period. Chemistry of the natural infiltration through the pads was represented in the model based on final, rinsed leachate data from column leach-rinse tests performed on spent heap leach material (McClelland, 2010) (Table 5). Concentrations of arsenic and WAD-CN were elevated in the leachate compared to Alaska reference standards.

Table 5 – Input Chemistry Data for the 2019 Pit Lake Modeling Update

Water Quality Modeling Input Data			Precipitation	Pit Area Groundwater	Downstream Groundwater	Surface Water	Pit Wall Runoff/ Pit Backfill Rinsing	Current TSF Chemistry	RO Brine Chemistry	Heap Leach Draindown Chemistry	
Parameter	Alaska Reference Standards		NADP Site AK01, Fairbanks site precipitation chemistry	Flow-weighted 2016-2018 dewatering well samples	Downstream monitoring well samples 2017-2019 (MW-5, MW-6 and MW-7)	Upper Barnes Creek, background data	Waste Rock MWMP data 2007-2017 (12 samples)	North TSF Pond "Barge Pond" 2017-2018 data (8 samples)	RO Plant Brine 2016-2017 (6 samples)	Heap Leach Pad "Pregnant Solution" 2017-2019 data (11 samples)	Post-Final Rinse MWMP Extract (column testing, 2010)
	Standard*	*Basis*									
pH (su)	*6.5 - 8.5*	*WQS*	**5.2**	7.6	7.6	7.0	na	7.5	7.8	**10.0**	**9.2**
Alkalinity as $CaCO_3$	*> 20*	*AQ(c)*	**0**	80	261	**15**	116	76	532	154	48
Aluminum	*0.75*	*AQ(a)*	0	0.016	0.019	0	0.14	0.58	0.018	0.11	0.32
Ammonia	*1.11 - 1.79*	*AQ(c)*	0.066	0.027	0.073	0.010	0	**3.0**	0.18	**19**	no data
Antimony	*0.006*	*DW*	0	0.0060	0.00020	0.0025	0.0040	**0.021**	**0.035**	**0.0062**	0
Arsenic	*0.01*	*DW*	0	**0.016**	0.00050	0.0030	0.0049	**0.038**	**0.12**	**0.030**	**0.021**
Barium	*2*	*DW*	0	0.0034	0.011	0.0050	0.0083	0.054	0.044	0.0083	0
Cadmium	*0.00027*	*AQ(c)*	0	0.000050	0.000049	0.00010	0.000055	0.000055	0	**0.0067**	0
Calcium	*NS*	-	0	33	77	4.4	28	50	355	152	5
Chloride	*230*	*AQ(c)*	0.055	1.4	10.0	0.7	2.0	39	50	124	0
Chromium	*0.1*	*DW*	0	0.00072	0.0049	0.0020	0.00041	0	0.0060	0	0
Copper	*0.0092*	*AQ(c)*	0	0.00035	0.0050	0	0.0043	**0.34**	0	**0.71**	0
WAD-cyanide	*0.0052*	*AQ(c)*	0	0	0	0	0	**0.70**	0	**65**	**0.027**
Fluoride	*1*	*IRR*	0	0.34	0.20	0.060	0.34	0.48	**1.2**	1	0
Iron	*1*	*AQ(c)*	0	0.058	**2.9**	0.22	0.049	0.59	0.95	**1.4**	0
Lead	*0.0031*	*AQ(c)*	0	0.0015	0.000055	**0.0040**	0.00020	0.0018	0	0	0
Magnesium	*NS*	-	0.0053	5	11	1.6	4.6	6.8	52	0.64	0
Manganese	*0.050*	*HH*	0	0.023	**0.60**	0	**0.053**	**0.055**	**0.67**	0.0030	0
Mercury	*0.00005*	*HH*	0	0	0	**0.00030**	0	0	0	**0.0022**	0
Nickel	*0.051*	*AQ(c)*	0	0.0011	0.0039	**1.0**	0.0010	0.020	0.036	**0.14**	0
Nitrate, as N	*10*	*DW*	0.14	0.93	0.018	0.25	2.4	**20**	**57**	**82**	0
Nitrite, as N	*1*	*DW*	0	0.11	0.0047	0.010	0	0.79	0.23	**5.0**	0.065
Phosphorus	*NS*	-	0	0.011	0.016	0.08	0.040	0.034	0.51	0.024	0
Potassium	*NS*	-	0.012	1.0	1.4	0.50	8.4	9.7	14	5.8	1.9
Selenium	*0.0050*	*AQ(c)*	0	0.00049	0.00074	0.0020	0.00041	0.0020	0.0034	**0.0098**	0
Silver	*0.0039*	*AQ(a)*	0	0	0	0.0010	0	0	0	**0.011**	0
Sodium	*NS*	-	0.025	13	26	2.0	16	78	101	121	18
Sulfate	*250*	*WQS*	0.13	99	27	6.7	0	141	**470**	155	8
Zinc	*0.12*	*AQ(c)*	0	0.0023	0.0065	0.0030	0.0091	0.011	0	**1.1**	0
TDS	*500*	*WQS*	0	247	348	80	152	487	**1665**	**990**	100

All data is in mg/L, unless otherwise noted. Zero indicates all samples were below the analytical detection limit for that parameter; value was set to zero in modeling.

AQ(c) - Aquatic standard (chronic) HH - Human health criteria for non-carcinogens

AC(a) - Aquatic standard (acute) DW - Drinking water standard

IRR – Irrigation standard NS = No Standard.

Alaska water quality standards based on ADEC 18 AAC 70 (amended as of April 6, 2018) and Alaska Water Quality Criteria Manual for Toxic and other Deleterious Organic and Inorganic Substances, December 12, 2008. Value shown is the lowest standard of drinking water, irrigation, stock water, aquatic, or human health standards. Standards for aluminium, cadmium, copper, lead, nickel, selenium, silver, and zinc are based on total recoverable analysis. Standards (aquatic) for cadmium, copper, lead, nickel, and zinc are hardness-based. The estimated calcium and magnesium concentrations in the pit lake at the spill point elevation were used to calculate the hardness value of 98 mg/L as CaCO3. The ammonia standard is based on the estimated pH of the pit lake, and the range of surface water temperatures (0 to 22 degrees C) at the Fresh Water Reservoir.

Table 6– Predicted TSF Decant Pond Water Chemistry for Closure Water Balance Modeling

Calculated Water Chemistry at TSF Decant Ponds			Jan-2022	Dec-2022	Jan-2026	Jan-2027
			North Decant Pond		South Decant Pond	
Parameter	*Alaska Reference Standards*		Start transfer to pit lake	End transfer to pit lake	Mid-transfer to pit lake	End transfer to pit lake
	Standard	Basis				
Alkalinity as $CaCO_3$	***> 20***	***AQ(c)***	282	277	160	320
Aluminum	***0.75***	***AQ(a)***	0.029	0.045	0.017	0.020
Ammonia	***1.11 - 1.79***	***AQ(c)***	**2.0**	**2.1**	0.30	0.30
Antimony	***0.006***	***DW***	**0.021**	**0.021**	**0.012**	**0.022**
Arsenic	***0.01***	***DW***	**0.063**	**0.063**	**0.035**	**0.07**
Barium	***2***	***DW***	0.028	0.029	0.016	0.029
Cadmium	***0.00027***	***AQ(c)***	<0.00005	<0.00005	<0.00005	<0.00005
Calcium	***NS***	-	186	183	103	210
Chloride	***230***	***AQ(c)***	31	32	16	31
Chromium	***0.1***	***DW***	<0.01	<0.01	<0.01	<0.01
Copper	***0.0092***	***AQ(c)***	**0.028**	**0.040**	**0.0096**	**0.0093**
WAD-cyanide	***0.0052***	***AQ(c)***	**0.67**	**0.673**	**0.079**	**0.091**
Fluoride	***1.0***	***IRR***	0.68	0.69	0.38	0.72
Iron	***1.0***	***AQ(c)***	0.54	0.55	0.38	0.66
Lead	***0.0031***	***AQ(c)***	0.0010	0.0011	0.0020	0.0021
Magnesium	***NS***	-	27	26	15	31
Manganese	***0.050***	***HH***	**0.34**	**0.33**	**0.19**	**0.39**
Mercury	***0.00005***	***HH***	<0.00001	<0.00001	<0.00001	<0.00001
Nickel	***0.051***	***AQ(c)***	**0.16**	**0.16**	**0.47**	**0.45**
Nitrate, as N	***10***	***DW***	**26**	**27**	**17**	**34**
Nitrite, as N	***1***	***DW***	0.59	0.61	0.13	0.18
Phosphorus	***NS***	-	0.29	0.288	0.18	0.34
Potassium	***NS***	-	8.9	9.1	4.6	8.8
Selenium	***0.0050***	***AQ(c)***	0.0023	0.0023	0.0019	0.0029
Silver	***0.0039***	***AQ(a)***	<0.001	<0.001	<0.001	<0.001
Sodium	***NS***	-	63	66	32	62
Sulfate	***250***	***WQS***	**256**	**256**	139	**280**
Zinc	***0.12***	***AQ(c)***	0.012	0.012	<0.01	0.014
TDS	***500***	***WQS***	**921**	**919**	**522**	**1020**

All data is in mg/L, unless otherwise noted.
Alaska standards are cited under Table 5.
< Indicates calculated value was less than typical analytical detection limit (DL). Value shown is DL.

Pit Lake Water Quality Geochemical Modeling

The 2019 closure pit lake model, developed in GoldSim, was linked with the geochemical equilibrium model, PHREEQC (Parkhurst and Appelo, 2013) in order to simulate thermodynamic, geochemical reactions and provide a more realistic estimate of pit lake water chemistry throughout the modeling period. The modeling approach conceptualizes the pit lake as a completely mixed solution that results from instantaneous mixing of inflowing waters with specific chemical loadings. Solute mass rinsed from reactive site materials (waste rock backfill) was represented based on the geochemical source term data described above.

The geochemical model (PHREEQC) has been used for all geochemical speciation, mixing, and reaction modeling conducted for this assessment. This code is publicly available through the United States Geologic Survey, has been rigorously tested, and has been used in numerous geochemical predictions. PHREEQC is an industry standard tool used for conducting geochemical calculations to predict the chemistry of natural or impacted waters in the environment. This software uses thermodynamic equilibrium and speciation calculations to determine the concentration of mixed solutions as they evolve after allowing for mineral precipitation and trace element sorption under imposed gas and redox conditions. The resulting model output contains the aqueous concentrations of simulated elements, the speciation of the aqueous solutes, the solubility of relevant minerals, and the effects of sorption based on number of available sites and competition for weak and strong sorption sites. The PHREEQC model utilized the MINTEQv4 thermodynamic database supplied with the v2.15.02 version of PHREEQC (released March 31, 2013). This database is widely used for geochemical modeling and was selected for this study because it includes the full range of elements present at the site, as well as key sorption reactions for iron oxyhydroxides (e.g. ferrihydrite). Sorption reactions can be an important process for removing a range of dissolved solutes from solution. Details of the geochemical modelling approach are bulleted below:

- The mixed pit lake chemistry was equilibrated with a carbon dioxide partial pressure slightly oversaturated compared to atmospheric conditions (log pCO2, -3.2), based on observations at mine sites (Eary, 1999), and with atmospheric oxygen content (log pO2, -0.67);

- This solution was equilibrated with specific mineral phases that, if oversaturated, were allowed to precipitate from the solution. The specific minerals (calcite, gypsum, ferrihydrite, and gibbsite) were selected based on literature review of mine waters by Eary (1999).

- Adsorption of species (antimony, arsenic, cadmium, copper, lead, nickel, calcium, phosphate, zinc, and sulfate) onto ferrihydrite was simulated according to Dzombak and Morel (1990). The mass of available ferrihydrite was limited to that precipitated by the solution under modeled conditions.

Pit Lake Water Balance/Water Quality Results

The closure pit lake water balance modeling indicates that the pit lake will fill to the estimated alluvium spill point elevation of 1,430 ft amsl (a maximum depth of approximately 1,000 ft) by the year 2086, approximately 64 years after the start of closure activities and pit lake filling in 2022. The pit filling curve is presented in Figure 3. Based on the Phase 10 final pit geometry, this elevation correlates to a volume of approximately 179,000 acre-feet. At this point, the pit lake water will begin to overflow into the Fish Creek alluvium and flow downgradient of the pit towards the current TSF area. Prior to this date, the pit lake will act as a hydraulic sink with continued inward hydraulic gradients that maintain groundwater flow toward the pit lake.

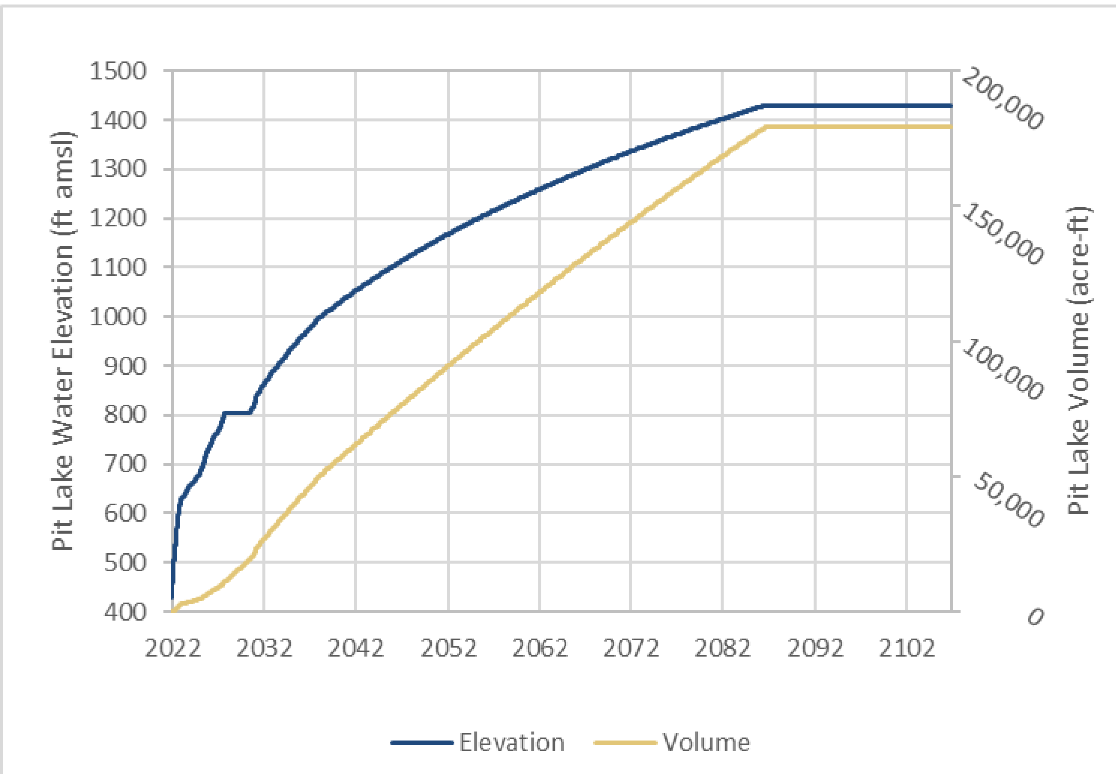

Figure 3 – Closure Pit Lake Filling Curve, 2019 Update Model Results

Pit lake water chemistry was predicted for Years: 2023 (1 year, post-filling), 2027 (5 years), 2030 (8 years), 2032 (10 years), 2037 (15 years), 2062 (40 years), 2086 (64 years), 2106 (84 years), corresponding with distinct intervals of water management operations or pit lake development events. The water chemistry results are presented in Table 7. The pH of the pit lake water is predicted to be circum-neutral throughout filling, typical of an alkaline water in equilibrium with atmospheric carbon dioxide. Alkalinity is predicted to average near 120 mg/L as $CaCO_3$, decreasing slightly over time to levels consistent with the inflowing groundwater and estimated pit wall runoff chemistry. This level of alkalinity throughout filling indicates consistent buffering in the pit lake. TDS levels in the lake generally decrease over time from approximately 300 mg/L during the first five years of filling, reflecting mostly TSF decant pond water mixed with groundwater, to approximately 200 mg/L at the spill point to the alluvium, representing dilution by groundwater, surface runoff, and precipitation.

Model results indicate that concentrations of WAD-cyanide and nitrate may exceed reference standards during early pit lake filling; this estimate is conservative. The modeling does not account for biological-mediated processes such as denitrification that limit nitrogen concentrations.

Concentrations of cadmium, copper, mercury, and nickel are elevated above the Alaska standards immediately following pumping of heap leach draindown to the pit lake, however, these constituent concentrations fall below the standards after a few years of pit filling, and well before discharge may occur. Concentrations of antimony, arsenic and manganese are also predicted to be above standards in the early pit lake and fall to just at or slightly below reference standards at the point of discharge to the alluvium. These constituents (antimony, arsenic, manganese) are elevated in the mine waters (e.g., TSF decant ponds and/or heap leach draindown) and remain elevated in the pit lake throughout filling because they are also at or slightly above Alaska standards in the pit area groundwater (antimony, arsenic) and/or pit wall runoff chemistry (manganese) estimates. Over time, as groundwater/runoff dominates the pit lake water chemistry, the levels of manganese and antimony will continue to decrease to below standards; however, the arsenic level is predicted to increase slightly over time, approaching the background groundwater/pit wall runoff concentration (Table 7).

Previous closure and reclamation plans included an alternative for adding ferric sulfate to the pit lake to enhance metals attenuation in the early pit lake water. This alternative was modelled, assuming addition of ferric sulfate only during year 2031, concurrent with addition of the initial heap leach draindown water. The results of the modeling are presented in Table 8. Predicted concentrations of arsenic, cadmium, copper, cyanide, lead, nickel, and zinc were all reduced in the early pit lake water quality (2032 – forward), and predicted arsenic concentrations were well below the Alaska reference standard prior to the spill point elevation.

Table 7 – 2019 Closure Pit Lake Water Chemistry Predictions (Base Case Model)

Date			2023	2027	2030	2032	2037	2062	2086	2106
Years, Pit Lake Filling			1	5	8	10	15	40	64	84
Pit Lake Elevation (ft)			630	765	818	863	978	1,259	1,430	1,430
Parameter	Alaska Reference Standards*		Move North Decant Pond to East Pit	Prior to spill point to West Pit	Combined East/West Pit Lake, Prior to Heap Leach Draindown	After One Year of Heap Leach Draindown	Early Pit Lake (15 Years of Filling)	Early Pit Lake (40 Years of Filling)	Pit Lake at Alluvium Spill Point (1430 ft)	Pit Lake +20 Years after Spill to Alluvium
	Standard	Basis								
pH (su)	*6.5 - 8.5*	*WQS*	8.2	8.2	8.3	8.2	8.3	8.2	8.2	8.2
Alkalinity as $CaCO_3$	*> 20*	*AQ(c)*	119	124	129	124	131	118	106	101
Aluminum	*0.75*	*AQ(a)*	0.011	0.012	0.012	0.012	0.013	0.012	0.010	<0.01
Ammonia	*1.11 - 1.79*	*AQ(c)*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Antimony	*0.006*	*DW*	**0.010**	**0.010**	**0.0084**	**0.0077**	**0.0064**	0.0050	0.0045	0.0042
Arsenic	*0.01*	*DW*	**0.015**	**0.015**	0.0052	0.0017	0.0012	0.0060	0.0087	0.0098
Barium	*2*	*DW*	0.013	0.013	0.011	0.010	0.0088	0.0055	0.0045	0.0041
Cadmium	*0.00027*	*AQ(c)*	<0.00005	<0.00005	<0.00005	**0.00057**	**0.00034**	0.00016	0.00012	0.00010
Calcium	*NS*	-	63	58	52	57	49	38	32	30
Chloride	*230*	*AQ(c)*	12	10	8.6	17	12	5.5	4.0	3.4
Chromium	*0.1*	*DW*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	*0.0092*	*AQ(c)*	0.0060	<0.005	<0.005	**0.025**	**0.013**	0.0060	<0.005	<0.005
WAD-cyanide	*0.0052*	*AQ(c)*	**0.24**	**0.10**	0.0032	**0.0099**	0.0039	<0.001	<0.001	<0.001
Fluoride	*1*	*IRR*	0.37	0.43	0.41	0.42	0.38	0.32	0.30	0.29
Iron	*1*	*AQ(c)*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead	*0.0031*	*AQ(c)*	0.00015	0.00023	<0.0001	0.00018	0.00010	0.00010	0.00010	<0.0001
Magnesium	*NS*	-	11	12	10	8.9	7.5	5.2	4.6	4.2
Manganese	*0.050*	*HH*	**0.13**	**0.13**	**0.15**	**0.13**	**0.13**	**0.067**	0.050	0.043
Mercury	*0.000050*	*HH*	<0.00001	<0.00001	<0.00001	**0.00016**	**0.000093**	0.000038	0.000026	0.000021
Nickel	*0.051*	*AQ(c)*	**0.19**	**0.19**	**0.10**	**0.091**	**0.053**	0.022	0.016	0.013
Nitrate, as N	*10*	*DW*	**11**	**10**	7.7	**15**	9.4	4.5	3.3	2.8
Nitrite, as N	*1*	*DW*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phosphorus	*NS*	-	0.12	0.11	0.078	0.064	0.044	0.026	0.021	0.018
Potassium	*NS*	-	5.2	5.8	4.6	4.6	4.0	3.0	2.7	2.5
Selenium	*0.0050*	*AQ(c)*	0.0013	0.0013	0.0010	0.0017	0.0012	0.00070	0.00057	0.00051
Silver	*0.0039*	*AQ(a)*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sodium	*NS*	-	29	28	26	33	28	20	18	17
Sulfate	*250*	*WQS*	106	108	103	101	83	69	64	61
Zinc	*0.12*	*AQ(c)*	<0.01	<0.01	<0.01	0.083	0.047	0.021	0.015	0.013
TDS	*500*	*WQS*	310	307	290	324	280	218	194	182

All data is in mg/L, unless otherwise noted.

< Indicates calculated value was less than typical analytical detection limit (DL). Value shown is DL.

Alaska standards are described under Table 5.

Table 8 – Pit Lake Treatment with Ferric Sulfate - 2019 Closure Pit Lake Water Chemistry Predictions

Date			2023	2027	2030	2032	2037	2062	2086	2106
Years, Pit Lake Filling			1	5	8	10	15	40	64	84
Pit Lake Elevation (ft)			630	765	818	863	978	1,259	1,430	1,430
Parameter	Alaska Reference Standards*		Move North Decant Pond to East Pit	Prior to spill point to West Pit	Combined East/West Pit Lake, Prior to Heap Leach Draindown	After One Year of Heap Leach Draindown	Early Pit Lake (15 Years of Filling)	Early Pit Lake (40 Years of Filling)	Pit Lake at Alluvium Spill Point (1430 ft)	Pit Lake +20 Years after Spill to Alluvium
	Standard	Basis								
pH (su)	*6.5 - 8.5*	*WQS*	8.2	8.2	8.3	8.2	8.3	8.2	8.2	8.2
Alkalinity as CaCO3	*> 20*	*AQ(c)*	119	124	129	122	130	118	106	101
Aluminum	*0.75*	*AQ(a)*	0.011	0.012	0.012	0.012	0.013	0.012	0.010	<0.01
Ammonia	*1.11 - 1.79*	*AQ(c)*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Antimony	*0.006*	*DW*	**0.010**	**0.010**	**0.0084**	**0.0077**	**0.0064**	0.0050	0.0045	0.0042
Arsenic	*0.01*	*DW*	**0.015**	**0.015**	0.0052	<0.0001	0.00023	0.0014	0.0036	0.0053
Barium	*2*	*DW*	0.013	0.013	0.011	0.010	0.0088	0.0055	0.0045	0.0041
Cadmium	*0.00027*	*AQ(c)*	<0.00005	<0.00005	<0.00005	**0.00036**	**0.00032**	0.00016	0.00012	0.00010
Calcium	*NS*	*-*	63	58	52	59	49	38	32	30
Chloride	*230*	*AQ(c)*	12	10	8.6	17	12	5.5	4.0	3.4
Chromium	*0.1*	*DW*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	*0.0092*	*AQ(c)*	0.0060	<0.005	<0.005	<0.005	0.0061	<0.005	<0.005	<0.005
WAD-cyanide	*0.0052*	*AQ(c)*	**0.24**	**0.10**	0.0032	**0.0079**	0.0037	<0.001	<0.001	<0.001
Fluoride	*1*	*IRR*	0.37	0.43	0.41	0.42	0.38	0.32	0.30	0.29
Iron	*1*	*AQ(c)*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead	*0.0031*	*AQ(c)*	0.00015	0.00023	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Magnesium	*NS*	*-*	11	12	10	9	7.5	5.2	4.6	4.2
Manganese	*0.050*	*HH*	**0.13**	**0.13**	**0.15**	**0.13**	**0.13**	**0.067**	0.050	0.043
Mercury	*0.000050*	*HH*	<0.00001	<0.00001	<0.00001	**0.00016**	**0.000093**	0.000038	0.000026	0.000021
Nickel	*0.051*	*AQ(c)*	**0.19**	**0.19**	**0.10**	0.049	0.047	0.021	0.015	0.013
Nitrate, as N	*10*	*DW*	**11**	**10**	7.7	**15**	9.4	4.5	3.3	2.8
Nitrite, as N	*1*	*DW*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phosphorus	*NS*	*-*	0.12	0.11	0.078	0.017	0.035	0.024	0.020	0.018
Potassium	*NS*	*-*	5.2	5.8	4.6	4.6	4.0	3.0	2.7	2.5
Selenium	*0.0050*	*AQ(c)*	0.0013	0.0013	0.0010	0.0017	0.0012	0.00070	0.00057	0.00051
Silver	*0.0039*	*AQ(a)*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sodium	*NS*	*-*	29	28	26	33	28	20	18	17
Sulfate	*250*	*WQS*	106	108	103	109	85	69	64	61
Zinc	*0.12*	*AQ(c)*	<0.01	<0.01	<0.01	0.024	0.035	0.018	0.013	0.011
TDS	*500*	*WQS*	310	307	290	313	273	217	193	182

All data is in mg/L, unless otherwise noted.

< Indicates calculated value was less than typical analytical detection limit (DL). Value shown is DL.

Alaska standards are described under Table 5.

Sensitivity Analysis

Additional model runs were developed to evaluate the sensitivity of the pit lake chemistry to variation in annual precipitation at the site during the post-closure period. The average annual precipitation record was varied by +/- 20 percent to evaluate the effect on the resulting pit lake filling curve, time to overflow, and pit lake water quality. Results of the sensitivity runs on the water balance results are presented in Table 9. The total size of the TSF decant pond transfer to the pit did not vary significantly because RO plant treatment rates were adjusted. The RO plant will be operated for 2 extra years for the high precipitation case, and one less year for the low precipitation case. The pit filling time to the spill point elevation ranged from 58 to 73 years post-mining. Water chemistry results for the high- and low-precipitation scenarios are presented in Tables 10 and 11, respectively. Impacts to long-term water quality of the pit lake were minimal for these scenarios, specifically with respect to comparisons to reference standards. This indicates that pit lake chemistry is not overly sensitive to the ranges of values for this input.

Table 9 - Sensitivity Analyses – Water Balance Results

Sensitivity Analyses	Base Case Model	High Precipitation Sensitivity Analysis	Low Precipitation Sensitivity Analysis
Site-wide precipitation	**average monthly climate data**	**+ 20 percent**	**- 20 percent**
Time to fill pit lake to alluvium spill point (1,430 ft amsl)	**64 years**	**58 years**	**73 years**

Table 10 – High Precipitation Sensitivity Results - 2019 Closure Pit Lake Water Chemistry Predictions

Date			2023	2027	2030	2032	2037	2062	2080	2100
Years, Pit Lake Filling			1	5	8	10	15	40	58	78
Pit Lake Elevation (ft)			678	766	821	869	990	1,291	1,430	1,430
Parameter	Alaska Reference Standards*		Move North Decant Pond to East Pit	Prior to spill point to West Pit	Combined East/West Pit Lake, Prior to Heap Leach Draindown	After One Year of Heap Leach Draindown	Early Pit Lake (15 Years of Filling)	Early Pit Lake (40 Years of Filling)	Pit Lake at Alluvium Spill Point (1430 ft)	Pit Lake +20 Years after Spill to Alluvium
	Standard	Basis								
pH (su)	*6.5 - 8.5*	*WQS*	8.2	8.2	8.3	8.2	8.3	8.2	8.2	8.1
Alkalinity as CaCO3	*> 20*	*AQ(c)*	117	125	130	124	131	113	103	97
Aluminum	*0.75*	*AQ(a)*	0.011	0.012	0.013	0.012	0.013	0.011	0.010	<0.01
Ammonia	*1.11 - 1.79*	*AQ(c)*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Antimony	*0.006*	*DW*	**0.011**	**0.0091**	**0.0082**	**0.0075**	**0.0061**	0.0046	0.0042	0.0038
Arsenic	*0.01*	*DW*	**0.017**	**0.014**	0.0051	0.0017	0.0012	0.0065	0.0086	0.010
Barium	*2*	*DW*	0.015	0.012	0.011	0.010	0.0085	0.0052	0.0044	0.0039
Cadmium	*0.00027*	*AQ(c)*	<0.00005	<0.00005	<0.00005	**0.00055**	**0.00033**	0.00015	0.000118	0.000098
Calcium	*NS*	*-*	68	55	51	56	48	35	31	28
Chloride	*230*	*AQ(c)*	15	10	8.3	16	11	5.1	3.9	3.2
Chromium	*0.1*	*DW*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	*0.0092*	*AQ(c)*	0.0063	<0.005	<0.005	**0.025**	**0.013**	0.0055	<0.005	<0.005
WAD-cyanide	*0.0052*	*AQ(c)*	**0.29**	**0.15**	0.0042	**0.0097**	0.0040	0.0011	<0.001	<0.001
Fluoride	*1*	*IRR*	0.41	0.42	0.41	0.42	0.37	0.31	0.29	0.28
Iron	*1*	*AQ(c)*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead	*0.0031*	*AQ(c)*	0.00012	0.00016	<0.0001	0.00016	<0.0001	<0.0001	<0.0001	<0.0001
Magnesium	*NS*	*-*	13	10	10	8.5	7.1	4.8	4.3	3.9
Manganese	*0.050*	*HH*	**0.16**	**0.12**	**0.14**	**0.13**	**0.12**	**0.062**	0.049	0.041
Mercury	*0.000050*	*HH*	<0.00001	<0.00001	<0.00001	**0.00015**	**0.000088**	0.000035	0.000026	0.000020
Nickel	*0.051*	*AQ(c)*	**0.20**	**0.13**	**0.074**	**0.071**	0.041	0.018	0.014	0.011
Nitrate, as N	*10*	*DW*	**14**	**9.5**	7.4	**14**	9.0	4.1	3.2	2.7
Nitrite, as N	*1*	*DW*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phosphorus	*NS*	*-*	0.14	0.10	0.074	0.060	0.042	0.024	0.020	0.017
Potassium	*NS*	*-*	6.0	5.9	4.7	4.7	4.1	3.0	2.7	2.6
Selenium	*0.0050*	*AQ(c)*	0.0014	0.0011	0.0010	0.0016	0.0011	0.0006	0.0005	0.0005
Silver	*0.0039*	*AQ(a)*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sodium	*NS*	*-*	33	27	26	32	27	20	18	17
Sulfate	*250*	*WQS*	120	98	99	96	78	63	58	55
Zinc	*0.12*	*AQ(c)*	<0.01	<0.01	<0.01	0.080	0.045	0.020	0.015	0.012
TDS	*500*	*WQS*	339	292	284	304	264	203	184	170

All data is in mg/L, unless otherwise noted.

< Indicates calculated value was less than typical analytical detection limit (DL). Value shown is DL.

Alaska standards are described under Table 5.

Table 11 – Low Precipitation Sensitivity Results - 2019 Closure Pit Lake Water Chemistry Predictions

Date			2023	2027	2030	2032	2037	2062	2095	2115
Years, Pit Lake Filling			1	5	8	10	15	40	73	93
Pit Lake Elevation (ft)			627	751	808	853	961	1,225	1,430	1,430
Parameter	Alaska Reference Standards*		Move North Decant Pond to East Pit	Prior to spill point to West Pit	Combined East/West Pit Lake, Prior to Heap Leach Draindown	After One Year of Heap Leach Draindown	Early Pit Lake (15 Years of Filling)	Early Pit Lake (40 Years of Filling)	Pit Lake at Alluvium Spill Point (1430 ft)	Pit Lake +20 Years after Spill to Alluvium
	Standard	Basis								
pH (su)	6.5 - 8.5	WQS	8.2	8.2	8.2	8.2	8.3	8.2	8.2	8.2
Alkalinity as CaCO3	> 20	AQ(c)	118	122	128	122	130	125	110	105
Aluminum	0.75	AQ(a)	0.011	0.012	0.012	0.012	0.013	0.012	0.011	0.010
Ammonia	1.11 - 1.79	AQ(c)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Antimony	0.006	DW	**0.011**	**0.011**	**0.0092**	**0.0083**	**0.0069**	0.0055	0.0049	0.0047
Arsenic	0.010	DW	**0.016**	**0.017**	0.0058	0.0019	0.0011	0.0055	0.0089	0.010
Barium	2	DW	0.015	0.014	0.012	0.011	0.009	0.0060	0.0047	0.0043
Cadmium	0.00027	AQ(c)	<0.00005	<0.00005	<0.00005	**0.00060**	**0.00037**	0.00018	0.000123	0.000107
Calcium	NS	-	66	61	54	60	50	41	34	32
Chloride	230	AQ(c)	14	12	10	18	13	6.2	4.1	3.6
Chromium	0.1	DW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.0092	AQ(c)	**0.010**	0.0054	<0.005	**0.026**	**0.014**	0.0069	<0.005	<0.005
WAD-cyanide	0.0052	AQ(c)	**0.39**	**0.18**	**0.0054**	**0.0105**	0.0038	<0.001	<0.001	<0.001
Fluoride	1	IRR	0.41	0.46	0.43	0.44	0.40	0.34	0.32	0.31
Iron	1	AQ(c)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead	0.0031	AQ(c)	0.00013	0.00019	<0.0001	0.00017	0.00010	0.00011	0.00011	0.00011
Magnesium	NS	-	12	12	11	10	8	5.8	4.9	4.6
Manganese	0.050	HH	**0.14**	**0.14**	**0.16**	**0.14**	**0.14**	**0.073**	**0.051**	0.046
Mercury	0.000050	HH	<0.00001	<0.00001	<0.00001	**0.00016**	**0.00010**	0.000042	0.000026	0.000021
Nickel	0.051	AQ(c)	**0.21**	**0.18**	**0.088**	**0.083**	0.049	0.021	0.013	0.011
Nitrate, as N	10	DW	**13**	**12**	8.7	**16**	**10**	5.0	3.4	2.9
Nitrite, as N	1	DW	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phosphorus	NS	-	0.13	0.12	0.085	0.069	0.047	0.028	0.021	0.019
Potassium	NS	-	5.7	6.0	4.7	4.7	4.1	3.1	2.6	2.5
Selenium	0.0050	AQ(c)	0.0014	0.0013	0.0011	0.0018	0.0013	0.0008	0.00060	0.00055
Silver	0.0039	AQ(a)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sodium	NS	-	34	32	28	35	30	21	19	18
Sulfate	250	WQS	116	121	114	110	91	77	71	69
Zinc	0.12	AQ(c)	<0.01	<0.01	<0.01	0.087	0.050	0.023	0.015	0.013
TDS	500	WQS	333	326	320	328	285	235	205	196

All data is in mg/L, unless otherwise noted.

< Indicates calculated value was less than typical analytical detection limit (DL). Value shown is DL.

Alaska standards are described under Table 5.

Pit Lake Stratification Analysis

As in natural lakes, mine pit lakes may permanently or seasonally, vertically stratify. Stratification in pit lakes is caused by density differences in the water column, which are based on temperature and salinity (i.e., TDS) differences. Factors that affect circulation include geometry of the lake (i.e., surface area to depth ratio) and surface wind shear stress. Mixing or seasonal turn-over of lake waters generally results when the kinetic energy of the shallower portion of the lake (i.e., water movement from wind shear and other currents) or increasing surface water density due to lower atmospheric temperatures (seasonally) is sufficiently high to displace the deeper, denser water in the lake.

Permanent stratification of the Fort Knox pit lake would affect pit lake water quality in the developing zones. A permanently stratified (meromictic) lake would result in a bottom layer that does not mix with the upper water column. Based on the Fort Knox closure concepts, the lower layer would likely be dominated by the higher-TDS waters from the decant pond transfers and heap leach facility draindown water mixed with groundwater. The upper, mixed water zones (mixolimnion) would undergo seasonal turnover based on seasonal temperature changes, and would generally reflect a mixture of groundwater, surface/pit wall runoff, and direct precipitation. This zone would be in contact with the upper alluvium through which the significant portion of groundwater discharge is predicted to occur.

Simple, analytical equations were applied to provide a screening-level assessment for evaluating stratification potential in the pit lake (These equations were developed by Tchobanoglous and Schroeder, 1985; USACE, 1986; USACE, 1987; Jewell, 2009; and Boehrer and Schultze, 2009). Key factors considered in this screening level evaluation are described in Table 12. During active water transfers to the pit lake (e.g., decant pond pumping, heap leach facility draindown, interception system pumping), it is expected that the pit lake water will be thoroughly mixed. Therefore, stratification potential was evaluated, beginning in year 2032 (~10 years after the start of pit lake filling). The results of the analytical calculations (also presented in Table 12) suggest there is a potential for permanent stratification in the pit lake during the post-closure period due to the pit geometry, specifically the relatively small pit lake surface area to depth ratio, shallow wind mix depth, and long residence times. However, the densities of the runoff and mixed operational waters are not significantly different suggesting that cooling surface water in the pit lake during the fall may be sufficiently dense to cause turnover to some depth. The likelihood and the depth of this seasonal turnover is uncertain.

Any permanent stratification that occurs would serve to isolate a portion of the higher-TDS water at depth and improve water quality in the upper portions of the pit lake, including any water that would be exposed to wildlife and any water that would flow into the Fish Creek alluvium.

Table 12 – Stratification Analyses Summary

Parameter	Description	Result	Unit	Indicators for Stratification
Density of pit wall runoff	Uses a temperature of 4 degrees Celcius and pit wall runoff TDS of 152 mg/L to compute the maximum density of surface inflow.	1000.12	kg/m3	n/a
Density of mixed operational inflows through 2032	Density of mixed operational water at 10 degrees Celcius and mixed TDS of 326 mg/L to compute the density of the pit lake water in year 2032, when operational flows are no longer directed to the pit lake.	999.99	kg/m3	n/a
Density difference	Operational flow density at year 2032 minus pit wall runoff density	-0.13	kg/m3	Negative number indicates lighter water at depth, suggesting that the lake will likely turn over in the winter/spring due to the dense cold water from ice formation and cold, spring runoff.
Pit Lake Depth	Pit lake surface elevation minus pit lake bottom elevation.	450	ft	The pit lake is very deep compared to most natural lakes, with a maximum depth of 1000 ft once completely full. Deeper lakes are more likely to stratify than shallow lakes.
Reservoir Length	Based on the pit lake area. Assumed the area was a circle to use average diameter.	2970	ft	Used to determine thermocline depth and wind mixing.
Relative Depth	Ratio of maximum depth to diameter of the reservoir	14.5	%	Smaller relative depths indicate greater influence of wind in disrupting thermal stratification
Hydraulic Residence Time	Volume of the pit divided by net inflow rate	10	years	Once operational transfers are complete, the net inflow rate to the pit is very small compared to the total volume of water there, so residence time is long.
Flushing Rate	Inverse of hydraulic residence time. Inflow rate to the pit divided by total volume of the pit.	0.00027	1/day	If flushing rate is less than 10 1/day, the reservoir may stratify. The result for Fort Knox is very small, so this indicates that stratification is likely.
Storm Event Flushing Rate	Flushing rate of a single storm event. Average inflow rate for a 5 inch, 1 day precipitation event divided by reservoir volume	0.006	1/day	If flushing rate is less than 0.5, the storm may not mix the reservoir.
Wind Mix Depth	The maximum wind mixing depth given surface temperature and wind speed. Assumes no wind mixing during the winter when the lake is covered in ice.	14.8	ft	Lakes with depths greater than the wind mix depth will be likely to stratify.
Froude Number	Ratio of inertial to buoyancy forces. The geometry of the system heavily influences this number, as well as the density gradient.	0.078*	unitless	In 2032, this value can not be reported. When the density is greatest in the operational flows, the pit lake has a potential for stratification because this value is less than the reference value of 1/pi. The mixed operational flows (in 2032) have a negative density gradient, indicating a mixed pit lake.
Thermocline Depth	Thermocline thickness is a function of wind strength and duration, but the calculation used is an empirical estimate relating thermocline thickness to reservoir length.	14.7	ft	Gradually increases over time to approximately 18 ft. Compared to pit lake maximum depth, this number is quite small, indicating that the lake may stratify.
Wedderburn Number	Comparison of density gradient to velocity shear.	0.9*	unitless	In 2032, this value can not be reported. When the density is greatest in the operational flows, this number near the reference value of 1, indicating that the lake may stratify, but seasonal turnover is a possibility. The mixed operational flows (in 2032) have a negative density gradient, indicating a mixed pit lake.

Conclusions

The results of the updated pit lake modeling indicate the following:

- During the several decades following mine closure, the pit lake will act as a hydraulic sink with continued inward hydraulic gradients that maintain groundwater flow toward the pit lake. During this period, pit lake water will not discharge to the environment and the water surface will be separated from the ground surface by steep high-walls.
- Based on the current mine reclamation and closure concepts (to date), the updated pit lake water balance model indicates that the pit lake will fill to the spill point elevation of 1,430 ft amsl in approximately 64 years (year 2086, based on the current closure schedule). At that time, it is expected that the pit lake water will begin to discharge to the Fish Creek alluvium and to mix with downgradient groundwater.
- The updated model predictions indicate that the pit lake chemistry will be alkaline (pH ~8.2 s.u., with alkalinity of approximately 120 mg/L as $CaCO_3$, and that the water will be low in TDS (~200-300 mg/L) throughout pit filling.
- Most water quality constituents are predicted to remain below the Alaska reference values for the entire model simulation period.
- Concentrations of cadmium, copper, mercury, nickel, WAD-CN, and nitrate are elevated above the Alaska reference standards immediately following pumping of the TSF decant ponds and/or heap leach draindown to the pit lake, however, these constituent concentrations are predicted to fall below the standards after a few years of pit filling, and well before discharge is expected to occur.
- Concentrations of antimony, arsenic and manganese are predicted to be above standards in the early pit lake and fall to just at or slightly below reference standards at the point of discharge to the alluvium. Over time, as groundwater/runoff dominates the pit lake water chemistry, the levels of manganese and antimony will continue to decrease to below standards; however, the arsenic level is predicted to increase slightly over time, approaching the background groundwater/pit wall runoff concentrations.
- Addition of ferric sulfate during addition of the heap leach draindown indicates significant reduction in concentrations of arsenic, cadmium, copper, cyanide, lead, nickel, and zinc.
- Variability in precipitation rates (+/- 20 percent) was evaluated using sensitivity modeling; the rate of filling to the spill point elevation varied by -6 to +9 years; the variability did not have a significant effect on the predicted water chemistry results.
- A screening-level evaluation of stratification indicates that there is potential for the pit lake to become permanently stratified; the driving factor is the pit lake geometry. However, the densities

of the runoff and operational waters indicate that seasonal turnover could occur to some depth. Permanent stratification would likely improve the water quality of pit lake water discharging to the environment once the lake level reaches the spill point elevation. The near-surface water quality, in direct contact with the alluvium, would likely reflect a mixture of precipitation, surface/pit wall runoff, and groundwater. More detailed modeling may be required to verify stratification and provide additional detail in the water quality predictions.

Recommendations

The following recommendations may be considered to edify future modeling efforts:

- The pit lake model should be updated as needed to reflect any changes in the Fort Knox Mine reclamation and closure plan and water management system, post-closure. In addition, ongoing monitoring and testing data should be used to revise the model input parameters accordingly.
- Improve the understanding of pit groundwater inflow sources and water quality. If possible, it would be valuable to investigate the source of elevated background arsenic and antimony concentrations.
- Improve the current understanding of backfill (waste rock) rinsing and pit wall runoff chemistry by advancing site geochemical characterization.
- Evaluate the potential benefit of conducting rigorous stratification modeling of the pit lake through the filling and post-closure period.

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ATTACHMENT A
PIT AREA GROUNDWATER CHEMISTRY DATA

Table A. Fort Knox Pit Dewatering Wells Water Chemistry Data Summary

Water Quality Modeling Input Data			Pit Area Groundwater 2017 Update	Pit Area Groundwater (2019 Update)		Dewatering Wells - Pit Well Sectors (Piteau, 2018) (Rate and percentage of total dewatering rate, Q3 2018)									
						East Pit Granite / Lower East Wall Average	Lower West Wall Average	Monte Cristo Average	North Wall Average	Northeast Wall Average	Northwest Wall Average	South Wall Average	Upper West Wall Granite Average	Upper West Wall Schist Average	West Pit Granite Average
						112 gpm	30 gpm	200 gpm	10 gpm	158 gpm	16 gpm	20 gpm	66 gpm	19 gpm	329 gpm
Parameter	Alaska Water Quality Reference Standards		Flow-weighted average 2015-2016 dewatering well samples	"RO Feed" from pit dewatering wells (geometric mean, 2016-2019)	Flow-weighted average 2016-2018 dewatering well samples	12%	3%	21%	1%	16%	2%	2%	7%	2%	34%
	Reference Standard	Basis				DW09-226; DW09-233; DW09-234; DW15-372; DW16-389	DW17-446	DW08-196; DW11-268; DW13-322; DW17-430	DW17-430	DW09-211; DW10-237; DW12-298; DW18-453	DW17-416; DW17-420	DW15-360; DW17-449	DW08-200; DW14-354; DW15-375; DW16-383; DW16-408; DW17-421	DW11-276; DW15-357; DW17-445	DW14-345; DW14-356; DW16-381; DW16-388; DW16-390
pH (su)	*6.5 - 8.5*	*WQS*	8.3	7.8	7.6	7.5	8.1	7.6	7.8	7.6	8.2	7.4	7.8	8.0	7.5
Alkalinity as $CaCO_3$	*> 20*	*AQ(c)*	87	no data	80	83	83	91	83	83	83	83	88	83	70
Aluminum	*0.75*	*AQ(a)*	not included	no data	0.016	0.016	0.016	0.015	0.016	0.016	0.016	0.016	0.020	0.015	0.015
Ammonia	*1.11 - 1.79*	*AQ(c)*	0.030	no data	0.027	0.028	0.028	0.025	0.028	0.028	0.028	0.028	0.035	0.025	0.025
Antimony	*0.006*	*DW*	0.0037	0.0056	0.0060	0.0059	**0.0137**	0.00029	**0.0073**	**0.013**	0.0049	0.00020	**0.0085**	**0.0069**	0.0053
Arsenic	*0.01*	*DW*	**0.015**	**0.021**	**0.016**	**0.029**	**0.018**	0.0017	0.0006	0.0083	**0.022**	0.00036	**0.025**	0.0051	**0.025**
Barium	*2*	*DW*	0.0036	no data	0.0034	0.0030	0.0030	0.0015	0.0030	0.0030	0.0030	0.0030	0.0039	0.0015	0.0050
Cadmium	*0.00027*	*AQ(c)*	0	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050
Calcium	*NS*	*-*	41	no data	33	33	33	27	33	33	33	33	36	31	37
Chloride	*230*	*AQ(c)*	1.6	0.54	1.4	0.8	1.2	1.0	1.2	4.1	1.2	1.2	0.39	0.80	0.82
Chromium	*0.1*	*DW*	0.00025	0.00026	0.00072	0.00025	0.00025	0.00025	0.00025	0.00025	0.00037	0.00032	0.00025	0.02384	0.00025
Copper	*0.0092*	*AQ(c)*	0.00092	0.00033	0.00035	0.00032	0.00066	0.00020	0.00020	0.00044	0.00058	0.00020	0.00040	0.00068	0.00035
WAD-cyanide	*0.0052*	*AQ(c)*	0	0	0	0	0	0	0	0	0	0	0	0	0
Fluoride	*1*	*IRR*	0.27	0.35	0.34	0.80	0.60	0.21	0.07	0.08	0.16	0.18	0.30	0.12	0.40
Iron	*1*	*AQ(c)*	0.13	no data	0.058	0.083	0.083	0.017	0.083	0.083	0.083	0.083	0.105	0.170	0.040
Lead	*0.0031*	*AQ(c)*	0.000090	0.00033	0.0015	0.0005	0.0004	0.0025	0.00010	0.0023	0.00021	0.00024	0.00026	**0.019**	0.00031
Magnesium	*NS*	*-*	6.8	no data	5.3	5.3	5.3	11.9	5.3	5.3	5.3	5.3	4.2	3.4	1.6
Manganese	*0.050*	*HH*	0.0090	0.014	0.023	0.017	0.020	0.007	**0.058**	**0.065**	0.046	0.006	0.017	**0.10**	0.010
Mercury	*0.00005*	*HH*	0	0	0	0	0	0	0	0	0	0	0	0	0
Nickel	*0.051*	*AQ(c)*	not included	0.00085	0.0011	0.00030	0.00035	0.00030	0.0041	0.0030	0.00059	0.00036	0.00033	0.017	0.00030
Nitrate, as N	*10*	*DW*	1.9	2.3	0.93	0.63	0.63	0.39	0.63	0.63	0.63	0.63	0.30	0.080	1.75
Nitrite, as N	*1*	*DW*	0.13	no data	0.11	0.070	0.07	0.01	0.07	0.07	0.07	0.07	0.02	0.005	0.25
Phosphorus	*NS*	*-*	0.011	no data	0.011	0.011	0.011	0.010	0.011	0.011	0.011	0.011	0.016	0.010	0.010
Potassium	*NS*	*-*	1.2	no data	1.0	1.0	1.0	1.4	1.0	1.0	1.0	1.0	0.7	1.1	0.9
Selenium	*0.0050*	*AQ(c)*	0.00052	no data	0.00049	0.00042	0.00042	0.00035	0.00042	0.00042	0.00042	0.00042	0.00033	0.00030	0.00070
Silver	*0.0039*	*AQ(a)*	0	no data	0	0	0	0	0	0	0	0	0	0	0
Sodium	*NS*	*-*	13	no data	13	10	10	3.2	10	10	10	10	8.4	4.9	23
Sulfate	*250*	*WQS*	78	96	99	146	118	60	51	134	46	78	40	30	109
Zinc	*0.12*	*AQ(c)*	0.0052	0.0025	0.0023	0.0020	0.0014	0.0041	0.0010	0.0019	0.0013	0.0013	0.0012	0.0048	0.0016
TDS	*500*	*WQS*	208	239	247	297	344	171	211	347	166	222	158	123	252

All data is in mg/L, unless otherwise noted. *Zero indicates all samples were below the analytical detection limit for that parameter; value was set to zero in modeling.*
AQ(c) - Aquatic standard (chronic) *HH - Human health criteria for non-carcinogens*
AC(a) - Aquatic standard (acute) *DW - Drinking water standard*
IRR – Irrigation standard *NS = No Standard.*
Alaska water quality standards based on ADEC 18 AAC 70 (amended as of April 6, 2018) and Alaska Water Quality Criteria Manual for Toxic and other Deleterious Organic and Inorganic Substances, December 12, 2008. Value shown is the lowest standard of drinking water, irrigation, stock water, aquatic, or human health standards. Standards for aluminium, cadmium, copper, lead, nickel, selenium, silver, and zinc are based on total recoverable analysis. Standards (aquatic) for cadmium, copper, lead, nickel, and zinc are hardness-based. The estimated calcium and magnesium concentrations in the pit lake at the spill point elevation were used to calculate the hardness value of 98 mg/L as CaCO3. The ammonia standard is based on the estimated pH of the pit lake, and the range of surface water temperatures (0 to 22 degrees C) at the Fresh Water Reservoir.