K4.13 GEOLOGY

This appendix contains supplemental information on impacts to paleontological resources.

K4.13.1 Paleontological Resources

Ground- and bedrock-disturbing actions have the potential to directly impact fossil-bearing deposits through physical disturbance, fragmentation, or destruction of fossil material. The following describes potential impacts to paleontological resources by project component.

K4.13.1.1 Alternative 1 – Applicant's Proposed Alternative

Mine Site

Due to the type of geological formations present, the possibility for paleontological resources in the mine site is unlikely.

Transportation Corridor

Because of the prevalence of igneous rock type on the transportation corridor (including the Iliamna Lake ferry terminals), paleontological findings along the transportation corridor outside the port area are unlikely (see "Amakdedori Port" section below). However, depending on depth of the paleontological resources beneath the surface Quaternary age beach deposits, 20 acres in the vicinity of the port facility have the potential to impact paleontological resources.

In the vicinity of the Amakdedori port, the transportation corridor has a footprint that covers about 20 acres of the fossil-bearing Quaternary age (i.e., 2.6 million years) beach deposits. The corridor near the port also comes within about 800 feet of the Talkeetna and Naknek formations (Wilson et al. 2012), which have produced vertebrate paleontological resources, as previously described. Further, there would be potential for indirect impact to paleontological resources present in the nearby Naknek and Talkeetna Formation exposures from increased access to the area resulting from the development of the transportation corridor.

Amakdedori Port

Indirect impacts may be caused by increased erosion or other landscape changes, or from increased accessibility to paleontological resources, resulting in an increased likelihood of vandalism or unauthorized collection. Increased access to the area from project development could result in unauthorized collection, removal, excavation, or casting of fossils, including dinosaur tracks, which could result in the damage or destruction of paleontological resources.

Potential paleontological resources that could be removed would likely be common, widespread invertebrate fossils found in sedimentary rocks. There is a chance that rare or unique fossils could be removed or destroyed, such as dinosaur fossils or tracks in Jurassic age rock, or Pleistocene age vertebrate/mammal fossils/remains in surficial glacial deposits.

The Amakdedori port construction footprint covers roughly 250 acres, all within Quaternary age beach deposits that have locally produced fossils considered to be significant paleontological resources (Sandy and Blodgett 2000; Wilson et al. 2012). Additionally, the Talkeetna and Naknek formations are exposed in outcrops in the immediate vicinity of the port facility. These formations are highly fossiliferous, with the Naknek Formation in the vicinity producing a vertebrate specimen of an extremely rare Jurassic age marine reptile, *Magelneusaurus*, which represents the only find of this species in Alaska, and one of only two occurrences of this genus in North America (Blodgett et al. 1995; Weems and Blodgett 1996). Because the subsurface geology of the port site has not been mapped in detail, it is possible that bedrock underlying the port site footprint is the Naknek and/or Talkeetna formations, with the potential for paleontological resources to be present beneath the port footprint.

Port facility construction, operations, and maintenance have the potential to directly impact paleontological resources (if present) over the entire 250-acre port site footprint. The potential also exists for indirect impacts to paleontological resources present in the nearby Naknek and Talkeetna Formation exposures, due to increased access to the area from port site development.

Natural Gas Pipeline Corridor

Although there is a possibility of the occurrence of paleontological resources in the pipeline corridor outside the port area, potential impacts to paleontological resources along most of the pipeline corridor are unlikely. The pipeline corridor in the vicinity of the Amakdedori port has a footprint that covers roughly 12 to 15 acres of the fossil-bearing Quaternary age beach deposits. The natural gas pipeline corridor would be within 820 feet of the Talkeetna and Naknek formations (Wilson et al. 2012). Accordingly, 12 to 15 acres of the pipeline corridor have the potential to impact paleontological resources. If ground-disturbing activities from pipeline construction, operations, or maintenance activities extend outside these 12 to 15 acres, there is additional potential for impacts.

K4.13.1.2 Alternative 1 – Summer-Only Ferry Operations Variant

The potential for paleontological resources under this variant are the same as Alternative 1.

K4.13.1.3 Alternative 1 – Kokhanok East Ferry Terminal

The potential for paleontological resources under this variant are the same as Alternative 1, based on similar substrate conditions at the Kokhanok east ferry terminal site.

K4.13.1.4 Alternative 1 – Pile-Supported Dock Variant

The potential for paleontological resources under this variant are the same as Alternative 1.

K4.13.1.5 Alternative 2 – North Road and Ferry with Downstream Dams, and Alternative 3 – North Road Only

The potential for paleontological resources under Alternative 2 and Alternative 3 are considered comparable to the mine site under Alternative 1; however, there would be a reduced potential for the Diamond Point port site, transportation corridor, and the natural gas pipeline corridor. This is due to the absence of Quaternary beach deposits that are considered to be significant paleontological resources under Alternative 1. The coastal margin footprints under Alternative 2 and Alternative 3 consist of coarse alluvium outwash and derived from igneous bedrock. These beach deposits are not considered amenable for fossil preservation and formation.

K4.15 GEOHAZARDS

This appendix contains technical information related to potential geohazards at the mine and port sites, including the following topics:

- Mine site
  - Embankments and impoundments
    - Construction materials
    - Design and construction
    - Seepage analysis
    - Static stability analysis
    - Seismic hazard and deformation analysis
  - Open pit
    - Pit wall stability analysis
- Port sites
  - Seismic hazard analysis.

K4.15.1 Mine Site

The following discussion addresses mine site facilities that would have the potential to be affected by geohazards, which could include internal erosion and slope failure of embankments and impoundments, and rock wall instability within the open pit.

K4.15.1.1 Overview of Mine Embankments and Impoundments

The mine embankments and impoundments would be designed and constructed to store tailings and contact water during mine operation that could pose a risk to the environment if released due to geohazards. The proposed mine site–related embankments and impoundments, shown on Chapter 2, Alternatives, Figure 2-4 and summarized in Table K4.15-1, include the bulk tailings storage facility (TSF), the pyritic TSF, water management ponds (WMPs), and seepage collection ponds (SCPs). Table K4.15-1 presents the buildout dimensions of the embankments and impoundments that would contain tailings, waste rock, and/or contact water at the mine site. These facilities are discussed hereafter.

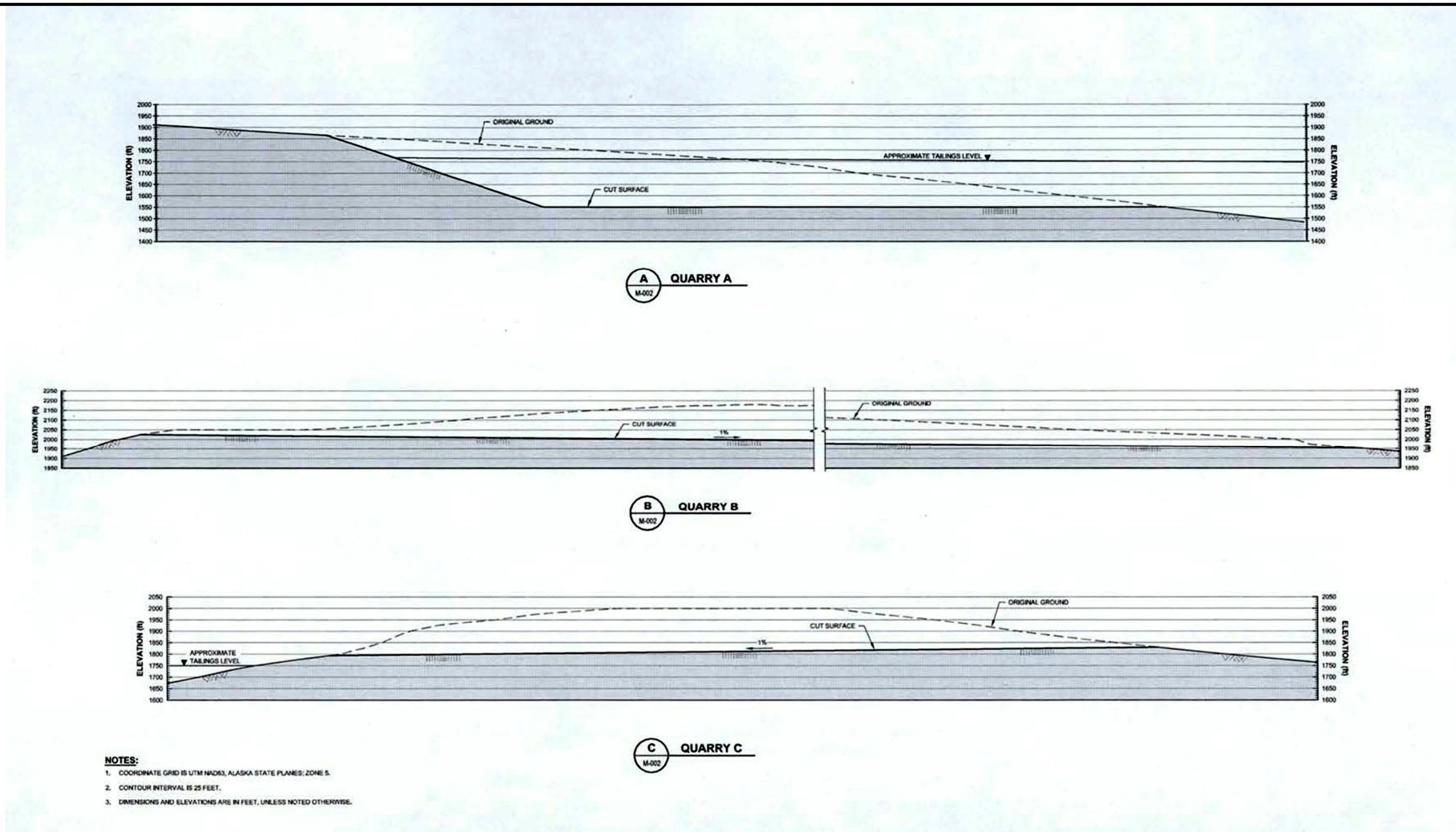
K4.15.1.2 Embankment Construction Materials

The embankments for the tailings and water management facilities would be constructed of drilled and blasted bedrock removed from quarries A through C, and the overburden in the open pit (Chapter 2, Alternatives, Figures 2-3 and K4.15-1). The three rock quarries would be developed in the western portion of the mine site in bedrock consisting of granodiorite associated with the Kaskanak batholith. The overburden in the open pit would consist of various types of sedimentary and igneous rock. See Section 3.13, Geology, for further discussion of mine site geology.

Table K4.15-1: Mine Embankment and Impoundment Dimensions

Impoundment / Embankment Name		Embankment													Impoundment		
		Max. Height (feet)	Crest Elev. (feet)	Footprint Area (acres)	Max. Crest Length (feet)	Crest Width (feet)	Max Width at Base (feet)	Downstream Slope (H:V)	Upstream Slope[1] (H:V)	Foundation Strata[2]	Construction Material Volume (M yd[3])	Seepage Control Method	Raise Method	Stored Material	Max. Footprint Area[3] (acres)	Pond Surface Area[4] (acres)	Max. Impoundment Volume[5] (acres-ft)
Alternative 1 – Applicant's Proposed Alternative																	
Bulk TSF	Main	545	1,730	310	13,700	200	2,340	2.6:1 Overall (including Buttress)	Vertical Serrated	Bedrock	76	Filter / Transition Zones, Flow-Through Embankment	Centerline	Bulk Tailings	2,875	520 to 940	561,900
Bulk TSF	South	300	1,730	90	4,900	200	1,530	2.6:1	3:1	Bedrock	11	U/S Liner, or C/F/T, & Grout Curtain[6,7]	Downstream	Bulk Tailings			
Bulk TSF Main Seepage Collection Pond		120	1,185	25	3,400	50	500	2.6:1	2:1	Bedrock	2	U/S Liner, or C/F/T, & Grout Curtain	N/A	Bulk Tailings Seepage	95	35 to 85	3,000
Bulk TSF South Seepage Collection Pond		75	1,395	4	1,300	50	200	2:1	2:1 to 3:1	Overburden	0.1	U/S Liner, or C/F/T, & Grout Curtain	N/A	Bulk Tailings Seepage	TBD, SCP to be operated with minimum pond volume and freeboard allowance for the required IDF.		
Bulk TSF East Seepage Collection Pond		35	1,775	3	1,100	50	170	2:1	2:1 to 3:1	Overburden	0.1	U/S Liner, or C/F/T, & Grout Curtain	N/A	Bulk Tailings Seepage	TBD, SCP to be operated with minimum pond volume and freeboard allowance for the required IDF.		
Open Pit Water Management Pond		45	1,030	25	4,500	50	280	2:1	3:1	Overburden	1	Fully Lined	N/A	Open Pit Water	70	42	845
Main Water Management Pond[8]		190	1,295	225	14,600 to 14,700[10]	100	870	2:1	3:1	Bedrock[11]	51[11]	Fully Lined	N/A	Contact Water	955	750 to 825	56,000
Pyritic TSF[9]	North	425	1,710	670	19,300	200	2,340	2.6:1	3:1	Bedrock	160	Fully Lined	Downstream	Pyritic Tailings	1,155	412	132,300
Pyritic TSF[9]	East	315	1,710														
Pyritic TSF[9]	South	305	1,710														
Pyritic TSF North Seepage Collection Pond		45	1,325	3	900	50	190	2:1	2:1 to 3:1	Overburden	0.1	U/S Liner, or C/F/T, & Grout Curtain	N/A	Pyritic Tailings Seepage	TBD, SCP to be operated with minimum pond volume and freeboard allowance for the required IDF.[12]		
Pyritic TSF South Seepage Collection Pond		30	1,425	2	625	50	190	2:1	2:1 to 3:1	Overburden	0.1	U/S Liner, or C/F/T, & Grout Curtain	N/A	Pyritic Tailings Seepage	TBD, SCP to be operated with minimum pond volume and freeboard allowance for the required IDF.		
Pyritic TSF East Seepage Collection Pond		55	1,400	2	570	50	200	2:1	2:1 to 3:1	Overburden	0.1	U/S Liner, or C/F/T, & Grout Curtain	N/A	Pyritic Tailings Seepage	TBD, SCP to be operated with minimum pond volume and freeboard allowance for the required IDF.		
Emergency Dump Pond		40	1,335	6	1,800	50	200	2:1	2:1	Overburden	TBD	Fully Lined	N/A	Tailings Slurry	TBD, Emergency Dump pond to remain empty outside of upset conditions in the tailings pipelines. Design storage TBD.		
Alternative 2 – Downstream Construction[13]																	
Bulk TSF	Bulk TSF Main	570	1,745	460	14,050	200	2,630	2.6:1 Overall (including Buttress)	2:1	Bedrock	124	Filter / Transition Zones	Downstream	Bulk Tailings	2,985	520 to 940	561,800
Bulk TSF	Bulk TSF South	320	1,745	5	5,100	200	1,700	2.6:1	3:1	Bedrock	14	U/S Slope Lined & Grout Curtain	Downstream	Bulk Tailings			

Notes:
[1] Upstream slope assumed to be 3 Horizontal (H):1 Vertical (V) for lined embankments, or 2H:1V for C/F/T seepage control.
[2] Removal of overburden may be required (where not otherwise indicated) based on the geotechnical and hydrogeological information collected during site investigations.
[3] The maximum impoundment footprint area is the entire facility, including embankments and storage/pond surface areas. The embankment footprint and pond surface areas may overlap in some cases.
[4] Range of pond areas indicates normal and maximum operation pond levels.
[5] Max impoundment volume below freeboard and storm storage; TSF storage volume is solids only.
[6] C/F/T = Core/Filter/Transition
[7] U/S = Upstream
[8] The presented embankment height and base width are from the top of the embankment toe backfill (as per discussion between PLP and ADSP), and not the excavated surface.
[9] The ultimate pyritic TSF embankment is a continuous structure between the north, east, and south embankments. The final footprint area, crest length, and fill volume are provided.
[10] Includes 100 to 150 feet at each abutment to reach bedrock (PLP 2019-RFI 108b).
[11] Pebble Limited Partnership (PLP) changes during Environmental Impact Statement (EIS)-Phase failure modes effects analysis, Oct. 24-25, 2018 (PLP 2019-RFI 108, 108a, 108b).
[12] IDF = Inflow Design Flood
[13] Alternative 1 from PLP 2018-RFI 075
N/A = not applicable
Source: PLP 2019-RFIs 108, 108a, 108b



Source: PLP 2017, Figure MX-007

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QUARRIES A THROUGH C CROSS SECTIONS - TYPICAL

PEBBLE PROJECT EIS

FIGURE K4.15-1

The characterization of rock types in the three rock quarries and the open pit area was based on both surface geological mapping and geotechnical drill holes (PLP 2018-RFI 015). Additional information regarding rock quality will be made available after the geotechnical field data collected in the latter part of 2018 have been processed.

Table K4.15-2 presents the estimated rock volumes of the three rock quarries plus the open pit overburden, based on the maximum footprints as presented on Figure 2-4. The table considers the differences between in-place versus post-removal and post-placement volumes and unit densities of the rockfill materials, as described in the table footnotes below.

Table K4.15-2: Summary of Available Embankment Rockfill Material

Material Source	Banked Volume		Reduction Factor[2]	Bulking Factor	Loose Volume		Compaction Factor	Compacted Materials		
	(Mft^3)	(Mcy)			(Mft^3)	(Mcy)		(Mft^3)	(Mcy)	(Mton)
Quarry A	1,440	53	0.9	1.6	2,074	77	1.3	1,685	62	101
Quarry B	2,693	100	0.9	1.6	3,878	144	1.3	3,151	117	189
Quarry C	1,208	45	0.9	1.6	1,739	64	1.3	1,413	52	86
Open Pit Overburden	1,573	58	0.5	1.2	944	35	0.95	747	28	41
TOTAL	**6,914**	**256**	**--**		**8,635**	**320**	**--**	**6,996**	**259**	**417**

Notes:
Mcy = million cubic yards
Mft^3 = million cubic feet
Mton = million tons
lb/ft^3 = pounds per cubic foot
[1] Material Definitions:
Banked Volume – Volume before excavation.
Banked Density – Density of in situ material before excavation.
Loose Volume – Volume after excavation.
Loose Density – Density of material after excavation.
Compacted Volume – Volume after compaction.
Compacted Density – Density of materials after compaction.
Bulking Factor – Loose volume/banked volume.
Compaction Factor – Compacted volume / banked volume.
Usable Material Reduction Factor (reduction to account for out-of-specification/unusable materials) = 0.9 (quarries), 0.5 (open pit overburden; reduced because of variability of rock quality).
[2] Loose and banked densities based on estimated compacted density and bulking/compaction factors.
[3] Neatline material volumes were rounded to the nearest million. Quarry volumes based on project description layout.
[4] Material densities assumed as follows:

Material Densities (lb/ft^3)			
Material	Banked	Loose	Compacted
Rockfill	156	98	120
Overburden	105	87	110

Source: PLP 2018-RFI 015b

The material banked densities and bulking factors were estimated based on Look (2007), and are considered reasonable. Compaction factors were based on Durham University (1997). The values for compacted density were applied to the material estimates.

Table K4.15-3 presents the estimated amount of rockfill material that would be needed to construct all proposed embankments at the mine site. The data indicate that quarries A through

C plus the open pit overburden would generate about 6 percent more rockfill material than needed to construct the embankments.[1]

Table K4.15-3: Embankment Rockfill Material Needs

Rockfill	Total	
	(Mft^3)	**(Mton^3)**
Pyritic TSF (All Pyritic Tailings/PAG Waste Rock Storage Facilities)	2,830	170
Bulk TSF Main Embankment	2,063	124
Bulk TSF South Embankment	296	18
Main Water Management Pond	1,200	72
Main Embankment Seepage Collection Pond	50	3
Road Coarse Replacement	22	1
Road Sanding	50	3
TOTAL	**6,516**	**391**

Notes:
lb/ft^3: pounds per cubic foot
Mton^3: million cubic tons
PAG: potentially acid-generating
[1] Volumes of neatline material were rounded to the nearest million.
[2] Rockfill compacted density assumed to be 120 lb/ft^3.
[3] Road sanding assumes 150,000 tons per year.
[4] Road coarse replacement assumes 6 inches of material replaced every 3 years.
Source: PLP 2019-RFI 108a

Table K4.15-1 shows several smaller impoundments (e.g., sediment ponds) that are not presented in Tables K4.15-2 and K4.15-3. These are generally smaller in height, and were of less concern during scoping with regard to geotechnical stability and contents that could be released in the event of failure (sediment versus contact water or tailings in the larger facilities). As with the larger embankments, detailed design and analysis of the smaller impoundments would be completed as part of project permitting as required under the Alaska Dam Safety Program (ADSP).

K4.15.1.3 Design and Construction of Embankments and Impoundments

The various mine site–related embankments and impoundments would be constructed of rockfill. Inherent in the construction of rockfill embankments and impoundments is the potential for groundwater to seep through the structures. The seepage would have the potential to reduce the stability of the structures by causing internal erosion. Therefore, the embankments and impoundments would be designed and constructed to minimize internal erosion during operation. The facilities would also be designed for stability during static (nonseismic) and seismic (earthquake) conditions.

[1] If an average usable bulking factor is used, which is 0.81, the calculated compacted material in Table K4.15-2 would be 515 Mtons versus 417 Mtons as shown, which would be 32 percent more material than needed.

The following discussion explains the general design and construction features relevant to geohazards, including elements to prevent internal erosion and instability, relevant closure-related aspects, and management and monitoring.

Bulk TSF

General. The proposed bulk TSF would consist of a main embankment (downgradient in terms of groundwater flow) and a south (upgradient) embankment (Figure 2-8). Considerations for siting a stable and resilient tailings facility include site-specific topography and geology (van Zyl 2015). The bulk TSF would be in watersheds that flow north into the North Fork Koktuli (NFK) River and the South Fork Koktuli (SFK) River, and would be mostly surrounded by bedrock knobs and slopes, which would generally promote stable foundation conditions at embankment abutments.

Under Alternatives 1 and 3, the upper 280 feet of the 545-foot-high bulk TSF main embankment would be centerline constructed. That is, during raising of the rockfill dam, rockfill would be placed concurrently on top of both the centerline and the downstream slope of the previous raise. This would result in a near-vertical upstream face at the dam crest for the upper portion of the embankment, and some rockfill fill could be placed on the upstream tailings beach (Figure 2-8).

In contrast, the south embankment would be downstream constructed. That is, during raising of the rockfill embankment, rockfill would be placed on top of the downstream slope of the previous raise during the raise process, which would result in a nearly symmetrical embankment (Figure 2-8).

Under Alternative 2, the bulk TSF main embankment would be downstream constructed with downstream buttresses to increase the embankment's stability (Figure 2-47).

The two embankments would be constructed of rockfill sourced primarily from quarry A. The rockfill would be placed and compacted in planned sequences and raise heights (PLP 2018d).

The size of the bulk TSF would assume a split in tailings from the process plant (average of 88 percent bulk tailings and 12 percent pyritic tailings), based on batch flotation tests on drillhole samples from the pit area. If this split were to deviate substantially from that planned, the embankment raise schedules for the bulk and pyritic TSFs would be adjusted to accommodate the changed tailings volumes (PLP 2018-RFI 010).

The bulk tailings volume and the related sizes of the bulk TSF embankments also assume that the tailings would be thickened to 55-percent-solids slurry by weight. If this could not be achieved, and greater water volumes were generated, additional pumping capacity would be provided to transfer the tailings slurry from the process plant to the TSFs, and to pump additional supernatant water from the TSFs and their seepage ponds (PLP 2018-RFI 010).

Embankment lifts and freeboard requirements would be reviewed as part of each dam lift and safety review (required by the ADSP), and would be adjusted as necessary to reflect actual tailings throughput, settled densities, mine water management conditions, and different site conditions encountered.

The south embankment would be constructed higher than the main embankment to ensure that the phreatic surface of water entrained in the tailings would slope to the north, and that seepage would be contained within the NFK west catchment facilities.

Seepage-Related Elements. The bulk TSF main embankment (both the centerline- and downstream-constructed options) would use a flow-through design to prevent internal erosion by minimizing water buildup in the TSF and seepage pressure on the embankment, and to provide controlled flow away from the other embankments (PLP 2018-RFI 006a). In contrast, the upstream south embankment would use a liner on the downstream slope face and would not include a flow-through design (Figure 2-8).

The main embankment's core would consist of two to three filter and transition zone materials (a designed gradation of sand- to gravel-sized particles), based on the industry-accepted no-internal-erosion filter criteria developed by Sherard and Dunnigan (1985) (Fell et al. 2015; USACE 2004; USDA 2017). The core materials would be developed and sourced from locations at the mine site to meet design gradation specifications. Materials with fines content between 30 and 60 percent passing the #200 sieve are expected to be suitable for use as core zone material. Materials meeting these gradation requirements were identified in the open pit area during geotechnical investigation programs completed between 2004 and 2011 (PLP 2018-RFI 006a). The quantity of on-site, low-permeability core materials would be confirmed during additional geotechnical investigations as the design progresses. If sufficient quantities of low-permeability materials are determined not to be available on site, alternatives such as a low-permeability face liner or asphalt core would be used.

The bulk TSF main embankment would be constructed in a manner to ensure the design performance of the core (AECOM 2018k). Material zones would be placed sequentially and not concurrently, and it is expected that the height differential would be limited to the thickness of one material lift.

Control of water in the bulk TSF is an important consideration in achieving a stable tailings deposit and embankment. Best available technology (BAT) principles established following the Mount Polley dam failure (IEEIRP 2015) include eliminating or minimizing surface water in impoundments, and promoting unsaturated conditions in tailings through drainage provisions. The size and location of the bulk TSF supernatant pond would be controlled in operations through pumping of excess water to the main WMP or bulk TSF main embankment SCP. The embankments would include basin and embankment underdrains to help maintain a reduced phreatic surface (or groundwater table) in the facility. Water would be managed to allow the continual development and maintenance of a tailings beach behind the bulk TSF main embankment. This would serve to protect the dam from seepage pressure that could reduce stability (Knight Piésold 2018a; PLP 2018-RFI 006, RFI-008f).

A grout curtain would be installed near the downstream toe of the south embankment to prevent upgradient groundwater from flowing into and beneath the impoundment (see Figure 2-8) (PLP 2018-RFI 008f). The grout curtain would be keyed into the bedrock underlying the main embankment before the placement of the embankment materials. The grout curtain zone would be injected through pipe sleeves embedded along a concrete plinth at the bedrock interface beneath the embankment.

The design freeboard would contain the entire volume of the inflow design flood (IDF) above the tailings beach. The freeboard would also account for wave run-up and wind set-up protection and post-seismic settlement (Knight Piésold 2018a; PLP 2018-RFI 019a, RFI 028).

A tailings beach would be developed in the eastern corner of the bulk TSF to promote pond development and subsurface drainage away from the topographic saddles. Water levels and freeboard in the bulk TSF pond would be maintained through proactive raise construction to account for the IDF within the elevation of the tailings beach (AECOM 2018k). Excess water would be controlled by pumping to the main TSF SCP or the main WMP (Knight Piésold 2018a).

Concern was expressed during the environmental impact statement (EIS)–phase failure modes effects analysis (FMEA) regarding the possibility of uneven deposition of tailings around the perimeter of the bulk TSF (because of spigot spacing and segregation of thickened tailings), leading to smaller beaches and added seepage pressure on the embankments. Deposition of tailings on ice in the winter (practiced at Red Dog Mine) was discussed as a possible method to mitigate this effect (AECOM 2018k).

Stability-Related Elements. The TSF embankment foundations would be prepared by removing overburden to expose competent bedrock before placement of the rockfill. Should colluvium and/or talus surficial deposits be encountered beneath the structure footprints, which could result in downslope movement (described in Section 3.15, Geohazards), they would be removed to avoid posing a stability issue for the embankments and/or liners.

As noted above, the bulk TSF main embankment under Alternatives 1 and 3 would use centerline construction to reduce the footprint. The upstream portion of successive dam raises would partially rest on tailings, and additional buttresses would be provided downstream to enhance overall stability. Alternative 2 would use a downstream construction design, which is typically considered more stable than centerline construction. The results of the preliminary stability analyses for both the centerline and downstream alternatives are described below under “Static Stability Analysis.”

The bulk TSF embankments would be regulated as Class I (high) hazard potential dams under ADSP guidelines (Alaska Department of Natural Resources [ADNR] 2017a), with an operating basis earthquake (OBE) and maximum design earthquake (MDE) established in accordance with criteria described in Section 4.15, Geohazards.

The main embankment’s internal filter zone would be thick enough to fulfill standard filter zone design criteria to prevent internal erosion and also remain intact after the MDE. The thickness of the filter zone must be wider than the maximum horizontal deformation that the embankment would undergo as a result of the MDE.

For example, assume the filter zone thickness is determined to be *X*, and the maximum horizontal deformation is calculated to be *Y.* In this case, the filter zone must be at least *X*+*Y* thick so that it would remain continuous and functional, with a thickness of at least *X* throughout the full height of the embankment after it has been sheared by the *Y* movement. The *X* and *Y* details would be conceptually developed after geotechnical programs are completed, the results analyzed, and dimensions finalized as design progresses.

Closure. The bulk TSF would be closed in place after Year 20, and would undergo dry closure and become a permanent landform (PLP 2018-RFI 024). Free water would be pumped out, and the tailings would be allowed to consolidate until they became suitable for equipment traffic.

The permeable design of the main embankment would allow the tailings to continue to drain, thereby lowering the phreatic (groundwater) level and improving embankment stability. The tailings surface would be regraded to facilitate surface drainage away from the TSF. The closure cover would consist of a capillary break layer composed of rockfill to promote horizontal drainage and minimize infiltration; an overlying low-permeability layer consisting of glacial till; topsoil and growth media placed over the final tailings surface; and revegetation (PLP 2018d; PLP 2018-RFI 091).

BAT principles that promote long-term stability include achieving dilatant conditions throughout the tailings deposit by compaction (IEEIRP 2015). The flow-through design would promote long-term consolidation and safe post-closure management of the tailings. It is estimated that the freely draining tailings in the proposed flow-through design would reach a terminal consolidation of about 80 to 85 percent in post-closure.

Management and Monitoring. Monitoring would be included in all phases of the TSF (PLP 2017, 2018d). In accordance with ADNR (2017) guidelines, monitoring would include the following elements:

- Construction quality assurance (CQA) and construction quality control (CQC) plans to assure that the TSF embankments are built in accordance with the approved design, drawings, and specifications, as well as design modifications that might arise during construction as a result of differing site conditions.
- An emergency action plan (EAP) that includes a dam break analysis with inundation maps and describes actions to be taken in the event of dam failure, along with information and in-place preparations needed to take those actions immediately and without unnecessary delays.
- An operations and maintenance (O&M) manual describing procedures to be implemented under normal and extreme water levels; an operator training program; monitoring to confirm that embankments are performing in accordance with the design; periodic safety inspections; extraordinary inspections after extreme events (e.g., major earthquakes, large floods, freeboard exceedance, vandalism); and mitigation to conduct repairs or structural modifications if the dam is not performing as designed.
- Monitoring after closure would include inspections for mass stability, seepage flows, and inspections after extreme events.

Pyritic TSF

General. The pyritic TSF would consist of a continuous embankment around the north (downgradient), east, and south (upgradient) sides (see Figures 2-4 and 2-9). This facility would be designed to isolate the most contaminated tailings and waste rock in a fully lined, subaqueous storage cell during operations to minimize acid generation (PLP 2018d). The majority of the pyritic TSF would be located in a single tributary valley that drains north toward the NFK, referred to as the "NFK east site." The southern portion of the pyritic TSF south embankment would be situated in a drainage divide between the NFK east watershed and a tributary that drains south toward the SFK River.

As with the bulk TSF, the embankments would be regulated as Class I (high) hazard potential dams under ADNR (2017) guidelines. An OBE and MDE would be established similar to those described above for the bulk TSF.

Seepage-Related Elements. The pyritic TSF would be a lined facility using a high-density polyethylene (HDPE) geosynthetic membrane to retain water. Therefore, the facility would likely not include core/filter/transition zones as described for the bulk TSF main embankment (PLP 2018-RFI 055). SCPs with pumpback and groundwater monitoring wells would be situated downgradient of the north, east, and south embankments, as required by the ADSP (ADNR 2017).

A bedding layer would be placed under the liner. The surface of the liner would be protected with processed materials (sand and gravel) after installation to prevent damage from equipment punctures or damage during placement of potentially acid-generating (PAG) waste rock material. Waste rock would be end-dumped in 20-foot lifts. Concern was expressed in the EIS-phase FMEA that this could result in liner damage even with a protective layer. Placing waste rock in smaller lifts was discussed as a possible method to minimize the risk of liner damage (AECOM 2018k).

Liner installation would be completed in accordance with standard industry practices for similar facilities, such as heap leach pads, and would be closely monitored during installation to confirm proper welding of the seams. The likelihood of liner leakage leading to internal erosion and potential failure of the embankment was the subject of failure modes in the EIS-phase FMEA (AECOM 2018l) as discussed in Section 4.27, Spills.

Referring to Figure 2-9, PAG waste rock would be placed around the facility perimeter to limit commingling of the tailings and waste rock. Pyritic tailings would be discharged into the interior of the facility, with deposition occurring concurrently with waste rock placement (PLP 2018-RFI 055).

Liner failure from chemical causes is considered unlikely because the pyritic tailings and PAG waste rock would be inundated throughout the mine life with a 5-foot water cover, which would limit the potential for the materials to be oxidized, turn acidic, and potentially react with the liner material. HDPE geomembranes are well understood to be extremely durable products with design service lives of up to several hundred years. The service life of an HDPE membrane is typically defined as its half-life, which is the point at which a 50 percent reduction in a specific design property is expected to occur (PLP 2018-RFI 055).

Water levels would be maintained for the life of the facility. Water quality would be monitored during the operation to confirm that acidic conditions are not developing (PLP 2018-RFI 055). As with the bulk TSF, water levels and freeboard in the facility would be maintained to account for the IDF, wave run-up, and wind set-up. Excess water would be controlled by pumping to the main WMP (Knight Piésold 2018a; PLP 2018-RFIs 019a, 028, 028a, 028b).

Stability-Related Elements. The embankment foundations would be prepared by removing overburden to competent bedrock, including solifluction surficial deposits if encountered beneath the embankment footprint. This type of deposit is present on the western side of the watershed, and could be subject to downslope movement (described in Section 3.15, Geohazards).

Closure. At closure, the pyritic tailings and PAG waste would be placed into the open pit, the liner removed, and the facility reclaimed (PLP 2018-RFI 024). The pyritic tailings would be removed from the pyritic TSF as a slurry using floating dredge pumps during closure. The tailings slurry would be pumped to the open pit for long-term storage. The PAG waste rock material would be removed using conventional hauling methods (excavators and haul trucks), and trucked into the open pit via the pit haul ramps. It is expected that the start of waste rock removal would lag behind tailings removal by approximately 1 year to allow the tailings and supernatant pond level to be lowered to dewater the waste rock. The tailings would be deposited subaqueously into the open pit, and the PAG waste rock would be inundated to limit exposure to a maximum of approximately 1 year. A minimum water cover would be maintained above the PAG waste rock and pyritic tailings throughout long-term closure.

After closure, the embankments would be breached, flattened, and contoured/graded to conform to the surrounding landscape, and promote natural runoff and drainage. Therefore, potential impacts associated with static and seismic stability of this facility would last no longer than the 20-year mine life.

Management and Monitoring. Monitoring would be included in all phases of the TSF (PLP 2017, 2018d). In accordance with ADNR (2017) guidelines, monitoring would include the same elements as described for the bulk TSF.

Water Management Ponds

General. Two WMPs would be at the mine site (see Figure 2-4 and Table K4.15-1): the main WMP north of the pyritic TSF, and the open pit WMP. Each of these facilities would require an embankment or berm with design considerations and potential geohazards effects similar to those described for the bulk TSF. The embankments are proposed to be downstream constructed.

Seepage-Related Elements. WMP berms or embankments would be constructed using rock and earthen fill (PLP 2017, 2018d), and the same general approach as described for the bulk TSF. The embankments would be fully lined.

Concern was expressed in the EIS-phase FMEA that the number of seepage pumpback wells currently proposed around the perimeter of the main WMP may be insufficient to identify and capture liner seepage along this 9,000-foot-long embankment. As indicated by PLP, the number of wells would be determined during final design based on additional field investigations, and may exceed those proposed to date. Deep continuous drains around the perimeter were also discussed as possible mitigation for intercepting potential seepage flow from the main WMP (AECOM 2018k).

Stability-Related Elements. The foundation materials would be prepared and the embankments designed and constructed to be stable under static and seismic conditions. The embankment foundation of the main WMP would be prepared by removing overburden to competent bedrock (proposed as a design change by PLP based on the results of the October 2018 EIS-phase FMEA) (AECOM 2018k, 2018l). The design concept for the open pit WMP embankment requires addressing any potential weak foundation conditions encountered in the overburden materials (e.g., glacial lake deposits found in this area) by excavating that material. Any potential mitigation requirements (including removal of the overburden if required) would be addressed based on the geotechnical and hydrogeological information collected for the area during site investigations.

Closure. The WMPs would be removed and reclaimed in post-closure when no longer required for water management and treatment (PLP 2018-RFI 024). Embankments and berms would be breached, flattened, and contoured/graded to conform to the surrounding landscape, and promote natural runoff and drainage.

Therefore, potential impacts of seepage and internal erosion on the static and seismic stability of these facilities would be long term, lasting until some point in post-closure after reclamation activities are complete and monitoring no longer required; however, the potential impacts would not be permanent.

Management and Monitoring. Monitoring would be included in all phases of the WMPs (PLP 2017, 2018d). In accordance with ADNR (2017) guidelines, monitoring would include the same elements as described for the bulk TSF.

Seepage Collection Ponds

General. SCPs would be located downstream of the TSF embankments and WMPs (see Figure 2-4 and Table K4.15-1), and would include the SCPs associated with the bulk TSF main and south embankments, and the pyritic TSF north, east, and south embankments.

These facilities would require an embankment or berm with design considerations and potential seismic and geohazards effects similar to those described for the bulk TSF south embankment. The embankments are proposed to be downstream constructed.

Seepage-Related Elements. These embankments would use similar design features as the bulk TSF south embankment, including low-permeability core zones with filter and transition zones; grout curtains to control seepage and enhance embankment stability; and downstream groundwater pumpback and monitoring wells to pump groundwater back into the TSF and monitor the quality of the downstream groundwater (PLP 2018-RFI 006).

Stability-Related Elements. The foundation materials would be prepared and the embankments designed and constructed to be stable under static and seismic conditions (see Section K4.15.1.3).

Closure. The seepage ponds associated with the pyritic TSF would be removed and reclaimed in post-closure, similar to the description of the WMPs (PLP 2018-RFI 024). Therefore, potential impacts of seepage and internal erosion on the static and seismic stability of these facilities would be long term, lasting until some point in post-closure after reclamation activities are complete and monitoring no longer required; however, the potential impacts would not be permanent.

The SCPs associated with the bulk TSF would remain in post-closure indefinitely, or until no longer required for water management and treatment. It is expected that seepage flow through the bulk TSF embankment would slow with increasing consolidation and reduced infiltration in closure. A preliminary estimate of maximum consolidation of the bulk tailings is on the order of 50 years (AECOM 2018k). However, there are no current plans to remove the bulk TSF SCPs. Therefore, potential impacts associated with seepage and stability of these facilities would range from long term to permanent.

Management and Monitoring. Monitoring would be included in all phases of the WMPs (PLP 2017). In accordance with ADNR (2017) guidelines, monitoring would include the same elements as described for the bulk TSF.

K4.15.1.4 Seepage Analysis

Seepage analyses were completed to support the design of the bulk TSF, which as noted above (see Section K4.15.1) would include a flow-through design with core filter/transition zones to control seepage and internal erosion. The results of the analyses are presented below.

The pyritic TSF and main WMP would be fully lined facilities, and the requirements for filter/transition zones for these lined structures would be evaluated during the design process.

<u>Bulk TSF</u>

The potential rate of seepage through the bulk TSF main embankment was estimated using a two-dimensional seepage model that incorporated the key project design assumptions and referenced available seepage rates at existing mine facilities with similar flow-through designs. The seepage analysis estimated a range of seepage rates, from 3 to 14 cubic feet per second (cfs) during operations, when the tailings pond would be at a normal operating size. The seepage rate could increase up to 20 cfs if the tailings pond were to extend within 500 feet of the main embankment (PLP 2018-RFI 006).

This range of predicted seepage rates represents the bounds of a sensitivity analysis that accounted for a variety of tailings characteristics, such as permeability and the anticipated width and length of the coarse-grained tailings unit immediately upstream of the main embankment.

Detailed seepage analyses would be completed for each embankment during the detailed design stage, which would comply with the stringent requirements of the ADSP permitting process as dictated by ADNR (2017a) (PLP 2018-RFI 006).

K4.15.1.5 Stability Analysis

Structural integrity is the most important priority in the design and management of tailings facilities (van Zyl 2015). As described above, all proposed embankments and impoundments in the mine site area would store water or potentially liquid-behaving contents that could pose a risk to the environment if released during a geologic event. The mine site facilities were designed to be stable during both static (nonseismic) and seismic conditions, which are addressed in the following subsections.

Static Stability Analysis

Input Parameters. The analyses of static slope stability considered conceptual-level embankment configurations and homogeneous material parameters. Table K4.15-4 below presents the geotechnical values assumed for these analyses.

Stability analyses were completed for embankment configurations under static loading conditions using the assumptions presented in Table K4.15-4 and using the limit equilibrium computer program SLOPE/W to model potential slip surfaces and resulting factor of safety (FoS) values. Cross sections were generated showing critical circles and calculated FoS for the following embankments:

- Bulk TSF main embankment
- Bulk TSF south embankment
- Pyritic TSF north embankment
- Main WMP
- Bulk TSF main SCP
- Open pit WMP.

The latter two embankments (not presented in Table K4.15-4) used the same input parameters as the other embankments.

Table K4.15-4: Geotechnical Material Parameters Used in Stability Analyses

Embankment	Material	Unit Weight[1] (pcf)	Strength Function[2]	Tau/Sigma Ratio[3]	Cohesion (psf)	Phi[4] (°)
Bulk TSF Main Embankment	Bedrock	160	–	–	0	40
	Tailings	90	–	0.25	–	–
	Rockfill	145	Low-density, poorly graded, weak particles	–	–	–
Bulk TSF South Embankment	Bedrock	160	–	–	0	40
	Tailings	90	–	0.25	–	–
	Rockfill	145	Low-density, poorly graded, weak particles	N/A	N/A	N/A
Pyritic TSF Main Embankment	Bedrock	160	N/A	N/A	0	40
	Tailings	100	N/A	0.25	N/A	N/A

Table K4.15-4: Geotechnical Material Parameters Used in Stability Analyses

Embankment	Material	Unit Weight[1] (pcf)	Strength Function[2]	Tau/Sigma Ratio[3]	Cohesion (psf)	Phi[4] (°)
	Rockfill	145	Low-density, poorly graded, weak particles	N/A	N/A	N/A
Main Water Management Pond	Overburden	120	N/A	N/A	0	35
	Rockfill	145	Low-density, poorly graded, weak particles	N/A	N/A	N/A

Notes:
N/A = Not Applicable
pcf = pounds per cubic foot
psf = pounds per square foot
[1] The basis for selection of the densities for bulk tailings, pyritic tailings, rockfill, and bedrock was the results of geotechnical laboratory testing performed in conjunction with previous field studies.
[2] Shear strength for rockfill was defined based on Leps (1970), using a function that defines the variation of shear strength with normal stress, rather than using a single friction angle or cohesion value.

a. Rockfill shear strength typically reduces at higher stresses because of the crushing of particle contact points within the material and a reduction in material dilatancy. Rockfill shear strength is also related to the density and durability of the material and the particle size distribution.
b. A lower-bound strength function (representative of low-density, poorly graded, weak particle rockfill) was considered. The lower-bound strength function was based on published information on the shear strength properties of rockfill materials.

[3] The basis for selection of the tau/sigma ratio of 0.25 for tailings was the peak undrained strength ratio (Su/p') for hard rock fine-grained tailings materials, which is typically in the range of 0.2 to 0.3. A value of 0.25 was assumed for the preliminary stability analyses.
[4] The basis for selection of the phi angles for bedrock was the results of past geotechnical drillhole investigations, which indicate the bedrock underlying the bulk TSF area comprises Cretaceous sedimentary and volcanic rocks, including mudstone, siltstone conglomerate, sandstone, and basalt; and Cretaceous intrusive rocks comprised of monzonite, diorite, and gabbro.

a. Bedrock was defined as a homogeneous geological unit for the stability analyses.
b. A friction angle of 40 degrees was used in the stability analyses based on findings of past geotechnical drillhole investigations.

Source: PLP 2018-RFI 008b

Bulk TSF Main Embankment. The bulk TSF main embankment is proposed to operate as a drained facility to promote long-term drainage and stability of the bulk tailings mass. The main embankment would be approximately 530 feet high, with an overall downstream slope of approximately 2.6:1 horizontal:vertical (H:V). Under Alternatives 1 and 3, centerline construction methods with buttressing would be used to limit the footprint, which would result in a serrated near-vertical upstream face at the dam crest for the upper 280 feet of the embankment (see Figure 2-8). The preliminary stability analysis for this design calculated an FoS value on the order of 1.9 to 2.0 under static loading conditions. Figure K4.15-2 shows a schematic section of the main embankment at its ultimate height with the predicted potential slip surface.

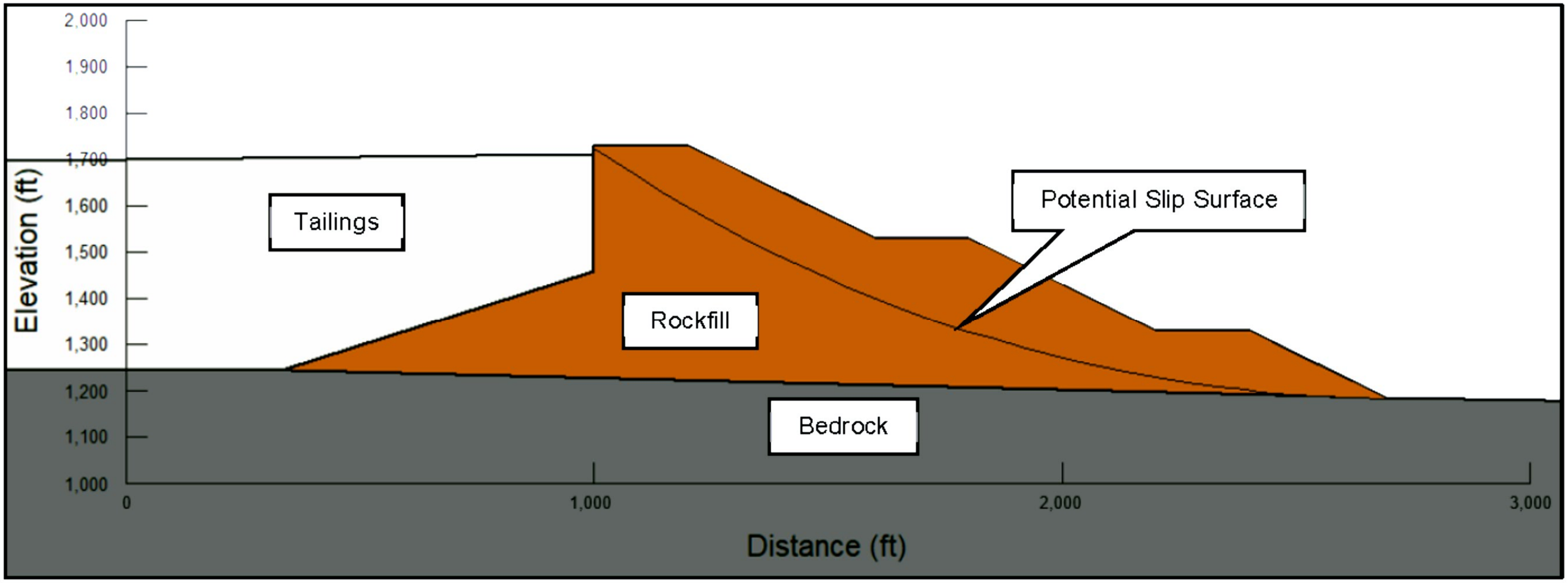
The stability of the centerline design was reviewed by a panel of geotechnical experts from the US Army Corps of Engineers (USACE) EIS team (AECOM), the State of Alaska, and Pebble Limited Partnership (PLP) (including its geotechnical contractor, Knight Piésold) during an EIS-phase FMEA in October 2018. The upstream portion of successive dam raises in the upper half of the embankment would partially rest on tailings, but the results of the stability analysis do not rely on the strength of these materials; rather, they rely on the strength of the rockfill materials directly beneath and downstream of successive raises, materials in the core/filter zone, and rockfill buttressing the downstream side of the core zone.

In other words, regardless of the strength of the tailings, the overall embankment did not fail in a downstream direction in the stability analysis. The potential for instability on the upstream side of the raises would be buttressed by the tailings mass, in such a manner that an unstable condition could occur only in an upstream direction (toward the tailings deposit) along an isolated slip surface restricted to the last raise/lift, which would not overwhelm freeboard (designed to be contained within the elevation of the tailings beach). Therefore, the FMEA panel concluded that the likelihood of global instability of the buttressed centerline embankment design would be very low (probability less than 1 in 10,000) (AECOM 2018k, 2018l).

Under Alternative 2, the main embankment would be downstream constructed, and would also include downstream buttresses to increase the stability. The preliminary stability analysis for the downstream-constructed main embankment calculated an FoS value on the order of 1.9 to 2.0 under static loading conditions, similar to the buttressed centerline design, thereby offering minimal additional stability over the proposed design. Figure 2-45 shows a schematic section of the main embankment at its ultimate height with the predicted potential slip surface.

Bulk TSF South Embankment. The bulk TSF south embankment would be downstream constructed with a fully lined downstream dam face. The conceptual south embankment would be approximately 305 feet high, with an overall downstream slope of approximately 2.6H:1V (PLP 2018-RFI 008b). Figure K4.15-3 shows a schematic section of the current concept for the south embankment at its ultimate height with the predicted potential slip surface. The preliminary stability analyses for the south embankment calculated an FoS value on the order of 1.9 to 2.0 under static loading conditions.

Pyritic TSF North Embankment. The pyritic TSF is proposed to be a fully lined facility. The north, south, and east embankments would be approximately 425, 315, and 305 feet high, respectively; with overall downstream slopes of approximately 2.6H:1V, and upstream slopes of 3H:1V (Figure 2-9). The stability of the upstream slopes would be enhanced by placement of PAG waste rock. Figure K4.15-4 shows a schematic section of the north embankment of the pyritic TSF at its ultimate height with the predicted potential slip surface. The preliminary stability analyses calculated an FoS value on the order of 1.9 to 2.0 under static loading conditions. Based on this conceptual design, the EIS-phase FMEA panel concluded that the likelihood of global instability of the north and south embankments of the pyritic TSF would be very low (probability less than 1 in 10,000) (AECOM 2018l).



Source: PLP (2018-RFI 008); SRK (2018c), Figure 3

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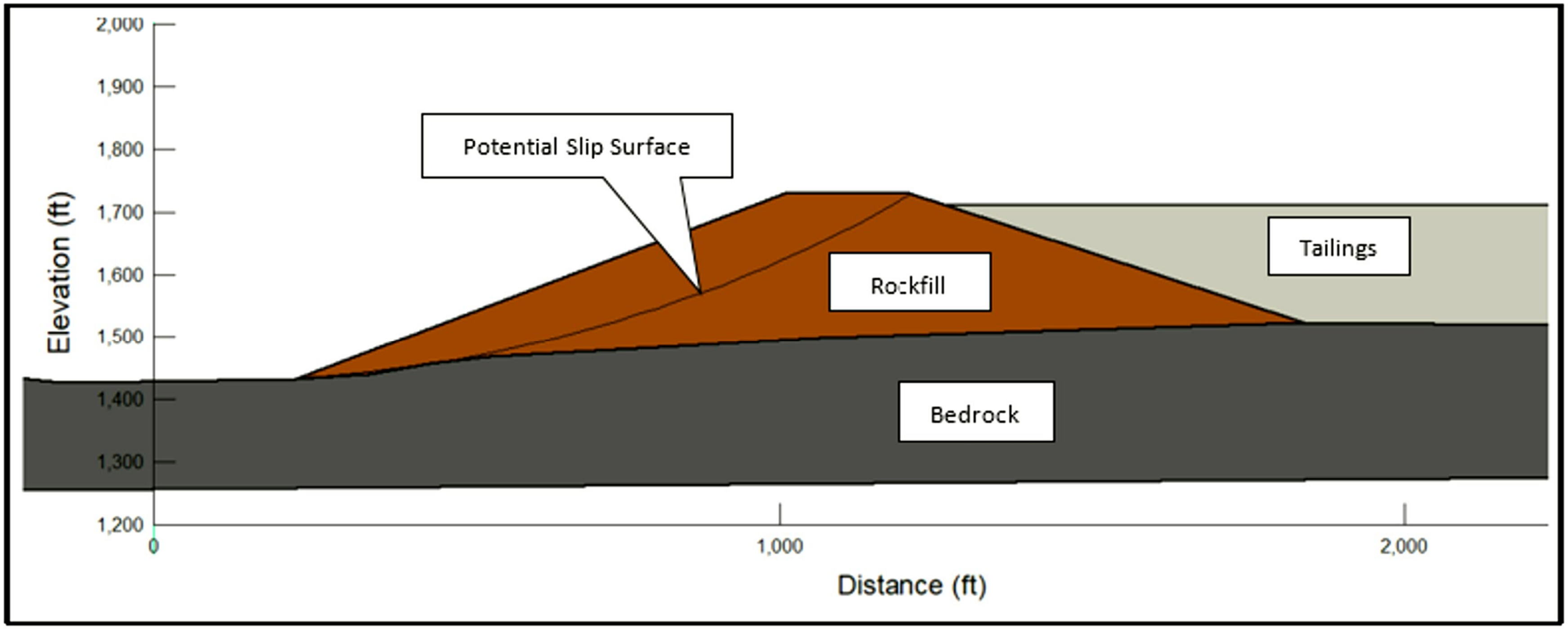
BULK TSF MAIN EMBANKMENT STATIC STABILITY ANALYSIS - BUTTRESSED CENTERLINE CONSTRUCTION



Source: PLP 2018-RFI 069

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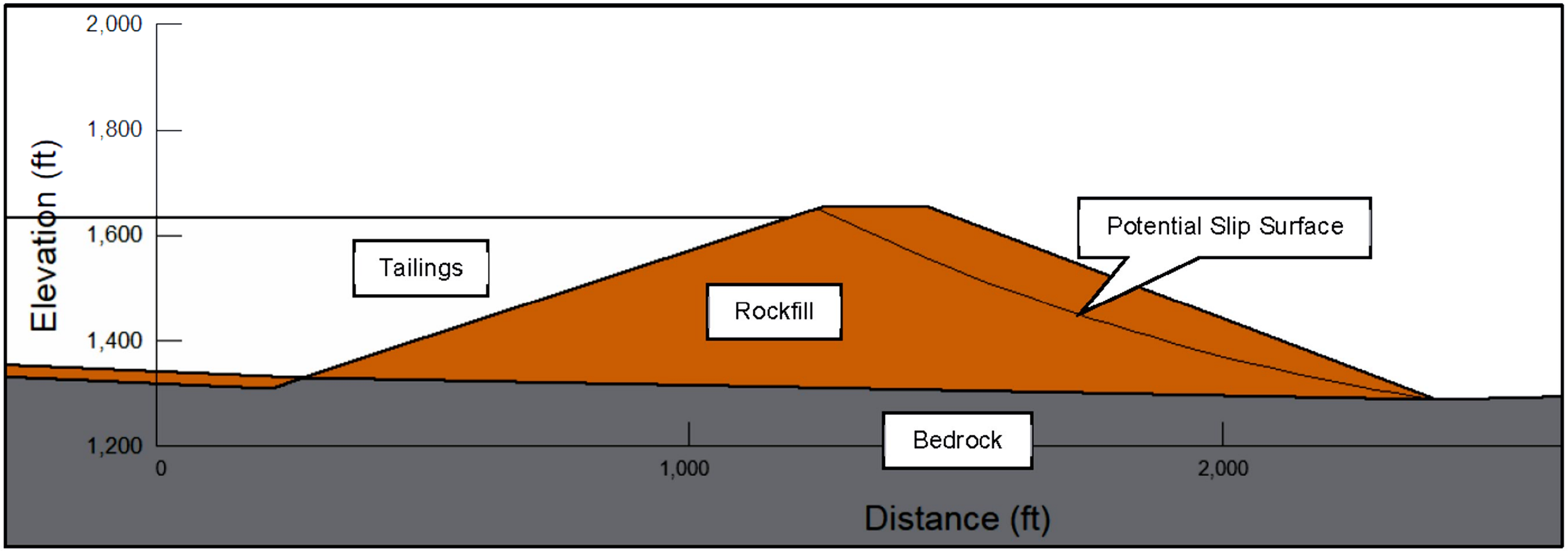
BULK TSF SOUTH EMBANKMENT STATIC STABILITY ANALYSIS



Source: PLP (2018-RFI 008); SRK (2018c), Figure 4

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PYRITIC TSF NORTH EMBANKMENT STATIC STABILITY ANALYSIS

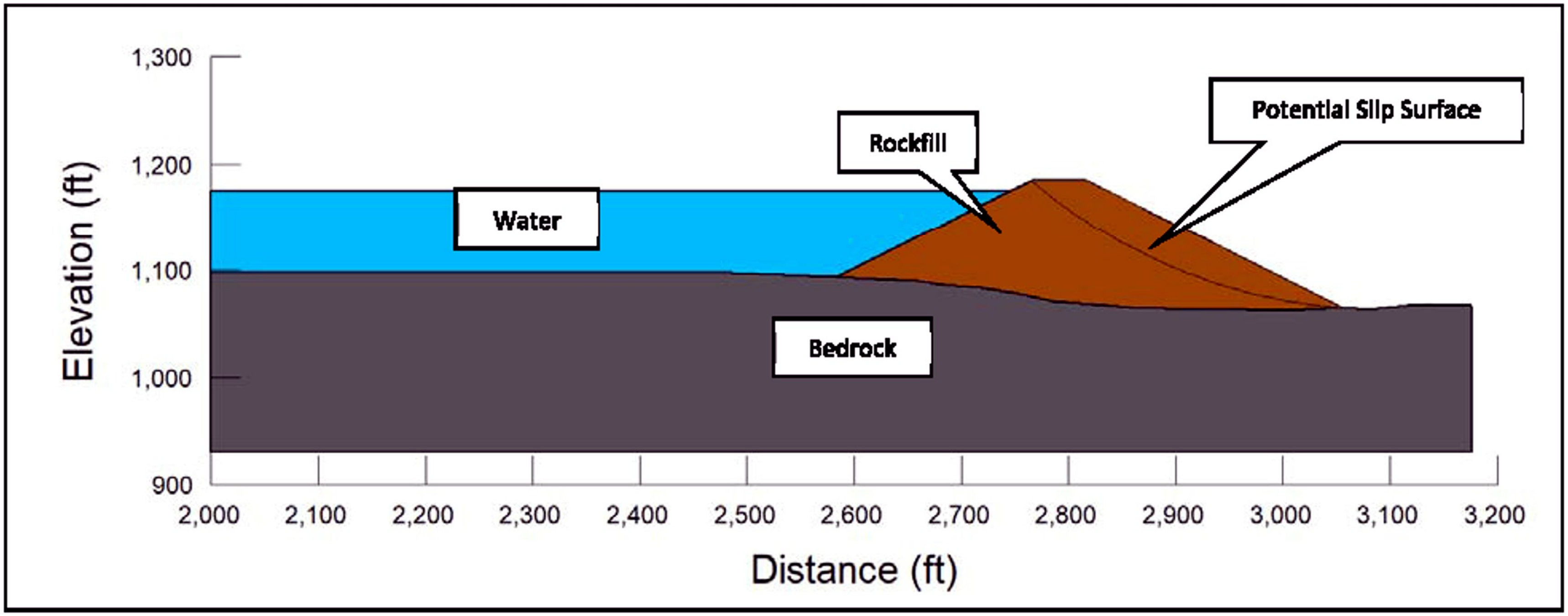
Bulk TSF SCP. The bulk TSF main SCP is proposed to be constructed using downstream methods. The embankment would be approximately 120 feet high, with an overall downstream slope of approximately 2.6H:1V and an upstream slope of 2H:1V (PLP 2018-RFI 008b). The preliminary stability analyses for this embankment used the same input parameters as for the bulk TSF, and calculated a downstream FoS value on the order of 1.9 to 2.0 under static loading conditions. Figure K4.15-5 shows a schematic representation of the stability analysis results for the bulk TSF SCP with the predicted potential slip surface.

Main WMP. The main WMP would be the primary water management structure at the mine site, and would be a fully lined facility. The embankment would be approximately 200 feet high, with an overall downstream slope of approximately 2H:1V. A schematic section of a previous concept for the main WMP embankment that was founded on overburden (see Figure K4.15-6), with a calculated FoS value on the order of 1.7 to 1.8 under static loading conditions. The calculation assumed that any potential weak foundation conditions encountered in the overburden materials would be mitigated during design and construction after the collection of additional geotechnical drillhole investigation data.

During the EIS-phase FMEA, geotechnical experts expressed concern regarding the possibility that weak foundation conditions (such as buried glacial clay layer) could be undetected by geotechnical investigations, and concluded that the probability of global instability could range from very low to low (less than 1 in 10,000 to 1 in 1,000). As a result, PLP proposed a design change to remove overburden to competent bedrock. The results of the static stability analysis of the revised design would be revisited after additional geotechnical investigation during final design. With foundation in bedrock, the static stability of the main WMP is expected to be similar to that of other downstream rockfill embankments founded in bedrock at the mine site (i.e., very low likelihood, or probability of less than 1 in 10,000).

Open Pit WMP. The open pit WMP would be founded on overburden, constructed using the downstream method, fully lined, and would have an overall downstream slope of approximately 2H:1V and an upstream slope of 3H:1V (PLP 2018-RFI 008b). At approximately 40 feet high, the embankment of this structure would be much smaller than that of the main WMP. Figure K4.15-6 shows a schematic representation of the stability analysis results for this embankment with the predicted potential slip surface.

The open pit WMP was not evaluated in the EIS-phase FMEA (Section 4.27, Spill Risk, provides the rationale for the selection of structures for analysis in the FMEA). Potentially weak layers such as glacial lake deposits are known to be present under most of the open pit WMP area (see Figure 3.13-2), and could underlie the embankment foundations. However, the concern that potentially undetected layers could affect global stability would be lower than at the main WMP, because the embankment height would be lower and the known glacial lake deposits would be targeted and analyzed as design progresses. Assuming that any potential weak foundation conditions encountered in the overburden materials would be mitigated during design and construction after the collection of additional geotechnical drillhole investigation data, the preliminary stability analyses calculated an FoS value on the order of 1.9 to 2.0 under static loading conditions.



Source: PLP (2018-RFI 008b), Figure 1

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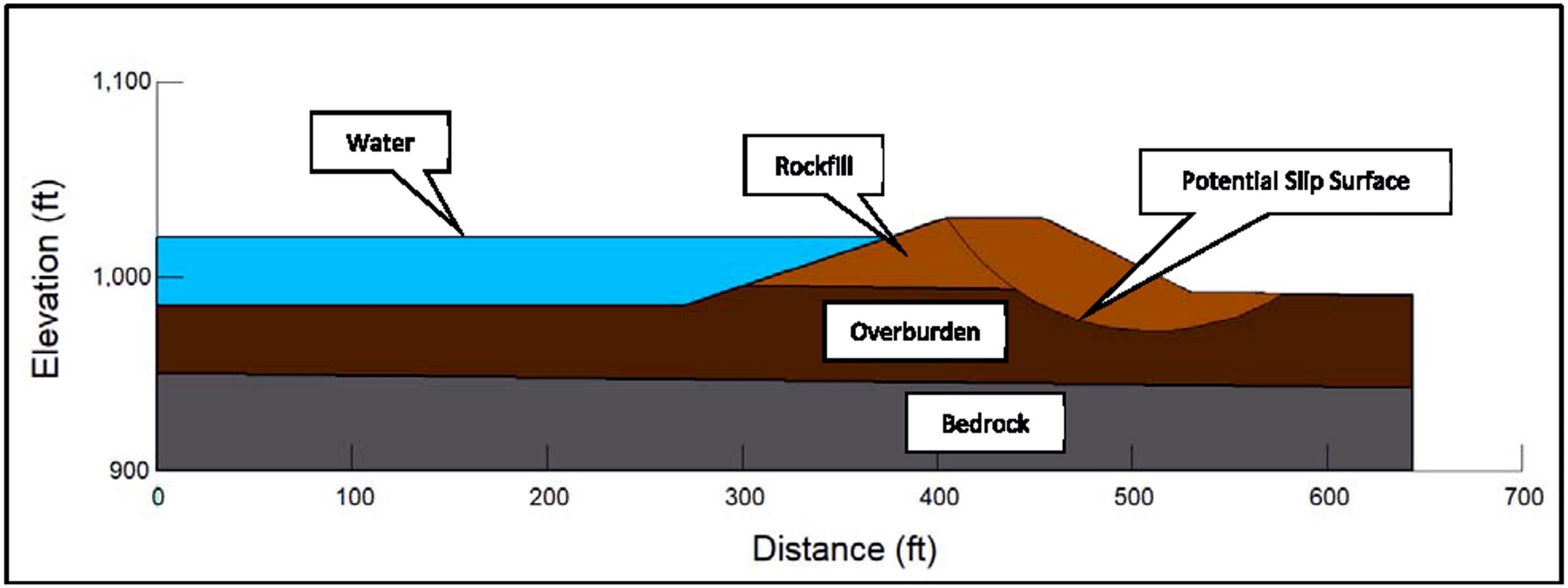
BULK TSF SCP STATIC STABILITY ANALYSIS

PEBBLE PROJECT EIS

FIGURE K4.15-5



Source: PLP (2018-RFI008b), Figure 2

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OPEN PIT WMP STATIC STABILITY ANALYSIS

Summary of Static Stability Analysis Results. Table K4.15-5 summarizes the results of the static stability analysis.

Table K4.15-5: Summary of Static Stability Analysis Results

Embankment	Construction Method	Max. Height (feet)	Downstream Slope Angle	Factor of Safety
Bulk TSF Main Embankment (Alternatives 1 and 3)	Buttressed Centerline	530	2.6H:1V	1.9 to 2.0
Bulk TSF Main Embankment (Alternative 2)	Downstream	570	2.6H:1V	1.9 to 2.0
Bulk TSF South Embankment	Downstream	305	2.6H:1V	1.9 to 2.0
Pyritic TSF North Embankment	Downstream	405	2.6H:1V	1.9 to 2.0
Main WMP	Downstream	200	2H:1V	1.7 to 1.8[1]
Bulk TSF Main SCP	Downstream	120	2.6H:1V	1.9 to 2.0
Open Pit WMP	Downstream	40	2H:1V	1.9 to 2.0

Notes:
[1] Results based on homogeneous overburden foundation with potential weak layers mitigated in design and construction. The stability analysis would be updated based on revised bedrock foundation as design progresses (AECOM 2018k, 2018l).
Sources: PLP 2018-RFI 008, 008b, 069, 075

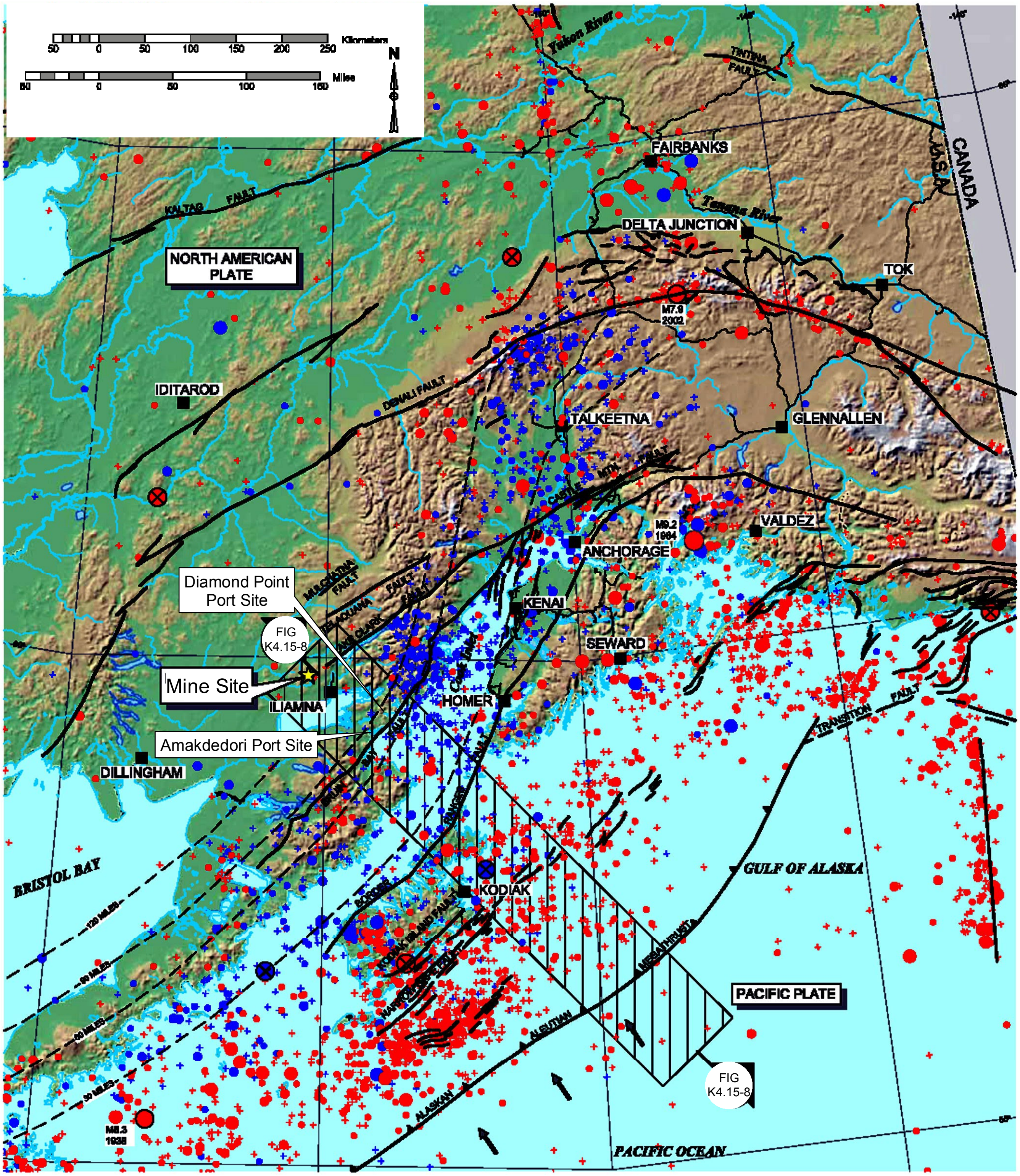
Allowances were included in the conceptual embankment cross sections for internal filter and transition zones, which were represented as a homogeneous rockfill material in the model domains. These zones would be defined further and included in future stability modeling. Potential future modifications to the embankments are not expected to affect the embankment footprint.

The static stability analyses would be updated for each embankment structure as the design progresses and additional field data are collected to support the understanding of geotechnical and hydrogeological conditions and the ADSP permitting process under ADNR.

Analyses of Seismic Hazards and Deformation

The mine site is situated in a seismically active area because of the convergence of the Pacific and North American tectonic plates (see Figure K4.15-7 and Figure K4.15-8). The most important seismically active geologic structure near the mine site is the Bruin Bay Fault, which lies about 70 to 80 miles east-southeast. Figure K4.15-7 shows a relatively high concentration of lower-magnitude earthquake events more than 25 miles in depth near Iliamna and Iniskin bays.

Seismic hazard analyses were completed in support of the proposed Pebble project. ADSP requires seismic analyses of dams to include both OBE and MDE scenarios. Table K4.15-6 shows the OBE and MDE return periods as related to ADSP classification of dam hazards.



Source: KP 2013, 2015 (Figure 6-2)

Active And Potentially Active Faults
Alignment Of Aleutian Trench
Direction Of Tectonic Plate Movement
Contour Of Approximate Oceanic Slab Depth
Zone Of Recorded Earthquakes Included On Section A-A

EARTHQUAKE FOCAL DEPTH
- Depth ≤ 25 miles
- Depth > 25 miles

EARTHQUAKE MAGNITUDE
- 4.0 - 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9
- 8.0 - 8.9
- 9.0 +
- Large magnitude earthquakes recorded between 1899 & 1904

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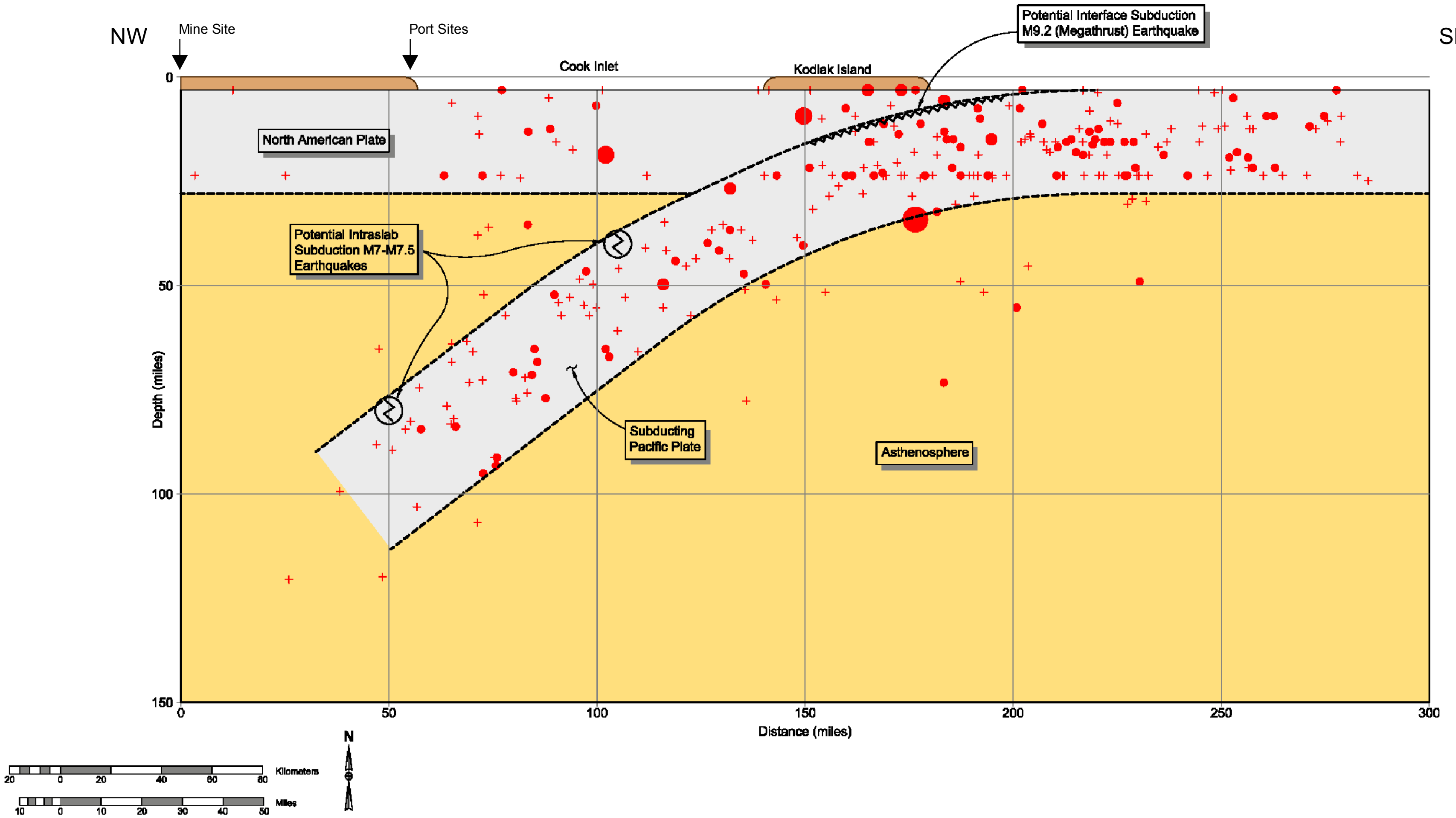
SEISMICITY AND EARTHQUAKE DEPTH

FIGURE K4.15-7



Source: KP 2013, 2015 (Figure 6-3)

Earthquake Magnitude
4.0 - 4.9
5.0 - 5.9
6.0 - 6.9
7.0 - 7.9
8.0 +
Lithosphere
Asthenosphere
Plate Boundaries
Potential Interface Subduction Earthquake Site
Potential Intraslab Subduction Earthquake Site

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CROSS-SECTION THROUGH ALASKA SUBDUCTION ZONE

PEBBLE PROJECT EIS

FIGURE K4.15-8

The OBE represents the ground motions or fault movements from an earthquake considered to have a reasonable probability of occurring during the functional life of a project. All critical elements of a structure need to be designed to remain functional during the OBE, and any resulting damage should be easily repairable in a limited time. The OBE can be defined based on probabilistic evaluations, in which the level of risk (the probability that the magnitude of ground motion would be exceeded during a particular length of time) is determined relative to the hazard potential classification and dam location (ADNR 2017).

The MDE represents the ground motions or fault movements from the most severe earthquake considered at the site, relative to the acceptable consequences of damage in terms of life and property. All critical elements of a dam and appurtenant structures for which the collapse or failure could result in or precipitate an uncontrolled release from the reservoir must be designed to resist the MDE. The MDE may be defined based on either probabilistic or deterministic evaluations, or both (ADNR 2017).

Table K4.15-6: Earthquake Return Periods for Alaska Dam Hazard Classifications

Dam Hazard Classification	Return Period, Years	
	Operating Basis Earthquake	Maximum Design Earthquake
I	150 to >250	2,500 to MCE
II	70 to 200	1,000 to 2,500
III	50 to 150	500 to 1,000

Notes:
MCE = Maximum Credible Earthquake.
1. The MCE is defined as ‘the largest earthquake magnitude that could occur along a recognized fault or within a particular seismo-tectonic province or source area under the current tectonic framework.
2. TSFs and the main WMP have a Class I dam hazard classification. Other mine site embankments may have a lower dam hazard classification.
Source: ADNR 2017

As shown in Table K4.15-6, the OBE should be selected from a range of return periods from 150 years to more than 250 years for a dam with a Class I hazard classification. A conservative OBE corresponding to a return period of 475 years was adopted for the Pebble TSF designs. The MDE should be selected from a range of return periods from 2,500 years up to the maximum credible earthquake (MCE) for a dam with a Class I hazard classification range. The MCE was selected as the MDE for the Pebble TSFs. As discussed below, both probabilistic and deterministic evaluations were completed for the Pebble Project to evaluate potential ground shaking associated with these earthquakes. The proposed design earthquakes associated with the OBE and MDE are presented in Section 4.15, Geohazards, and highlighted in bold in Tables K4.15-7 and K4.15-8.

Probabilistic Seismic Hazard Analysis. Table K4.15-7 shows the results of a probabilistic seismic hazard analysis completed for the mine site. The estimated maximum acceleration for the 1-in-475-year earthquake (OBE) is 0.14g.

Table K4.15-7: Probabilistic Seismic Hazard Analysis for Mine Site

Return Period (Years)	Probability of Exceedance [1]	Maximum Acceleration [2] (g)
50	63	0.06
100	39	0.07
200	22	0.10
475	**10**	**0.14**
1,000	5	0.19
2,500	2	0.25
5,000	1	0.31
10,000	0.5	0.38

Notes:
[1] Probability of exceedance calculated for a design life of 50 years; Q = 1 - exp (-L/T), where Q = probability of exceedance, L = design life in years, T = return period in years.
[2] Maximum accelerations are for values on firm rock.
[3] Information based on the USGS Seismic Hazard Program database.
Bold = proposed OBE
Source: KP 2013; PLP 2018-RFI 008a

Table K4.15-8: Deterministic Seismic Hazard Analysis for Mine Site

Earthquake Source Type	Earthquake Source Name	Source/ Fault Mechanism	Maximum Magnitude	Epicentral Distance[1]	Focal Depth	Peak Ground Acceleration[2]	
			(Mw)	(miles)	(miles)	Median (g)	84th Percentile (g)
Interface Subduction	**Alaska-Aleutian Megathrust**	**Thrust**	**9.2 (8.5)[3]**	**120**	**25**	0.08	**0.14**
Intraslab Subduction	Intraslab Event	In-slab	7.5	110	40	0.05	0.11
			8.0	110	40	0.09	0.16
	Deep Intraslab Event	**In-slab**	7.5	50	80	–	0.28
			8.0	**50**	**80**	0.26	**0.48**
Shallow Crustal Fault[4]	**Lake Clark Fault (Mapped)**	**Reverse (Thrust)**	**7.5**	**15**	**3**	0.17	**0.29**
	Castle Mountain Fault	Strike-slip	7.3	170	3	0.01	0.02
	Bruin Bay Fault	Reverse (Thrust)	8.0	60	3	0.07	0.12
	Border Ranges Fault	Strike-slip	8.0	130	3	0.02	0.04
	Kodiak Island / Narrow Cape Faults	Strike-slip	7.5	190	3	<0.01	0.01
	Telaquana Fault	Strike-slip	7.0	40	3	0.06	0.09
	Mulchatna Fault	Strike-slip	6.5	55	3	0.03	0.05

Table K4.15-8: Deterministic Seismic Hazard Analysis for Mine Site

Earthquake Source Type	Earthquake Source Name	Source/ Fault Mechanism	Maximum Magnitude	Epicentral Distance[1]	Focal Depth	Peak Ground Acceleration[2]	
			(Mw)	(miles)	(miles)	Median (g)	84th Percentile (g)
	Denali Fault	Strike-slip	8.0	125	3	0.03	0.05
	Maximum Background Earthquake[5]	**Reverse (Thrust)**	**6.5**	**< 1**	**~7**	0.35	**0.61**

Notes:
[1] Fault locations are from KP (2011, 2015).
[2] PGAs are for values on firm rock.
[3] Ground shaking from a magnitude 9+ earthquake would cover a larger area than a magnitude 8.0-8.5 earthquake, but is likely to have a similar maximum acceleration as an 8.0-8.5 event; thus, PGAs for the megathrust event were calculated using a representative magnitude 8.5. However, the duration, frequency characteristics, and amplitude of shaking for a magnitude 9.2 event would be considered in design.
[4] The adopted faulting mechanism for each shallow crustal fault was based on a review of available information defining the fault type. The predominant faulting mechanism assumed for all of the shallow crustal faults is strike-slip, with the exception of the Bruin Bay and Lake Clark faults for which reverse faulting was used. Reverse faulting was also conservatively assumed for the maximum background earthquake.
[5] Seismic event with no apparent association with known faults, but which could contribute to the seismic hazard.
Bold = MCE scenarios considered in TSF design
Source: KP 2013; PLP 2018-RFI 008a

Based on experience with similar studies at other mines in Alaska, the probabilistic seismic hazard analysis in Knight Piésold (2013) appears reasonable for its stated intentions (AECOM 2018f). The analysis relies on US Geological Survey (USGS) ground motion maps for Alaska (Wesson et al. 2007). As noted in the report and confirmed by AECOM (2018f), USGS plans to update these maps, but has not done so yet. The seismic hazard analysis would be updated as design progresses to support the design and reporting requirements outlined in the ADSP. A seismic report is one of the engineering science reports to be included in the preliminary design package submitted to ADNR. The analysis would incorporate current best practices for analysis and updated USGS ground motion data as available (PLP 2018-RFI 008c).

Deterministic Seismic Hazard Analysis. Table K4.15-8 shows the results of a deterministic analysis for the mine site based on the regional seismic sources.

The maximum acceleration values shown in Tables K4.15-7 and K4.15-8 were completed in 2013. Seismic activity since 2013 included the following large earthquakes, which were within the magnitude and maximum acceleration values shown in Table K4.15-8:

- Magnitude 7.9 earthquake experienced in the Gulf of Alaska (about 600 miles southeast of the mine site) on January 23, 2018
- Magnitude 7.1 earthquake experienced about 7 miles east of Iliamna Bay (about 75 miles east/southeast of the mine site) on January 24, 2016.

Knight Piésold (2013) cites New Generation Attenuation (NGA) equations (Earthquake Spectra 2008) used in the deterministic analysis for shallow crustal earthquakes. Revised NGA West 2 equations were published in 2014 after the Knight Piésold report date (e.g., Boore et al. 2014; Borzorgnia et al. 2014). The portion of the deterministic analysis that relies on these relationships would typically be updated using the NGA West 2 equations in the next phase of engineering. As indicated above, PLP plans to update the seismic hazard analyses as design progresses, incorporating current best practices into the analysis (AECOM 2018f; PLP 2018-RFI 008c).

Pseudo-Static Deformation Analysis. Embankment stability during hypothetical earthquake loading conditions was assessed previously for an earlier, larger (650-foot-high) design of the bulk TSF main embankment by performing a pseudo-static analysis. Estimates of horizontal and vertical displacement for mine site embankments would be analyzed further for current embankment designs during future seismic analysis as part of detailed design work undertaken in fulfillment of the ADSP review process. That work is anticipated to be performed after the EIS process is completed.

In the previous pseudo-static analysis, preliminary deformation values were estimated to support the conceptual level of study. A horizontal force (seismic coefficient) was applied to the embankment to simulate earthquake loading, and to determine the critical (yield) acceleration required to reduce the FoS to 1.0. Embankment deformation could occur if the yield acceleration would be lower than the predicted maximum ground acceleration along a potential slip surface. Preliminary deformations were previously evaluated for the bulk TSF main embankment for the following seismic sources:

- OBE
- Magnitude 9.2 interface subduction earthquake
- Magnitude 8.0 deep intraslab subduction earthquake
- Magnitude 7.5 shallow crustal earthquake on the Lake Clark Fault
- Magnitude 6.5 maximum background earthquake.

Previous deformation analyses indicated that some deformation of the embankments may occur during extreme earthquake shaking. Potential displacements under earthquake loading from the OBE and different MCE scenarios were estimated using the methods of Newmark (1965), Makdisi and Seed (1977), and Bray and Travasarou (2007). The yield acceleration values for the bulk TSF main embankment for the upstream and downstream configurations were higher than the ground accelerations associated with the OBE event, indicating that minimal deformations were anticipated as a result of an OBE event. The yield acceleration values were lower than the ground accelerations associated with the various MCE events, indicating that some deformation may occur as a result of an MCE event. Displacements were estimated to be on the order of 4 to 5 feet along the potential slip surface under MCE loading conditions.

Potential settlement of the embankment crest was also previously estimated for different MCE scenarios using the empirical relationship provided by Swaisgood (2003). This relationship was developed from an extensive review of case histories of embankment dam behaviors resulting from earthquake loading. Settlement of the embankment crest was estimated to be on the order of 4 feet under MCE loading conditions (Knight Piésold 2018c; PLP 2018-RFI 008).

The displacements were apparently not large enough to truncate the filter or transition zones, and would not affect the functionality of the embankment. The estimated crest deformation/settlement values were added to the minimum freeboard requirements for the bulk TSF embankments, so that the minimum required freeboard would be maintained after the MDE event.

Seismic stability analyses and crest deformation would be updated for each embankment structure as design progresses and additional field data are collected to support the understanding of geotechnical and hydrogeological conditions and the ADSP permitting process under ADNR. Future design phases would include cross sections for pseudo-static stability analyses that would show critical circles and calculated FoS, plus target FoS for embankments at the following facilities as required by the ADSP:

- Bulk TSF (main embankment)
- Pyritic TSF
- Bulk TSF main SCP
- Main WMP
- Open pit WMP.

Additional detailed modeling, including FLAC analyses, would be completed during detailed design of the facilities to better define embankment displacements.

Post-liquefaction Analyses. Previous results from a post-liquefaction analysis completed for the bulk TSF main embankment indicate that the FoS exceeded the required value of 1.2 under post-liquefaction conditions, using the post-liquefaction residual strength of the tailings. This finding indicated that the embankment was not dependent on the strength of the tailings for stability. Post-liquefaction analysis for the current design concepts would be completed as the project advances through the ADSP permitting phase (Knight Piésold 2018c; PLP 2018-RFI 008).

K4.15.1.6 Analysis of Open Pit Wall Stability

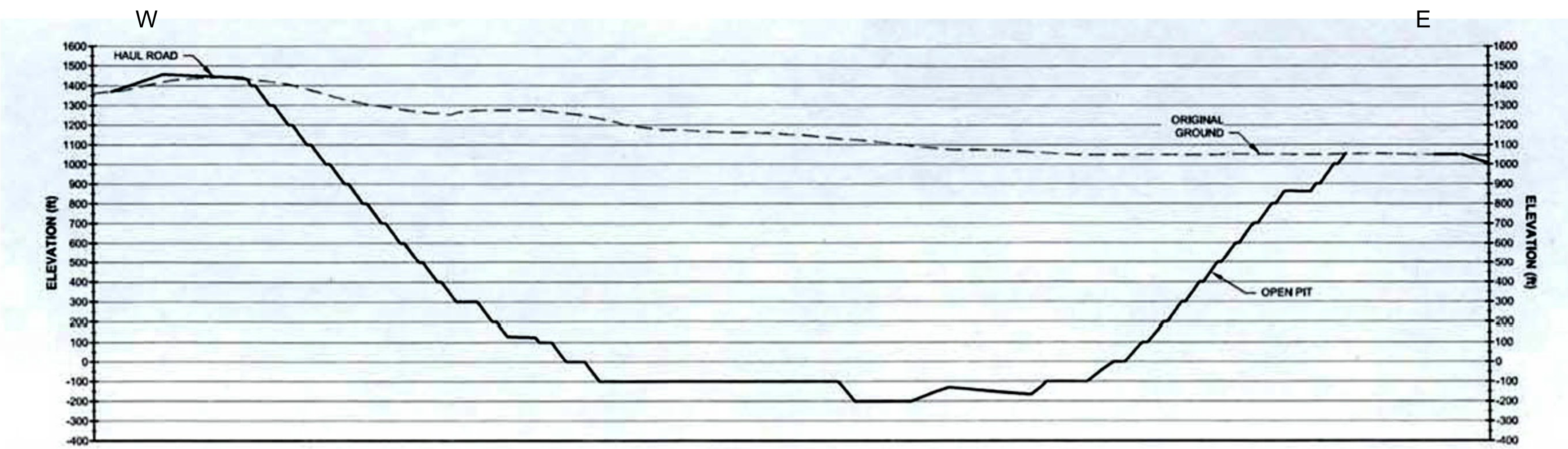
Referring to Figure 2-4 and Figure K4.15-9, the open pit would be constructed in the easternmost portion of the mine site. The pit would be 6,800 by 5,600 feet in width and 1,970 feet deep (PLP 2018d). As described in Section 3.13, the geology of the open pit area is complex, and consists of a variety of rock types. The surface is blanketed with mostly glacial deposits that are underlain by bedrock consisting of a mixture of Mesozoic-age andesitic sedimentary flysch with Cretaceous quartz monzodiorite, granodiorite, and diorite sills.

Pit wall stability analyses were calculated by SRK (2018c) and PLP (2018-RFI 023a) through three sections of the pit, as shown on Figure K4.15-10 and summarized in Table K4.15-9.

The modeling evaluated two different water table scenarios: 1) during mining with the groundwater levels immediately below the pit bottom; and 2) during early closure after discontinuation of groundwater drawdown with water levels recovered to about half full. A peak ground acceleration (PGA) of 0.14g was used for the dynamic modeling case.

The white (gray) lines that roughly parallel the pit wall face on Figures K4.15-12 and K4.15-13 are modeled disturbance factor (D) zones that represent zones of bedrock damage caused by relaxation and rebound of the rock mass from pit excavation and blast damage close to the excavation surface (Hoek 2012). Two inactive faults that intersect Section A (see Figure K4.15-11) appear to affect wall stability, along with heavily jointed rock represented by the white cross-hatching on Figures K4.15-12 and K4.15-13.

Most of the modeling was completed simulating 20 years of mining (immediately before closure), which would represent the worst-case scenario. As the pit is deepened, there do not appear to be any large intersections of weaker rock exposed, other than localized areas near the faults. Future designs would investigate improved optimization angles of the interim walls.



Source: PLP 2017, Figure MX-015

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OPEN PIT TOPOGRAPHIC CROSS-SECTION

PEBBLE PROJECT EIS

FIGURE K4.15-9

Table K4.15-9: Pit Wall Stability Modeling Results

Section	EoM FoS	EoM FoS Early Closure	EoM FoS Pit Lake	EoM FoS	EoM FoS Early Closure	EoM FoS Pit Lake
	Static			Dynamic		
A	1.3	0.8	1.4	1.2	0.7	1.4
B	1.6	1.4	1.9	1.4	1.2	1.7
C	1.4	1.2	2.2	1.2	1.1	2.0

Notes:
EoM = end of mine
FoS = factor of safety
1. Dynamic stability due to earthquake loading.
Source: PLP2018-RFI 023a

Table K4.15-9 presents the initial results of the open pit wall modeling. The minimum acceptable FoS for the open pit walls during operations was set at 1.3 for static conditions and 1.05 for dynamic conditions (Read and Stacey 2009). These values were selected as the upper bound, because there is only a single entry into the pit, and any instability involving the ramp would likely result in a loss of production. Acceptance criteria for the pit just after closure would be set at 1.1 because of the lack of access required into the pit during this time, but this would be reviewed during detailed design. The initial results indicate an FoS below 1.1 for the worst-case scenario in Section A under both static and dynamic conditions. The results for Sections B and C indicated FoSs of 1.1 or greater.

At closure, the pit walls would be stabilized and monitored to meet ADNR (2006) requirements so that they would not be expected to collapse (PLP 2018-RFI 024). However, the results for Section A in early closure suggest that depressurization caused by dewatering and lowering the water table would need to continue until the pit lake rise could buttress/stabilize the area of potential instability, which is below the faults. Two additional scenarios were therefore examined for Section A:

- Continued groundwater depressurization focused on the toe of the slope
- Pit lake at a level above the instability (the two faults in the face).

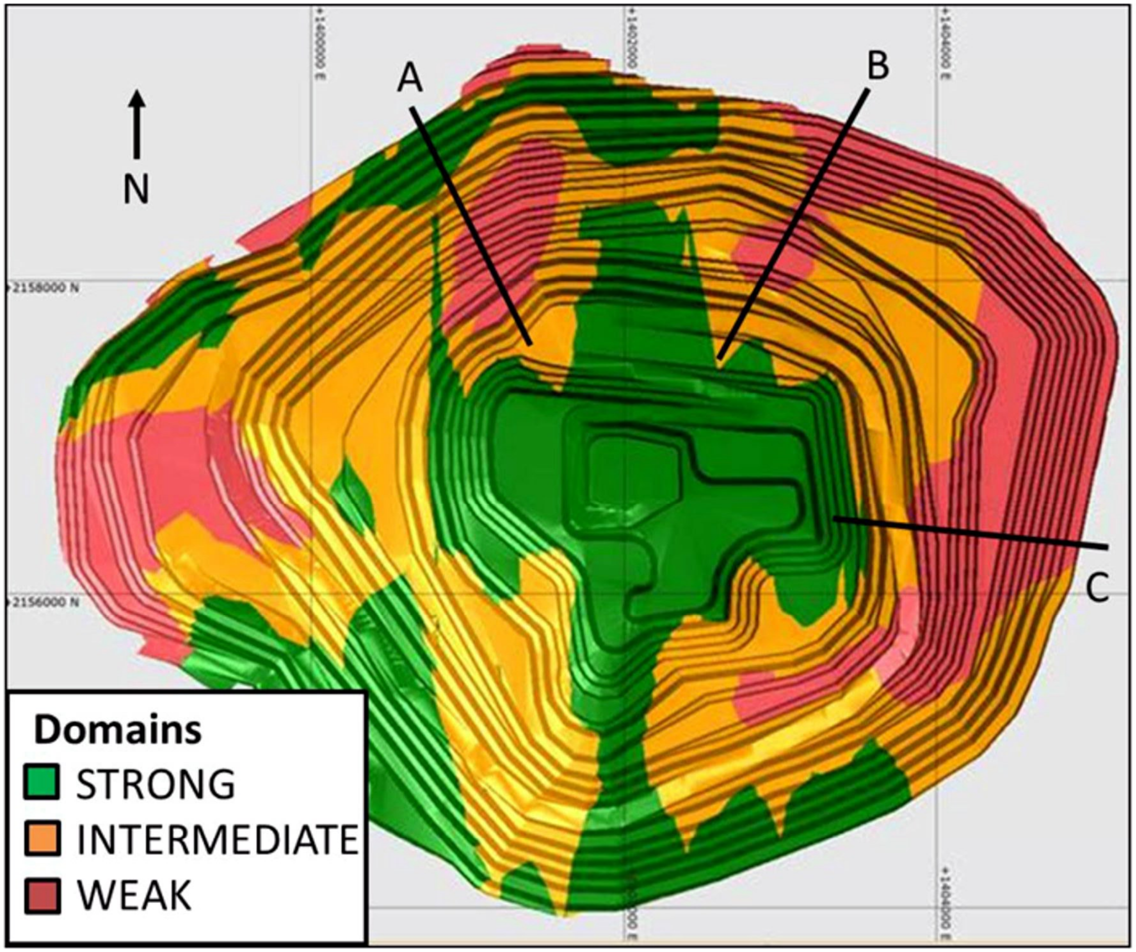
The results of the additional analyses, shown on Figures K4.15-12 and K4.15-13, indicate FoSs for the two scenarios of 1.1 and 1.4, respectively. These results suggest that with continued depressurization in the localized area of Section A during early closure activities (e.g., backfilling), the wall stability would meet acceptability criteria.

K4.15.2 Port Site

The port sites are located at Amakdedori and Diamond Point for Alternative 1 and Alternatives 2 and 3, respectively (see Figure 2-64). As noted on Figure 4.15-10, the port sites are situated in a seismically active area. Therefore, seismic hazard analyses were conducted for the port sites in conjunction with the analysis for the mine site using the same methods, including analyses of probabilistic and deterministic seismic hazards.

K4.15.2.1 Probabilistic Seismic Hazard Analysis

Table K4.15-10 shows the results of the probabilistic seismic hazard analyses completed for the Diamond Point port site.



Source: SRK 2018, PLP 2018-RFI 23

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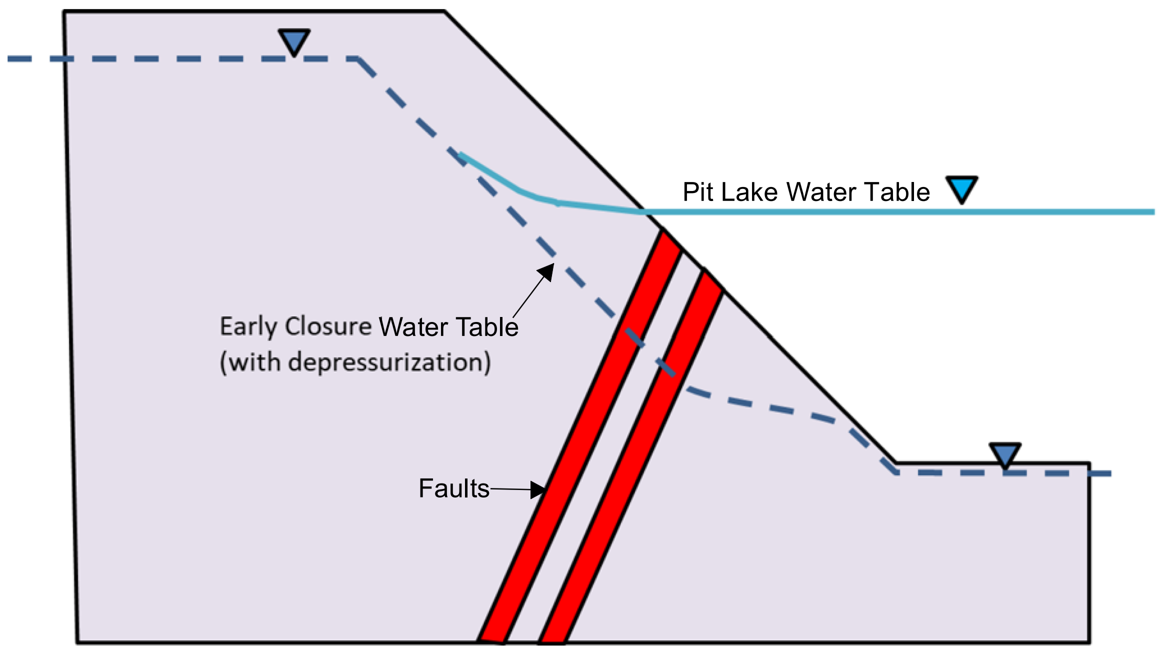
GEOTECHNICAL DOMAINS AND LOCATION OF PIT WALL STABILITY SECTIONS



Source: PLP 2018-RFI 023a

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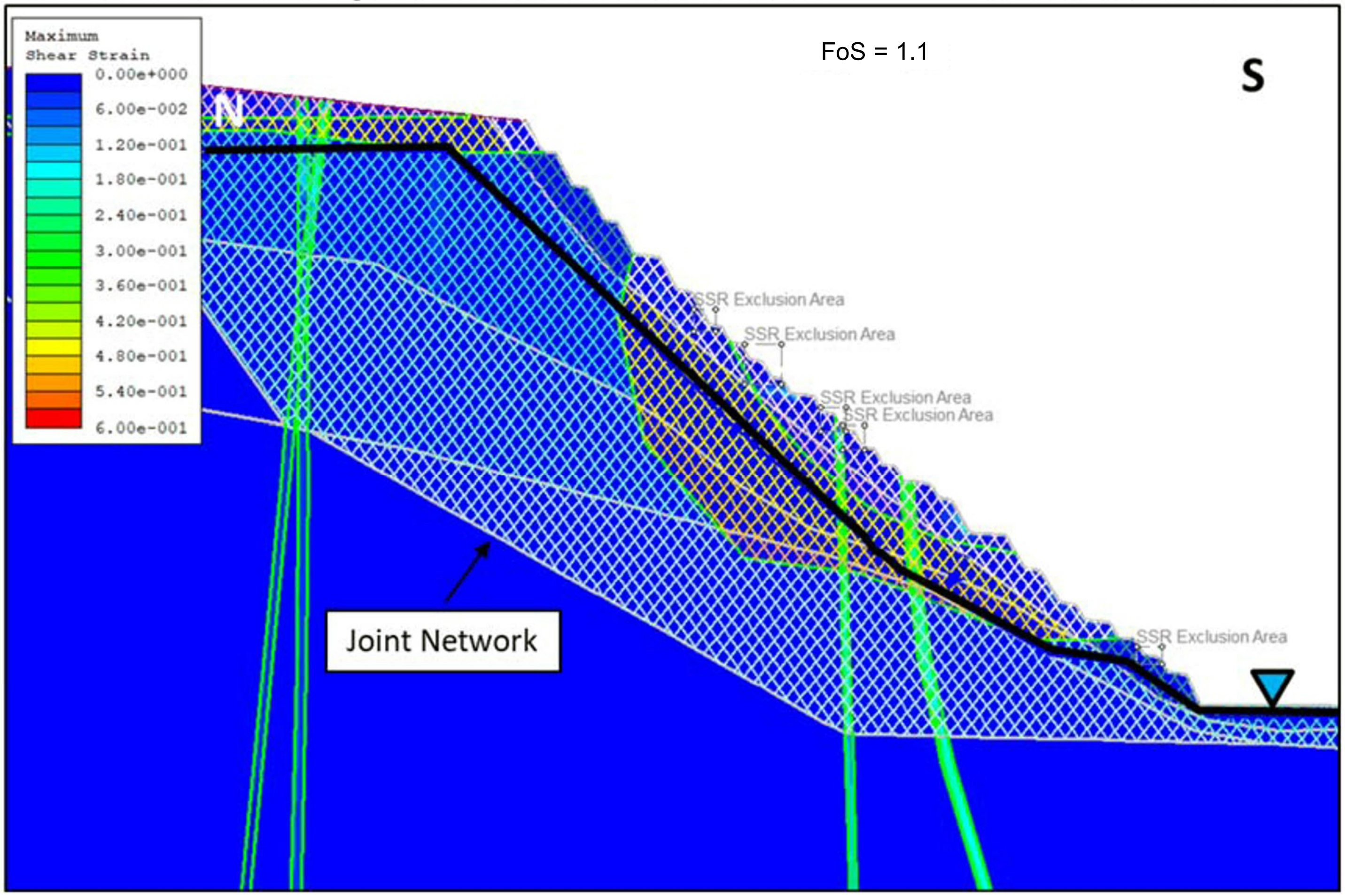
PIT WALL SECTION A - WATER TABLE SCENARIOS



Note: Shows pit water table below the faults in the slope

Source: PLP 2018-RFI 023a

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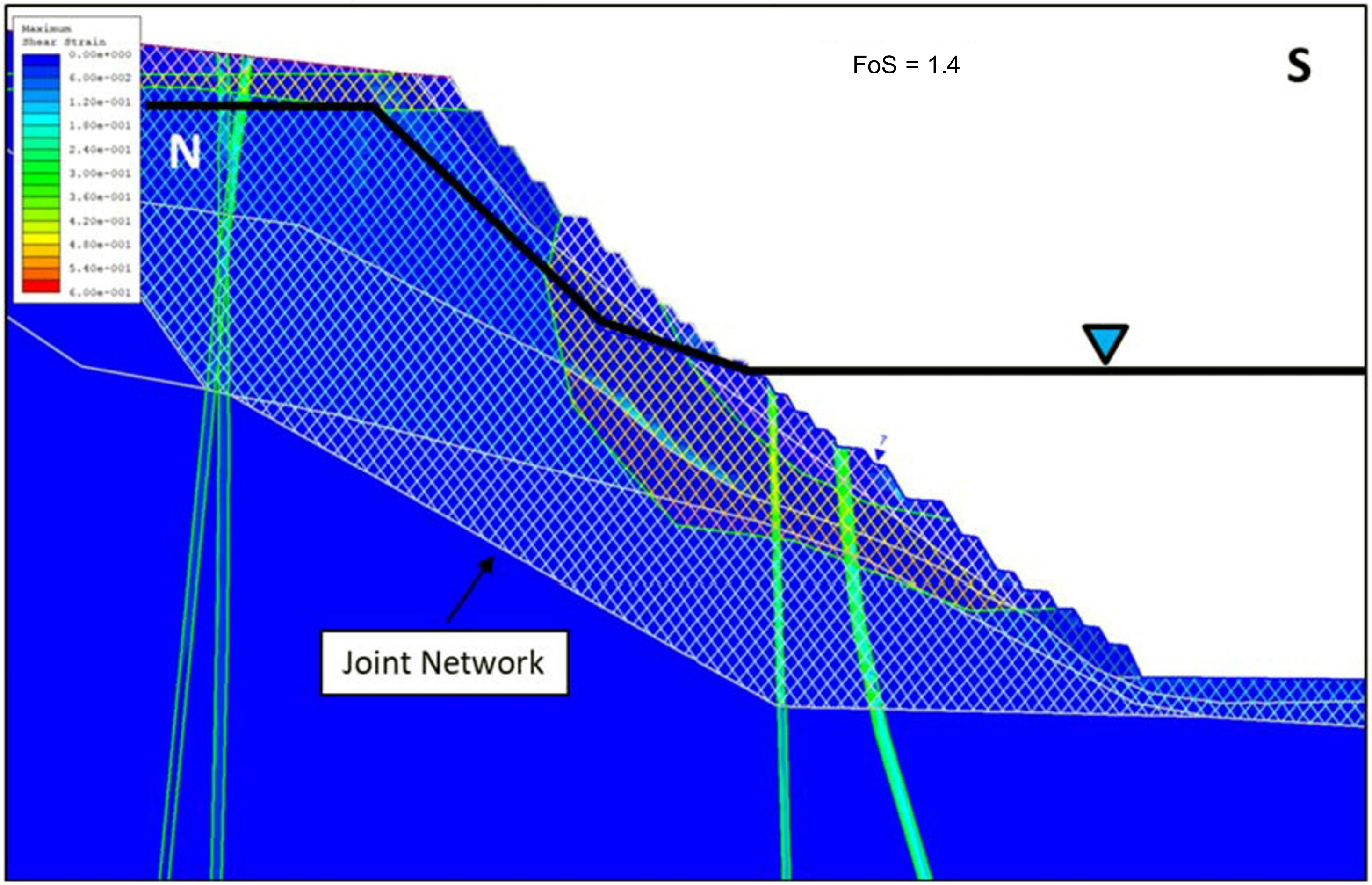
PIT WALL STABILITY SECTION A - SCENARIO WITH ACTIVE DRAINS IN EARLY CLOSURE



Note: Shows pit lake above the faults in the slope

Source: PLP 2018-RFI 023a

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PIT WALL STABILITY SECTION A - SCENARIO WITH HALF-FULL PIT LAKE

Table K4.15-10: Probabilistic Seismic Hazard Analysis for Diamond Point Port Site

Return Period (Years)	Probability of Exceedance [1] (%)	Maximum Acceleration [2] (g)
50	63	0.12
100	39	0.17
200	22	0.22
475	10	0.29
1,000	5	0.38
2,500	2	0.51
5,000	1	0.62
10,000	0.5	0.74

Notes:
[1] Probability of exceedance calculated for a design life of 50 years; Q = 1 - exp (-L/T). Where Q = probability of exceedance, L = design life in years, T = return period in years.
[2] Maximum accelerations are for values on firm rock.
[3] Information based on the USGS Seismic Hazard Program database.
Source: Knight Piésold 2013

The resulting estimated maximum accelerations for the 1-in-475-year and 1-in-2,500-year earthquakes are 0.29g and 0.51g, respectively, or nearly double that predicted for the mine site. This reflects the closer proximity of the port to the potential intraslab subduction earthquakes shown on Figures K4.15-7 and K4.15-8.

Based on fault conditions and seismicity in the region (see Figures 3.15-2 and K4.15-7), ground shaking effects at the Amakdedori port site are expected to be similar to or less than the effects predicted for the Diamond Point port site.

K4.15.2.2 Deterministic Seismic Hazard Analysis

Table K4.15-11 shows the results of a deterministic analysis for the Diamond Point port site based on the regional seismic sources. As noted for Table K4.15-8, the maximum acceleration values shown in Tables K4.15-10 and K4.15-11 were completed in 2013. Seismic activity since 2013 included two large earthquakes (listed in Section K4.15.1), which were within the magnitude and maximum acceleration values shown in Tables K4.15-8 and K4.15-11.

Table K4.15-11: Deterministic Seismic Hazard Analysis for the Diamond Point Port Site

Earthquake Source Type	Earthquake Source Name	Source/ Fault Mechanism	Maximum Magnitude (Mw)	Epicentral Distance (miles)	Focal Depth (miles)	Peak Ground Acceleration[1] Median (g)	Peak Ground Acceleration[1] 84th Percentile (g)
Interface Subduction[2]	Alaskan-Aleutian Megathrust	Thrust	9.2 (8.5)	70	25	0.13	0.23
Intraslab Subduction	Intraslab Event[3]	In-slab	7.5	35	45	0.20	0.37
			8.0	35	45	0.29	0.55
	Deep Intraslab Event[3]	In-slab	7.5	0	70	0.24	0.45
			8.0	0	70	0.40	0.74
Shallow Crustal Fault[4]	Lake Clark Fault	Reverse (Thrust)	7.5	50	3	0.06	0.10
	Bruin Bay Fault	Reverse (Thrust)	8.0	5	3	0.38	0.64
	Border Ranges Fault	Strike-slip	8.0	65	3	0.06	0.10
	Kodiak Island / Narrow Cape Faults	Strike-slip	7.5	150	3	0.01	0.02

Notes:
Mw: Moment magnitude
[1] PGAs are for values on firm rock.
[2] The PGA values for the interface subduction (megathrust) event have been calculated using a representative Magnitude 8.5 event.
[3] See Figures K4.15-7 and K4.15-8 for the locations of intraslab subduction earthquakes relative to the Pebble port sites (roughly 40 to 80 miles beneath and away from the port sites).
[4] The adopted faulting mechanism for each shallow crustal fault was based on a review of available information defining the fault type. The predominant faulting mechanism assumed for all shallow crustal faults is strike-slip, with the exception of the Bruin Bay and Lake Clark faults, for which reverse faulting was used.
Source: Knight Piésold 2013

The previous analyses of seismic stability based on the PGA values presented in Tables K4.15-10 and K4.15-11 would be the design basis for the ports, with updates as design progresses at the selected port site. The values are similar to those presented in Table K4.15-8 for the mine site, but differences are attributable to the respective proximities to the earthquake sources.

As noted for the probabilistic analysis for the port sites, based on the fault conditions and seismicity in the region (Figure 3.15-2), ground shaking effects are expected to be similar or less at the Amakdedori port site than at Diamond Point.

K4.15.2.3 Stability Analysis of Rockfill Causeway and Sheetpile Dock

A rockfill causeway and sheetpile dock design is proposed for both the port at Amakdedori under Alternative 1 and the port at Diamond Point under Alternatives 2 and 3. As described in Chapter 2, the Amakdedori port would consist of a causeway constructed of earthfill embankment, and a barge berth and wharf constructed of a sheetpile wall wharf structure filled with granular material (see Figures 2-28 and 2-29). The Diamond Point port would use the same design concept as the Amakdedori port, but would have a different, larger layout (see Figure 2-51).

The stability of port structures is typically determined through stability analyses conducted under both static and seismic conditions. Inputs are based on water depths, tidal fluctuations, winter ice formations, subsurface geotechnical conditions, construction materials, and proposed design features. Material site characterization and stability analyses would be conducted for the respective ports' major structures (such as the terminal patio and sheetpile wharf) during final design (PLP 2018-RFI 005).

Available subsurface foundation information for the Amakdedori port site is limited, and includes two vibracores to a depth of 3 feet below mudline, a multibeam bathymetric survey, and extrapolation of onshore geophysical data (Section 3.15, Geohazards, PLP 2018-RFI 039; Zonge 2017). Although geotechnical conditions at the port site could be variable, bedrock is likely sufficiently deep that marine structures would not need to be socketed, and that sheetpiles could be designed for installation to a design embedment depth (PLP 2018-RFI 005).

Subsurface foundation conditions at the Diamond Point site are also generally unknown. Water depth is shallower at this location than at Amakdedori, which would require dredging a 20-foot-deep navigation channel (PLP 2018d). More detailed subsurface foundation information is available for Williamsport, about 3 miles north of Diamond Point. Based on geotechnical borings and a geophysical survey completed by USACE in 1995, the depth to bedrock in the vicinity of the existing dock ranged between approximately 65 and 130 feet. The bedrock was mainly overlain by fine-grained sediments. In contrast, the marine channels through Iliamna Bay and Iniskin Bay (east of Iliamna Bay) were noted as having a mantle of unconsolidated, fine-grained sediment, with particle size typically decreasing with water depth and distance from the shoreline. Coarse-grained sediments with cobbles and boulders were observed along the shorelines of both Iliamna Bay and Iniskin Bay (Knight Piésold 2011d).

Design details available for the Amakdedori site are provided in PLP (2018-RFI 005). Construction of the Amakdedori terminal would require installing approximately 2,200 lineal feet of protected rock slope along an access causeway, and 2,000 lineal feet (in plan) of steel sheetpiles that may be 110 feet long (the length may be as short as 50 feet), with tie-backs into the fill behind the sheets to provide sufficient lateral capacity. The lineal sheetpile and tie-back design proposed for the wharf is not considered as vulnerable to an "unzipping" type of failure in a large earthquake as the open-cell structure at the Port of Anchorage (CH2MHill 2013). The sheetpiles would be installed in 15 to 20 feet of water. The causeway would be constructed by infilling on top of the seabed with competent fill and rock protection for the slopes. The sheetpiles would be installed using a vibratory hammer. If it is discovered that bedrock or similarly hard soil is within 20 to 30 feet of the design seabed elevation, driving the sheets for the last 1 to 2 feet may be required to anchor the sheets in the ground. If bedrock or similarly hard soil is found to be very shallow, pile socketing and a revised concept may be required. If investigations find that the seabed is susceptible to liquefaction under seismic conditions, soil improvement work such as stone column installation may be required (PLP 2018-RFI 005).

The types of impacts that could occur at the ports include structural instability and potential failure of the sheetpile wharf as a result of seismic loading or foundation conditions; erosion at the base of the sheetpiles; icing that increases gravity load on the sheets; and corrosion requiring regular monitoring of cathodic protection systems. These impacts would be addressed as design progresses. Experience at other sheetpile docks in Cook Inlet (Port of Anchorage, Port MacKenzie) suggest that these issues could also be of concern at the Amakdedori and Diamond Point port sites, as discussed below.

Subsurface conditions (e.g., buried sensitive clay layers like at the Port of Anchorage) that have the potential to lead to translational failure of a structure in a major earthquake (Simpson, Gumpertz & Heger 2013) likely do not exist at the Amakdedori port site; where, based on the information available, subsurface deposits consist primarily of silty sand and gravel (see Section 3.15). It is also unlikely but possible that these conditions exist at the Diamond Point site.

A stability analysis of the sheetpile wharf at the Amakdedori and Diamond port sites that takes seismic loads into account would be considered to be the state-of-the-practice for this type of structure in this seismic setting. The PGA for a major earthquake at this location could range from an estimated 0.3g to 0.5g for a 500-year to 2,500-year event, respectively (see Figure 3.15-2) (Wesson et al. 2007). These PGA values are supported by the probabilistic and deterministic seismic hazard analyses described above that were completed at the Diamond Point site (Knight Piésold 2013). The results indicated a PGA of 0.51g for a 2,475-year event. This is consistent with Figure 3.15-2 in Section 3.15, Geohazards (Wesson et al. 2007), which suggests that the PGA at the Amakdedori port site would be slightly less—at 0.50g. Additional seismic analyses would be completed before detailed design to support engineering and construction (PLP 2018-RFI 005).

Liquefaction of the seabed during a major earthquake could also cause wharf damage, although the expected sand and gravel conditions at the Amakdedori site may be too coarse and inhomogeneous for liquefaction to occur (see Section 3.15, Geohazards) (e.g., Youd and Perkins 1978). However, as noted above, the particle size of the relevant sediment at the Diamond Point site is less certain. Should the seabed conditions be found to be susceptible to liquefaction, soil improvement work such as installation of stone columns or other densification methods would be considered (PLP 2018-RFI 005).

Boulders have been documented on the seafloor near both port sites, and may be present in subsurface deposits (see Section 3.15, Geohazards). The boulders could prevent the installation of sheetpiles and/or possibly damage the piles. Both the Port of Anchorage and Port MacKenzie experienced sheetpile damage caused by subsurface obstructions such as old earthquake fill, riprap, or unexpected hard layers that were not detected by geotechnical investigations (e.g., CH2MHill 2013; Port of Alaska 2018; Lockyer 2016).

If sheetpile defects were to occur during construction, they could allow retained fill to escape, potentially covering the seafloor near the wharf, and may damage the wharf's surface and equipment, and interrupt shipping operations.

Another hazard experienced at the Port MacKenzie dock is erosion from seawater and tidal currents undermining the base of the sheetpile at the mudline, and causing a loss of fill (e.g., Hollander 2017). This hazard is unlikely to occur at the Amakdedori port site, given the design depth of sheetpile anchoring and design contingencies described above, but may be a concern at the Diamond Point site.

If struck by a tsunami, the sheetpile bulkhead design would expose the cross sectional area to the hydrodynamic impact of the wave. A critical loading condition for the bulkhead could be the very low water level during the “retreat phase” of the tsunami, during which the stabilizing effect of water on the outside of the sheetpile is absent or diminished.

Based on the uncertainties and impacts experienced at other sheetpile structures as described above, it is possible that the sheetpile wharf could experience a release of fill material, ranging from partial loss through a damaged or eroded sheetpile to a major loss in an earthquake. The fill material for the Amakdedori port site would be sourced from a local geologic materials site (blasted granitic material) or imported by ship (PLP 2018-RFI 005), and could range from rockfill to material similar to that present on the seafloor (sand and gravel). At the Diamond Point site, the sheetpile wharf is proposed to be backfilled with the material dredged from the adjacent 20-foot-deep navigation channel.

In the event of the loss of fill from the sheetpile, the released material could cause a temporary turbidity plume in the water column. Wharf damage and loss of fill could also disrupt barging and concentrate lightering activities, potentially causing a buildup of concentrate containers at the port and ferry terminals. Chapter 5, Mitigation, provides measures to reduce the likelihood of these impacts, such as geotechnical investigations and stability analyses.

In summary, the proposed rockfill causeway and sheet-pile dock design would have the potential to result in adverse impacts on the environment during construction, operation, and closure. Additional field investigations would be performed to support detailed design to confirm that the design is feasible; and if so, to ensure construction, operation, and closure procedures that would be protective of the environment. Alternative design solutions, such as the Pile-Supported Dock Variant considered under Alternatives 1 and 2, could also be considered and implemented.

K4.16 SURFACE WATER HYDROLOGY

This appendix contains average annual flow balance tables and water balance flow schematics for the following project phases (Knight Piésold 2018d):

- Operations Phase
- Closure Phase 1 – Year 10
- Closure Phase 2 – Year 20
- Closure Phase 3 – Year 40
- Closure Phase 4 – Year 50

Table K4.16-1: Average Annual Flow Balance – Operations

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions (Realization #36)	Average Conditions (Realization #5)	Relatively Wet Conditions (Realization #10)
Open Pit				
Open Pit Inflows				
1	Direct Precipitation	2	3	4
2	Undisturbed Surface Runoff	<1	<1	1
3	Diversion Channel Leakage	<1	1	2
4	Groundwater	6	6	6
5	Additional Snowblow	1	1	1
	Subtotal Inflows	**9**	**11**	**14**
Open Pit Outflows				
6	Dewatering to OP WMP	9	11	14
	Subtotal Outflows	**9**	**11**	**14**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Open Pit Water Management Pond (OP WMP)				
OP WMP Inflows				
7	Direct Precipitation	<1	<1	1
8	Undisturbed Surface Runoff	<1	<1	1
6	Dewatering from Open Pit	9	11	14
	Subtotal Inflows	**9**	**11**	**15**
OP WMP Outflows				
9	Pond Evaporation	<1	<1	<1
10	Dust Suppression	<1	<1	<1
11	Surplus to Main WMP	0	1	5
12	Surplus to WTP#1	9	10	11
	Subtotal Outflows	**9**	**11**	**16**
	Change in Storage	**0**	**0**	**0**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**

Table K4.16-1: Average Annual Flow Balance – Operations

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions (Realization #36)	Average Conditions (Realization #5)	Relatively Wet Conditions (Realization #10)
Mill/Process				
Process Inflows				
13	Water in Ore	2	2	2
14	Treated Water	3	3	3
15	Reclaim Water from Main WMP	48	48	48
	Subtotal Inflows	**53**	**53**	**53**
Process Outflows				
16	Water in Concentrate	<1	<1	<1
17	Bulk Tailings Slurry Water	46	46	46
18	Pyritic Tailings Slurry Water	7	7	7
	Subtotal Outflows	**53**	**53**	**53**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Power Plant				
Power Plant Inflows				
19	Treated Water for Cooling Towers	3	3	3
	Subtotal Inflows	**3**	**3**	**3**
Power Plant Outflows				
20	Cooling Tower Evaporation	2	2	2
21	Blowdown Water to Main WMP	1	1	1
	Subtotal Outflows	**3**	**3**	**3**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Pyritic Tailings and PAG Waste Rock Management Facility (Pyritic TSF)				
Pyritic TSF Inflows				
22	Direct Precipitation	2	4	7
23	Undisturbed Surface Runoff	<1	1	2
24	Diversion Channel Leakage	<1	<1	<1
25	Seepage Collection Recycle Ponds	<1	<1	1
55 + 57	Reject Flows from WTPs	<1	1	1
18	Pyritic Tailings Slurry Water	7	7	7
	Subtotal Inflows	**9**	**13**	**18**
Pyritic TSF Outflows				
26	Pond Evaporation	1	1	1
27	Pyritic Tailings Void Losses	2	2	2
28	PAG Waste Rock Void Losses	1	1	1
29	Surplus to Main WMP	5	8	8
	Subtotal Outflows	**9**	**12**	**12**

Table K4.16-1: Average Annual Flow Balance – Operations

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions (Realization #36)	Average Conditions (Realization #5)	Relatively Wet Conditions (Realization #10)
	Change in Storage	**0**	**1**	**5**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk Tailings Management Facility (Bulk TSF)				
Bulk TSF Inflows				
30	Direct Precipitation on Supernatant Pond	1	2	6
31	Undisturbed Surface Runoff	2	5	10
32	Diversion Channel Leakage	<1	<1	<1
33	Recycle from Seepage Collection Recycle Ponds	1	2	3
34	Bulk Tailings Beach Runoff	4	9	16
17	Bulk Tailings Slurry Water	46	46	46
	Subtotal Inflows	**54**	**64**	**81**
Bulk TSF Outflows				
35	Pond Evaporation	1	1	1
36	Bulk Tailings Void Losses	17	17	17
37	Seepage through Main Embankment	9	9	9
38	Surplus to Main WMP	28	37	50
	Subtotal Outflows	**55**	**64**	**77**
	Change in Storage	**−1**	**0**	**4**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF Main Embankment Seepage Collection Pond (Bulk TSF Main SCP)				
Seepage Pond Inflows				
39	Direct Precipitation	<1	<1	1
40	Undisturbed Surface Runoff	1	3	5
41	Diversion Channel Leakage	<1	<1	1
42	Bulk TSF Main Embankment Runoff	1	1	2
37	Seepage through main embankment	9	9	9
	Subtotal Inflows	**11**	**13**	**18**
Seepage Pond Outflows				
43	Pond Evaporation	<1	<1	<1
44	Surplus to Main WMP	11	13	14
	Subtotal Outflows	**11**	**13**	**14**
	Change in Storage	**0**	**0**	**4**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF South Embankment Seepage Collection Pond				
Seepage Pond Inflows				
45	Undisturbed Surface Runoff	1	1	2

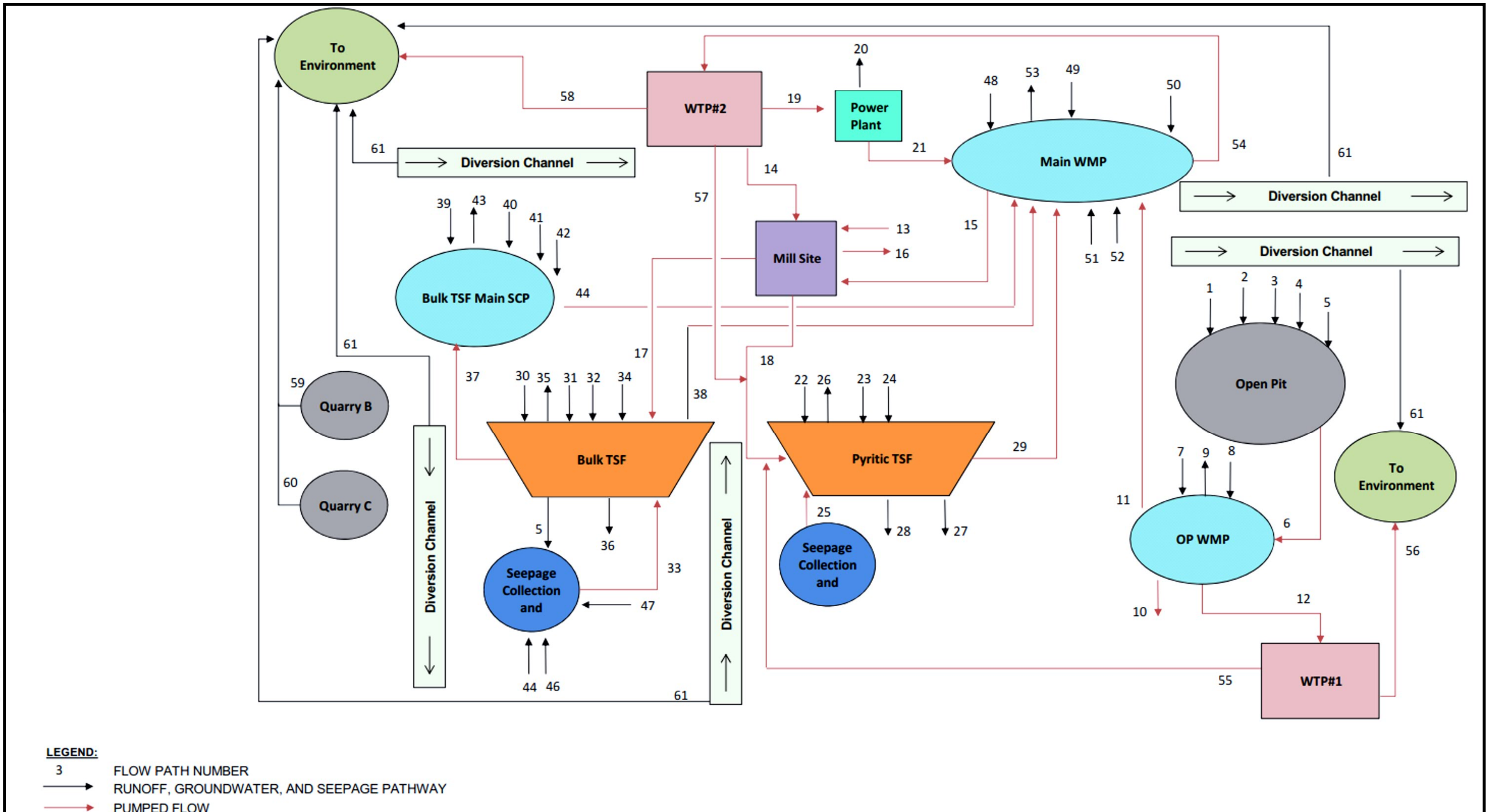
Table K4.16-1: Average Annual Flow Balance – Operations

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions (Realization #36)	Average Conditions (Realization #5)	Relatively Wet Conditions (Realization #10)
46	Diversion Channel Leakage	<1	<1	1
47	Bulk TSF South Embankment Runoff	<1	<1	<1
	Subtotal Inflows	**1**	**1**	**3**
Seepage Pond Outflows				
33	Recycle to Bulk TSF	1	1	3
	Subtotal Outflows	1	1	3
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Main Water Management Pond (Main WMP)				
Main WMP Inflows				
48	Direct Precipitation	1	4	7
49	Undisturbed Surface Runoff	1	3	5
50	Diversion Channel Leakage	<1	<1	1
51	Mill Site Runoff	<1	1	1
52	Pyritic TSF Main Embankment Runoff	<1	1	1
11	Surplus from OP WMP	0	1	5
29	Surplus from Pyritic TSF	5	8	8
38	Surplus from Bulk TSF	28	37	50
44	Surplus from Bulk TSF Main SCP	11	13	14
21	Blowdown Water to Main WMP	1	1	1
	Subtotal Inflows	**47**	**69**	**93**
Main WMP Outflows				
53	Pond Evaporation	1	1	1
15	Reclaim Water to Process	48	48	48
54	Water to WTP#2	17	25	28
	Subtotal Outflows	**66**	**74**	**77**
	Change in Storage	**−19**	**−5**	**16**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Water Treatment Plant #1 (WTP #1)				
WTP#1 Inflows				
12	Surplus from OP WMP	9	10	11
	Subtotal Inflows	**9**	**10**	**11**
WTP#1 Outflows				
55	Reject Flows	<1	<1	<1
56	Flows Released to Environment	9	10	11
	Subtotal Outflows	**9**	**10**	**11**

Table K4.16-1: Average Annual Flow Balance – Operations

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions (Realization #36)	**Average Conditions (Realization #5)**	**Relatively Wet Conditions (Realization #10)**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Water Treatment Plant #2 (WTP #2)				
WTP#2 Inflows				
54	Surplus from Main WMP	17	25	28
	Subtotal Inflows	**17**	**25**	**28**
WTP#2 Outflows				
57	Reject Flows	<1	<1	1
14	Treated Water to Process	3	3	3
19	Treated Water to Power Plant Cooling Towers	3	3	3
58	Flows Released to Environment	11	19	21
	Subtotal Outflows	**17**	**25**	**28**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Diverted Flows				
59	Runoff from Quarry B	1	3	5
60	Runoff from Quarry C	1	1	3
61	Diversion Channel Flow	3	6	12
	Total Diverted Flows to Downstream Environment	**5**	**10**	**20**
Flows Released to Downstream Environment				
59 + 60 + 61	Total Diverted Flows to Downstream Environment	5	10	20
56	Treated Flows from WTP#1	9	10	11
58	Treated Flows from WTP#2	11	19	21
	Total Flows Released to Downstream Environment	**25**	**39**	**52**

Notes:
Flow path number corresponds to flow schematic presented on Figure K4.16-1.
Change is storage within the ponds as a function of the water management operating criteria. A change in storage indicates if the pond has accumulated or decreased pond volume.
OP = open pit
PAG = potentially acid generating
TSF = tailings storage facility
WMP = water management pond
WTP = water treatment plant
Source: Knight Piésold 2018a, Table A.1



Sources: Knight Piesold 2018a, Figure A.1
Note: Flow path numbers correspond with flow values summarized in Table K4.16-1.

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WATER BALANCE FLOW SCHEMATIC - OPERATIONS

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FIGURE K4.16-1

Table K4.16-2: Flow Path Numbers and Descriptions

Flow Path Number and Description		Flow Path Number and Description (continued)	
1	Direct Precipitation on Open Pit	40	Undisturbed Surface Runoff to Bulk TSF Main SCP
2	Undisturbed Surface Runoff to Open Pit	41	Diversion Channel Leakage to Bulk TSF Main SCP
3	Diversion Channel Leakage to Open Pit	42	Bulk TSF Main Embankment Runoff
4	Groundwater to Open Pit	43	Pond Evaporation from Bulk TSF Main SCP
5	Additional Snow blow to Open Pit	44	Surplus Water from Bulk TSF Main SCP
6	Open Pit Dewatering	45	Undisturbed Surface Runoff to Bulk TSF South Embankment SCP
7	Direct Precipitation on OP WMP	46	Diversion Channel Leakage to Bulk TSF South Embankment SCP
8	Undisturbed Surface Runoff to OP WMP	47	Bulk TSF South Embankment Runoff
9	Pond Evaporation from OP WMP	48	Direct Precipitation on Main WMP
10	Dust Suppression	49	Undisturbed Surface Runoff to Main WMP
11	Surplus to Main WMP from OP WMP	50	Diversion Channel Leakage to Main WMP
12	Surplus to WTP#1 from OP WMP	51	Mill Site Runoff
13	Water in Ore	52	Pyritic TSF Main Embankment Runoff
14	Treated Water from Mill/Process	53	Pond Evaporation from Main WMP
15	Reclaim Water from Main WMP for Mill/Process	54	Main WMP Water to WTP#2
16	Water in Concentrate	55	Reject Flows from WTP #1
17	Bulk Tailings Slurry Water	56	Flows Released to Environment from WTP #1
18	Pyritic Tailings Slurry Water	57	Reject Flows from WTP #2
19	Treated Water for Cooling Towers	58	Flows Released to Environment from WTP #2
20	Cooling Tower Evaporation	59	Diverted Runoff from Quarry B
21	Blowdown Water to Main WMP	60	Diverted Runoff from Quarry C
22	Direct Precipitation on Pyritic TSF	61	Diversion Channel Flow
23	Undisturbed Surface Runoff to Pyritic TSF	62	Reject Flows from WTP #3
24	Diversion Channel Leakage to Pyritic TSF	63	Flows Released to Environment from WTP #3
25	Recycle from Seepage Collection Ponds to Pyritic TSF	64	Pyritic Tailings Re-Slurry Make-up Water from Open Pit
26	Pond Evaporation from Pyritic TSF	65	Pyritic Tailings Re-Slurry Water to Open Pit
27	Pyritic Tailings Void Losses in the Pyritic TSF	66	Pyritic Tailings Re-Slurry Make-up Water from Main WMP
28	PAG Waste Rock Void Losses in the Pyritic TSF	67	Pyritic Tailings Void Losses in the Open Pit
29	Surplus Water from Pyritic TSF	68	PAG Waste Rock Void Losses in the Open Pit
30	Direct Precipitation on Supernatant Pond	69	Reclaimed Bulk Tailings Beach Runoff
31	Undisturbed Surface Runoff to Bulk TSF	70	Pond Evaporation from Open Pit
32	Diversion Channel Leakage to Bulk TSF	71	Surplus to WTP#3 from OP WMP during drainage
33	Recycle from Seepage Collection Ponds to Bulk TSF	72	Pit Wall Runoff from Open Pit

Table K4.16-2: Flow Path Numbers and Descriptions

Flow Path Number and Description		Flow Path Number and Description (continued)	
34	Bulk Tailings Beach Runoff	73	Sludge Flows from WTP#2
35	Pond Evaporation from Supernatant Pond	74	Sludge Flows from WTP#3
36	Bulk Tailings Void Losses	75	Seepage through South and East Embankments
37	Seepage through Main Embankment	76	Recycle from Seepage Collection Ponds to Bulk TSF Main SCP
38	Surplus Water from Bulk TSF	77	Tailings Consolidation Seepage
39	Direct Precipitation on Bulk TSF Main SCP		

Notes:
Flow path number corresponds to flow schematic presented on Knight Piésold 2018d, Figures A.1 to A.4.
OP = open pit
PAG = potentially acid generating
SCP = sediment collection pond
TSF = tailing storage facility
WMP = water management pond
WTP = water treatment plant
Source: Knight Piésold 2018d, Table A.1

Table K4.16-3: Average Annual Flow Balance, Closure Phase 1 – Year 10

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	**Average Conditions**	**Relatively Wet Conditions**
Open Pit				
Open Pit Inflows				
1	Direct Precipitation	1	1	2
2	Undisturbed Surface Runoff	<1	1	1
3	Diversion Channel Leakage	<1	<1	1
4	Groundwater	5	5	5
5	Additional Snowblow	1	1	1
65	Pyritic Tailings Re-Slurry Water to Open Pit	36	36	36
72	Pit Wall Runoff	2	3	3
57+73	Reject Flows and Sludge Flows from WTP #2	1	1	1
62+74	Reject Flows and Sludge Flows from WTP #3	0	0	0
	Subtotal Inflows	**46**	**47**	**50**
Open Pit Outflows				
6	Open Pit Dewatering to WTP#3	<1	<1	<1
64	Make-up Water to Pyritic TSF	28	26	24
67	Pyritic Tailings Void Losses	3	3	3
68	PAG Waste Rock Void Losses	2	2	2
70	Pond Evaporation	<1	<1	<1
	Subtotal Outflows	**33**	**31**	**29**
	Change in Storage	**13**	**16**	**21**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Pyritic Tailings and PAG Waste Rock Management Facility (Pyritic TSF)				
Pyritic TSF Inflows				
22	Direct Precipitation	2	3	3
23	Undisturbed Surface Runoff	2	4	5
24	Diversion Channel Leakage	<1	<1	<1
25	Seepage Collection Recycle Ponds	<1	<1	<1
64	Make-up Water from Open Pit	28	26	24
66	Make-up Water from Main WMP	0	0	0
	Subtotal Inflows	**32**	**32**	**32**
Pyritic TSF Outflows				
26	Pond Evaporation	1	1	<1
29	Surplus Water from Pyritic TSF	0	0	0

Table K4.16-3: Average Annual Flow Balance, Closure Phase 1 – Year 10

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	**Average Conditions**	**Relatively Wet Conditions**
65	Pyritic Tailings Re-Slurry Water to Open Pit	36	36	36
	Subtotal Outflows	**36**	**37**	**36**
	Change in Storage	**-4**	**-4**	**-4**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk Tailings Management Facility (Bulk TSF)				
Bulk TSF Inflows				
30	Direct Precipitation on Supernatant Pond	1	2	3
31	Undisturbed Surface Runoff	5	8	10
32	Diversion Channel Leakage	<1	<1	<1
34	Bulk Tailings Beach Runoff - Reclamation in Progress	9	14	18
77	Bulk Tailings Consolidation Seepage	2	2	2
	Subtotal Inflows	**17**	**26**	**34**
Bulk TSF Outflows				
35	Pond Evaporation	<1	<1	<1
37+75	Seepage through Embankments	5	6	6
38	Surplus water from Bulk TSF to Main WMP	17	25	33
	Subtotal Outflows	**23**	**31**	**40**
	Change in Storage	**-5**	**-4**	**-6**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF Main Embankment Seepage Collection Pond (Bulk TSF Main SCP)				
Bulk TSF Main SCP Inflows				
39	Direct Precipitation	<1	1	1
40	Undisturbed Surface Runoff	2	4	5
41	Diversion Channel Leakage	<1	1	1
42	Bulk TSF Main Embankment Runoff	1	2	2
37	Seepage through Embankments	5	6	6
76	Surplus from South and East SCRP	2	3	3
	Subtotal Inflows	**10**	**17**	**17**
Bulk TSF Main SCP Outflows				
43	Pond Evaporation	<1	<1	<1
44	Surplus Water to Main WMP	9	13	14
	Subtotal Outflows	**9**	**13**	**14**
	Change in Storage	**1**	**4**	**4**

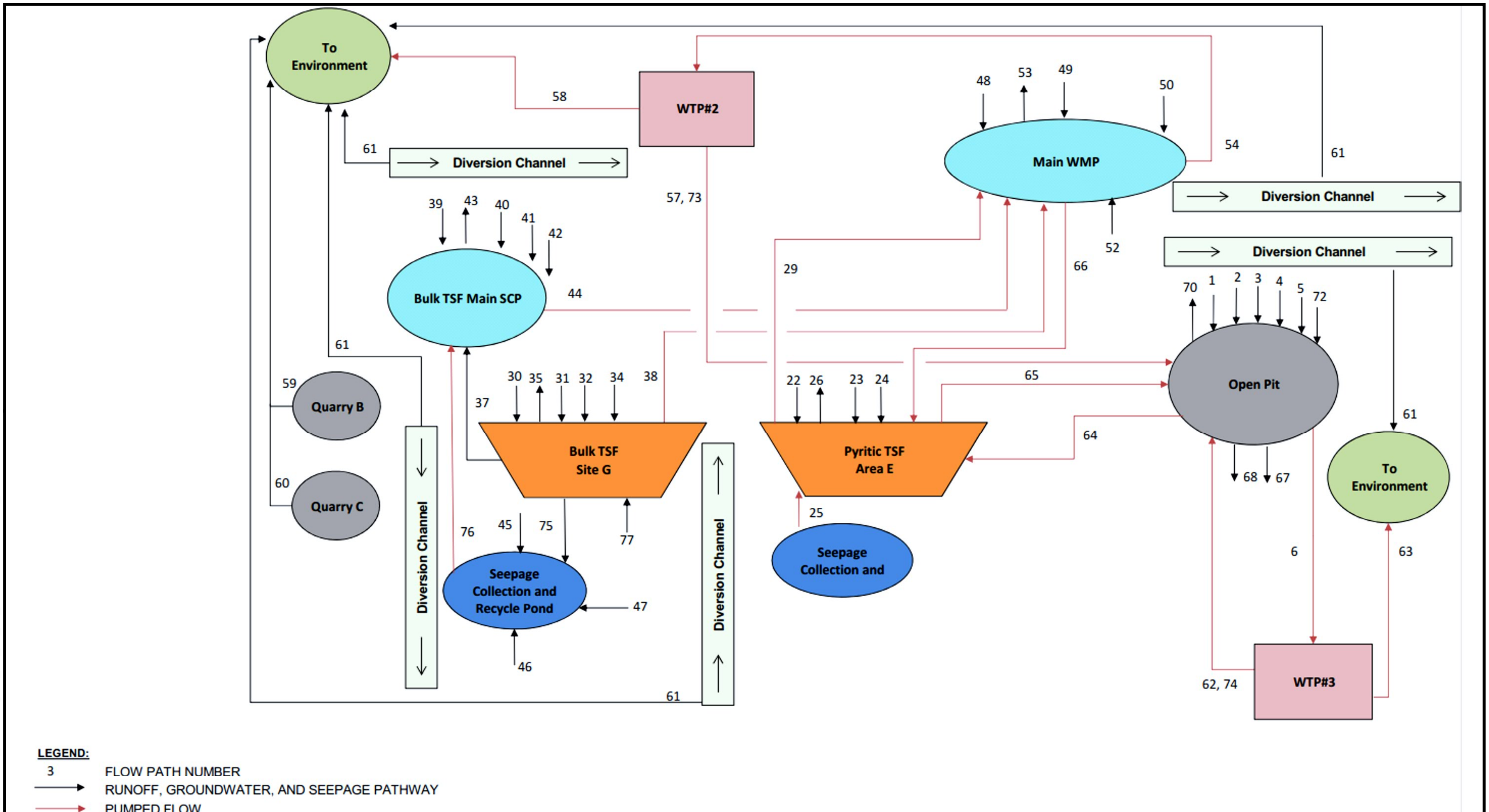
Table K4.16-3: Average Annual Flow Balance, Closure Phase 1 – Year 10

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	Average Conditions	Relatively Wet Conditions
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF South and East Seepage and Recycle Collection Pond				
Seepage Pond Inflows				
45	Undisturbed Surface Runoff	1	2	2
46	Diversion Channel Leakage	<1	0	1
47	Bulk TSF South Embankment Runoff	<1	<1	<1
75	Bulk TSF Seepage	<1	<1	<1
	Subtotal Inflows	**2**	**3**	**3**
Seepage Pond Outflows				
76	Surplus Water to Bulk TSF Main SCP	2	3	3
	Subtotal Outflows	**2**	**3**	**3**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Main Water Management Pond (Main WMP)				
Main WMP Inflows				
29	Surplus Water from Pyritic TSF	0	0	0
38	Surplus from Bulk TSF	17	25	33
44	Surplus Water from Bulk TSF Main SCP	9	13	14
48	Direct Precipitation	3	4	6
49	Undisturbed Surface Runoff	5	8	11
50	Diversion Channel Leakage	<1	<1	<1
52	Pyritic TSF Main Embankment Runoff	1	1	1
	Subtotal Inflows	**35**	**52**	**66**
Main WMP Outflows				
53	Pond Evaporation	1	1	1
54	Surplus Water to WTP#2	41	41	41
66	Make-up Water to Pyritic TSF	0	0	0
	Subtotal Outflows	**42**	**42**	**43**
	Change in Storage	**-7**	**10**	**23**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Water Treatment Plant #2 (WTP #2)				
WTP#2 Inflows				
54	Surplus from Main WMP	41	41	41

Table K4.16-3: Average Annual Flow Balance, Closure Phase 1 – Year 10

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	**Average Conditions**	**Relatively Wet Conditions**
	Subtotal Inflows	**41**	**41**	**41**
WTP#2 Outflows				
57+73	Reject Flows and Sludge Flows from WTP #2	1	1	1
58	Flows Released to Environment	40	40	40
	Subtotal Outflows	**41**	**41**	**41**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Water Treatment Plant #3 (WTP #3)				
WTP#3 Inflows				
6	Open Pit Dewatering	0	0	0
	Subtotal Inflow	**0**	**0**	**0**
WTP#3 Outflows				
62+74	Reject Flows and Sludge Flows from WTP #3	0	0	0
63	Flows Released to Environment	0	0	0
	Subtotal Outflows	**0**	**0**	**0**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Flows Released from WTPs to Downstream Environment				
58	Treated Flows from WTP#2	40	40	40
63	Treated Flows from WTP#3	0	0	0
	Total Flows Released to Downstream Environment	**40**	**40**	**40**

Notes:
Flow path number corresponds to flow schematic presented on Figure K4.16-2.
Change in storage within the ponds are a function of the water management operating criteria. A change in storage indicates if the pond has accumulated or decreased pond volume from the start of the year.
PAG = potentially acid generating
SCP = seepage collection pond
TSF = tailings storage facility
WMP = water management pond
WTP = water treatment plant
Source Knight Piésold 2018d, Table A.2



Sources: Knight Piesold 2018d, Figure A.1
Note: Flow path numbers correspond with flow values summarized in Table K4.16-3.

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WATER BALANCE FLOW SCHEMATIC, CLOSURE - PHASE 1

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FIGURE K4.16-2

Table K4.16-4: Average Annual Flow Balance, Closure Phase 2 – Year 20

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	Average Conditions	Relatively Wet Conditions
Open Pit				
Open Pit Inflows				
1	Direct Precipitation	3	3	4
2	Undisturbed Surface Runoff	2	2	3
4	Groundwater	4	4	4
5	Additional Snowblow	1	1	1
38	Surplus from Bulk TSF	17	17	17
44	Surplus from Bulk TSF Main SCP	9	12	16
62+74	Reject Flows and Sludge Flows from WTP #3	0	0	0
72	Pit Wall Runoff from Open Pit	1	1	1
	Subtotal Inflows	**36**	**41**	**47**
Open Pit Outflows				
6	Open Pit Dewatering	0	0	0
70	Pond Evaporation	1	1	1
	Subtotal Outflows	**1**	**1**	**1**
	Change in Storage	**35**	**40**	**46**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk Tailings Management Facility (Bulk TSF)				
Bulk TSF Inflows				
30	Direct Precipitation on Supernatant Pond	1	1	3
31	Undisturbed Surface Runoff	5	6	10
69	Bulk Tailings Reclaimed Beach Runoff	9	12	19
77	Bulk Tailings Consolidation Seepage	1	1	1
	Subtotal Inflows	**16**	**21**	**33**
Bulk TSF Outflows				
35	Pond Evaporation	<1	<1	<1
37	Seepage through Embankments	4	4	4
38	Surplus to Open Pit	17	17	17
	Subtotal Outflows	**20**	**21**	**21**
	Change in Storage	**-4**	**0**	**12**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF Main Embankment Seepage Collection Pond (Bulk TSF Main SCP)				
Seepage Pond Inflows				

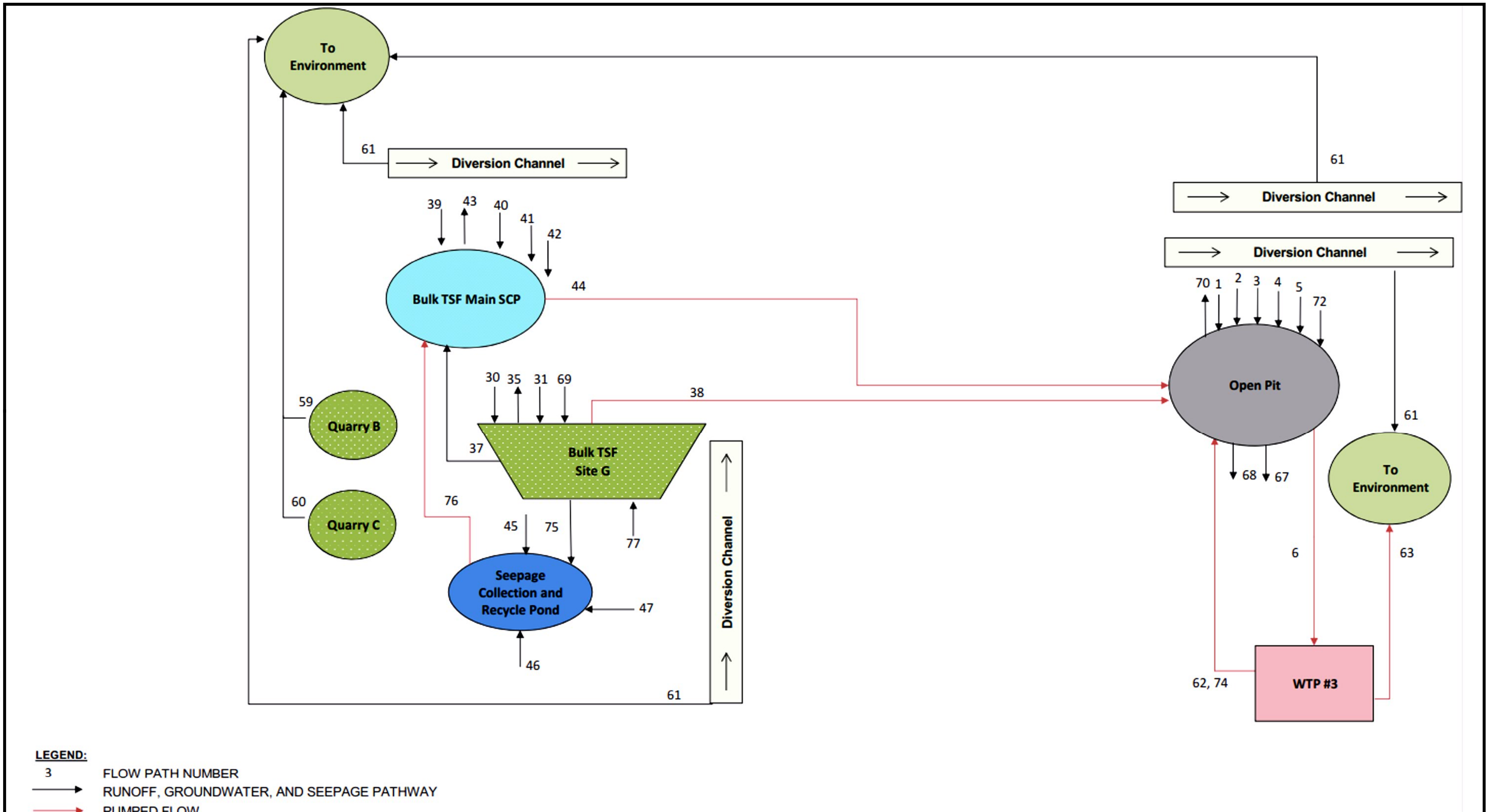
Table K4.16-4: Average Annual Flow Balance, Closure Phase 2 – Year 20

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	**Average Conditions**	**Relatively Wet Conditions**
39	Direct Precipitation	<1	1	1
40	Undisturbed Surface Runoff	2	3	5
41	Diversion Channel Leakage	<1	1	1
42	Bulk TSF Main Embankment Runoff	1	1	2
37	Seepage through Embankments	4	4	4
76	Recycle from Seepage Collection Ponds to Bulk TSF Main SCP	2	2	3
	Subtotal Inflows	**9**	**12**	**16**
Seepage Pond Outflows				
43	Pond Evaporation	<1	<1	<1
44	Surplus Water to Open Pit	9	12	16
	Subtotal Outflows	**9**	**12**	**16**
	Change in Storage	**0**	**0**	**0**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF South and East Seepage and Recycle Collection Pond				
Seepage Pond Inflows				
45	Undisturbed Surface Runoff	1	2	2
46	Diversion Channel Leakage	<1	<1	1
47	Bulk TSF South Embankment Runoff	<1	<1	<1
75	Bulk TSF Seepage	<1	<1	<1
	Subtotal Inflows	**2**	**2**	**3**
Seepage Pond Outflows				
76	Surplus Water to Bulk TSF Main SCP	2	2	3
	Subtotal Outflows	**2**	**2**	**3**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Water Treatment Plant #3 (WTP #3)				
WTP#3 Inflows				
6	Open Pit Dewatering	0	0	0
	Subtotal Inflows	**0**	**0**	**0**
WTP#3 Outflows				
62+74	Reject Flows and Sludge Flows from WTP #3	0	0	0
63	Flows Released to Environment	0	0	0
	Subtotal Outflows	**0**	**0**	**0**

Table K4.16-4: Average Annual Flow Balance, Closure Phase 2 – Year 20

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	Average Conditions	Relatively Wet Conditions
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Flows Released to Downstream Environment				
63	Treated Flows from WTP#3	0	0	0
	Total Flows Released to Downstream Environment	**0**	**0**	**0**

Notes:
Flow path number corresponds to flow schematic presented on Figure 4.16-3.
Change in storage within the ponds are a function of the water management operating criteria. A change in storage indicates if the pond has accumulated or decreased pond volume from the start of the year.
PAG = potentially acid generating
SCP = seepage collection pond
TSF = tailings storage facility
WTP = water treatment plant
Source: Knight Piésold 2081d, Table A.3



Sources: Knight Piesold 2018d, Figure A.2
Note: Flow path numbers correspond with flow values summarized in Table K4.16-4.

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WATER BALANCE FLOW SCHEMATIC, CLOSURE - PHASE 2

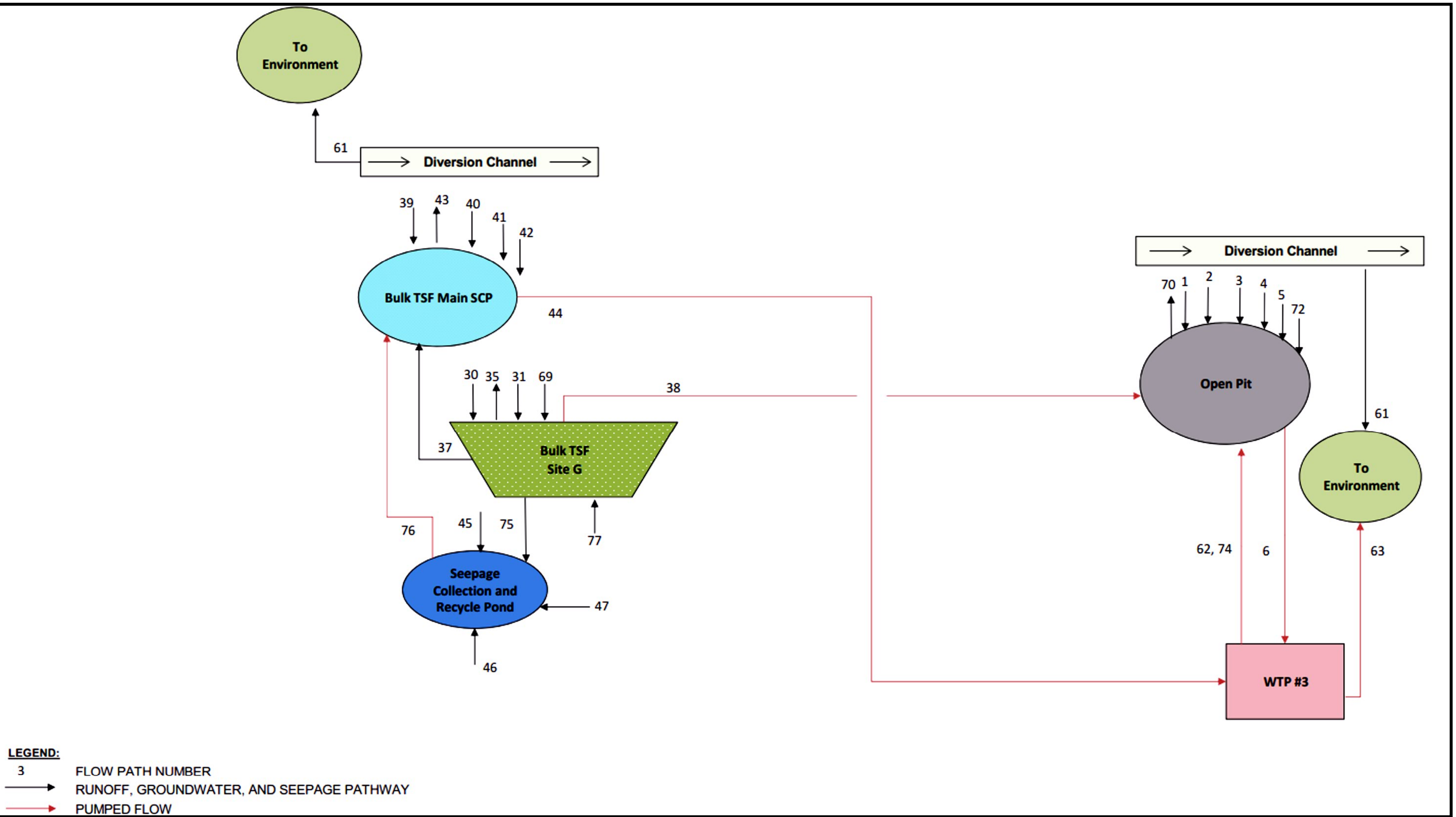
Table K4.16-5: Average Annual Flow Balance, Closure Phase 3 – Year 40

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	**Average Conditions**	**Relatively Wet Conditions**
Open Pit				
Open Pit Inflows				
1	Direct Precipitation	2	3	4
2	Undisturbed Surface Runoff	1	3	3
4	Groundwater	4	4	4
5	Additional Snowblow	1	1	1
38	Surplus Water from Bulk TSF	0	25	42
62+74	Reject Flows and Sludge Flows from WTP #3	1	1	1
72	Pit Wall Runoff from Open Pit	<1	1	1
	Subtotal Inflows	**10**	**37**	**56**
Open Pit Outflows				
6	Surplus to WTP#3	19	29	30
70	Pond Evaporation	1	1	1
	Subtotal Outflows	**20**	**29**	**31**
	Change in Storage	**-9**	**8**	**26**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk Tailings Management Facility (Bulk TSF)				
Bulk TSF Inflows				
30	Direct Precipitation on Supernatant Pond	1	1	2
31	Undisturbed Surface Runoff	4	7	10
69	Reclaimed Bulk Tailings Beach Runoff	9	15	19
77	Bulk Tailings Consolidation Seepage	<1	<1	<1
	Subtotal Inflows	**13**	**24**	**31**
Bulk TSF Outflows				
35	Pond Evaporation	<1	<1	<1
37+75	Seepage through the Embankments	2	2	2
38	Surplus to Open Pit	0	25	42
	Subtotal Outflows	**2**	**27**	**44**
	Change in Storage	**12**	**−3**	**−13**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF Main Embankment Seepage Collection Pond (Bulk TSF Main SCP)				
Seepage Pond Inflows				
39	Direct Precipitation	<1	1	1
40	Undisturbed Surface Runoff	2	4	5
41	Diversion Channel Leakage	<1	1	1
42	Bulk TSF Main Embankment Runoff	1	2	2
37	Seepage through the Embankments	2	2	2
76	Recycle from Seepage Collection Ponds to Bulk TSF Main	1	2	3

Table K4.16-5: Average Annual Flow Balance, Closure Phase 3 – Year 40

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	Average Conditions	Relatively Wet Conditions
	SCP			
	Subtotal Inflows	**6**	**10**	**13**
Seepage Pond Outflows				
43	Pond Evaporation	<1	<1	<1
44	Surplus Water to WTP#3	<1	<1	<1
	Subtotal Outflows	**0**	**0**	**0**
	Change in Storage	**6**	**10**	**13**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF South and East Seepage and Recycle Collection Pond				
Seepage Pond Inflows				
45	Undisturbed Surface Runoff	1	2	2
46	Diversion Channel Leakage	<1	<1	1
47	Bulk TSF South Embankment Runoff	<1	<1	<1
75	Bulk TSF Seepage	<1	<1	<1
	Subtotal Inflows	**1**	**2**	**3**
Seepage Pond Outflows				
76	Surplus Water to Bulk TSF Main SCP	1	2	3
	Subtotal Outflows	**1**	**2**	**3**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Water Treatment Plant #3 (WTP #3)				
WTP#3 Inflows				
6	Open Pit Dewatering	19	29	30
44	Surplus from Bulk TSF Main SCP	<1	<1	<1
	Subtotal Inflows	**19**	**29**	**30**
WTP#3 Outflows				
62+74	Reject Flows and Sludge Flows from WTP #3	1	1	1
63	Flows Released to Environment	18	28	29
	Subtotal Outflows	**19**	**29**	**30**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Flows Released to Downstream Environment				
63	Treated Flows from WTP#3	18	28	29
	Total Flows Released to Downstream Environment	**18**	**28**	**29**

Notes:
Flow path number corresponds to flow schematic presented on K4.16-4.
Change in storage within the ponds are a function of the water management operating criteria. A change in storage indicates if the pond has accumulated or decreased pond volume from the start of the year.
SCP = seepage collection pond
TSF = tailings storage facility
WTP = water treatment plant
Source: Knight Piésold 2081d, Table A.4



Sources: Knight Piesold 2018d, Figure A.3

Note: Flow path numbers correspond with flow values summarized in Table K4.16-5.

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WATER BALANCE FLOW SCHEMATIC, CLOSURE - PHASE 3

Table K4.16-6: Average Annual Flow Balance, Closure Phase 4 – Year 50

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	Average Conditions	Relatively Wet Conditions
Open Pit				
Open Pit Inflows				
1	Direct Precipitation	2	3	5
2	Undisturbed Surface Runoff	1	2	3
4	Groundwater	4	4	4
5	Additional Snowblow	1	1	1
62+74	Reject Flows and Sludge Flows from WTP #3	<1	<1	<1
72	Pit Wall Runoff from Open Pit	<1	1	1
	Subtotal Inflows	**7**	**10**	**14**
Open Pit Outflows				
6	Open Pit Dewatering	2	6	6
70	Pond Evaporation	1	1	1
	Subtotal Outflows	**3**	**6**	**7**
	Change in Storage	**4**	**4**	**7**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk Tailings Management Facility (Bulk TSF)				
Bulk TSF Inflows				
30	Direct Precipitation on Supernatant Pond	<1	1	2
31	Undisturbed Surface Runoff	3	7	12
69	Reclaimed Bulk Tailings Beach Runoff	5	13	19
77	Bulk Tailings Consolidation Seepage	0	0	0
	Subtotal Inflows	**7**	**21**	**33**
Bulk TSF Outflows				
35	Pond Evaporation	<1	<1	<1
37	Seepage through Main Embankment	1	1	1
38	Surplus to Environment	7	20	32
75	Seepage through South and East Embankments	<1	<1	<1
	Subtotal Outflows	**7**	**21**	**33**
	Change in Storage	**0**	**0**	**0**
	Balance (Inflows −Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF Main Embankment Seepage Collection Pond (Bulk TSF Main SCP)				
Seepage Pond Inflows				

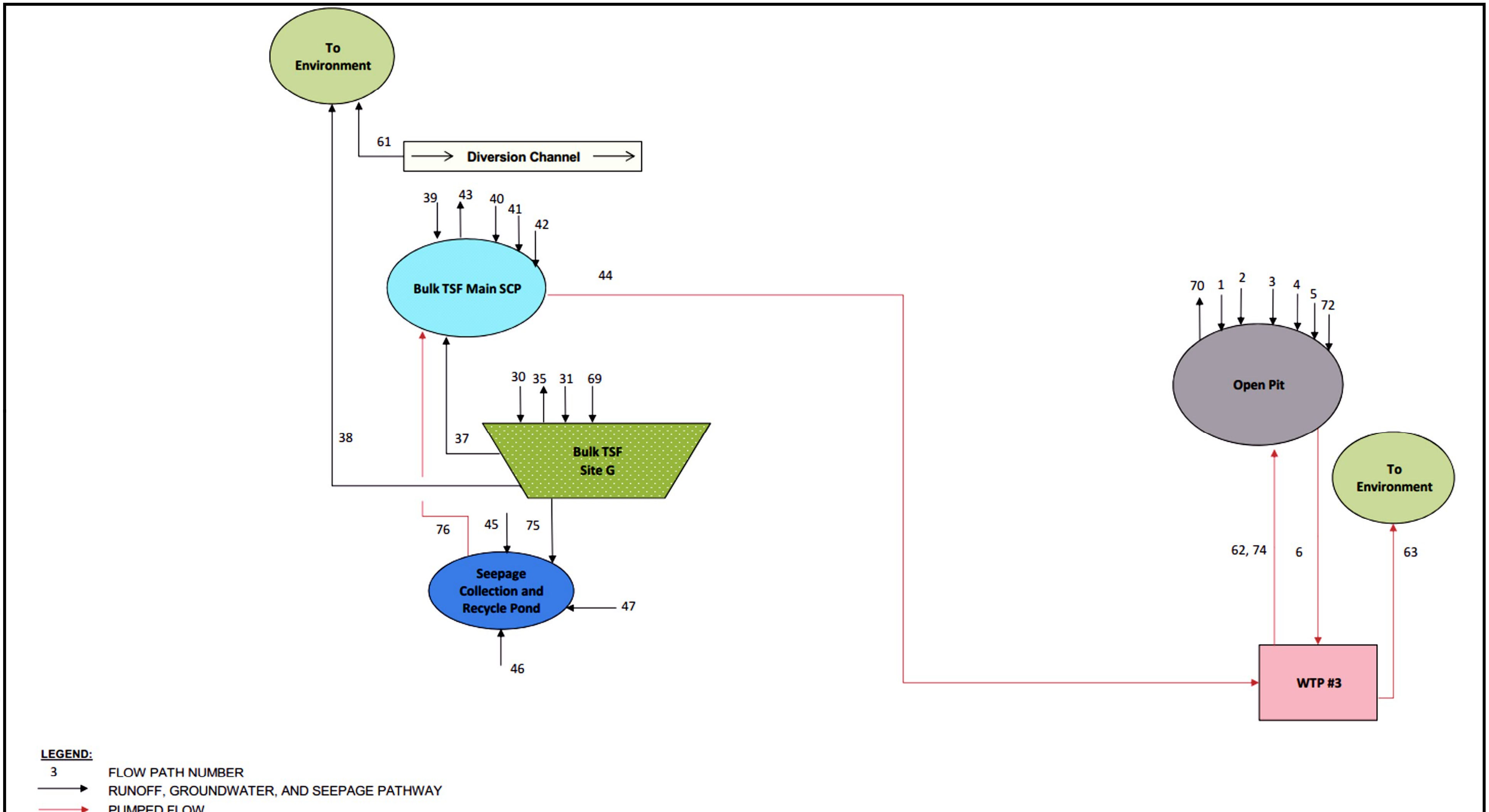
Table K4.16-6: Average Annual Flow Balance, Closure Phase 4 – Year 50

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	**Average Conditions**	**Relatively Wet Conditions**
39	Direct Precipitation	<1	1	1
40	Undisturbed Surface Runoff	1	3	5
41	Diversion Channel Leakage	<1	1	1
42	Bulk TSF Main Embankment Runoff	1	1	2
37	Seepage through Main Embankment	1	1	1
76	Recycle from Seepage Collection Ponds to Bulk TSF Main SCP	1	1	3
	Subtotal Inflows	**4**	**9**	**13**
Seepage Pond Outflows				
43	Pond Evaporation	<1	<1	<1
44	Surplus Water to WTP#3	3	5	8
	Subtotal Outflows	**3**	**5**	**9**
	Change in Storage	**1**	**4**	**4**
	Balance (Inflows−Outflows−Change in Storage)	**0**	**0**	**0**
Bulk TSF South and East Seepage and Recycle Collection Pond				
Seepage Pond Inflows				
45	Undisturbed Surface Runoff	1	1	2
46	Diversion Channel Leakage	<1	<1	1
47	Bulk TSF South Embankment Runoff	<1	<1	<1
75	Bulk TSF Seepage	<1	<1	<1
	Subtotal Inflows	**1**	**1**	**3**
Seepage Pond Outflows				
76	Surplus Water to Bulk TSF Main SCP	1	1	3
	Subtotal Outflows	**1**	**1**	**3**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Water Treatment Plant #3 (WTP #3)				
WTP#3 Inflows				
6	Open Pit Dewatering	2	6	6
44	Surplus Water from Bulk TSF Main SCP	3	5	8
	Subtotal Inflows	**5**	**10**	**14**
WTP#3 Outflows				
62+74	Reject Flows and Sludge Flows from WTP #3	<1	<1	<1
63	Flows Released to Environment	5	10	14
	Subtotal Outflows	**5**	**10**	**14**

Table K4.16-6: Average Annual Flow Balance, Closure Phase 4 – Year 50

Flow Path Number and Description		Average Annual Flow (cfs)		
		Relatively Dry Conditions	**Average Conditions**	**Relatively Wet Conditions**
	Balance (Inflows−Outflows)	**0**	**0**	**0**
Flows Released to Downstream Environment				
63	Treated Flows from WTP#3	5	10	14
	Total Flows Released to Downstream Environment	**5**	**10**	**14**

Notes:
Flow path number corresponds to flow schematic presented on Figure 4.16-5.
Change in storage within the ponds are a function of the water management operating criteria. A change in storage indicates if the pond has accumulated or decreased pond volume from the start of the year.
SCP = seepage collection pond
TSF = tailings storage facility
WTP = water treatment plant
Source: Knight Piésold 2018d, Table A.5



Sources: Knight Piesold 2018d, Figure A.4
Note: Flow path numbers correspond with flow values summarized in Table K4.16-6.

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WATER BALANCE FLOW SCHEMATIC, CLOSURE - PHASE 4

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FIGURE K4.16-5

K4.17 GROUNDWATER HYDROLOGY

Information on the development and calibration of the groundwater model at the mine site is provided in Section 3.17, Groundwater Hydrology and Appendix K3.17. Use of the model to predict impacts to groundwater from mine site activities is described in Section 4.17, Groundwater Hydrology. This appendix contains additional technical information regarding the following impact analyses using the groundwater model:

- Input parameters and scenarios used in the model.
- Open pit groundwater capture zones.
- Uncertainty analysis.
- Groundwater flow and seepage beneath the tailings storage facilities (TSFs) and main water management pond (WMP).

K4.17.1 Model Development, Calibration, Input Scenarios, and Uncertainty

The groundwater model has been developed over a number of years and the most recent version, containing 10 layers, is known as the 2018 version (Piteau Associates 2018a). The most thorough model calibration report was prepared for an earlier version of the model that has five layers (Schlumberger 2011a). Miscellaneous information about the 2018 model detailing layers, boundary conditions, input parameters, and calibration results are available (PLP 2018-RFI 019c; Knight Piésold 2018n; PLP 2019-RFI 109, 109a, 109b, and 109c); however, the model is “still in the process of being updated and is not fully calibrated” (PLP 2019-RFI 109).

The groundwater model analysis considered a range of scenarios that evaluated variability in hydrogeologic properties, model boundary conditions, and recharge rate. Groundwater impacts were modeled in the pit area using 96 scenarios to estimate a range of uncertainties in the capture zone and groundwater discharge reduction (Piteau Associates 2018a). These were developed using a Null Space Monte Carlo technique (Doherty 2015), which is useful in quantifying the amount of uncertainty in phenomena with a wide range of values for input parameters, such as hydraulic conductivity, and has been used in similar mine pit dewatering applications worldwide (e.g., Gabora et al. 2014). Model parameters representing hydraulic conductivity, storage (specific storage, specific yield), river conductance, and boundary conditions were varied over a range, but constrained by selected calibration targets at piezometers in the upper South Fork Koktuli (SFK) and Upper Talarik Creek (UTC) drainages. The parameter sets determined from the Null Space Monte Carlo analysis (i.e., scenarios or realizations) were then used for steady state simulations of capture zones. A transient model was used for model calibration and UTC flow reduction estimates using storage values.

Knight Piésold (2018n: Figures 10 and 11, and Table 1) provides the range of hydraulic conductivity and storage values between the 5^{th} and 95^{th} percentile realizations for model layers and zones used in the pit capture zone analysis (shown on Knight Piésold 2018n: Figures 1 through to 7). While the ratio of the 25^{th} and 75^{th} percentile parameter values in this approach typically ranged from a factor of 10 to 100 (Piteau Associates 2018a), several parameters for individual zones and layers suggest there may be more uncertainty than what the results of the simulations show:

- The value of hydraulic conductivity used for the weathered and fractured bedrock layer (layer 4 in the model) and overburden (layer 3) in the pit area were not varied significantly (Knight Piésold 2018n).
- The value of hydraulic conductivity used for layer 4 in the pit area is lower than mean values of hydraulic conductivity determined from response and pump tests in

bedrock by about an order of magnitude (Schlumberger 2015a: Tables 8.1-1 through 8.1-6, and Appendix K3.17, Figure K3.17-14).

- Hydraulic conductivity values measured in the weathered bedrock zone vary in the general vicinity by about five orders of magnitude (Appendix K3.17, Groundwater Hydrology, Table K3.17-2), and the weathered and fractured bedrock zone is known to be a pervasive aquifer in the area (e.g., see Section 3.17, Groundwater Hydrology, Figure 3.17-3), both of which suggest that the Monte Carlo simulations are not robust indicators of potential model variability.
- Hydraulic conductivity values assigned to deeper bedrock (Knight Piésold 2018n; layers 5-10) appear to be an order of magnitude or more lower than field-measured values (Section 3.17, Groundwater Hydrology, Figure 3.17-7 through Figure 3.17-9, and Appendix K3.17, Figure K3.17-14). Pebble Limited Partnership (PLP) (2019-RFI 109c) noted that the low hydraulic conductivity values used in the model were needed to achieve an adequate calibration, and that field and literature evidence suggests that bulk bedrock values may be lower than indicated by field tests.

If bedrock hydraulic conductivity values are higher than those used in the model scenarios, the general effect would be an increase in the amount of groundwater produced by the dewatering system at the pit or pit lake, and a general widening of the cone of depression. Completion of a model calibration report demonstrating adequate calibration of the model and including a more robust sensitivity analysis would enhance the reliability of the model findings. Additional calibration, validation, and sensitivity analyses are the subject of ongoing evaluations by PLP (2019-RFI 109, 109b, 109c).

Modeling of groundwater conditions in the TSF and WMP areas used baseline values for aquifers and confining units in these areas (described in Appendix K3.17, Groundwater Hydrology) as inputs. Appendix K3.17, Table K3.17-1 and Table K3.17-2 summarize the units and hydraulic conductivities in the North Fork Koktuli (NFK) drainage, which would contain the TSFs and main WMP.

Recharge rates assigned to the groundwater model were the average rates generated by the watershed module (Schlumberger 2011a), which take climate variability into consideration by incorporating long-term precipitation data for the study area (Knight Piésold 2018a). To further evaluate the effect of increased precipitation from climate variability on groundwater conditions, the model was also run using twice the base case recharge rate.

K4.17.2 Pit Capture Zones

K4.17.2.1 Operations

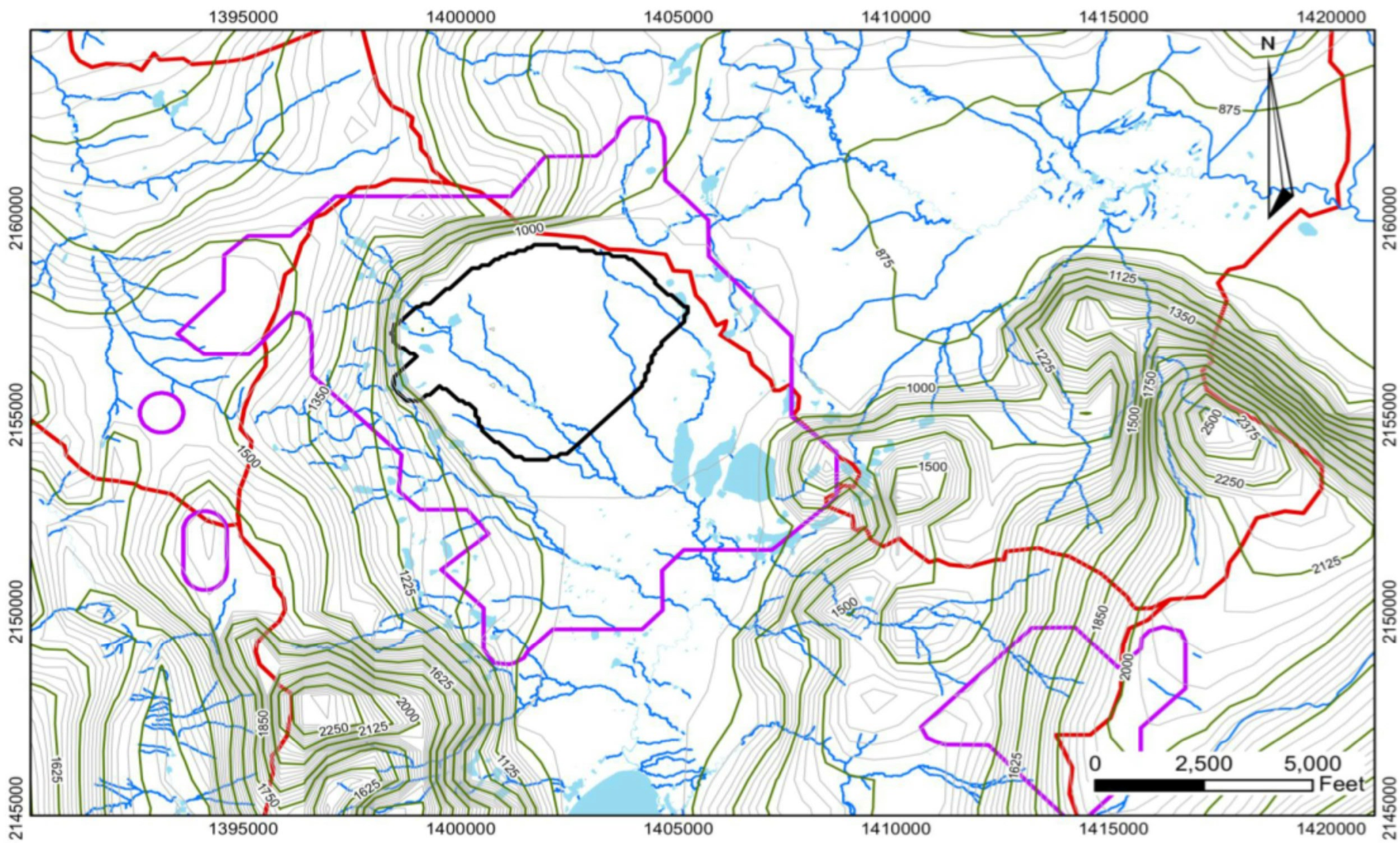
The range of modeled capture zone results at the pit at the end of operations are shown on Figure 4.17-2 for the 5th, 50th, and 90th percentile model realizations. The model simulated a steady state capture zone encompassing the immediate area around the pit, as well as along parts of upland ridges to the east and west of the pit (indicated by watershed boundary lines on Section 4.17, Groundwater Hydrology, Figure 4.17-2).

The capture zone in the immediate area around the pit represents relatively shallow flowpaths, and the outlying areas represent deeper flowpaths with very low groundwater velocities. Travel time from the outlying areas to the pit associated with the 95th percentile capture zone averages about 80 years, and would likely be longer because the model assumes that the pit is instantaneously full-size at the start of operations. Thus, recharge from the outlying areas would be expected to reach the pit in post-closure. Groundwater between the immediate pit capture zone and the outlying ridge areas is predicted to discharge to local streams or seeps as they do currently, and not be affected by the capture zone (Piteau Associates 2018a; Knight Piésold 2018n).

The size and extent of the 5th to 95th percentile capture zones at the end of operations are very similar to one another. Similarly, the model predicts that the rates of groundwater inflow to the pit would be within a relatively narrow range of 2,200 to 2,400 gallons per minute for the 5th to 95th percentile scenarios, respectively (Piteau Associates 2018a). These similar model outcomes may reflect a lack of robustness in the Monte Carlo analysis.

Most of the capture zone extents for each scenario are located in the SFK watershed, with small zones extending under the pyritic TSF and into upper tributaries of the UTC watershed (Section 4.17, Groundwater Hydrology, Figure 4.17-2). Figure K4.17-1a and Figure K4.17-1b show the simulated water level contours for shallow (layer 1) and deep (layer 8) zones, respectively, for the end of operations scenario. Figure K4.17-1c shows simulated drawdown contours at the end of operations.

The reduction in groundwater discharge to the headwaters of UTC was analyzed by the model scenarios for late winter months January-March using a transient model simulation at dynamic equilibrium (Piteau Associates 2018a). Without the addition of water treatment plant (WTP) outflows, groundwater discharge to the upper UTC drainage is predicted to decline 14 to 19 percent at the end of operations for the 5th to 95th percentile model scenarios, respectively (Figure K4.17-2). However, this reduction is expected to be mitigated by releases from the east WTP discharge location, such that groundwater flow would not change relative to natural conditions and surface flows would increase slightly (Knight Piésold 2018n).



Sources: PLP (2019-RFI 109a)

Legend

Groundwater Elevation (ft AMSL)

Watershed Boundary

50th percentile Capture Zone

Pit Outline

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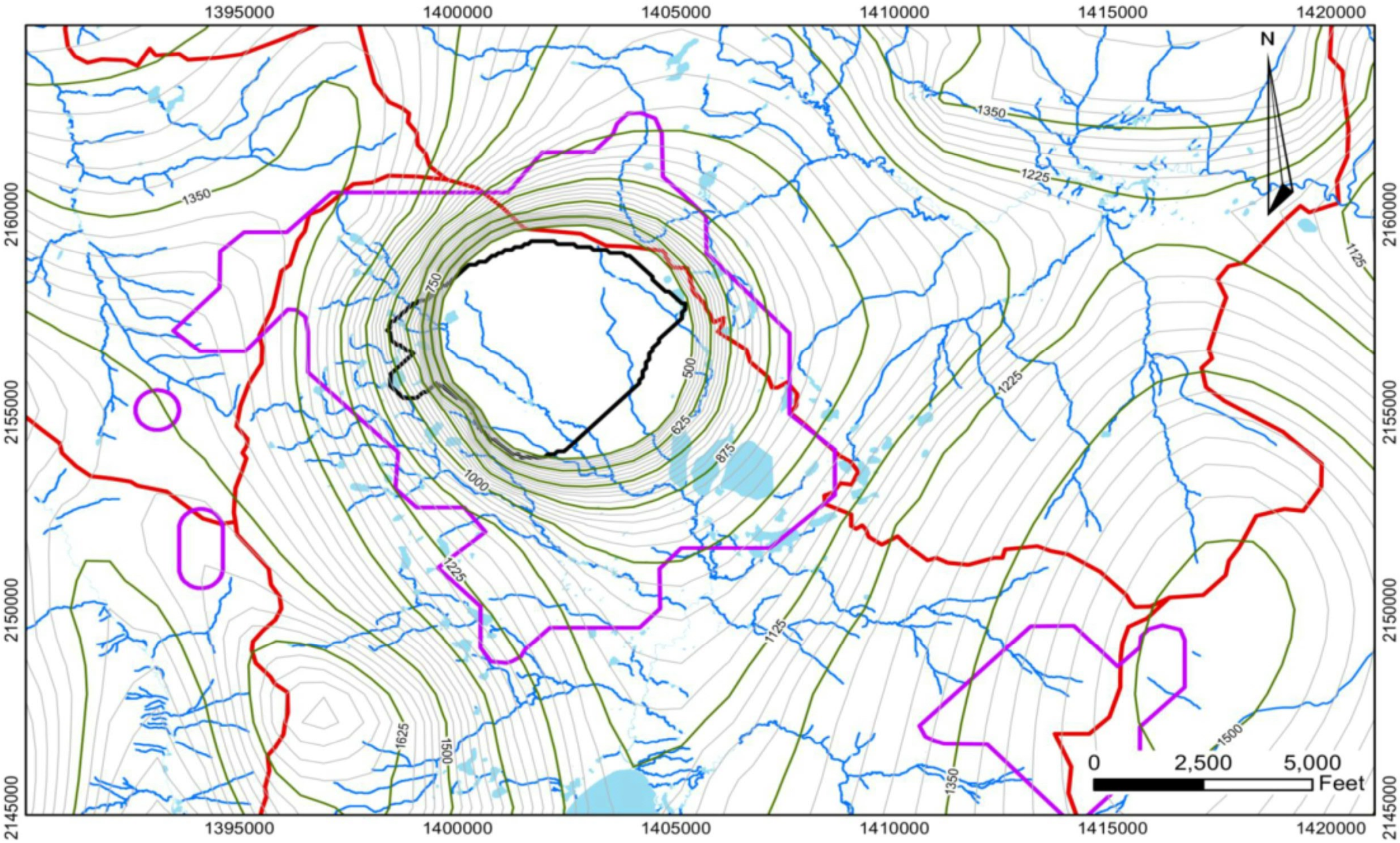
SIMULATED SHALLOW GROUNDWATER ELEVATION AT END OF OPERATIONS FOR 50TH PERCENTILE CAPTURE ZONE (MODEL LAYER 1)



Sources: PLP (2019-RFI 109a)

Legend

Groundwater Elevation (ft AMSL)

Watershed Boundary

50th percentile Capture Zone

Pit Outline

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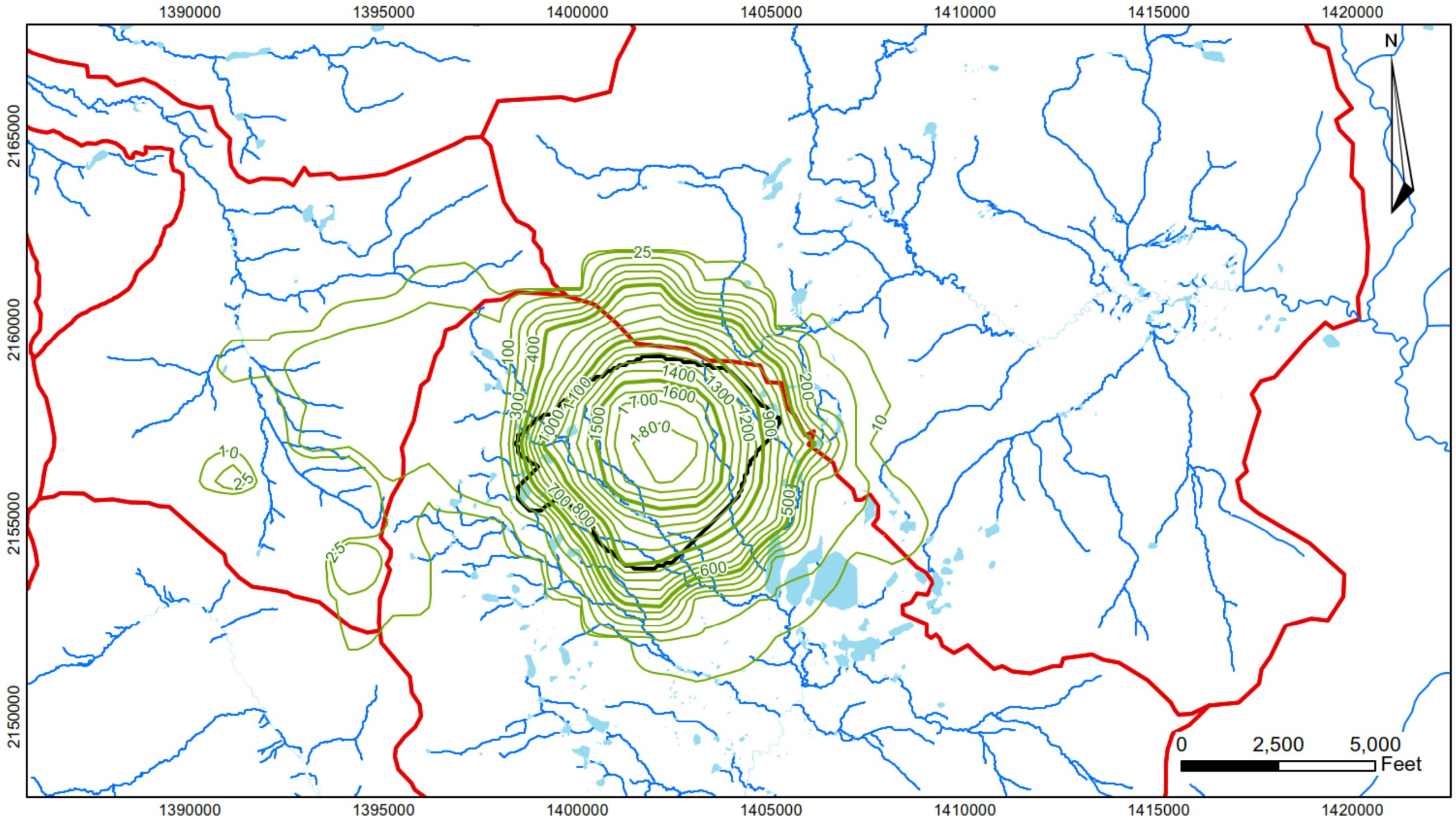
SIMULATED DEEP GROUNDWATER ELEVATION AT END OF OPERATIONS FOR 50TH PERCENTILE CAPTURE ZONE (MODEL LAYER 8)

FIGURE K4.17-1B



Sources: PLP (2019-RFI 109b)

Legend

Drawdown Contour (ft)

500 ft Drawdown Contour

Pit Outline

Watershed Boundary

Note: Drawdown contours at 10 ft and 25 ft.
Subsequent contours every 100 ft beginning at 100 ft.

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SIMULATED DRAWDOWN CONTOURS AT END OF OPERATIONS FOR THE PIT AREA MODEL

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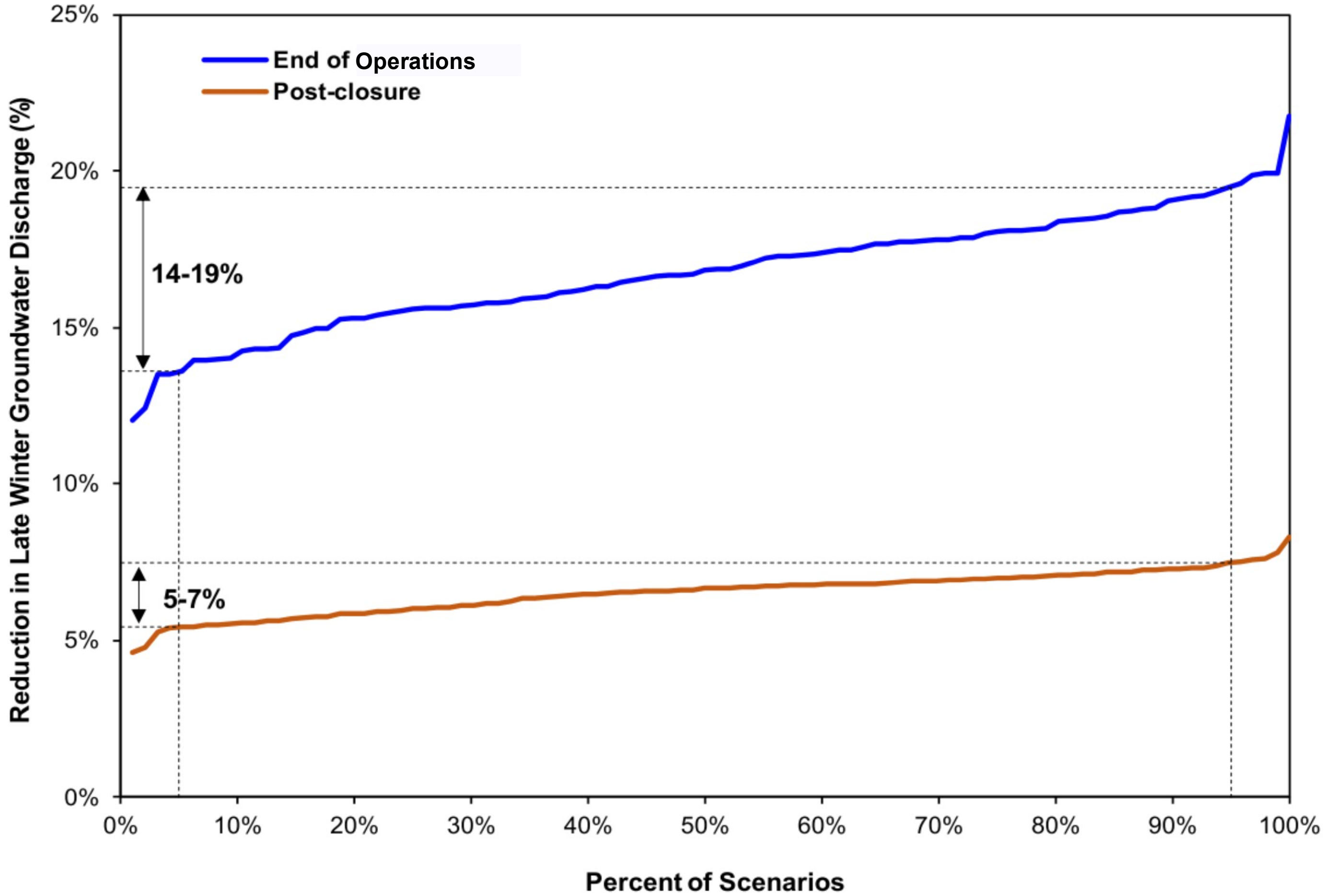
FIGURE K4.17-1C



Sources: Piteau Associates 2018a, Fig 6.

Note: 1. Data for headwaters of UTC above Station UT100D.

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ESTIMATED RANGE OF REDUCTION IN GROUNDWATER DISCHARGE TO UTC HEADWATERS AT END OF OPERATIONS AND POST-CLOSURE

K4.17.2.2 Closure

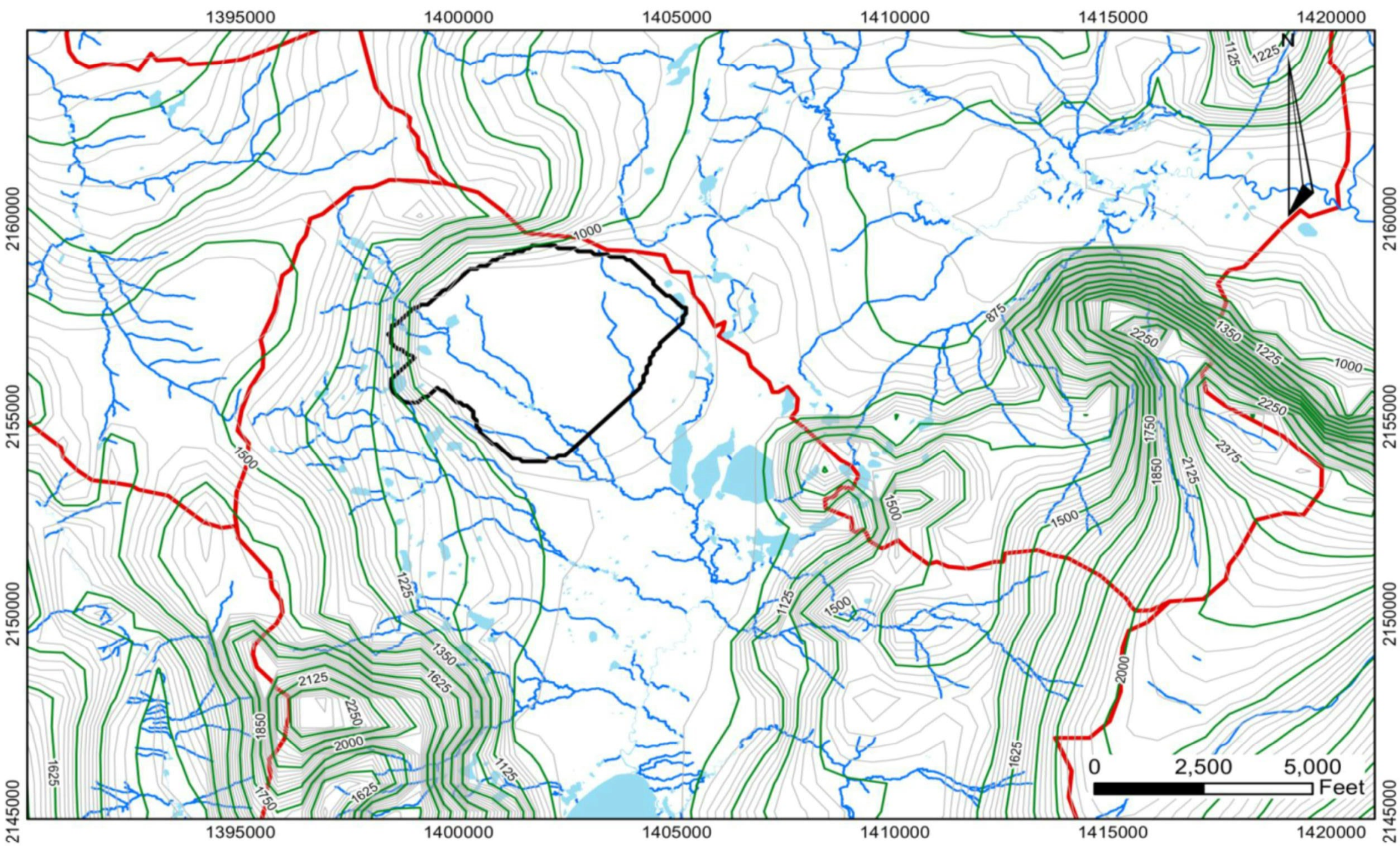
The predicted rate of lake level rise in the pit lake at closure in relation to pit backfill is shown on Figure K4.18-1. Section 4.17, Groundwater Hydrology, Figure 4.17-3 shows the range of capture zone results for the 5th, 50th, and 90th percentile model realizations at the pit in the post-closure period after the lake elevation has reached its maximum managed (MM) level. The model was used to select the MM level based on the elevation below which the model predicts all flow directions are toward the pit. Groundwater levels would be monitored during closure and post-closure to determine whether the MM elevation needs to be adjusted to prevent groundwater outflow from the pit (Knight Piésold 2018n). The groundwater inflow rate to the pit would gradually decrease in the first 20 years of closure as the pit lake rises. The long-term steady-state average annual groundwater inflow to the pit in post-closure is estimated to be about 1,300 gallons per minute (about 3 cubic feet per second [cfs]) (Piteau Associates 2018a).

Similar to operations, the post-closure model results show a capture zone in an immediate area around the pit representing relatively shallow flowpaths; several outlying zones along upland ridges east and west of the pit representing deeper flowpaths; and intermediate areas where groundwater recharge is expected to discharge to local streams and seeps and not be affected by the capture zone. The amount of water from the outlying areas is expected to be minimal compared to that coming from the shallow groundwater zones close to the pit (Piteau Associates 2018a). Like the operations case, the size and extent of the 5th to 95th percentile scenarios are very similar to one another, and cover similar areas in the SFK and uppermost UTC drainages.

Figure K4.17-3a and Figure K4.17-3b show the simulated water level contours for shallow (layer 1) and deep (layer 8) zones, respectively, for the post-closure scenario. Figure K4.17-3c shows simulated drawdown contours for the post-closure scenario.

The reduction in late winter discharge to the headwaters of the UTC watershed in post-closure is estimated to range from 5 to 7 percent based on the 5th to 95th percentile scenarios, respectively (Figure K4.17-2) (Piteau Associates 2018a), which would be mitigated by closure WTP outflows estimated to average a total 13 cfs from both the east and south WTP discharge points (Knight Piésold 2018d: Figure 3.5, Table 5.1).

In order to test the modeled pit capture zone against field data, a comparison of the projected hydraulic head at the bottom of the pit lake (which would be equal to the elevation of the lake surface, assuming static, fresh, and isothermal water in the lake) and hydraulic head data collected at deep monitoring well WB-1 located near the edge of the pit was performed. The land surface elevation at the well site is approximately 935 feet above mean sea level (amsl). Water levels measured at multiple depths up to 4,000 feet deep between 2006 and 2012 were almost all less than 25 feet below land surface (Schlumberger 2015a: Appendix 8.1K), meaning that the hydraulic head (at most ports, see below) was at an elevation of more than 910 feet amsl, compared to the proposed not-to-exceed lake elevation (head) of 900 feet. This means that the deeper groundwater levels had a higher head than the lake would have, and that deep groundwater below the pit bottom would flow upwards toward the bottom of the lake. The exception to these measurements is that three water-level measuring ports between depths of 3,800 and 4,000 feet exhibited heads between 25 and 35.7 feet below land surface between 2009 and 2012. These deeper values do not change the conclusion that the proposed not-to-exceed lake elevation of 900 feet above mean sea level (amsl) would achieve hydraulic containment of the pit lake capture zone and groundwater would flow towards the lake.



Sources: PLP (2019-RFI 109a)

Legend

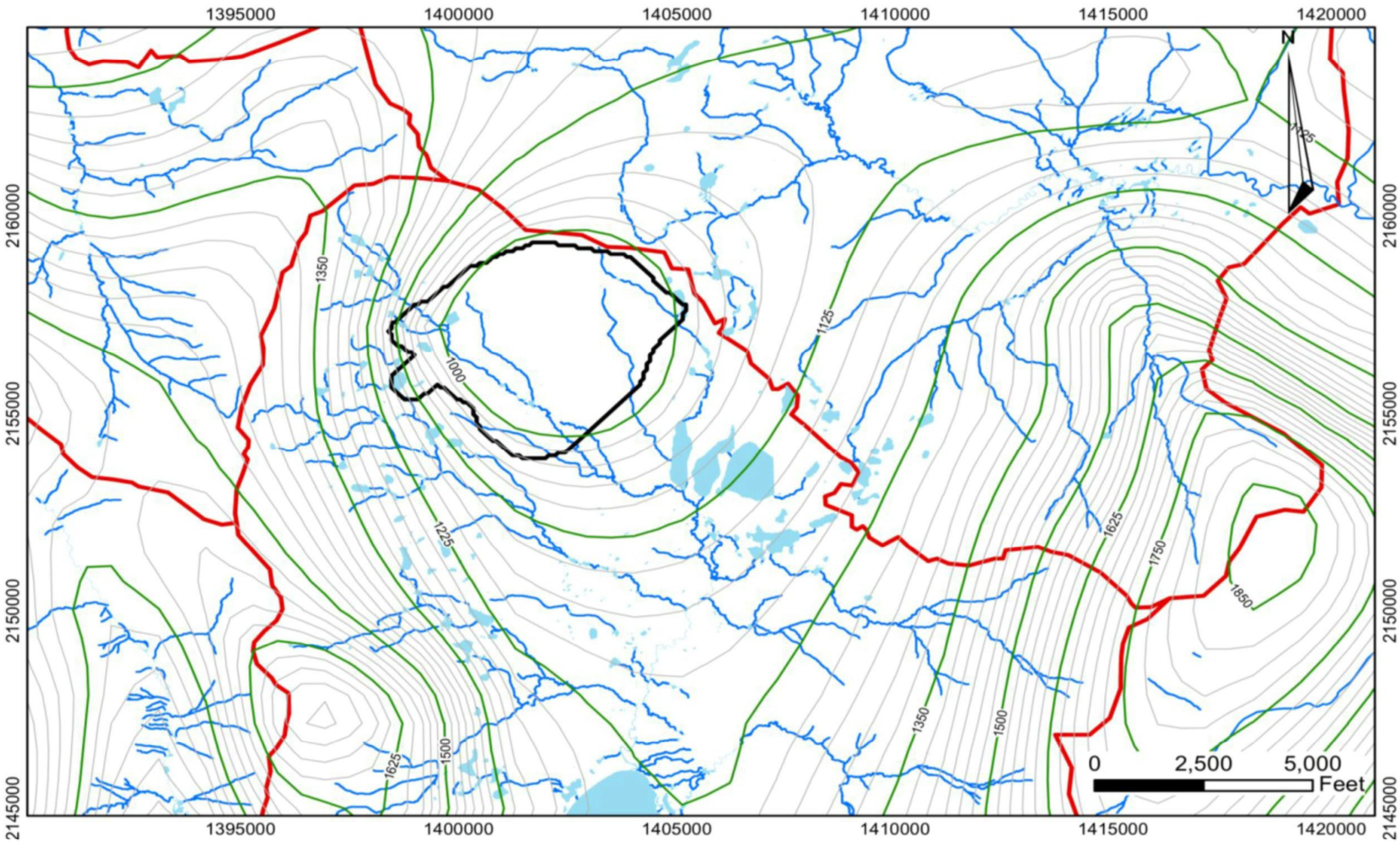
Groundwater Elevation (ft AMSL)

Watershed Boundary

Pit Outline

US Army Corps of Engineers

SIMULATED SHALLOW GROUNDWATER ELEVATION AT STEADY STATE POST-CLOSURE FOR 50TH PERCENTILE CAPTURE ZONE (MODEL LAYER 1)



Sources: PLP (2019-RFI 109a)

Legend

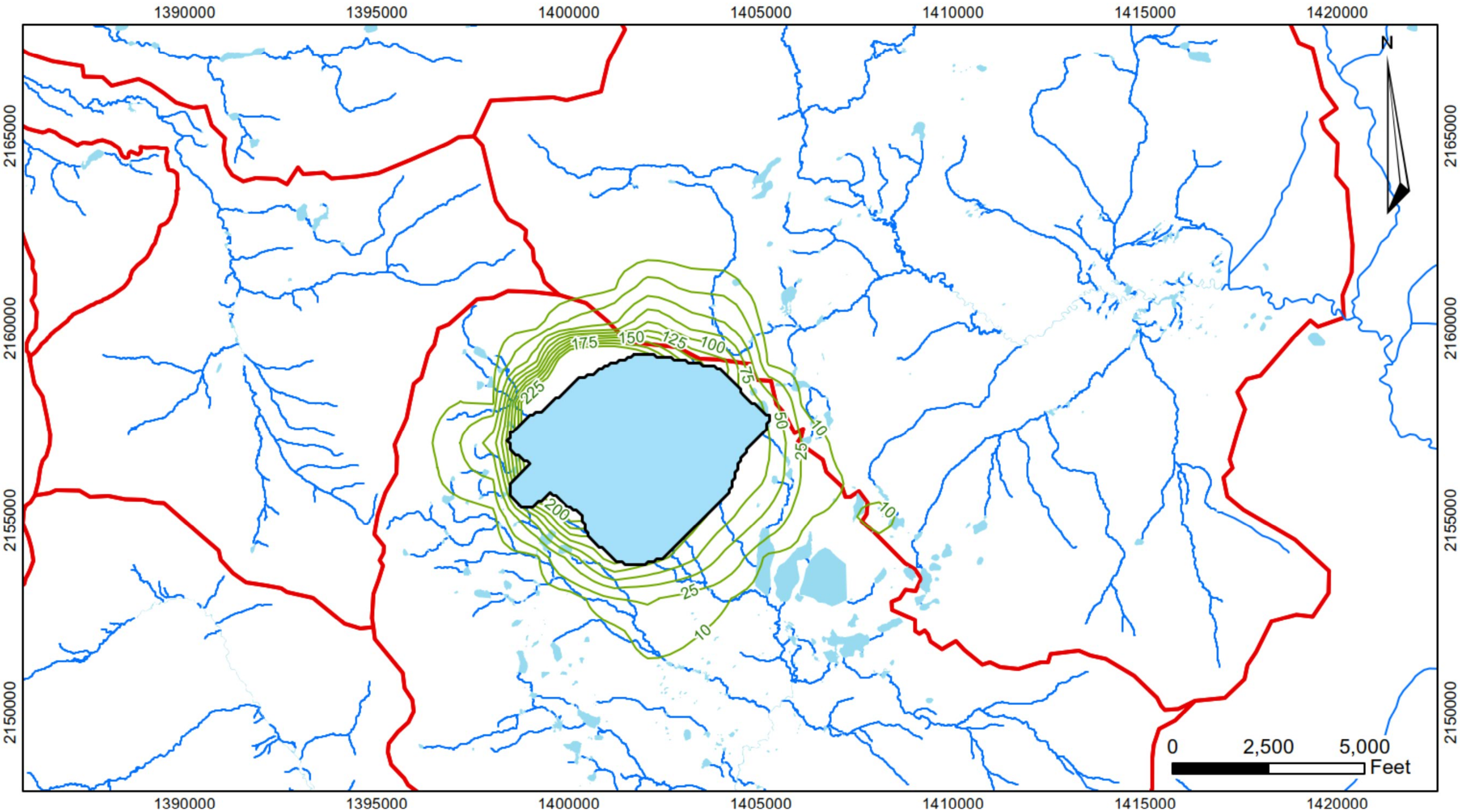
Groundwater Elevation (ft AMSL)

Watershed Boundary

Pit Outline

US Army Corps of Engineers

SIMULATED DEEP GROUNDWATER ELEVATION AT OPERATIONS POST-CLOSURE FOR 50TH PERCENTILE CAPTURE ZONE (MODEL LAYER 8)



Sources: PLP (2019-RFI 109b)

Legend

Pit Lake

Drawdown Contour (ft)

Watershed Boundary

Note: First drawdown contour at 10ft.
Subsequent contours every 25 ft beginning at 25 ft.

US Army Corps of Engineers®

SIMULATED DRAWDOWN CONTOURS FOR STEADY-STATE POST-CLOSURE FOR THE PIT AREA MODEL

K4.17.2.3 Double Recharge Scenario

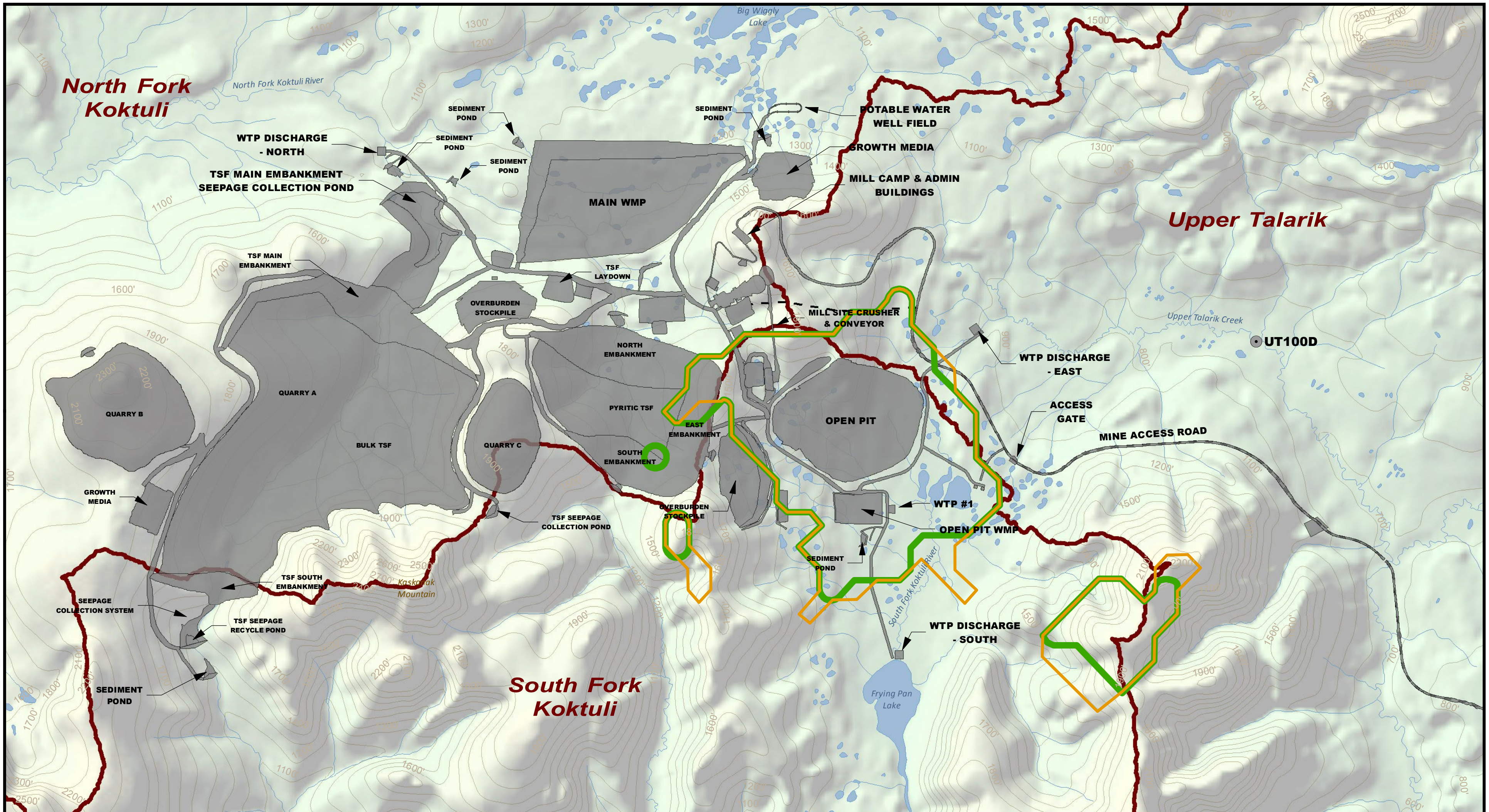
To evaluate the effect of potential increased precipitation from climate change, and the effect of uncertainty in the recharge rate input on the groundwater model results, the model was run using twice the base-case recharge rate. As shown on Figure K4.17-4 and Figure K4.17-5 for operations and post-closure, respectively, the capture zones associated with the double recharge scenarios are similar to the 50^{th} percentile base-case recharge scenarios. The main differences were in outlying areas to the south in the SFK drainage, with very little change in the NFK and UTC drainages.

In operations, the double recharge scenario resulted in a groundwater pumping rate required for pit dewatering about twice that of the 50^{th} percentile base case, or about 5 cfs greater (Piteau Associates 2018a). Although the flows are higher, the flowpaths are similar because recharge and hydraulic conductivity are strongly correlated parameters (Piteau Associates 2018a). In other words, there would be twice as much meteoric recharge flowing through similar groundwater flowpaths. Water from pit dewatering would report to the open pit WMP and would be treated by WTP#1, which would have an average treatment capacity of 9 cfs and a maximum of 14 cfs; thus, the increased water under the double recharge scenario could use up all the additional WTP capacity between the average and maximum. However, during operations the two WTPs together would have an average capacity of 29 cfs and maximum of 38 cfs. In the event that greater recharge causes a greater pumping volume to report to the open pit WMP, flexibility is built into the water management strategy such that water could be pumped to the main WMP pond and treated at WTP #2 (Knight Piésold 2018f). Adding 5 cfs to the main WMP, which can handle about 22 to 35 cfs at 50^{th} percentile capacity, results in flows that are well below its maximum capacity (about 45 cfs) based on modeling a succession of wet years in the water balance model (Knight Piésold 2018a).

K4.17.3 Seepage from Tailings Storage Facilities and Main Water Management Pond

Bulk TSF - The bulk TSF would contain a supernatant pond during the period of time that the TSF is filling, and the tailings and sediments below the tailings would be saturated. Thus, the water table adjacent to the pond would be slightly higher than the pond elevation throughout operations except near the main embankment, which would be a flow-through dam, where the water table would be lower than the pond elevation (Piteau Associates 2018a).

The groundwater model was used to estimate the foundation seepage rate that would reach groundwater beneath the bulk TSF. The total flow estimated from the model, 0.7 cfs, would come from a combination of groundwater beneath bedrock ridges on either side of the TSF (about 80 percent) and the overlying tailings (about 20 percent). In the absence of the south embankment, seepage flow that reaches groundwater beneath the TSF would flow both south and north out of this drainage (about half in either direction). However, the lined face and grout curtain at the south TSF embankment, as well as tailings beach placement during operations, are expected to direct most of this groundwater flow north toward the main seepage collection pond (SCP) (Piteau Associates 2018a; Knight Piésold 2018n). There would also be a larger component of flow through the north embankment itself, predicted to be about 9 cfs (Knight Piésold 2018a), which would be captured at the main SCP.



Sources: Piteau Associates 2018a, Fig. 8

Groundwater Capture Zones
- Double Recharge Scenario
- 50th percentile Base Case

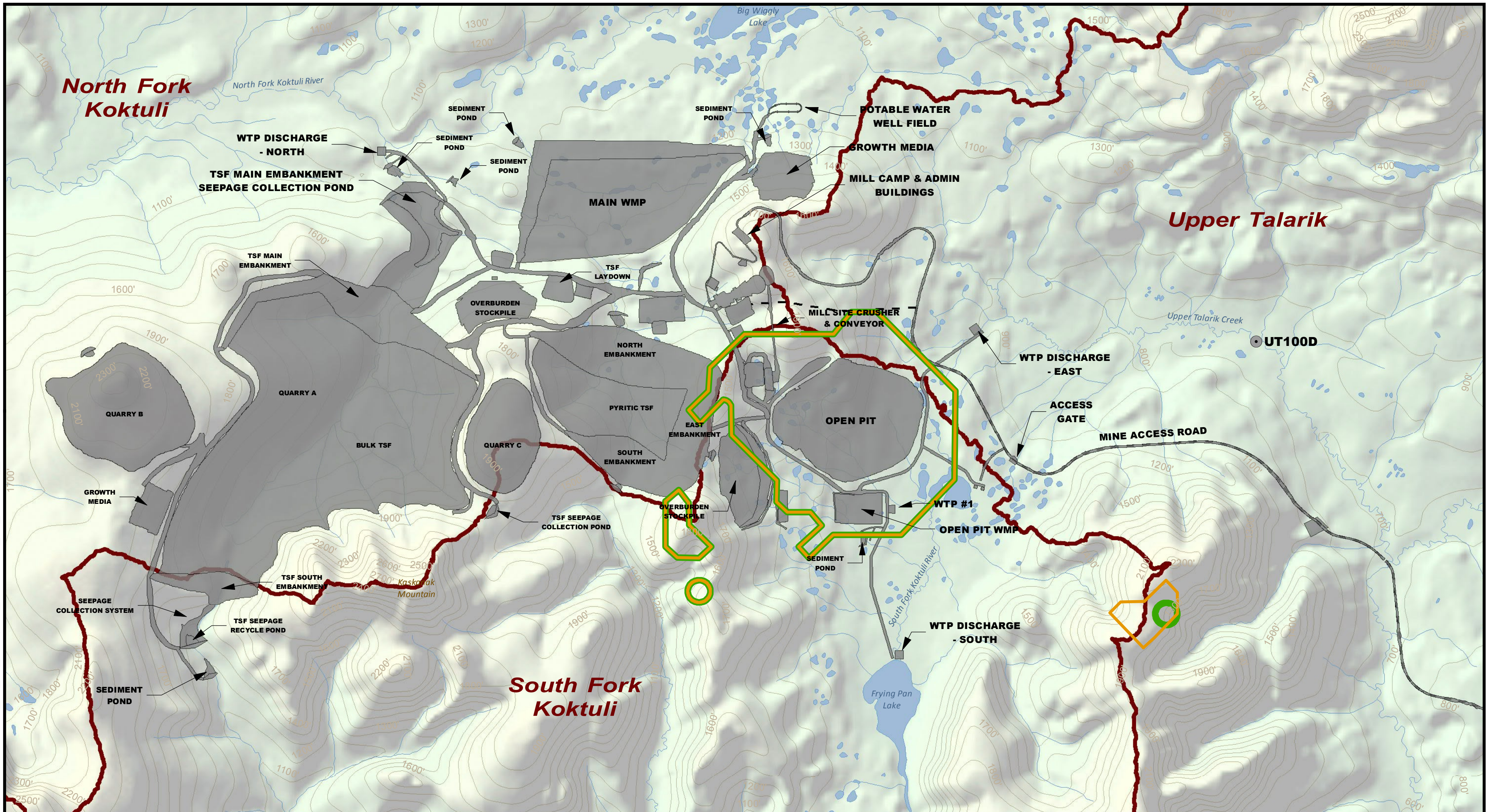
Alternative 1
- Natural Gas Pipeline
- Project Features

Other Features
- 100' Contour (Existing)
- River/Stream
- Lake/Pond
- Major Drainage Boundary

US Army Corps of Engineers

0.5 0 0.5 1
Miles

COMPARISON BETWEEN BASE CASE AND DOUBLE RECHARGE SCENARIOS AT END OF OPERATIONS



Sources: Piteau Associates 2018a, Fig. 10

Groundwater Capture Zones
- Double Recharge Scenario
- 50th percentile Base Case

Alternative 1
- Natural Gas Pipeline
- Project Features

Other Features
- 100' Contour (Existing)
- River/Stream
- Lake/Pond
- Major Drainage Boundary

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0.5 0 0.5 1
Miles

COMPARISON BETWEEN BASE CASE AND DOUBLE RECHARGE SCENARIOS IN POST-CLOSURE

PEBBLE PROJECT EIS

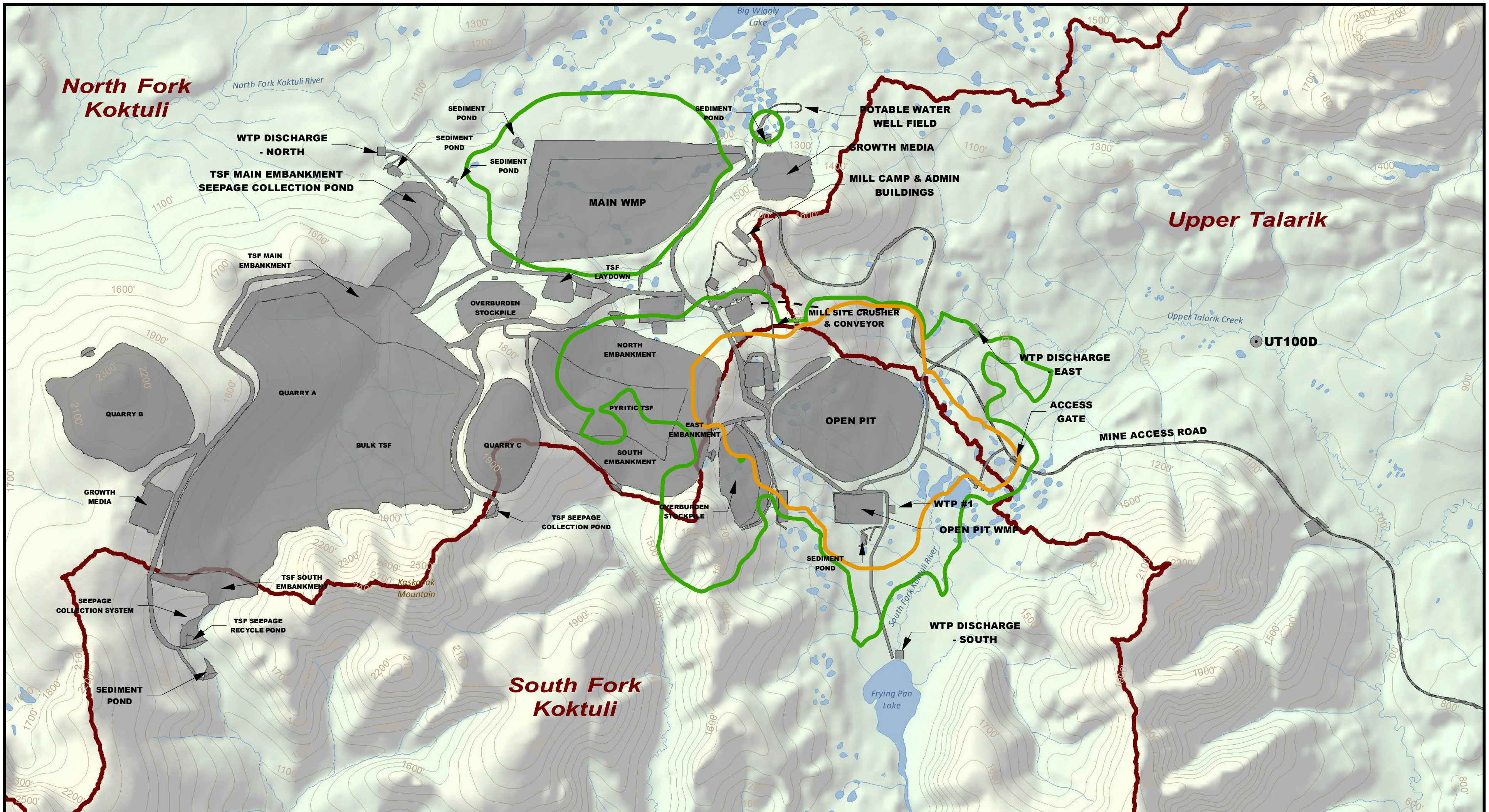
FIGURE K4.17-5

The northward groundwater flow path would be through a narrow valley, and the groundwater model predicted that there would be no seepage through the bedrock ridges on either side of the TSF. However, because the ultimate tailings height along the northwest ridge would be about 50 to 120 feet higher than the two saddles along this ridge, it is possible that groundwater flow paths could develop through these saddles during late operations (Piteau Associates 2018a). Groundwater levels would be monitored during operations in piezometers along the ridge and downstream of the embankment, and operational rules would be established to maintain hydraulic containment. If seepage through the northwest ridge is detected, contingencies such as relief wells and/or seepage recovery wells would be implemented. Monitoring and contingencies would be further developed as design progresses (Knight Piésold 2018n).

Pyritic TSF. The groundwater model was used to analyze the area of the zone of influence around the pyritic TSF, within which project-induced hydraulic stress is predicted to change the water table elevation. The model shows that groundwater levels would be lowered by about 3 feet beneath the northern two-thirds of this facility during operations, due to the liner blocking natural recharge from reaching groundwater (Piteau Associates 2018a) (Figure K4.17-6), which could reduce the amount of natural shallow groundwater discharge to the tributary beneath and downgradient of the pyritic TSF. Flow in this tributary would also be blocked by the presence of the pyritic TSF north embankment, north SCP, and main WMP (see Section 4.16, Surface Water Hydrology, for estimated streamflow reductions). The zone of influence area is wider than that of the pit capture zone in operations (Section 4.17, Groundwater Hydrology, Figure 4.17-2), because the zone of influence includes areas where water level changes occur but water does not flow towards the pit, while the capture zone includes only those areas where flow would be towards the pit.

The fate of liner leakage that reaches shallow groundwater beneath the pyritic TSF was modeled assuming a leakage rate of 1 liter/second (L/s) or about 30 gallons/acre/day (Knight Piésold 2018n) based on a composite liner system with excellent contact between the liner and subgrade (Giroud and Bonaparte 1989). Most of the liner leakage that reaches shallow groundwater at this rate is predicted to migrate northward. This flow would be effectively captured by the proposed downgradient SCP, which would contain a lined embankment, grout curtain, and pumpback wells (Piteau Associates 2018a). The model indicated that a small amount of seepage could migrate eastward from the pyritic TSF, which would either be captured by the eastern SCP or report to the pit, because part of this facility lies within the capture zone and zone of influence of the pit (Figure 4.17-2; Knight Piésold 2018n: Figure 5). Seepage flow to the south is not predicted to occur due to a groundwater divide located south of the south embankment. Regardless, the pyritic TSF south SCP would have the same seepage collection features as the north and east SCPs (Table K4.15-1). Liner leakage would also be mitigated by placing foundation drains beneath the liner to direct leakage flow towards the SCPs, as well as drains above the liner and under the tailings to collect waters for treatment and reduce the potential for a high head to develop on the liner (Knight Piésold 2018n).

Removing the pyritic TSF after closure would allow natural recharge to be re-established and groundwater elevations to recover. This change in recharge would cause the simulated zone of influence in this area to contract to the point that groundwater elevations are influenced only by the open pit capture zone in the northeast corner of the former pyritic TSF footprint (Section 4.17, Groundwater Hydrology, Figure 4.17-3; Piteau Associates 2018a: Figures 5 and 8).



Sources: Piteau Associates 2018a, Fig. 5

Zones of Influence
- End of Operations[1]
- Post-Closure[1]

Alternative 1
- Natural Gas Pipeline
- Project Features

Other Features
- 100' Contour (Existing)
- River/Stream
- Lake/Pond
- Major Drainage Boundary

Note:
1. Area of approximate 3-ft drawdown of water table from pit dewatering and recharge reduction due to liners, based on base case (50th percentile) recharge.

US Army Corps of Engineers

0.5 0 0.5 1
Miles

ZONES OF INFLUENCE FOR PIT, PYRITIC TSF, AND MAIN WMP AT END OF OPERATIONS AND POST-CLOSURE

PEBBLE PROJECT EIS

FIGURE K4.17-6

Main WMP - The groundwater model results for the main WMP indicate that groundwater levels would be lowered by about 3 feet in the area surrounding the facility for distances ranging from about 1,000 to 3,000 feet from the embankment, due to the liner blocking natural recharge from reaching groundwater (Piteau Associates 2018a: Figure 5). Like the pyritic TSF, removing the main WMP after closure would allow natural recharge to be re-established and groundwater elevations to recover.

The model was also used to predict the fate of liner leakage reaching shallow groundwater, assuming that no mitigation occurs (i.e., detection and capture by monitoring/pumpback wells). Based on the same liner leakage assumptions described above, contact water that leaks to shallow groundwater would migrate a distance of about 2 miles after 40 years (to just below station NK100C). This timeframe would include both operations and the first 20 years of closure (closure phase 2) when the main WMP would be decommissioned (Knight Piésold 2018d). However, liner leakage would be mitigated by the monitoring/pumpback wells, and by placing foundation drains beneath the liner to direct leakage flow towards the wells.

A monitoring plan would be developed as part of future design work that would target zones of expected higher permeability between the main WMP and receiving environment identified from site investigations. These areas may include fractured bedrock zones, deeper weathering profiles along streams, and thicker permeable overburden deposits. A monitoring network that includes both wells and streamflow measurements would be developed prior to the beginning of mining to identify potential impacts from the project. Monitoring would be expanded as required based on data collected during construction and operations. After decommissioning of the main WMP, the monitoring wells would continue to operate as long as required to intercept potential leakage (Knight Piésold 2018n).

K4.18 WATER AND SEDIMENT QUALITY

This appendix contains additional technical information on the following topics related to mine site impacts to surface water, groundwater, and substrate/sediment quality described in Section 4.18, Water and Sediment Quality:

- Water quality modeling
- Water treatment plant (WTP) methodologies
- Dust deposition methodologies

K4.18.1 Water Quality Modeling

This section provides a description and analysis of modeling conducted at the mine site to estimate the chemical content of water stored in onsite facilities and provide source information for preliminary design of WTPs.

K4.18.1.1 Operations

Contact water at the mine site is being collected and held in various on-site facilities prior to treatment and reuse or discharge. These include the tailings storage facilities (TSFs), water management ponds (WMPs), seepage collection ponds (SCPs), open pit, process plant, and WTPs. The collection, storage, and movement of water around these facilities is described in Section 4.16, Surface Water Hydrology, and Section 4.18, Water and Sediment Quality, and shown on figures in Section 4.16 and Appendix K4.16. All mine facilities that collect, store, treat, and discharge water have been incorporated into water balance and water quality models developed by Knight Piésold (2018a) using both in-house and GoldSim Technology Group GoldSim® software. The models used for the operations phase of the project are based on the conceptual 20-year life of mine footprint shown on Section 4.16, Surface Water Hydrology, Figure 4.16-1.

<u>Water Balance Model</u>

The water balance model is comprised of three modules: the watershed, groundwater, and mine plan modules. The mine plan module is representative of the movement of water in the mine system and uses inputs from the watershed and groundwater modules. The mine plan module estimates the amount of water to be managed at the mine site during the operations phase of the mine under a full range of historic climate conditions. As described in Section 3.16, Surface Water Quality, and Appendix K3.16, climate variability is incorporated in the model using a 76-year synthetic time series of monthly temperature and precipitation values to simulate the cyclical nature of the climate record. The climate model was developed using climate data from the nearby Iliamna airport which has been recorded daily since 1940. The application of this data allowed for local climate trends and cycles to be calibrated and applied to the study area to create a more robust synthetic time series data. A 76-year model analysis period was used to resemble the 76-year dataset from Iliamna airport used to create the model. Monthly outputs were examined to simulate seasonally trends and variability (AECOM 2018o).

The water balance model was run with 20 years of consecutive data at a time. Seventy-six, 20-year runs were made, each starting with a different year in the 76-year synthetic record. This method of analysis was used to preserve the inherent cyclical nature of the climate record (Knight Piésold 2018a), and resulted in 76, 20-year period evaluations of water flow and storage. Thus, the model generated 76 unique sets of monthly water flow and storage results for each year. Three of these model runs were selected to represent dry, average, and wet climate conditions in the Knight Piésold (2018a) to illustrate the range of potential flows for the mine site under these varying conditions. Additional details regarding the water balance model inputs and assumptions are provided in Knight Piésold (2018a) and discussed in Section 3.16, Surface Water Hydrology.

Table K4.18-1 summarizes average predicted monthly and annual total release from the WTPs to downstream of the mine site for relatively dry, average, and relatively wet climate conditions. Each realization represents a unique model run selected from the 76 total model runs (Knight Piésold 2018a). Proposed discharge locations for treated water include the South Fork Koktuli (SFK) River, North Fork Koktuli (NFK) River, and Upper Talarik Creek (UTC) catchments (Knight Piésold 2018a). WTP discharge locations are depicted in Section 4.16, Surface Water Quality, Figure 4.16-1 and Section 4.18, Water and Sediment Quality, Figure 4.18-1.

The combined annual average WTP discharges from the three WTPs for dry, average, and wet periods are anticipated to be 20, 29, and 32 cubic feet per second (cfs), respectively. For context, the combined mean annual flows for the three streams near the discharge locations are on the order of 110 cfs (Knight Piésold 2018h). Discharge volumes may vary month-to-month based on the timing and magnitude of precipitation and snowmelt; however, in general on an annual basis, the dry scenario had the lowest total discharge and the wet scenario yielded the greatest total discharge. Higher discharge rates correspond to higher levels of precipitation, and lower discharge rates correspond to lower levels of precipitation.

Table K4.18-1: Predicted Water Release Quantity from WTPs

Month	Relatively Dry Conditions[1]	Average Conditions[1]	Relatively Wet Conditions[1]
	(Realization #36)	(Realization #5)	(Realization #10)
Jan	22	26	22
Feb	17	17	17
Mar	17	22	17
Apr	22	22	22
May	26	22	22
Jun	27	36	27
Jul	17	36	36
Aug	22	36	45
Sep	22	36	45
Oct	22	36	45
Nov	8	31	45
Dec	12	26	40
Annual Average	20	29	32

Notes:
[1] units = cubic feet per second (cfs)
Source: Knight Piésold 2018a, Table 4.3

Geochemical Source Terms and Water Quality Model

The water quality model for the operations period developed in GoldSim® uses a mass balance approach, which leverages conservation of mass in the system for material entering and leaving the system to ensure it is all accounted for (Knight Piésold [2018a]). This model was used to estimate constituent loading in and out of each of the mine facilities based on geochemical source terms and flow path information from the water balance model. The water quality model is coupled with the water balance model to estimate constituent loads under completely mixed, steady-state conditions. The model considers the inflow, outflow, and storage volumes and constituent concentrations to calculate constituent loads for all contact water facilities, and predicts water quality in on-site water storage facilities and influent water quality to the WTPs under varying climate conditions.

Geochemical source term inputs for the water quality model were developed by SRK Consulting (Canada) Inc. (SRK 2018a). The source terms were developed utilizing a combination of data from humidity cell tests, barrel tests, and shake flask tests in the Pebble East Zone and Pebble West Zone, as well as pilot test supernatant analyses (SRK 2018f). Source term-specific adjustments were made for oxygen available, temperature, particle surface area, and water contact in order to adjust to field conditions, and included consideration of explosive residues (SRK 2018a).

Detailed methods used to calculate the source terms are provided in SRK (2018f). In general, upside inputs for contact water source terms were developed and provided as single values using assessments of statistical variability appropriate to each input parameter and its intended use:

- Where the mean would be considered the best representation of the most likely condition and extreme low and high values offset each other, the input was calculated as the upper 95 percent confidence limit on the mean (i.e., representing the statistical uncertainty on the mean).
- Where high values in a dataset are considered a reasonable representation of variability about an expected condition, the 95^{th} percentile value was used, which is an approximation of inputs that would occur 1 time in 20.
- Where datasets are used to evaluate solubility of ions in solution, upper values provide the best representation of the expected value because lower values are probably affected by dilution. In this case, the 99^{th} percentile was used mainly to screen anomalously high values that may be a result of data quality issues.
- For non-contact terms, median values were used as an appropriate indicator of central tendency in datasets. Due to the low chemical loads provided by these sources, the overall model outcomes are not sensitive to this assumption.

Table K4.18-2 provides the predicted constituent concentrations and physical parameters expected to be produced from various geochemical sources at the mine site that would be captured onsite, such as waste rock, pit wall runoff, tailings, existing streams, and groundwater. These concentrations were used as conservative (95^{th} percentile) inputs to the water quality model to predict the water quality in various mine site facilities and analyze water treatment processes.

Water quality model mass loading data for the final year of mining operations is provided in Table K4.18-3. The relative contributions of inflow loads to several mine site facilities for total dissolved solids (TDS), copper, sulfate, arsenic, mercury, and molybdenum are depicted in Figure K4.18-1 through Figure K4.18-5. For example, about half of the arsenic entering the main WMP (Figure K4.18-5) would come from the main SCP, about a quarter from the bulk TSF pond, less than a quarter from the pyritic TSF pond, and smaller amounts from other sources such as embankment and mill site runoff.

Table K4.18-2: Predicted Water Quality from Mine Site Geochemical Sources[a] – Part 1

Parameters	Background				Other Rock				Open Pit				
	Direct Precipitation	Non-Contact Surface Water	Non-Contact Surface Water	Ground-water	Waste Rock	Waste Rock	Quarried Rock Fill (Dams)	Quarried Rock Fill (Dams)	Wall Runoff	Wall Runoff	Wall Runoff	In-Pit Stockpile	In-Pit Stockpile
		NFK (NK119A)	SFK SK100F	Pit Area	Tertiary	Tertiary	Non-Acidic	Non-Acidic	Pre-Tertiary - Non-Acidic	Pre-Tertiary - Acidic	Tertiary - Non-Acidic	Non-Acidic	Non-Acidic
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/t of new rock	mg/L	mg/t of new rock	mg/L	mg/L	mg/L	mg/L	mg/t of new rock
pH (pH Units)	**5.5**[b]	6.5	6.8	6.7	7.7	-	8.4	-	8.1	**3.5**	8.2	8.0	-
TDS	-	31.5	42.6	44.4	**2158.0**	-	**3600.3**	-	286.0	453.0	241.0	**4473.2**	-
Alkalinity	-	**14.6**	**18.0**	33.0	26.4	-	490.0	-	49.3	-	69.0	800.0	-
Acidity	-	2.5	3.8	7.5	5.8	-	-	-	7.1	305.6	0.5	24.9	-
Chloride	-	0.622	0.711	0.804	23.000	-	8.300	-	2.242	6.935	2.260	23.000	-
Fluoride	-	0.032	0.040	0.072	0.863	-	0.870	-	0.316	0.447	0.112	**1.800**	-
Sulfate	-	1.2	7.8	4.9	**1456.2**	-	**2350.1**	-	87.5	**276.8**	29.2	**2350.1**	-
Aluminum	-	0.0363	0.0544	0.0034	0.0487	-	**1.3000**	-	0.0011	**22.9945**	0.0015	**2.6000**	-
Antimony	-	0.0001	0.0001	0.0000	**0.2000**	-	**0.1500**	-	0.0022	0.0010	**0.0183**	**0.2000**	-
Arsenic	-	0.0002	0.0004	0.0004	**0.1898**	-	**0.1900**	-	**0.0196**	**0.0341**	**0.0430**	**0.4000**	-
Barium	-	0.0025	0.0049	0.0064	**6.1823**	-	0.1000	-	0.1391	0.0600	1.0025	0.3600	-
Beryllium	-	0.00001	0.00001	0.00002	**0.00500**	-	**0.00500**	-	0.00002	**0.00852**	0.00005	**0.00500**	-
Bismuth	-	0.00013	0.00010	0.00002	0.10811	-	0.10000	-	0.00005	0.00005	0.00005	0.20000	-
Boron	-	0.00158	0.00153	0.00150	0.73000	-	0.50000	-	0.07779	0.15069	0.19222	0.73000	-
Cadmium	-	0.00001	0.00001	0.00002	**0.01097**	-	**0.00550**	-	**0.00202**	**0.02638**	**0.00023**	**0.22000**	-
Calcium	-	3.9	6.1	13.8	538.1	-	760.0	-	30.4	9.9	25.3	940.0	-
Chromium	-	0.0002	0.0003	0.0005	0.0200	-	0.0200	-	0.0008	0.0017	0.0011	0.0200	-
Cobalt	-	0.0001	0.0001	0.0001	0.0219	-	0.0490	-	0.0204	**0.2515**	0.0006	**0.8800**	-
Copper	-	0.0004	0.0021	0.0004	**0.0249**	-	**0.1600**	-	**0.0064**	**6.3730**	**0.0041**	**1.3000**	-
Iron	-	0.1500	0.5480	0.0200	0.0021	-	**1.7000**	-	0.0020	**38.5700**	0.0020	**16.0000**	-
Lead	-	0.0002	0.0003	0.0001	**0.0120**	-	**0.0500**	-	0.0001	**0.0081**	**0.0005**	**0.0620**	-
Magnesium	-	0.7340	1.4800	1.0700	48.8700	-	99.0000	-	10.0300	1.9050	2.5080	120.0000	-
Manganese	-	0.00899	0.0493	**0.441**	**1.492907**	-	**2.4**	-	**1.9484214**	**13.205**	**0.1408455**	**6.2**	-
Mercury	-	0.000001	0.000001	0.000001	**0.002170**	-	**0.000500**	-	0.000004	0.000011	0.000003	**0.006200**	-
Molybdenum	-	0.000158	0.000509	0.000256	**0.445513**	-	**9.800000**	-	**0.051323**	0.008362	**0.150278**	**7.800000**	-
Nickel	-	0.000220	0.000354	0.000647	**0.109241**	-	**0.050000**	-	**0.013449**	**0.195004**	0.002342	**0.320000**	-
Potassium	-	0.206	0.373	0.342	50.000	3282.126	36.000	2597.446	4.692	0.000	4.700	-	2597.446
Selenium	-	0.000140	0.000413	0.001090	**0.217050**	-	**0.055000**	-	**0.015695**	**0.125842**	**0.016380**	**0.048000**	-
Silver	-	0.000005	0.000004	0.000006	**0.002210**	-	**0.010000**	-	0.000030	0.000092	0.000042	**0.010000**	-

Table K4.18-2: Predicted Water Quality from Mine Site Geochemical Sources[a] – Part 1

Parameters	Background				Other Rock				Open Pit				
	Direct Precipitation	Non-Contact Surface Water	Non-Contact Surface Water	Ground-water	Waste Rock	Waste Rock	Quarried Rock Fill (Dams)	Quarried Rock Fill (Dams)	Wall Runoff	Wall Runoff	Wall Runoff	In-Pit Stockpile	In-Pit Stockpile
		NFK (NK119A)	SFK SK100F	Pit Area	Tertiary	Tertiary	Non-Acidic	Non-Acidic	Pre-Tertiary - Non-Acidic	Pre-Tertiary - Acidic	Tertiary - Non-Acidic	Non-Acidic	Non-Acidic
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/t of new rock	mg/L	mg/t of new rock	mg/L	mg/L	mg/L	mg/L	mg/t of new rock
Sodium	-	2.03	2.40	2.47	487.38	45271.20	110.00	3978.95	8.70	0.01	9.75	-	3978.95
Thallium	-	0.00001	0.00001	0.00001	0.00100	-	0.00049	-	0.00080	**0.00216**	0.00046	0.00100	-
Silicon	-	5.43000	4.02000	5.88000	32.64000	-	31.00000	-	-	-	-	47.00000	-
Tin	-	0.00006	0.00006	0.00010	0.02296	-	0.19000	-	0.00017	0.00016	0.00020	0.03000	-
Vanadium	-	0.00033	0.00035	0.00055	0.03000	-	0.03000	-	0.00081	0.00151	0.01000	0.03000	-
Zinc	-	0.00167	0.00317	0.00150	**0.24258**	-	**0.97000**	-	**0.36342**	**2.03400**	0.00780	**8.80000**	-
Nitrate-N	-	-	-	-	-	-	-	4672.5	-	-	-	-	389.4
Nitrate	-	-	-	-	-	-	-	20684.2	-	-	-	-	1723.7
Nitrite	-	-	-	-	-	-	-	413.7	-	-	-	-	34.5
Ammonia	-	-	-	-	-	-	-	467.2	-	-	-	-	38.9

Notes:
[a] 95th percentile geochemical source terms
[b] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1)
[c] Adjustments made for specific location and orographic effects. Tailings Pond Adjustment values were applied for Al, SO_4, Fe, Cu and Mn in the Bulk TSF and Pyritic TSF.
[d] The 50th percentile (or median) supernatant mercury concentration (10 ng/L) was used for the bulk tailings water given that about 70% of the results were not detected at <10 ng/L.
Nitrate-N = Nitrate as nitrogen; the concentration of nitrogen in solution due to nitrates.
mg/L = milligrams/liter
mg/t = milligrams/ton
TDS = total dissolved solids
Source: Knight Piésold (2018a, Table B1.1); SRK (2018a, Table 4)

Table K4.18-2: Predicted Water Quality from Mine Site Geochemical Sources[a] – Part 2

Parameters	Tailings						PAG Waste Rock
	Bulk Tailings SCP Water	Fresh Ore Leaching + reagent	Pyritic tailings	Ore	Tailings Pond Adjustment[c]	Pyritic Tailings Sand Wedge	17% of Pyritic TSF Area
	Supernatant		Runoff	Entrained moisture	Pond	Seepage	Total Load
	mg/L	mg/t of ore	mg/m²/week	mg/L	mg/L	mg/L	kg/year
pH (pH units)	8.0	-	-	6.7	8.0	8.6	-
TDS	198.0	-	378.3	44.4	-	**4136.6**	1285207.1
Alkalinity	97.4	217086.5	216.3	33.0	-	770.0	23403.9
Acidity	-	-	-	7.5	-	7.5	27760.7
Chloride	17.000	2068.840	1.684	0.804	-	9.300	6042.718
Fluoride	0.480	-	0.547	0.072	-	0.900	1931.820
Sulfate	159.5	921809.6	66.6	4.9	2350.1	2350.1	795940.3
Aluminum	0.0109	478.2510	0.3845	0.0034	0.0006	**2.5000**	980.5286
Antimony	0.0025	2.3607	0.0209	0.0000	-	**0.2000**	76.2858
Arsenic	0.0020	3.3020	0.0961	0.0004	-	**0.2600**	66.5914
Barium	0.0226	41.5838	0.0427	0.0064	-	0.1500	374.7911
Beryllium	0.00020	33.22308	0.00064	0.00002	-	**0.00500**	2.41709
Bismuth	0.00050	3.06842	0.00160	0.00002	-	0.10000	6.04272
Boron	0.02200	175.52728	0.03202	0.00150	-	0.52000	209.65366
Cadmium	0.00006	13.57445	0.00017	0.00002	-	**0.01000**	7.16786
Calcium	66.2	153076.1	71.6	13.8	-	770.0	288138.4
Chromium	0.0005	3.0684	0.0016	0.0005	-	0.0200	6.1232
Cobalt	0.0006	31.4835	0.0003	0.0001	-	**0.0500**	55.0902
Copper	**0.0102**	29924.1742	**0.0174**	0.0004	**0.0100**	**0.3700**	1395.2035
Iron	0.0300	10692.5014	0.1011	0.0200	0.0020	**1.8000**	366.3925
Lead	0.0001	20.5394	0.0002	0.0001	-	**0.0500**	3.4251
Magnesium	15.6000	84592.4968	18.1849	1.0700	-	99.0000	92003.8556
Manganese	**0.56**	18431.342	0.213374524	**0.441**	**2.000**	**2.9**	5251.365439
Mercury	0.000010[d]	0.101264	0.000036	0.000001	-	**0.000500**	0.135523
Molybdenum	**0.038300**	7.454516	0.068144	0.000256	-	**12.000000**	138.326226
Nickel	0.002120	91.866767	0.001939	0.000647	-	**0.050000**	36.247710
Potassium	31.300	34793.196	21.037	0.342	-	36.000	19793.459
Selenium	**0.006000**	19.801217	0.003438	0.001090	-	**0.055000**	42.301751
Silver	0.000017	0.068625	0.000032	0.000006	-	**0.010000**	0.144415
Sodium	28.40	104093.88	6.89	2.47	-	130.00	30321.02
Thallium	0.00007	0.62473	0.00017	0.00001	-	0.00050	1.07323

Table K4.18-2: Predicted Water Quality from Mine Site Geochemical Sources[a] – Part 2

Parameters	Tailings						PAG Waste Rock
	Bulk Tailings SCP Water	Fresh Ore Leaching + reagent	Pyritic tailings	Ore	Tailings Pond Adjustment[c]	Pyritic Tailings Sand Wedge	17% of Pyritic TSF Area
	Supernatant		Runoff	Entrained moisture	Pond	Seepage	Total Load
	mg/L	mg/t of ore	mg/m^2/week	mg/L	mg/L	mg/L	kg/year
Silicon	2.80000	3520.69974	-	5.88000	-	32.00000	-
Tin	0.00010	0.61368	0.00034	0.00010	-	0.20000	32.19700
Vanadium	0.00050	3.46735	0.01000	0.00055	-	0.03000	7.62389
Zinc	0.00290	1828.50054	0.00458	0.00150	-	**1.90000**	1267.43960
Nitrate-N	-	-	-	-	-	-	-
Nitrate	-	-	-	-	-	-	-
Nitrite	-	-	-	-	-	-	-
Ammonia	-	-	-	-	-	-	-

Notes:
[a] 95th percentile geochemical source terms
[b] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1)
[c] Adjustments made for specific location and orographic effects. Tailings Pond Adjustment values were applied for Al, SO4, Fe, Cu and Mn in the Bulk TSF and Pyritic TSF.
[d] The 50[th] percentile (or median) supernatant mercury concentration (10 ng/L) was used for the bulk tailings water given that about 70% of the results were not detected at <10 ng/L.
Nitrate-N = Nitrate as nitrogen; the concentration of nitrogen in solution due to nitrates.
kg = kilogram
mg/L = milligrams/liter
mg/m^2 = milligrams/square meters
mg/t = milligrams/tonne
TDS = total dissolved solids
Source: Knight Piésold (2018a, Table B1.1); SRK (2018a, Table 4)

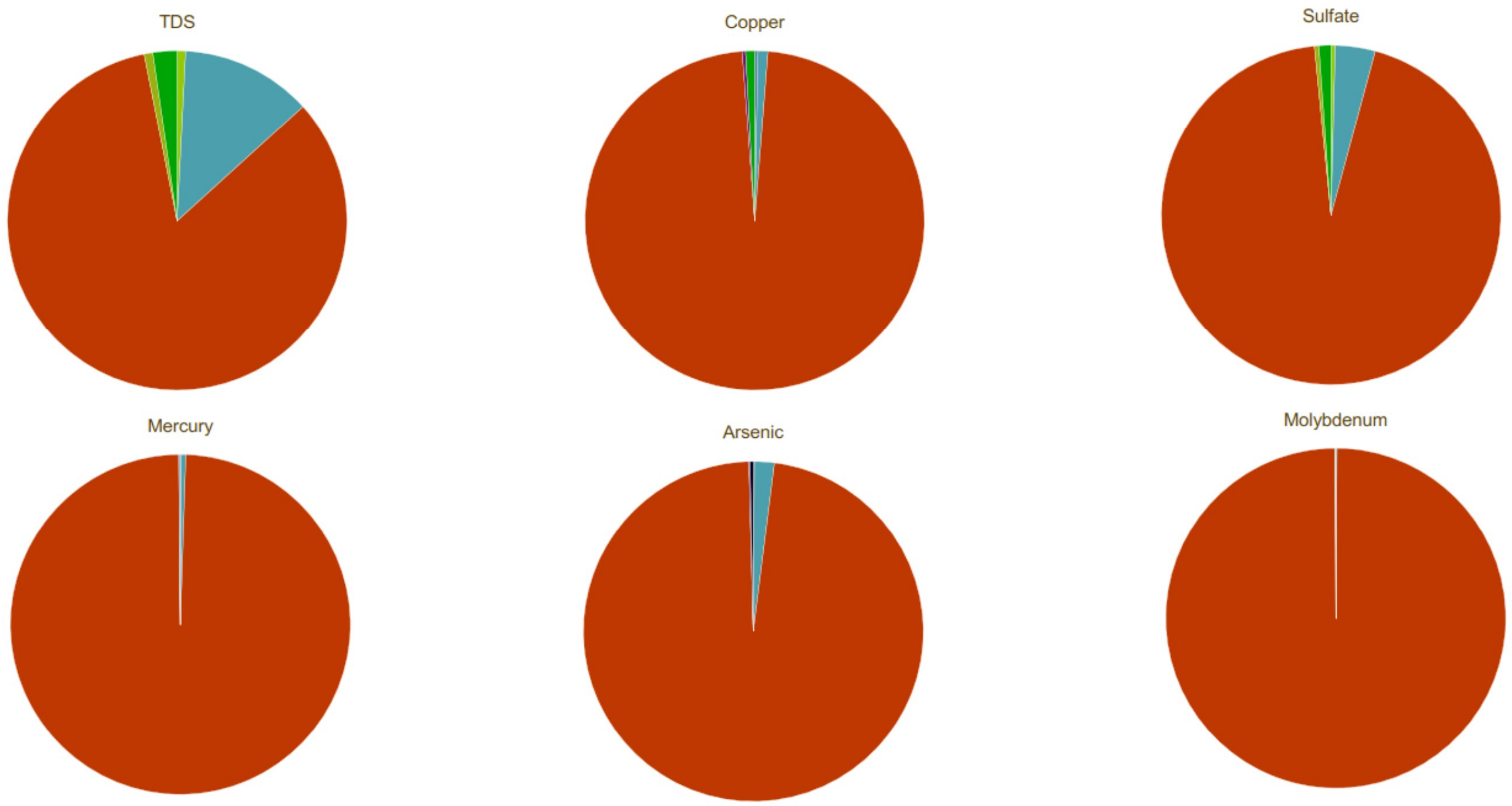
Table K4.18-3: Modeled Mass Loads – Final Year of Operations

Parameter	WTP#1 Inflows	WTP#2 Inflows	Open Pit Water Management Pond	Bulk TSF	Main Embankment Seepage Collection Pond	Pyritic TSF	Main Water Management Pond
	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)
pH	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8
TDS	271,616	2,995,532	281,622	3,337,588	2,829,158	12,550,035	57,000,562
Alkalinity	58,329	444,000	63,338	529,691	525,160	1,068,000	8,435,000
Acidity	7,052	3,665	7,085	2,983	5,136	5,853	70,329
Chloride	2,040	16,660	2,230	26,491	6,350	50,998	318,752
Fluoride	215	581	236	651	612	1,559	11,037
Sulfate	110,846	1,746,000	122,635	1,894,000	1,599,000	8,010,000	33,230,000
Aluminum	97	441	107	13,192	1,707	31,261	8,463
Antimony	7	63	8	32	136	221	1,204
Arsenic	20	83	23	45	177	285	1,588
Barium	72	94	79	107	102	309	1,786
Beryllium	0.2	37	0.2	61	3	114	650
Bismuth	6	36	7	16	68	161	684
Boron	55	319	61	350	354	989	6,039
Cadmium	7	17	8	25	7	90	332
Calcium	46,165	413,180	50,609	368,659	523,781	1,611,000	7,819,000
Chromium	1	8	1	6	14	24	160
Cobalt	35	52	39	58	34	299	995
Copper	43	73	47	14	253	7,680	1,396
Iron	661	410	731	27,683	1,256	3,750,000	7,791

Table K4.18-3: Modeled Mass Loads – Final Year of Operations

Parameter	WTP#1 Inflows	WTP#2 Inflows	Open Pit Water Management Pond	Bulk TSF	Main Embankment Seepage Collection Pond	Pyritic TSF	Main Water Management Pond
	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)	Maximum Monthly Load (kg)
Lead	2	33	2	38	34	98	618
Magnesium	8,506	118,900	9,383	175,300	67,330	372,621	2,269,000
Manganese	1,116	2,239	1,220	2,673	1,976	8,541	42,524
Mercury	0.2	0.3	0.2	0.2	0.3	2	5
Molybdenum	257	3,875	285	2,318	8,177	9,599	73,283
Nickel	16	107	17	170	34	392	2,036
Potassium	15,663	79,344	10,982	105,569	22,875	560,767	1,528,000
Selenium	8	38	9.2	44	37	119	717
Silver	0.3	3	0.4	2	7	9	65
Sodium	25,461	159,602	18,217	227,698	60,954	791,660	3,056,000
Thallium	0.4	0.8	0.4	1	0.3	3	15
Silicon	4,606	17,846	4,228	10,180	23,708	84,989	344,810
Tin	1	68	1	40	136	167	1,279
Vanadium	1	16	2	7	20	141	313
Zinc	418	2,234	463	3,335	1,298	8,191	42,644
Nitrate_N	2,117	4,416	1,396	3,629	3,343	11,633	87,099
Nitrate (ion)	9,370	17,140	6,182	12,264	14,798	34,821	337,681
Nitrite	187	343	124	245	296	696	6,754
Ammonia	212	742	140	565	334	5,738	14,369
Hardness as $CaCO_3$	150,302	1,521,341	165,010	1,642,427	1,585,146	5,557,120	28,867,785

Notes:
Tailings pond adjustment values were applied for Al, SO_4, Fe, Cu, and Mn in the Bulk TSF and Pyritic TSF.
TDS values were calculated by summing alkalinity, Cl, F, SO_4, Ca, Mg, K, Na, and Si.
Model assumes return of sludge and reject flows from WTP#1 and WTP#2 to the pyritic TSF via the pyritic tailings line.
Hardness Values were calculated based on the following: Hardness ($CaCO_3$) = Calcium Concentration (mg/L)*2.497+Magnersium Concentration (mg/L)*4.118
Percentile results are based on 76 Realizations of model simulations.
$CaCo_3$ = calcium carbonate
Model assumes additional loading from in-pit stockpile in the open pit during the summer months.
Model assumes the loading from the PAG waste rock in the Pyritic TSF as a flushing term as provided by SRK 2018a.
pH was not modeled and pH values are based on the range of pH source terms provided by SRK 2018a.
Results are presented as the seasonal maximum load for the final year of operation; the maximum month with the load is not necessarily the same as the month with the maximum concentration.
kg = kilogram
Source: Knight Piésold 2019a



Sources: Knight Piesold 2019a

Legend

- OPWMP Direct Precipitation (Precipitation Source Term)
- OPWMP Undiverted Runoff (SFK Source Term)
- OP Groundwater (Groundwater Source Term)
- OP Pitwall Runoff (Pre-Tertiary Non-Acidic, Pre-Tertiary Acidic, Tertiary Non-Acidic Source Terms)
- OP Undiverted Runoff (SFK Source Term)
- OP Diversion Leakage (SFK Source Term)

NOTES:

1. LOADS ARE SHOWN AS TOTAL ANNUAL INPUTS FOR THE FINAL YEAR OF OPERATIONS AND ARE BASED ON THE 50TH PERCENTILE RESULTS FROM 76 MODEL REALIZATION FROM THE CLIMATE VARIABLE MODEL (KP 2018a).

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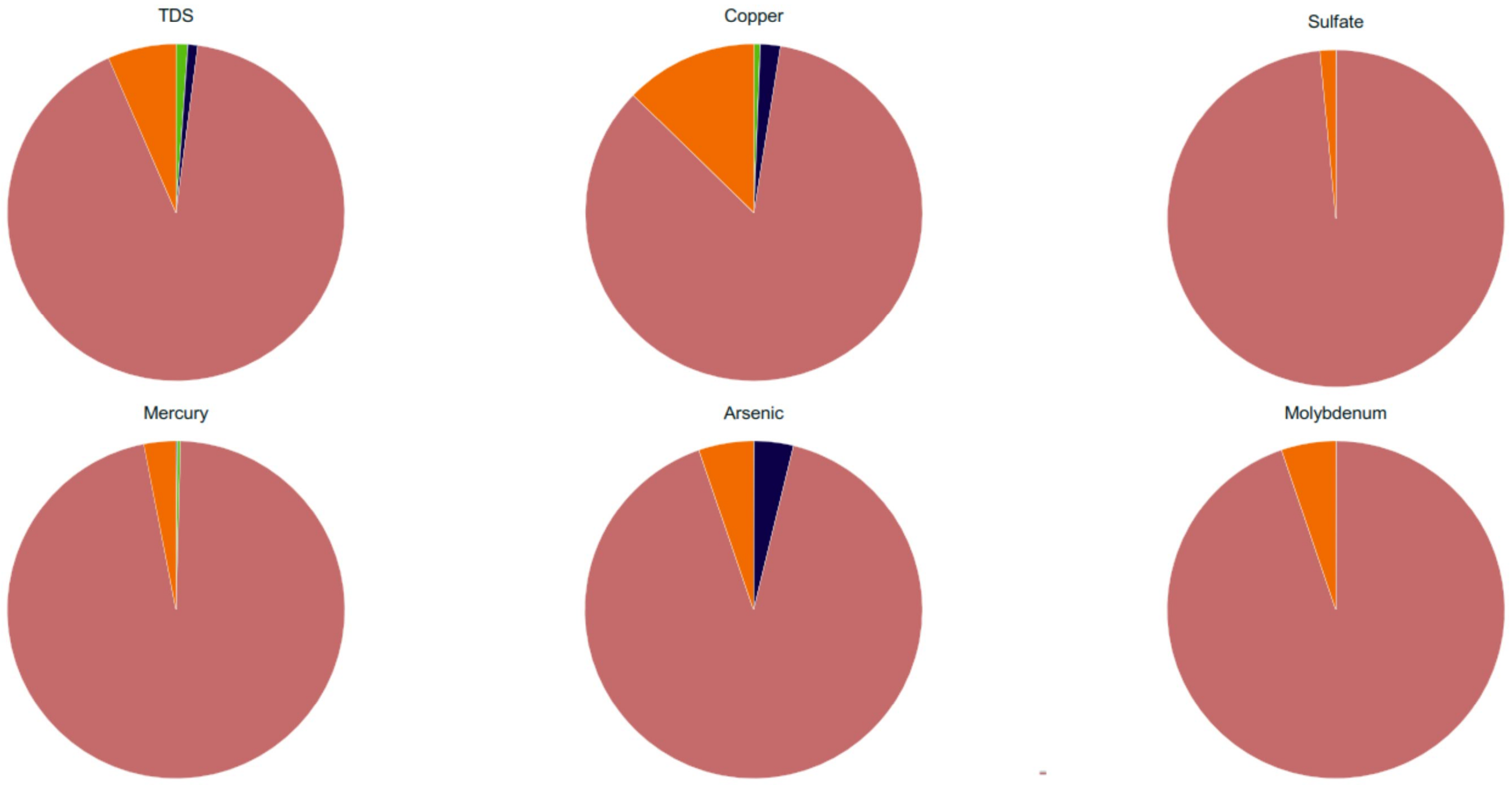
INFLOW LOADS – OPEN PIT WATER MANAGEMENT POND



Sources: Knight Piesold 2019a

Legend

- Direct Precipitation (Precipitation Source Term)
- Undiverted Runoff (NFK Source Term)
- Diversion Leakage (NFK Source Term)
- Beach Runoff (Rougher Tailings Source Term)
- Tailings Slurry (Concentration in Mill after Tailings Pond Adjustment)
- Recycle from South SCP (Concentration in SCP)

NOTES:

1. LOADS ARE SHOWN AS TOTAL ANNUAL INPUTS FOR THE FINAL YEAR OF OPERATIONS AND ARE BASED ON THE 50TH PERCENTILE RESULTS FROM 76 MODEL REALIZATION FROM THE CLIMATE VARIABLE MODEL (KP 2018a).

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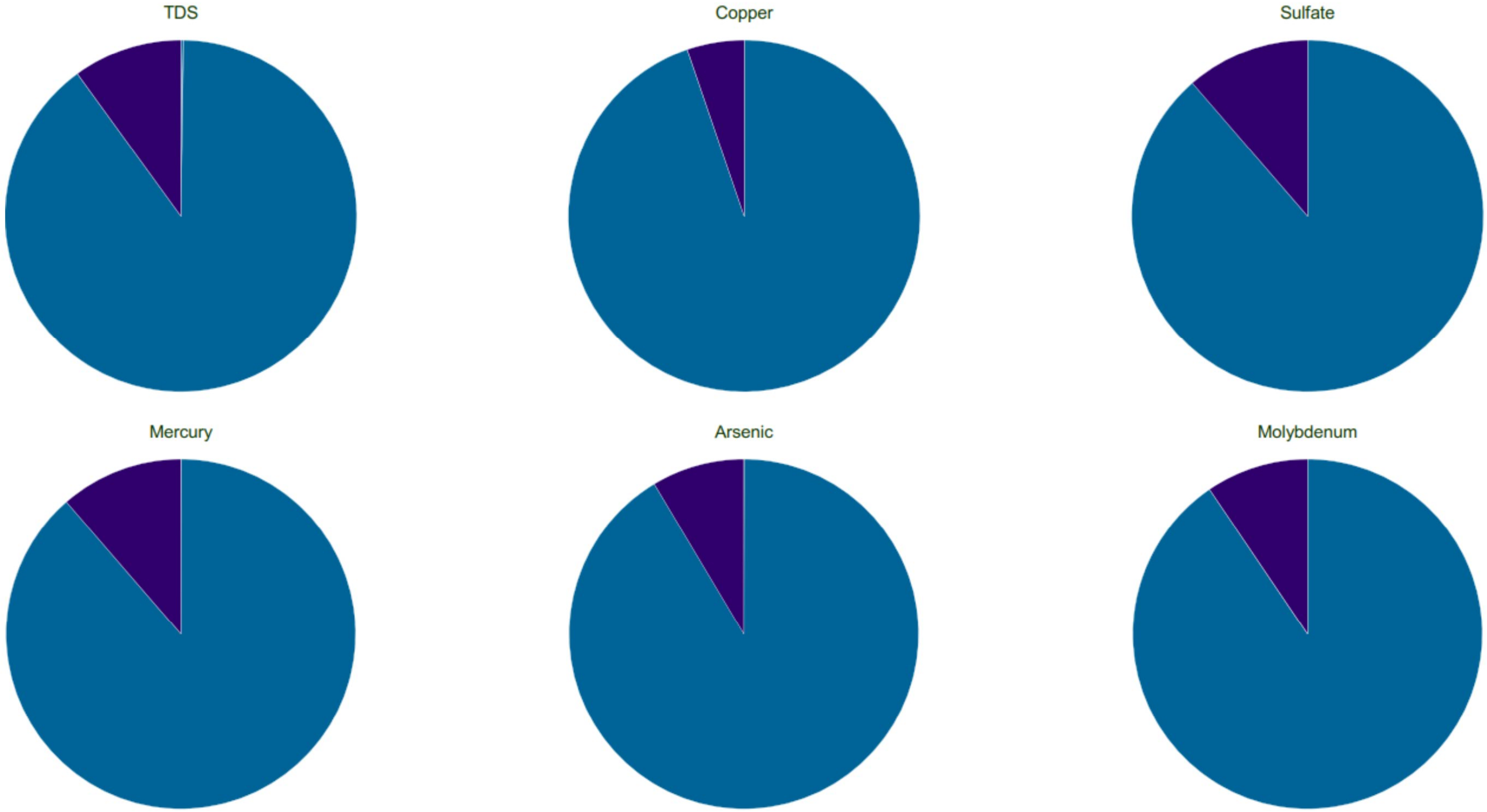
INFLOW LOADS – BULK TSF

PEBBLE PROJECT EIS

FIGURE K4.18-2



Sources: Knight Piesold 2019a

Legend

- Precipitation (Direct Precipitation Source Term)
- Undiverted Runoff (NFK Source Term)
- Diversion Leakage (NFK Source Term)
- Embankment Seepage (Rougher Tails Seepage Source Term)
- Embankment Runoff (Quarried Rockfill Source Term)

NOTES:

1. LOADS ARE SHOWN AS TOTAL ANNUAL INPUTS FOR THE FINAL YEAR OF OPERATIONS AND ARE BASED ON THE 50TH PERCENTILE RESULTS FROM 76 MODEL REALIZATION FROM THE CLIMATE VARIABLE MODEL (KP 2018a).

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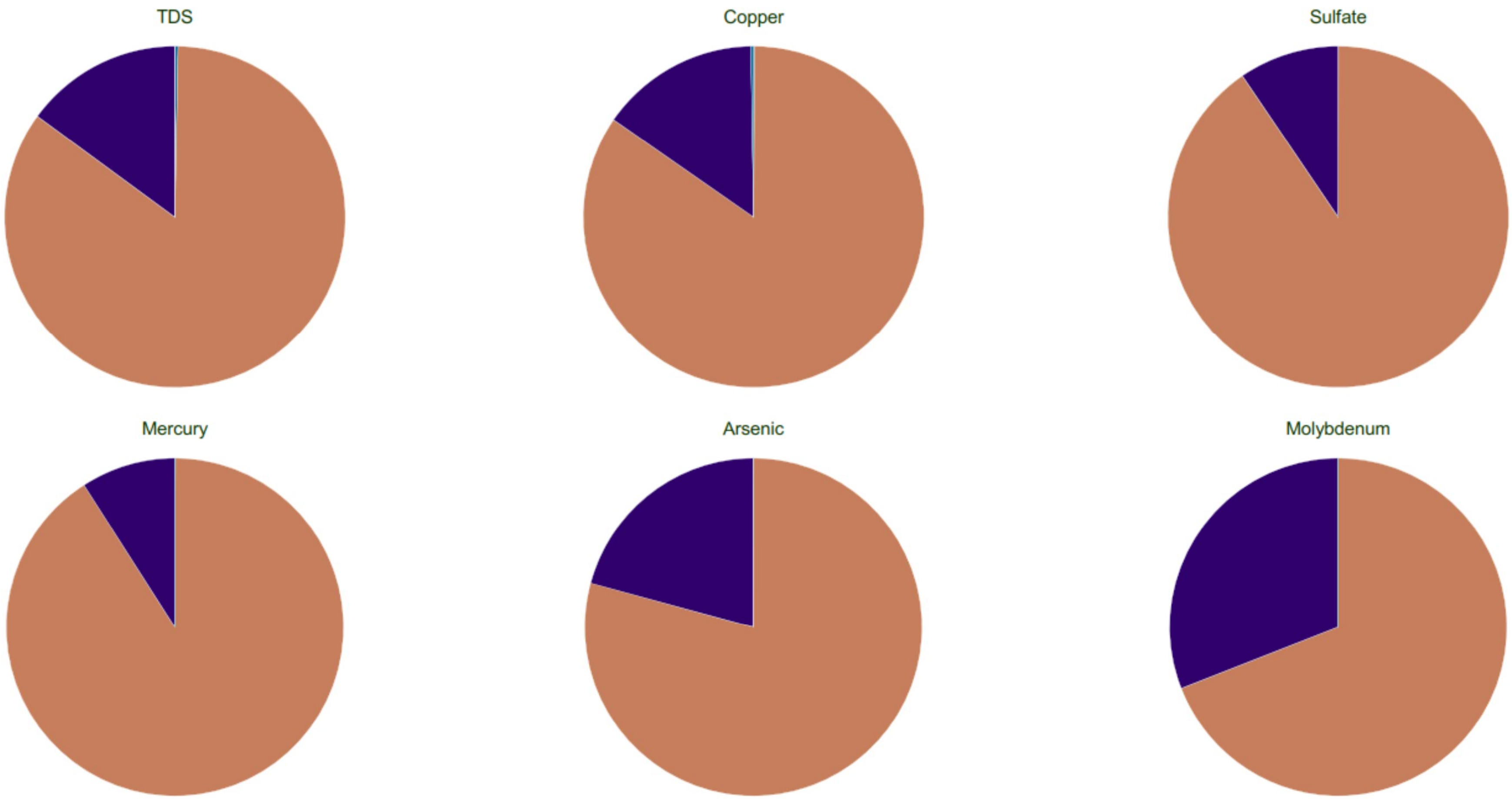
INFLOW LOADS – MAIN EMBANKMENT SEEPAGE COLLECTION POND



Sources: Knight Piesold 2019a

Legend

- Direct Precipitation (Precipitation Source Term)
- Diversion Leakage (NFK Source Term)
- Undiverted Runoff (NFK Source Term)
- Pyritic Slurry (Ore Source Term, Plus Reclaim Loads and WTP Sludge and Reject
- Embankment Runoff (Quarry Source Term)
- PAG Waste Rock (PAG WR Source Term)

NOTES:

1. LOADS ARE SHOWN AS TOTAL ANNUAL INPUTS FOR THE FINAL YEAR OF OPERATIONS AND ARE BASED ON THE 50TH PERCENTILE RESULTS FROM 76 MODEL REALIZATION FROM THE CLIMATE VARIABLE MODEL (KP 2018a).

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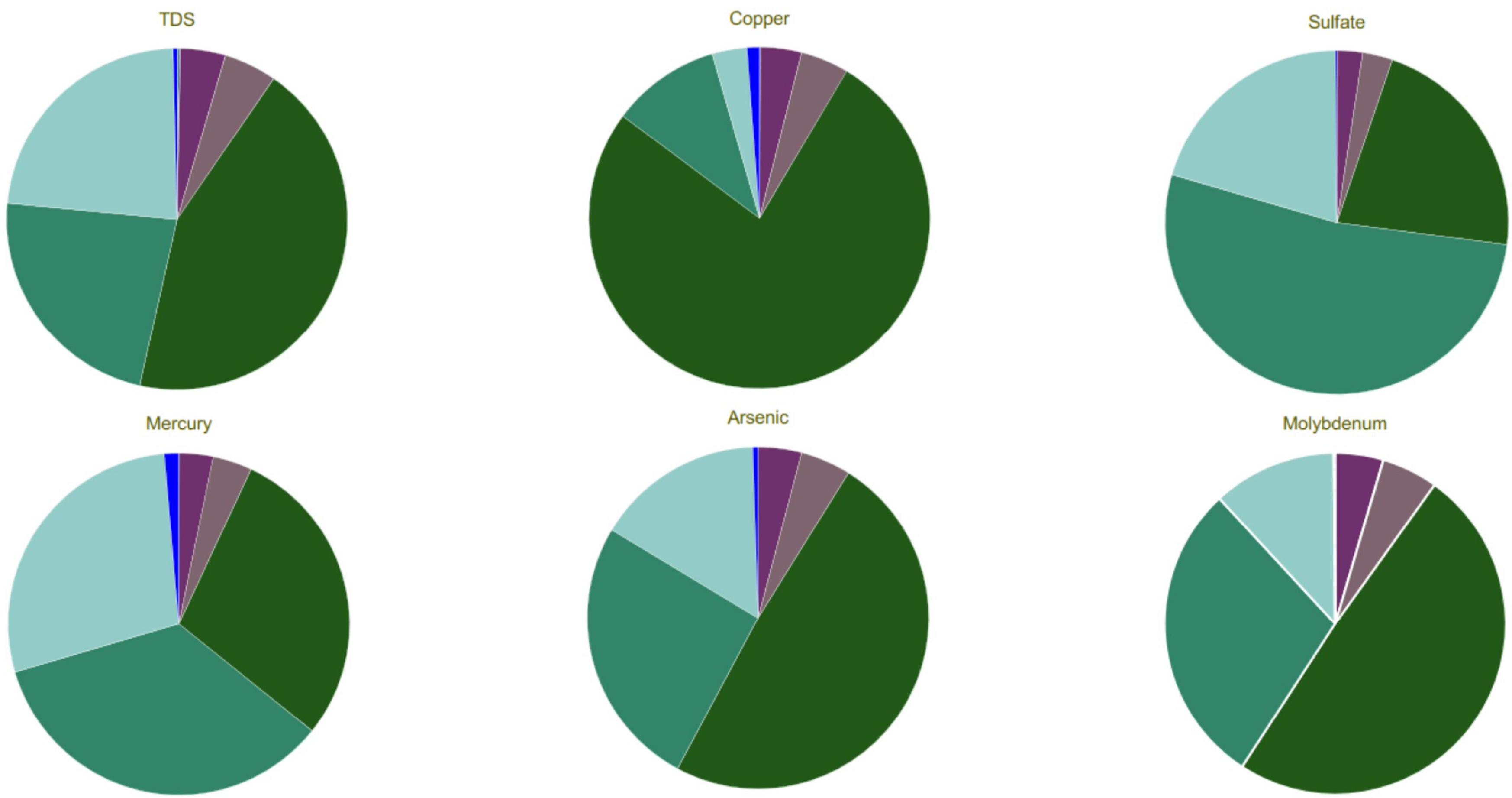
INFLOW LOADS – PYRITIC TSF



Sources: Knight Piesold 2019a

- Direct Precipitation (Precipitation Source Term)
- Diversion Leakage (NFK Source Term)
- Undiverted Runoff (NFK Source Term)
- Blow Down Water (WTP Effluent Source Term)
- Pyritic TSF Embankment Runoff (Quarry Source Term)
- Mill Site Runoff (Quarry Source Term)
- MESCP Surplus (Concentration of the MESCP)
- Bulk TSF Surplus (Concentration of the Bulk TSF)
- Pyritic TSF Surplus (Concentration of the Pyritic TSF)
- Open Pit WMP Surplus (Concentration of the OP WMP)

NOTES:

1. LOADS ARE SHOWN AS TOTAL ANNUAL INPUTS FOR THE FINAL YEAR OF OPERATIONS AND ARE BASED ON THE 50TH PERCENTILE RESULTS FROM 76 MODEL REALIZATION FROM THE CLIMATE VARIABLE MODEL (KP 2018a).

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INFLOW LOADS – MAIN WATER MANAGEMENT POND

Predicted Water Quality

Table K4.18-4 shows the predicted water quality in mine site facility ponds during the final year of operations from the Knight Piésold (2018a) water quality model. Values in the table represent the maximum monthly predicted concentrations for the 10^{th}, 50^{th}, and 90^{th} percentile flow values, using the 95^{th} percentile source term concentrations, for waste streams going to the WTPs from each facility. As described above, the 95^{th} percentile represents a source term input to the water quality model that would be greater than 95 percent of all possible inputs to the WTP, hence insuring a conservative range of estimates from the water quality model.

Water quality feeding the WTPs would be primarily controlled by constituent concentrations from the open pit WMP for WTP#1 and the main WMP for WTP#2. Modeled water quality for inflow into WTP#1 and WTP#2 in operations are provided in Table K4.18-5. Water quality predictions for WTP#1 are dominated by loading from open pit dewatering. The maximum predicted concentrations in the open pit WMP would occur during the summer months because of the in-pit stockpile loads from the open pit. The influent water quality to WTP#1 would be expected to gradually worsen with each year of mine activity as more pre-Tertiary age rock is exposed to oxygen and water. Thus, pit wall runoff in early years of mining would be expected to be of better quality than at the end of mine life (i.e., after 20 years). To be conservative, the water quality estimate for end of mine life was used in all simulations to represent all years of mining.

The main WMP manages surplus water from the mine site. The majority of loading to the main WMP would be primarily from the bulk and pyritic TSFs. However, the maximum predicted concentrations in the main WMP would be less than in the bulk and pyritic TSFs because of the continuous removal of loads from the main WMP via reclaim water that is directed to the process plant and to WTP#2. The bulk tailings slurry water drives the loading in the bulk TSF supernatant pond. Similarly, the pyritic tailings slurry water drives the majority of loading in the pyritic TSF, with both sludge reject and reverse osmosis (RO) reject flows from the WTPs contributing to the loading. The flushing load from potentially acid generating (PAG) waste rock in the pyritic TSF provides loading to the pyritic TSF supernatant pond; however, the load from the PAG waste rock is not as great as that from the tailing slurry water.

As described below, water collected at the mine site that does not meet discharge water quality criteria would be treated in the WTPs prior to discharge to the environment. Treated water in excess of process requirements would be released to the environment in the NFK, SFK, and UTC watersheds at flows protective of the environment to the extent possible given the capacities of the WTPs and need for process water use onsite. Impacts on flows in these watersheds are discussed in Section 4.16, Surface Water Hydrology, and Section 4.24, Fish Values.

Table K4.18-4: Predicted Water Quality in Mine Site Storage Ponds[a,b] in Operations

Parameters (mg/L)	Open Pit Water Management Pond[c]			Bulk TSF[d]			Main Embankment Seepage Collection Pond			Pyritic TSF[d,e,f]			Main Water Management Pond		
	Maximum Monthly[a]			Maximum Monthly			Maximum Monthly			Maximum Monthly			Maximum Monthly		
Percentile	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
TDS[g]	214.57	267.22	292.54	**2451.59**	**2492.68**	**2493.12**	**1112.05**	**3939.99**	**4211.05**	**2428.60**	**2932.66**	**3029.68**	**1469.77**	**1676.71**	**1825.69**
Alkalinity	50.14	56.05	57.71	389.20	395.30	395.50	182.40	746.00	770.30	203.20	234.10	247.70	222.90	251.50	277.00
Acidity	7.42	7.42	7.49	1.85	2.49	2.03	2.02	7.11	7.51	1.17	6.09	1.39	1.79	2.53	2.00
Chloride	1.67	1.98	2.06	19.46	19.79	19.79	2.68	8.86	9.33	9.58	12.02	11.98	8.41	9.56	10.63
Fluoride	0.17	0.21	0.22	0.48	0.49	0.49	0.26	0.86	0.90	0.31	0.65	0.36	0.29	0.35	0.35
Sulfate	81.03	108.50	116.20	**1,391.00**	**1,415.00**	**1,415.00**	**651.00**	**2,250.00**	**2,359.00**	**1,554.00**	**1,873.00**	**1,943.00**	**850.80**	**972.50**	**1,057.00**
Aluminum	0.0703	**0.0947**	**0.1019**	0.0006	0.0006	0.0006	**0.5478**	**2.4350**	**2.5010**	0.0006	0.0006	0.0006	**0.2373**	**0.2514**	**0.2697**
Antimony	0.005	**0.007**	**0.007**	**0.022**	**0.026**	**0.027**	**0.048**	**0.193**	**0.200**	**0.042**	**0.061**	**0.055**	**0.032**	**0.036**	**0.038**
Arsenic	**0.015**[h]	**0.020**	**0.021**	**0.031**	**0.035**	**0.038**	**0.063**	**0.252**	**0.260**	**0.054**	**0.073**	**0.070**	**0.042**	**0.047**	**0.050**
Barium	0.053	0.070	0.075	0.078	0.080	0.080	0.036	0.145	0.150	0.061	0.127	0.071	0.047	0.058	0.058
Beryllium	0.0001	0.0002	0.0002	**0.0447**	**0.0455**	**0.0455**	0.0014	**0.0048**	**0.0050**	**0.0212**	**0.0250**	**0.0269**	**0.0172**	**0.0197**	**0.0223**
Bismuth	0.004	0.006	0.006	0.010	0.012	0.013	0.028	0.096	0.100	0.030	0.036	0.041	0.017	0.019	0.020
Boron	0.04	0.05	0.06	0.26	0.26	0.26	0.14	0.50	0.52	0.20	0.25	0.23	0.16	0.18	0.19
Cadmium	**0.0054**	**0.0073**	**0.0079**	**0.0182**	**0.0186**	**0.0186**	**0.0022**	**0.0097**	**0.0100**	**0.0176**	**0.0206**	**0.0212**	**0.0085**	**0.0099**	**0.0110**
Calcium	36.72	44.86	47.15	270.90	275.10	275.30	213.30	737.10	772.70	314.90	398.80	390.00	202.20	228.10	244.00
Chromium	0.001	0.001	0.001	0.005	0.005	0.005	0.006	0.019	0.020	0.005	0.006	0.005	0.004	0.005	0.005
Cobalt	0.025	0.034	0.037	0.043	0.044	0.044	0.014	0.048	**0.050**	**0.057**	**0.074**	**0.075**	0.025	0.029	0.031
Copper	**0.031**	**0.042**	**0.045**	**0.010**	**0.010**	**0.010**	**0.075**	**0.362**	**0.370**	**0.010**	**0.010**	**0.010**	**0.039**	**0.042**	**0.045**
Iron	0.478	0.646	0.697	0.002	0.002	0.002	0.535	1.707	1.806	0.002	0.002	0.002	0.202	0.212	0.221
Lead	**0.001**	**0.002**	**0.002**	**0.028**	**0.028**	**0.028**	**0.014**	**0.048**	**0.050**	**0.020**	**0.022**	**0.022**	**0.016**	**0.018**	**0.020**
Magnesium	6.38	8.30	8.84	128.80	130.90	130.90	27.70	94.69	99.36	72.19	95.34	85.98	59.66	68.64	75.35
Manganese	**0.92**	**1.08**	**1.13**	**1.96**	**2.00**	**2.00**	**0.74**	**2.80**	**2.90**	**1.69**	**2.00**	**1.97**	**1.10**	**1.30**	**1.38**
Mercury	**0.00014**	**0.00019**	**0.00020**	**0.00015**	**0.00015**	**0.00015**	**0.00014**	**0.00048**	**0.00050**	**0.00033**	**0.00041**	**0.00046**	**0.00014**	**0.00015**	**0.00016**
Molybdenum	**0.19**	**0.25**	**0.27**	**1.59**	**1.77**	**1.97**	**3.02**	**11.57**	**12.01**	**1.92**	**2.10**	**2.21**	**1.94**	**2.13**	**2.34**
Nickel	0.011	**0.015**	**0.016**	**0.125**	**0.127**	**0.127**	**0.014**	**0.048**	**0.050**	**0.077**	**0.090**	**0.091**	**0.053**	**0.061**	**0.068**
Potassium	12.72	15.94	20.91	77.53	78.79	78.83	5.57	17.31	36.31	105.10	125.10	142.50	38.38	45.16	49.19
Selenium	**0.006**	**0.008**	**0.009**	**0.032**	**0.033**	**0.033**	**0.015**	**0.053**	**0.055**	**0.024**	**0.032**	**0.027**	**0.019**	**0.022**	**0.023**
Silver	0.0002	0.0003	0.0003	**0.0013**	**0.0015**	**0.0016**	**0.0028**	**0.0096**	**0.0100**	**0.0018**	**0.0020**	**0.0021**	**0.0017**	**0.0018**	**0.0020**
Sodium	21.12	26.12	33.81	167.20	170.20	170.20	19.82	65.13	131.90	153.60	175.90	186.90	78.90	92.26	103.10
Thallium	0.00026	0.00036	0.00038	0.00090	0.00092	0.00092	0.00014	0.00048	0.00050	0.00052	0.00076	0.00062	0.00040	0.00047	0.00051
Silicon	4.80	5.47	5.86	7.50	7.60	7.60	9.58	20.90	32.15	16.03	18.40	21.62	8.53	8.99	9.42
Tin	0.001	0.001	0.001	0.027	0.031	0.034	0.054	0.192	0.201	0.034	0.042	0.038	0.034	0.037	0.040
Vanadium	0.001	0.001	0.002	0.005	0.005	0.005	0.008	0.029	0.030	0.025	0.032	0.037	0.008	0.009	0.009

Parameters (mg/L)	Open Pit Water Management Pond[c]			Bulk TSF[d]			Main Embankment Seepage Collection Pond			Pyritic TSF[d,e,f]			Main Water Management Pond		
	Maximum Monthly[a]			Maximum Monthly			Maximum Monthly			Maximum Monthly			Maximum Monthly		
Zinc	**0.30**	**0.41**	**0.44**	**2.45**	**2.49**	**2.49**	**0.40**	**1.86**	**1.90**	**1.60**	**1.97**	**1.89**	**1.12**	**1.30**	**1.44**
Nitrate_N	1.64	2.16	2.97	2.36	2.73	3.17	4.87	4.87	4.87	2.17	2.51	2.85	2.08	2.42	2.92
Nitrate (ion)	7.25	**9.57**	**13.13**	7.79	9.15	**10.90**	**21.56**	**21.56**	**21.56**	6.29	7.53	9.07	7.94	9.38	**11.43**
Nitrite	0.14	0.19	0.26	0.16	0.18	0.22	0.43	0.43	0.43	0.13	0.15	0.18	0.16	0.19	0.23
Ammonia	0.16	0.22	0.30	0.37	0.43	0.48	0.49	0.49	0.49	1.07	1.25	1.49	0.34	0.40	0.45
Hardness as $CaCO_3$[i]	117.98	146.19	154.14	1206.84	1225.97	1226.47	646.68	2230.47	2338.60	1083.58	1388.41	1327.90	750.57	852.23	919.56
pH[j]	-	7 to 8	-	-	7 to 8	-	-	7 to 8	-	-	7 to 8	-	-	7 to 8	-

Notes:
[a] End of mine life maximum monthly 10th, 50th, and 90th percentile results based on 76 realizations of model simulations.
[b] Model input concentrations provided by SRK (dated 20 June 2018).
[c] Model assumes loading from in-pit stockpile in the open pit during summer months.
[d] Tailings pond adjustment values were applied for Al, SO4, Fe, Cu and Mn in the bulk and pyritic TSFs.
[e] Model assumes return of sludge and reject flows from WTP#1 and WTP#2 to the pyritic TSF via the pyritic tailings line. WTP effluent, sludge, and reject concentrations were provided by HDR (dated 4 January 2018).
[f] Model assumes loading from PAG waste rock in the pyritic TSF as a flushing term provided by SRK (dated 20 June 2018).
[g] TDS values were calculated by summing alkalinity, Cl, F, SO4, Ca, Mg, K, Na, and Si.
[h] Bold values indicate exceedances of most stringent water quality parameters (Appendix K3.18, Table K3.18-1).
[i] Hardness values were calculated based on the equation, hardness (CaCO3) = calcium concentration (mg/l) x 2.497 + magnesium concentration (mg/L) x 4.118.
[j] pH was not modeled; pH values are based on the range of pH source terms provided by SRK (dated 20 June 2018) (Knight Piésold 2018a).
$CaCo_3$ = calcium carbonate
TDS = total dissolved solids
Source: Knight Piesold 2019a

Table K4.18-5: Predicted Water Quality Inflows for WTPs in Operations

Parameters (mg/L)	WTP#1			WTP#2		
	10th Percentile	50th Percentile	90th Percentile	10th Percentile	50th Percentile	90th Percentile
Flows[5]	14			38		
pH	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8
TDS	214.57	267.22	292.54	**1,469.77**	**1,676.71**	**1,825.69**
Alkalinity	50.14	56.05	57.71	222.90	251.50	277.00
Acidity	7.42	7.42	7.49	1.79	2.53	2.00
Chloride	1.67	1.98	2.06	8.41	9.56	10.63
Fluoride	0.17	0.21	0.22	0.29	0.35	0.35
Sulfate	81.03	108.50	116.20	**850.80**	**972.50**	**1,057.00**
Aluminum	0.0703	**0.0947**	**0.1019**	**0.2373**	**0.2514**	**0.2697**
Antimony	0.0050	**0.0068**	**0.007**	**0.032**	**0.036**	**0.038**
Arsenic	**0.0148**	**0.0200**	**0.021**	**0.042**	**0.047**	**0.050**
Barium	0.0532	0.0699	0.075	0.047	0.058	0.058
Beryllium	0.00013	0.00017	0.0002	**0.0172**	**0.0197**	**0.0223**
Bismuth	0.0044	0.0060	0.006	0.017	0.019	0.020
Boron	0.040	0.054	0.06	0.16	0.18	0.19
Cadmium	**0.00540**	**0.00734**	**0.0079**	**0.0085**	**0.0099**	**0.0110**
Calcium	36.72	44.86	47.15	202.20	228.10	244.00
Chromium	0.00095	0.00111	0.001	0.004	0.005	0.005
Cobalt	0.02531	0.03439	0.037	0.025	0.029	0.031
Copper	**0.0308**	**0.0418**	**0.045**	**0.039**	**0.042**	**0.045**
Iron	0.478	0.646	0.697	0.202	0.212	0.221
Lead	**0.0015**	**0.0020**	**0.002**	**0.016**	**0.018**	**0.020**
Magnesium	6.38	8.30	8.84	59.66	68.64	75.35
Manganese	**0.92**	**1.08**	**1.13**	**1.10**	**1.30**	**1.38**
Mercury	**0.000137**	**0.000185**	**0.00020**	**0.00014**	**0.00015**	**0.00016**
Molybdenum	**0.19**	**0.25**	**0.27**	**1.94**	**2.13**	**2.34**

Parameters (mg/L)	WTP#1			WTP#2		
	10th Percentile	50th Percentile	90th Percentile	10th Percentile	50th Percentile	90th Percentile
Nickel	0.0113	**0.0152**	**0.016**	**0.053**	**0.061**	**0.068**
Potassium	12.72	15.94	20.91	38.38	45.16	49.19
Selenium	**0.0063**	**0.0081**	**0.009**	**0.019**	**0.022**	**0.023**
Silver	0.00023	0.00031	0.00033	**0.0017**	**0.0018**	**0.0020**
Sodium	21.12	26.12	33.81	78.90	92.26	103.10
Thallium	0.000265	0.000357	0.00038	0.00040	0.00047	0.00051
Silicon	4.80	5.47	5.86	8.53	8.99	9.42
Tin	0.0008	0.0010	0.001	0.034	0.037	0.040
Vanadium	0.0012	0.0014	0.002	0.008	0.009	0.009
Zinc	**0.301**	**0.409**	**0.44**	**1.12**	**1.30**	**1.44**
Nitrate_N	1.64	2.16	2.97	2.08	2.42	2.92
Nitrate (ion)	7.25	9.57	**13.13**	7.94	9.38	**11.43**
Nitrite	0.145	0.191	0.26	0.16	0.19	0.23
Ammonia	0.164	0.216	0.30	0.34	0.40	0.45
Hardness as $CaCO_3$	117.98	146.19	154.14	750.57	852.23	919.56

Notes:
Bold values indicate exceedances of the most stringent water quality criteria.
50^{th} and 90^{th} percentile results are based on variable climate inputs to the water balance model and do not represent other areas of variability in the model.
Hardness values were calculated based on the following: Hardness ($CaCO_3$) = Calcium Concentration (mg/L)*2.497+Magnesium Concentration (mg/L)*4.118
Flow values presented are maximum inflow rates and do not necessarily coincide with the predicted 10^{th}, 50^{th}, or 90^{th} percentile water quality results.
$CaCo_3$ = calcium carbonate
mg/L = milligrams/liter
Source: Knight Piésold 2019a

K4.18.1.2 Closure and Post-Closure

The closure strategy for the mine site is to decommission and reclaim facilities that leave the mine site in a stable condition that complies with regulations and closure criteria, and prevents unnecessary degradation of land and water resources. To assess closure effectiveness, water balance, water quality, and pit lake models for the closure and post-closure periods of the mine were based on a four-phase closure plan as outlined below:

- **Phase 1** – reclamation of quarries and bulk TSF; backfilling of open pit by Closure Year 15.
- **Phase 2** – bulk TSF and quarries reclaimed; backfilling of open pit complete; reclamation of pyritic TSF and main WMP; pit dewatering ceases; water flow into the pit creating a lake; no water treatment needed in Closure Years 16 through approximately 20 as the pit fills to its maximum maintenance level (WTP #3 used for treatment if necessary to meet downstream flows based on adaptive management and monitoring).
- **Phase 3** – pyritic TSF and main WMP reclaimed; ongoing treatment of surplus water in open pit in Closure Years 20 through 50 to maintain pit as hydraulic sink to capture groundwater and mitigate potential for contaminant release along subsurface pathways.
- **Phase 4** – post-closure long-term conditions.

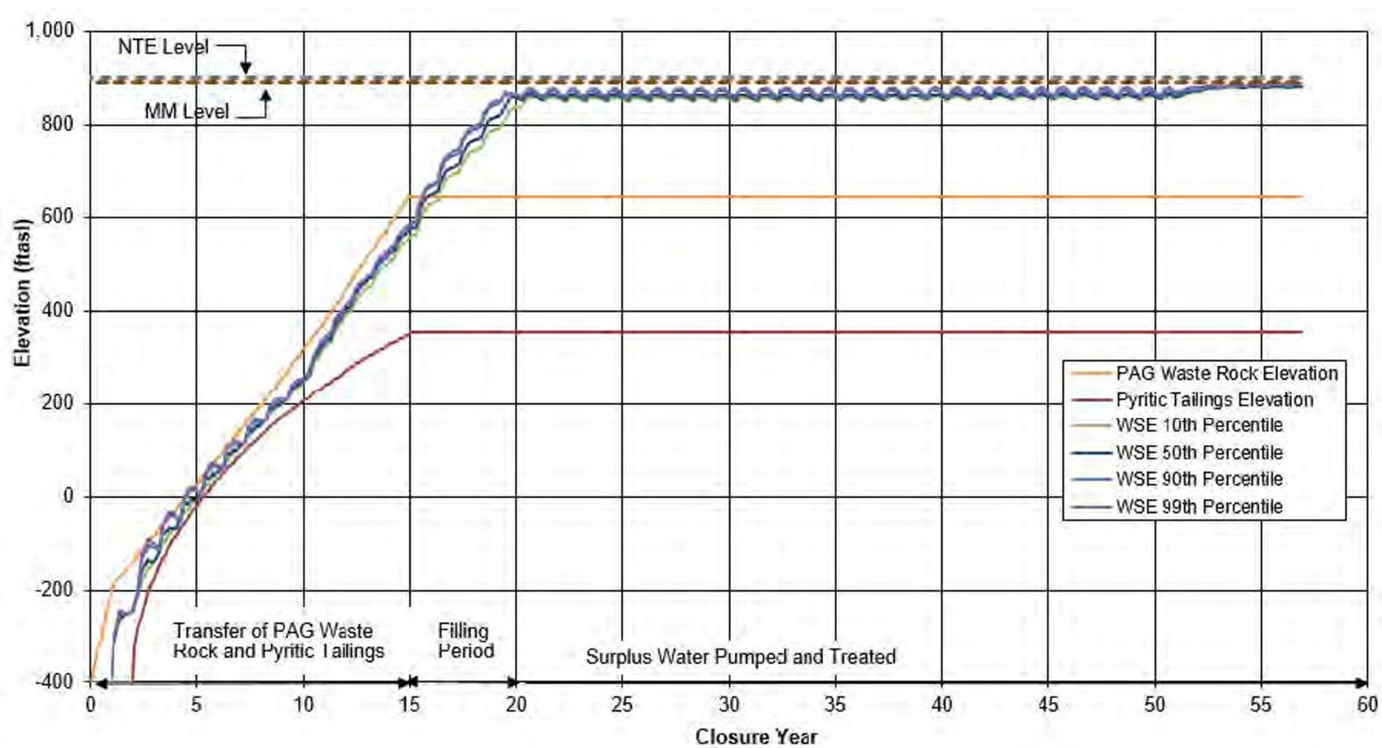
The mine layout during each of the closure phases is described and shown on figures in Section 4.16, Surface Water Hydrology, and reclamation of project facilities is described in more detail in Knight Piésold (2018d).

This section contains the results of water balance and water quality modeling for mine site facilities in closure, including the TSFs, main WMP, main SCP, WTPs, and open pit (Phases 1 and 2 only). Additional modeling of pit lake water quality in later closure phases related to lake water stratification is provided at the end of this section.

Water Balance Model

The closure and post-closure water balance model was developed similar to the operations model to estimate water flow volumes for the various facilities during the closure phases under varying historical climate conditions. The development and methodologies used in the closure phase models are similar to those described above for operations phase. Details regarding model inputs and assumptions are provided in Knight Piésold (2018d).

Water balance model information in Section 4.16, Surface Water Hydrology, and Appendix K4.16 describes the sources of contact water entering the main WMP, the WTPs, and the open pit in the closure phases. The results of the closure and post-closure water balance model are summarized in Figure K4.18-6 through Figure K4.18-8. Figure K4.18-6 shows the estimated open pit water surface elevations during closure. The approximate elevations of the PAG waste rock and pyritic tailings are also shown for reference. Figure K4.18-6 indicates that it would take 19 to 21 years to fill the open pit to the maximum management (MM) level depending on climatic conditions. The MM level is set at 890 feet above mean sea level, 10 feet below the not to exceed (NTE) level of 900 feet (Piteau Associates 2018a), so that the open pit can store the probable maximum flood without encroaching on the NTE level. The NTE level is set below the static groundwater level so that the open pit functions as a hydraulic sink maintaining groundwater flow towards the pit. Surplus from the open pit yields a flow rate of about 3 cfs, when averaged throughout the year. This water would be pumped and treated to maintain the water surface elevation below the MM level throughout post-closure.



NOTES:

1. NTE LEVEL: NOT TO EXCEED LEVEL.
2. MM LEVEL: MAXIMUM MANAGEMENT LEVEL.

Source: KP 2018d, Figure 5.1

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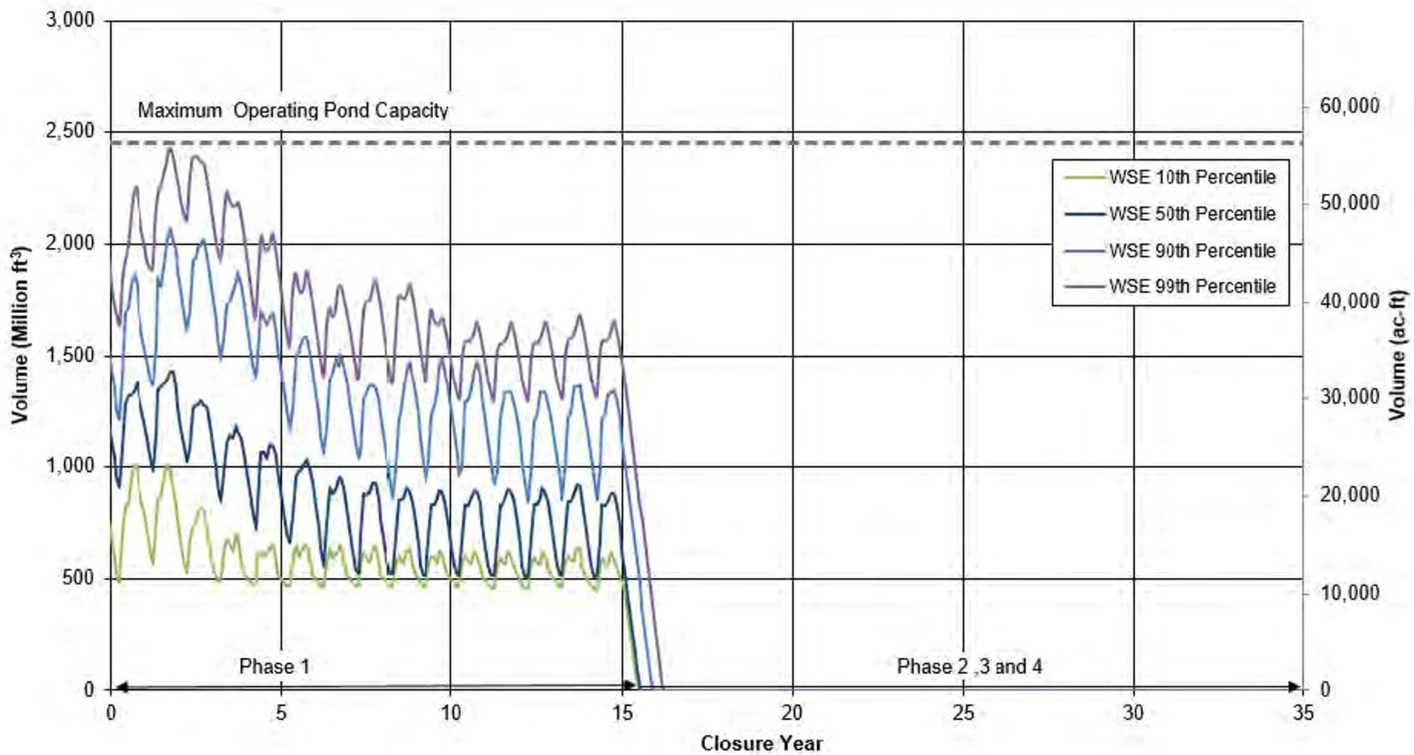
OPEN PIT WATER SURFACE ELEVATIONS



Source: KP 2018d, Figure 5.2

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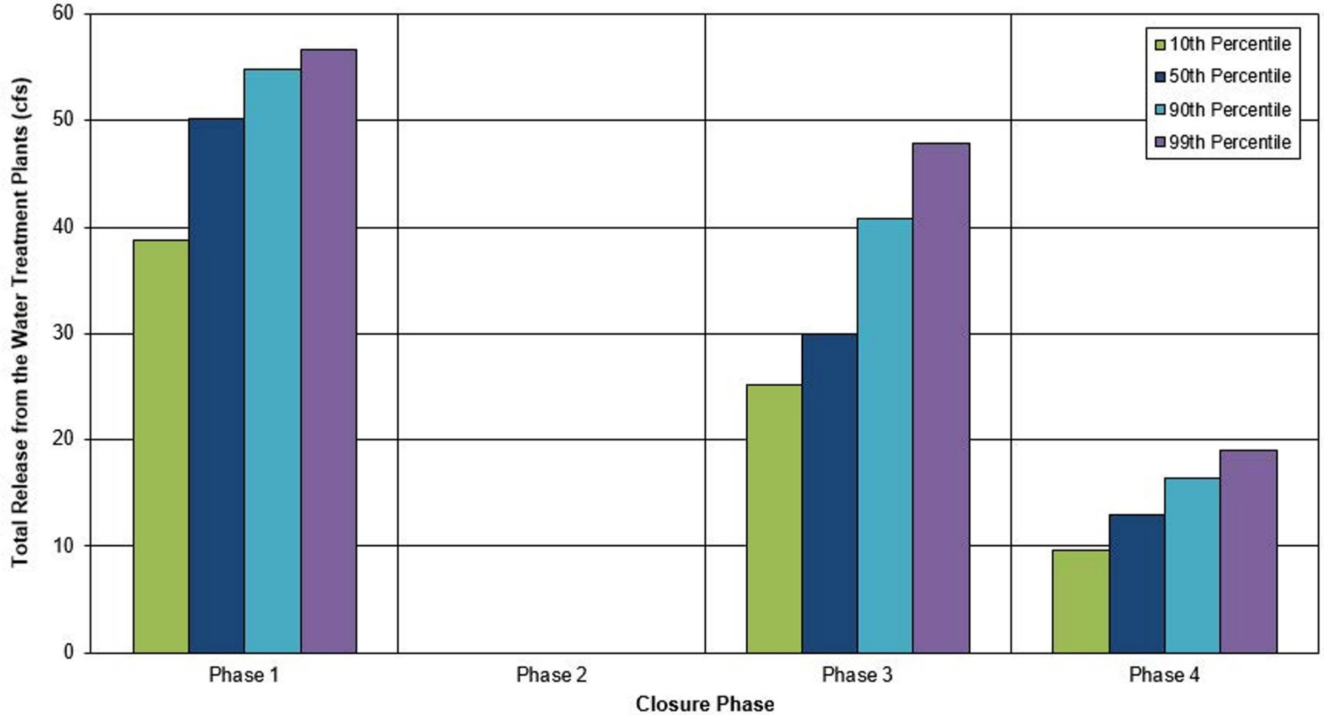
MAIN WMP VOLUMES IN EARLY CLOSURE



NOTE: RELEASES INCLUDE THOSE FROM BOTH WTP#2 AND WTP#3 IN CLOSURE PHASE 3.

Source: KP 2018d, Figure 5.3

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AVERAGE ANNUAL FLOW FROM WTPS IN CLOSURE

Main WMP pond volumes are expected to vary based on the amount of water captured at the mine site, which depends on climate variability. Figure K4.18-7 shows the expected range of pond volumes in early closure representing dry to wet conditions. The results depicted on this figure indicate that the main WMP has the capacity to manage surplus water from the mine site during closure phases 1 and 2, when the bulk and pyritic TSF are being reclaimed. The water in the main WMP is estimated to operate below the maximum operating pond capacity at all times during closure.

Table K4.18-6 and Figure K4.18-8 show the estimated average annual flows and flow volumes from the WTPs during closure. Data is presented on a monthly basis for various different modeled scenarios ranging from the 1st percentile (near minimum discharge volume anticipated) to the 99th percentile (near maximum discharge volume anticipated). Phase 2 shows no expected water discharge, because water treatment would not be required as the pyritic TSF and main WMP are empty, and the pit lake is filling to its MM level. Closure phase discharge locations for WTP#3 are located in the SFK and UTC catchments. Figure K4.18-8 indicates that the total amount of water treatment required is greatest during the early closure phase when the mine site footprint is larger, and lowest during closure phase 4 once all the mine facilities are reclaimed and the only water being treated is surplus pumped from the open pit to maintain water levels. Total flow releases from the WTPs are estimated to vary from a high of 58 cfs during Closure Phase 1, to a low of 3 cfs during Closure Phase 4 (post-closure). The total flow released downstream of the mine site is a combination of freshwater from diversion channels, surface runoff from reclaimed facilities, and treated water from WTPs. The WTP flows are estimated to vary with historical climatic patterns.

Table K4.18-6: Total WTP Discharge Flows in Closure

Closure Phase 1						Closure Phase 2					
Month	Total Release[a] from WTPs (cfs)					Month	Total Release from WTPs (cfs)				
	1st Percentile[b]	10th Percentile	50th Percentile	90th Percentile	99th Percentile		1st Percentile	10th Percentile	50th Percentile	90th Percentile	99th Percentile
Jan	16	23	46	53	55	Jan	0	0	0	0	0
Feb	15	21	45	51	55	Feb	0	0	0	0	0
Mar	15	21	37	49	55	Mar	0	0	0	0	0
Apr	15	22	40	51	56	Apr	0	0	0	0	0
May	33	51	55	57	57	May	0	0	0	0	0
Jun	24	54	57	57	58	Jun	0	0	0	0	0
Jul	17	51	56	57	57	Jul	0	0	0	0	0
Aug	32	52	56	57	57	Aug	0	0	0	0	0
Sep	34	53	56	57	58	Sep	0	0	0	0	0
Oct	15	49	55	56	57	Oct	0	0	0	0	0
Nov	15	44	53	56	57	Nov	0	0	0	0	0
Dec	15	25	47	55	56	Dec	0	0	0	0	0
Annual Average	21	39	50	55	57	Annual Average	0	0	0	0	0
Closure Phase 3						Closure Phase 4					
Month	Total Release from WTPs (cfs)					Month	Total Release from WTPs (cfs)				
	1st Percentile	10th Percentile	50th Percentile	90th Percentile	99th Percentile		1st Percentile	10th Percentile	50th Percentile	90th Percentile	99th Percentile
Jan	19	19	23	29	48	Jan	3	4	7	10	19
Feb	20	20	20	29	48	Feb	3	4	7	9	19
Mar	19	19	19	29	48	Mar	4	4	7	9	18
Apr	21	22	26	29	48	Apr	5	7	11	16	19

Table K4.18-6: Total WTP Discharge Flows in Closure

Closure Phase 1						Closure Phase 2					
Month	Total Release[a] from WTPs (cfs)					Month	Total Release from WTPs (cfs)				
	1st Percentile[b]	10th Percentile	50th Percentile	90th Percentile	99th Percentile		1st Percentile	10th Percentile	50th Percentile	90th Percentile	99th Percentile
May	29	29	30	41	48	May	13	17	18	19	20
Jun	26	29	40	48	48	Jun	6	14	18	19	20
Jul	22	29	34	48	48	Jul	6	14	18	20	20
Aug	29	29	36	48	48	Aug	11	15	18	20	20
Sep	27	29	39	48	48	Sep	10	14	18	20	20
Oct	24	29	34	48	48	Oct	6	10	17	20	20
Nov	20	27	29	48	48	Nov	5	8	9	20	20
Dec	19	19	29	45	48	Dec	4	5	8	16	17
Annual Average	23	25	30	41	48	Annual Average	6	10	13	16	19

Notes:
[a] Total release from WTP is the sum of the flows available for release from WTP#2 and WTP#3 during closure phases.
[b] Percentiles represent predicted variations in closure water balance due to modeled climate variability.
Source: Knight Piésold 2018d, Table 5.1

Water Quality Model

A closure and post-closure water quality model was developed in GoldSim® by Knight Piésold (2018d). It is coupled with the closure and post-closure water balance model to calculate constituent loads in the various mine facilities under completely mixed, steady-state conditions. Details regarding the model inputs and assumptions are provided in Knight Piésold (2018d, 2019a).

The maximum monthly predicted constituent concentrations in on-site ponds for the four closure phases are provided in Table K4.18-7 through Table K4.18-10, and Table K4.18-11 displays predicted water quality inflows to WTPs through all phases of closure (predictions for the open pit in Closure Phases 3 and 4 are superseded by the pit lake model described in the following section). Bolded values in these tables indicate where predicted constituent concentrations exceed the discharge water quality criteria and would require treatment at the WTPs. Use of 95th percentile geochemical source terms in the water quality model represents an upper bound condition in which concentrations are greater than 95 percent of all expected inputs. Because of this, water quality predictions in Table K4.18-7 through Table K4.18-11 are considered to represent a conservative range of estimates for dry to wet flow conditions (10th to 90th percentile flows).

Figure K4.18-9 shows 50th percentile water quality predictions (based on 95th percentile source terms) for several constituents in the bulk TSF supernatant pond in Closure Phases 3 and 4 compared to water quality standards. As shown on this figure as well as Table K4.18-10, the predicted water quality in in the bulk TSF pond in Closure Year 50 meets discharge water quality criteria for all parameters modeled except for alkalinity, which would be below the minimum criterion of 20 milligram per liter (mg/L) due to low alkalinity concentrations in non-contact water from the reclaimed beaches. The pond water would continue to be treated and the water quality of the pond monitored, and surplus water from precipitation events would only be discharged from the bulk TSF to the downstream NFK catchment once it meets discharge water quality criteria.

Table K4.18-7: Predicted Water Quality in Mine Site Ponds – Closure Phase 1

Parameters (mg/L)	Bulk TSF[a,b]			Main Embankment Seepage Collection Pond			Pyritic TSF[c]			Main Water Management Pond			Open Pit[d]		
	Maximum Monthly			Maximum Monthly			Maximum Monthly			Maximum Monthly			Maximum Monthly		
Percentile[e]	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
TDS[f]	167.00	484.21	**1,267.25[g]**	**582.23**	**2,471.90**	**4,621.59**	**2,476.55**	**2,707.67**	**2,870.89**	**564.60**	**668.97**	**785.95**	**2,504.02**	**2,705.53**	**2,855.41**
Alkalinity	31.56	81.09	238.10	111.70	453.40	848.20	175.30	216.30	242.50	102.00	121.10	141.40	138.70	144.50	155.80
Acidity	1.32	2.27	4.56	2.34	6.92	8.32	26.73	28.61	30.33	2.23	2.44	2.68	32.17	35.01	37.77
Chloride	1.43	3.93	9.79	1.61	8.55	10.26	6.69	7.42	7.88	1.75	1.96	2.25	5.64	5.81	6.07
Fluoride	0.05	0.11	0.25	0.14	0.83	0.99	0.41	0.48	0.54	0.13	0.15	0.18	0.36	0.38	0.41
Sulfate	88.03	**269.10**	**691.30**	**318.20**	**1,374.00**	**2,588.00**	**1,556.00**	**1,687.00**	**1,784.00**	**312.80**	**371.50**	**438.40**	**1,607.00**	**1,744.00**	**1,844.00**
Aluminum	0.0006	0.0006	0.0006	**0.3580**	**1.47**	**2.7540**	0.0006	0.0006	0.0006	**0.2911**	**0.3480**	**0.4138**	0.0006	0.0006	0.0006
Antimony	0.0029	**0.0079**	**0.0200**	**0.0271**	**0.1169**	**0.2202**	**0.0641**	**0.0671**	**0.0696**	**0.0244**	**0.0292**	**0.0344**	**0.065**	**0.07**	**0.073**
Arsenic	**0.0043**	**0.0100**	**0.0247**	**0.0352**	**0.1520**	**0.2863**	**0.0996**	**0.1145**	**0.1210**	**0.0321**	**0.0385**	**0.0452**	**0.10**	**0.109**	**0.113**
Barium	0.006	0.016	0.040	0.022	0.088	0.165	0.099	0.108	0.113	0.021	0.025	0.029	0.099	0.106	0.112
Beryllium	0.00280	**0.00862**	**0.02217**	0.00068	0.00293	**0.00551**	**0.00784**	**0.00830**	**0.00857**	0.00151	0.00171	0.00194	**0.00645**	**0.00684**	**0.00708**
Bismuth	0.0008	0.0023	0.0070	0.0136	0.0585	0.1101	0.0545	0.0598	0.0622	0.0124	0.0148	0.0176	0.056	0.061	0.063
Boron	0.017	0.052	0.132	0.071	0.304	0.573	0.197	0.221	0.231	0.067	0.080	0.094	0.19	0.21	0.21
Cadmium	**0.00114**	**0.00352**	**0.00905**	**0.00136**	**0.00585**	**0.01101**	**0.04400**	**0.05362**	**0.06075**	**0.00216**	**0.00247**	**0.00279**	**0.039**	**0.042**	**0.045**
Calcium	19.00	53.96	136.30	105.90	450.90	847.90	358.20	377.10	395.00	98.78	117.60	138.00	368.80	394.50	411.80
Chromium	0.0004	0.0010	0.0024	0.0028	0.0117	0.0220	0.0052	0.0060	0.0063	0.0025	0.0030	0.0035	0.0051	0.0055	0.0057
Cobalt	0.0027	0.0083	0.0212	0.0068	0.0292	**0.0551**	**0.1819**	**0.2191**	**0.2460**	0.0093	0.0108	0.0122	**0.17**	**0.18**	**0.2**
Copper	0.0010	**0.0022**	**0.0054**	**0.0501**	**0.2163**	**0.4074**	**0.0100**	**0.0100**	**0.0100**	**0.0423**	**0.0508**	**0.0605**	**0.01**	**0.01**	**0.01**
Iron	0.002	0.002	0.002	0.324	1.655	1.986	0.002	0.002	0.002	0.239	0.280	0.327	0.0020	0.0020	0.0020
Lead	**0.0018**	**0.0054**	**0.0137**	**0.0068**	**0.0293**	**0.0551**	**0.0165**	**0.0185**	**0.0196**	**0.0065**	**0.0077**	**0.0090**	**0.0154**	**0.0164**	**0.0168**
Magnesium	8.49	25.20	64.32	13.76	58.03	109.00	40.63	42.68	43.68	14.59	16.78	19.61	37.00	37.92	38.53
Manganese	**0.13**	**0.38**	**0.98**	**0.40**	**1.70**	**3.19**	**1.99**	**2.00**	**2.00**	**0.40**	**0.47**	**0.55**	**2.00**	**2.00**	**2.00**
Mercury	**0.000010**	**0.000029**	**0.000073**	**0.000068**	**0.000293**	**0.000551**	**0.001179**	**0.001466**	**0.001676**	**0.000078**	**0.000090**	**0.000106**	**0.00103**	**0.00113**	**0.00122**
Molybdenum	**0.1061**	**0.3175**	**0.9617**	**1.6230**	**7.0130**	**13.2100**	**1.9990**	**2.2870**	**2.4110**	**1.3890**	**1.7000**	**2.0100**	**1.98**	**2.15**	**2.22**
Nickel	0.0079	**0.0242**	**0.0621**	0.0069	**0.0293**	**0.0551**	**0.0858**	**0.0952**	**0.0999**	**0.0094**	**0.0107**	**0.0124**	**0.082**	**0.086**	**0.091**
Potassium	5.17	15.22	38.88	4.97	21.09	39.64	114.10	127.60	137.40	7.05	8.22	9.71	119.00	133.00	143.90
Selenium	0.0021	**0.0063**	**0.0162**	**0.0075**	**0.0322**	**0.0606**	**0.0259**	**0.0270**	**0.0276**	**0.0072**	**0.0086**	**0.0101**	**0.0263**	**0.0278**	**0.0291**
Silver	0.000090	0.000269	0.000811	**0.001354**	**0.005845**	**0.011010**	**0.002278**	**0.002711**	**0.002940**	**0.001167**	**0.001429**	**0.001689**	**0.0022**	**0.0023**	**0.0024**
Sodium	11.16	32.84	83.41	18.60	76.45	143.20	206.60	228.50	237.80	21.77	25.16	29.11	207.80	223.50	231.30
Thallium	0.00006	0.00018	0.00045	0.00007	0.00029	0.00055	0.00048	0.00049	0.00051	0.00008	0.00010	0.00011	0.00047	0.00049	0.00051

Table K4.18-7: Predicted Water Quality in Mine Site Ponds – Closure Phase 1

Parameters (mg/L)	Bulk TSF[a,b]			Main Embankment Seepage Collection Pond			Pyritic TSF[c]			Main Water Management Pond			Open Pit[d]		
	Maximum Monthly			Maximum Monthly			Maximum Monthly			Maximum Monthly			Maximum Monthly		
Silicon	2.16	2.87	5.16	7.49	29.48	35.39	19.03	21.07	22.63	5.87	6.65	7.47	20.08	22.30	24.01
Tin	0.0023	0.0069	0.0175	0.0271	0.1169	0.2202	0.0226	0.0246	0.0259	0.0236	0.0282	0.0334	0.0227	0.0247	0.0261
Vanadium	0.0006	0.0012	0.0029	0.0042	0.0176	0.0330	0.0363	0.0404	0.0433	0.0041	0.0049	0.0058	0.0388	0.0432	0.0464
Zinc	**0.154**	**0.473**	**1.215**	**0.257**	**1.111**	**2.092**	**2.043**	**2.368**	**2.599**	**0.294**	**0.341**	**0.393**	**1.85**	**1.98**	**2.08**
Nitrate_N	0.15	0.44	1.12	0.00	0.00	0.00	0.84	0.93	1.00	0.05	0.06	0.07	0.80	0.88	0.96
Nitrate (ion)	0.47	1.39	3.56	0.00	0.00	0.00	0.97	1.11	1.23	0.14	0.17	0.20	0.75	0.85	0.96
Nitrite	0.01	0.03	0.1	0	0.00	0	0.02	0.02	0.02	0.003	0.00	0.004	0.01	0.02	0.02
Ammonia	0.023	0.070	0.179	0.000	0.000	0.000	1.227	1.389	1.508	0.020	0.025	0.032	1.297	1.469	1.604
Hardness as $CaCO_3$[h]	82.42	238.51	605.21	321.10	1,364.86	2,566.07	1,061.74	1,117.37	1,166.19	306.74	362.75	425.34	1,073.26	1,141.22	1,186.93

Notes:
[a] Tailings pond adjustment values were applied for Al, SO_4, Fe, Cu, and Mn in the bulk TSF and pyritic TSF.
[b] Background water quality was assumed during reclamation phase in the bulk TSF.
[c] Model assumes the loading from the PAG waste rock in the pyritic TSF as a flushing term as provided by SRK 2018a.
[d] Model assumes return of sludge and reject flows from WTP#2 and WTP#3 to the open pit.
[e] Percentile results are based on 76 realizations of model simulations.
[f] TDS values were calculated by summing alkalinity, Cl, F, SO_4, Ca, Mg, K, Na, and Si.
[g] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).
[h] Hardness values were calculated based on the following: hardness ($CaCO_3$) = calcium concentration (mg/L)*2.497 + magnesium concentration (mg/L)*4.118
[i] pH was not modeled.
$CaCo_3$ = calcium carbonate
mg/L = milligrams/liter
Source: Knight Piésold 2019a

Table K4.18-8: Predicted Water Quality in Mine Site Ponds – Closure Phase 2

Parameters (mg/L)	Bulk TSF[a,b]			Main Embankment Seepage Collection Pond			Open Pit		
	Maximum Monthly			Maximum Monthly			Maximum Monthly		
Percentile[c]	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
TDS[d]	**2,436[e]**	**2,518**	**2,637**	**584**	**3,610**	**5,069**	**1,291**	**1,347**	**1,404**
Alkalinity	313.60	327.40	343.10	107.30	665.30	930.70	145.90	153.40	164.00
Acidity	1.06	2.27	3.70	2.02	4.64	9.19	12.87	13.63	14.70
Chloride	5.84	8.16	10.85	1.36	8.05	11.27	3.14	3.23	3.45
Fluoride	0.55	0.56	0.58	0.13	0.78	1.09	0.26	0.27	0.29
Sulfate	**1,466.00**	**1,491.00**	**1,537.00**	**325.60**	**2,029.00**	**2,838.00**	**785.60**	**814.30**	**836.40**
Aluminum	0.0006	0.0006	0.0006	**0.3478**	**2.1600**	**3.0210**	0.0006	0.0006	0.0006
Antimony	**0.0919**	**0.0927**	**0.0950**	**0.0277**	**0.1727**	**0.2415**	**0.045**	**0.047**	**0.049**
Arsenic	**0.1162**	**0.1173**	**0.1200**	**0.0360**	**0.2245**	**0.3140**	**0.061**	**0.063**	**0.066**
Barium	0.064	0.066	0.069	0.021	0.130	0.181	0.047	0.049	0.051
Beryllium	**0.00445**	**0.01122**	**0.01916**	0.00069	**0.00432**	**0.00604**	0.00257	0.00269	0.00314
Bismuth	0.0608	0.0614	0.0627	0.0139	0.0863	0.1208	0.03	0.031	0.033
Boron	0.312	0.315	0.325	0.072	0.449	0.628	0.14	0.15	0.16
Cadmium	**0.00392**	**0.00634**	**0.00917**	**0.00139**	**0.00863**	**0.01208**	**0.008**	**0.009**	**0.011**
Calcium	468.6	473.4	484.8	106.8	664.9	930.1	225.8	234.2	245.1
Chromium	0.0123	0.0124	0.0127	0.0028	0.0173	0.0242	0.0051	0.0054	0.0057
Cobalt	0.0311	0.0332	0.0356	0.0069	0.0432	0.0604	0.04	**0.05**	**0.05**
Copper	**0.0100**	**0.0100**	**0.0100**	**0.0513**	**0.3195**	**0.4468**	**0.01**	**0.01**	**0.01**
Iron	0.002	0.002	0.002	0.283	1.559	2.182	0.002	0.002	0.002
Lead	**0.0312**	**0.0316**	**0.0326**	**0.0069**	**0.0432**	**0.0604**	**0.0131**	**0.0138**	**0.0147**
Magnesium	64.33	75.45	88.29	13.74	85.50	119.60	27.46	28.83	30.71
Manganese	**1.52**	**1.60**	**1.69**	**0.40**	**2.50**	**3.50**	**1.25**	**1.27**	**1.29**
Mercury	**0.000307**	**0.000310**	**0.000317**	**0.000069**	**0.000432**	**0.000604**	**0.00027**	**0.0003**	**0.00032**
Molybdenum	**5.97**	**6.03**	**6.17**	**1.66**	**10.36**	**14.49**	**2.47**	**2.61**	**2.80**

Table K4.18-8: Predicted Water Quality in Mine Site Ponds – Closure Phase 2

Parameters (mg/L)	Bulk TSF[a,b]			Main Embankment Seepage Collection Pond			Open Pit		
	Maximum Monthly			Maximum Monthly			Maximum Monthly		
Nickel	**0.0344**	**0.0498**	**0.0677**	0.0069	**0.0432**	**0.0604**	**0.029**	**0.03**	**0.032**
Potassium	24.34	33.35	43.86	5.00	31.09	43.49	30.75	34.83	39.00
Selenium	**0.0344**	**0.0349**	**0.0360**	**0.0076**	**0.0475**	**0.0664**	**0.0188**	**0.0194**	**0.0201**
Silver	**0.006079**	**0.006144**	**0.006278**	**0.001385**	**0.008634**	**0.012080**	**0.0024**	**0.0025**	**0.0027**
Sodium	72.63	88.89	107.70	18.09	112.30	157.10	60.27	66.15	72.17
Thallium	0.00033	0.00043	0.00054	0.00007	0.00043	0.00060	0.00023	0.00024	0.00025
Silicon	20.66	20.85	21.28	6.46	13.97	38.96	11.73	12.26	13.43
Tin	0.1158	0.1170	0.1195	0.0277	0.1727	0.2415	0.0433	0.0466	0.0501
Vanadium	0.0184	0.0186	0.0190	0.0042	0.0259	0.0363	0.0137	0.0148	0.0157
Zinc	**0.666**	**0.969**	**1.323**	**0.263**	**1.641**	**2.295**	**0.61**	**0.65**	**0.70**
Nitrate_N	0.08	0.44	0.86	0.00	0.00	0.00	0.17	0.20	0.25
Nitrate (ion)	0.24	1.39	2.69	0.00	0.00	0.00	0.18	0.21	0.29
Nitrite	0.00	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.01
Ammonia	0.01	0.07	0.14	0.00	0.00	0.00	0.26	0.31	0.36
Hardness as $CaCO_3$[f]	1435.01	1492.78	1574.12	323.26	2012.34	2814.97	676.90	703.52	738.48

[a] Tailings pond adjustment values were applied for Al, SO_4, Fe, Cu, and Mn in the bulk TSF.
[b] Background water quality was assumed during reclamation phase in the bulk TSF.
[c] Percentile results are based on 76 realizations of model simulations.
[d] TDS values were calculated by summing alkalinity, Cl, F, SO_4, Ca, Mg, K, Na, and Si.
[e] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).
[f] Hardness values were calculated based on the following: hardness ($CaCO_3$) = calcium concentration (mg/L)*2.497 + magnesium concentration (mg/L)*4.118
[g] pH was not modeled.
$CaCo_3$ = calcium carbonate
TDS = total dissolved solids
Source: Knight Piésold 2019a

Table K4.18-9: Predicted Water Quality in Mine Site Ponds - Closure Phase 3

Parameters (mg/L)	Bulk TSF[a]			Main Embankment Seepage Collection Pond		
	Maximum Monthly			Maximum Monthly		
Percentile[b]	10th	50th	90th	10th	50th	90th
TDS[c]	49	204	358	275	**1,750[d]**	**4,825**
Alkalinity	**17.36**	41.60	69.64	58.94	322.30	888.60
Acidity	2.43	2.83	3.21	1.00	3.43	9.45
Chloride	0.77	1.97	3.13	1.13	3.95	10.89
Fluoride	0.03	0.06	0.09	0.08	0.38	**1.04**
Sulfate	13.48	102.40	187.70	140.80	**978.10**	**2,697.00**
Aluminum	0.0006	0.0006	0.0006	**0.1843**	**1.0450**	**2.8810**
Antimony	0.0004	0.0030	0.0054	**0.0120**	**0.0832**	**0.2295**
Arsenic	0.0005	0.0034	0.0062	0.0156	0.1082	0.2984
Barium	0.003	0.008	0.013	**0.011**	**0.063**	**0.173**
Beryllium	0.00041	0.00326	**0.00601**	0.00031	0.00208	**0.00574**
Bismuth	0.0002	0.0010	0.0018	0.0061	0.0416	0.1148
Boron	0.004	0.021	0.037	0.032	0.217	0.597
Cadmium	**0.00017**	**0.00134**	**0.00246**	**0.00060**	**0.00416**	**0.01148**
Calcium	6.07	23.12	39.47	49.51	320.90	884.90
Chromium	0.0003	0.0005	0.0008	0.0014	0.0084	0.0230
Cobalt	0.0005	0.0032	0.0058	0.0030	0.0208	**0.0574**
Copper	0.0004	0.0010	0.0016	**0.0224**	**0.1540**	**0.4247**
Iron	0.002	0.002	0.002	0.232	0.768	**2.118**
Lead	**0.0004**	**0.0022**	**0.0038**	**0.0031**	**0.0208**	**0.0574**
Magnesium	1.84	10.02	17.87	6.62	41.29	113.90
Manganese	0.03	**0.15**	**0.27**	**0.18**	**1.21**	**3.33**
Mercury	0.000002	**0.000012**	**0.000020**	**0.000031**	**0.000208**	**0.000574**
Molybdenum	**0.0145**	**0.1218**	**0.2455**	**0.7119**	**4.9940**	**13.7700**
Nickel	0.0013	0.0093	**0.0170**	0.0032	**0.0208**	**0.0575**
Potassium	0.88	5.81	10.55	2.34	15.01	41.38
Selenium	0.0004	0.0025	0.0045	0.0034	**0.0229**	**0.0632**
Silver	0.000017	0.000107	0.000211	0.000598	**0.004162**	**0.011480**
Sodium	3.42	14.00	24.15	9.70	54.35	149.90
Thallium	0.00001	0.00007	0.00013	0.00004	0.00021	0.00058
Silicon	5.24	5.42	5.58	5.64	13.99	38.58
Tin	0.0004	0.0026	0.0048	0.0119	0.0832	0.2295

Table K4.18-9: Predicted Water Quality in Mine Site Ponds - Closure Phase 3

Parameters (mg/L)	Bulk TSF[a]			Main Embankment Seepage Collection Pond		
	Maximum Monthly			Maximum Monthly		
Vanadium	0.0004	0.0007	0.0010	0.0021	0.0125	0.0345
Zinc	0.023	**0.180**	**0.330**	**0.114**	**0.791**	**2.181**
Nitrate_N	0.02	0.17	0.32	0.00	0.00	0.00
Nitrate (ion)	0.06	0.53	1.02	0.00	0.00	0.00
Nitrite	0.001	0.01	0.02	0.00	0.00	0.00
Ammonia	0.003	0.03	0.05	0.00	0.00	0.00
Hardness as $CaCO_3$[e]	22.73	98.99	172.15	150.87	971.32	2,678.64

[a] Tailings pond adjustment values were applied for Al, SO_4, Fe, Cu, and Mn in the bulk TSF.
[b] Percentile results are based on 76 realizations of model simulations.
[c] TDS values were calculated by summing alkalinity, Cl, F, SO_4, Ca, Mg, K, Na, and Si.
[d] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).
[e] Hardness values were calculated based on the following: hardness ($CaCO_3$) = calcium concentration (mg/L)*2.497 + magnesium concentration (mg/L)*4.118
[f] pH was not modeled.
[g] Predicted concentrations in the open pit are superseded by the pit lake model (Lorax 2018), and shown in Figures K4.18-10 to K4.18-15.
$CaCo_3$ = calcium carbonate
TDS = total dissolved solids
Source: Knight Piésold 2019a

Table K4.18-10: Predicted Water Quality in Mine Site Ponds - Closure Phase 4

Parameters (mg/L)	Bulk TSF[a]			Main Embankment Seepage Collection Pond		
	Maximum Monthly			Maximum Monthly		
Percentile[b]	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
TDS[c]	28.02	28.33	29.14	**1,419[d]**	**4,036**	**4,198**
Alkalinity	**14.24**	**14.40**	**14.81**	261	741	771
Acidity	2.41	2.44	2.51	3.07	7.23	7.64
Chloride	0.61	0.61	0.63	3.20	8.95	9.34
Fluoride	0.03	0.03	0.03	0.31	0.87	0.90
Sulphate	1.21	1.22	1.26	**793**	**2,260**	**2,350**
Aluminum	0.0006	0.0006	0.0006	**0.8473**	**2.4050**	**2.5020**
Antimony	0.0001	0.0001	0.0001	**0.0675**	**0.1923**	**0.2000**
Arsenic	0.0001	0.0001	0.0002	**0.0878**	**0.2500**	**0.2600**
Barium	0.002	0.002	0.003	0.051	0.144	0.150
Beryllium	0.00001	0.00001	0.00001	0.00169	**0.00481**	**0.00500**
Bismuth	0.0001	0.0001	0.0001	0.0338	0.0962	0.1000
Boron	0.002	0.002	0.002	0.176	0.500	0.520
Cadmium	0.00001	0.00001	0.00001	**0.00338**	**0.00962**	**0.01000**

Table K4.18-10: Predicted Water Quality in Mine Site Ponds - Closure Phase 4

Parameters (mg/L)	Bulk TSF[a]			Main Embankment Seepage Collection Pond		
	Maximum Monthly			Maximum Monthly		
Calcium	3.77	3.81	3.92	260.30	740.50	770.20
Chromium	0.0002	0.0002	0.0002	0.0068	0.0192	0.0200
Cobalt	0.0001	0.0001	0.0001	0.0169	0.0481	**0.0500**
Copper	0.0004	0.0004	0.0004	**0.1249**	**0.3558**	**0.3700**
Iron	0.002	0.002	0.002	0.622	**1.733**	**1.809**
Lead	0.000159	0.000161	0.000165	**0.0169**	**0.0481**	**0.0500**
Magnesium	0.72	0.72	0.74	33.5	95.2	99.0
Manganese	0.01	0.01	0.01	**0.98**	**2.79**	**2.90**
Mercury	0.000001	0.000001	0.000001	**0.000169**	**0.000481**	**0.000500**
Molybdenum	0.0002	0.0002	0.0002	**4.0500**	**11.5400**	**12.0000**
Nickel	0.0002	0.0002	0.0002	**0.0169**	**0.0481**	**0.0500**
Potassium	0.20	0.20	0.21	12.17	34.62	36.01
Selenium	0.0001	0.0001	0.0001	**0.0186**	**0.0529**	**0.0550**
Silver	0.000004	0.000005	0.000005	**0.003376**	**0.009616**	**0.010000**
Sodium	1.98	2.00	2.06	44.07	125.00	130.10
Thallium	0.00001	0.00001	0.00001	0.00017	0.00048	0.00050
Silicon	5.30	5.36	5.51	11.32	30.84	32.33
Tin	0.0001	0.0001	0.0001	0.0675	0.1923	0.2000
Vanadium	0.0003	0.0003	0.0003	0.0102	0.0289	0.0300
Zinc	0.002	0.002	0.002	**0.641**	**1.827**	**1.900**
Nitrate_N	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate (ion)	0.00	0.00	0.00	0.00	0.00	0.00
Nitrite	0.00	0.00	0.00	0.00	0.00	0.00
Ammonia	0.00	0.00	0.00	0.00	0.00	0.00
Hardness as $CaCO_3$[e]	12.35	12.49	12.84	787.84	2,241.10	2,331.04

Notes:
[a] Tailings pond adjustment values were applied for Al, SO_4, Fe, Cu, and Mn in the bulk TSF.
[b] Percentile results are based on 76 realizations of model simulations.
[c] TDS values were calculated by summing alkalinity, Cl, F, SO_4, Ca, Mg, K, Na, and Si.
[d] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).
[e] Hardness values were calculated based on the following: hardness ($CaCO_3$) = calcium concentration (mg/L)*2.497 + magnesium concentration (mg/L)*4.118
[f] pH was not modeled.
[g] Predicted concentrations in the open pit are superseded by the pit lake model (Lorax Environmental 2018), and shown in Figures K4.18-10 to K4.18-15.
$CaCo_3$ = calcium carbonate
mg/L = milligrams/liter
TDS = total dissolved solids
Source: Knight Piésold 2019a

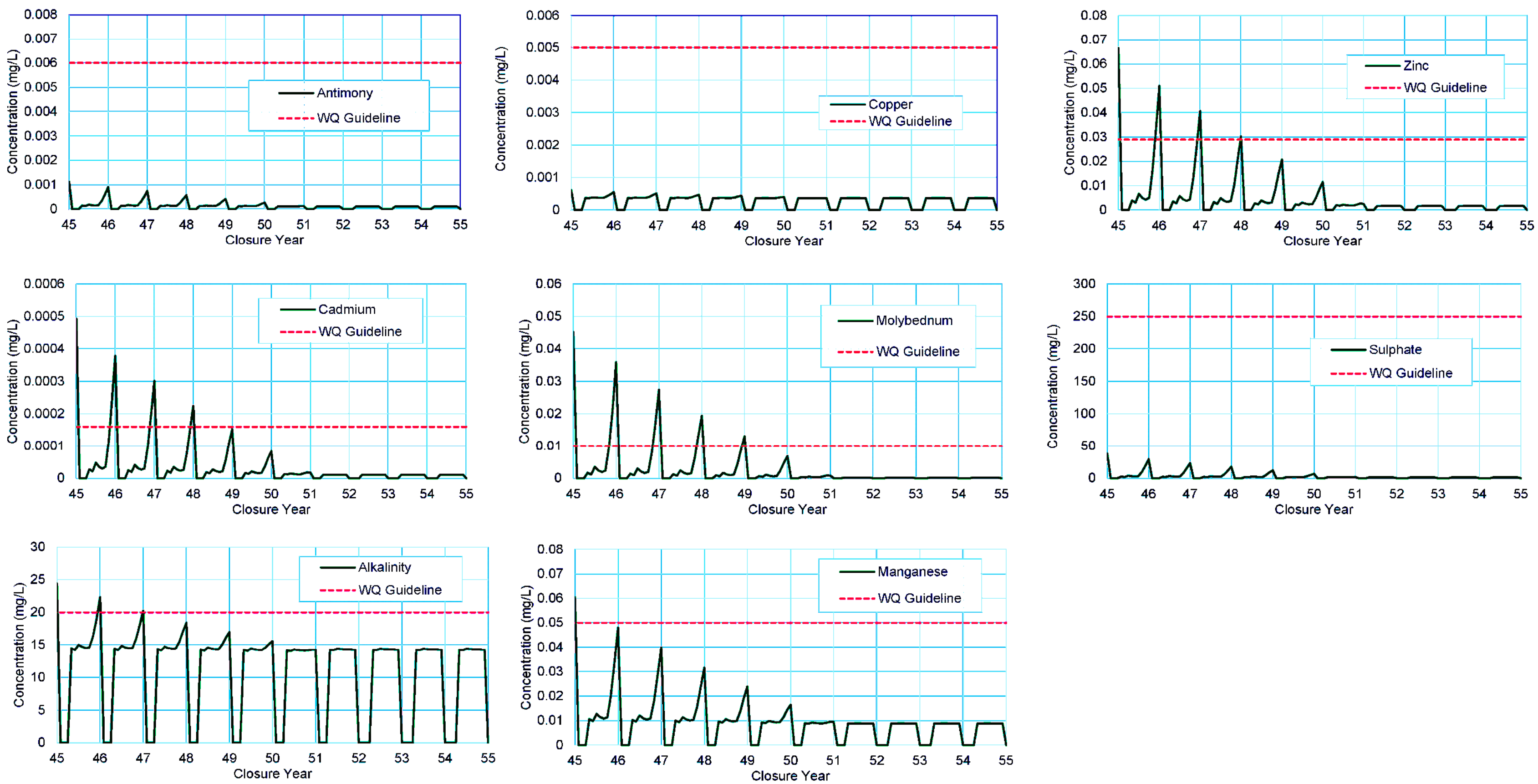
Table K4.18-11: Predicted Water Quality of WTP Inflows in Closure Phases

Parameters[c,d] (mg/L)	Phase 1[a,b]						Phase 3			Phase 4		
	WTP#2			WTP#3			Bulk TSF Main SCP Stream			Bulk TSF Main SCP Stream		
	10th Percentile[e]	50th Percentile	90th Percentile	10th Percentile	50th Percentile	90th Percentile	10th Percentile	50th Percentile	90th Percentile	10th Percentile	50th Percentile	90th Percentile
Flows	41			13			11			11		
pH[f]	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8	7 to 8
TDS[g]	**564.60[g]**	**668.97**	**785.95**	**2,504.02**	**2,705.53**	**2,855.41**	**274.67**	**1,749.89**	**4,825.15**	**1,419.14**	**4,035.72**	**4,197.92**
Alkalinity	102.00	121.10	141.40	138.70	144.50	155.80	58.94	322.30	888.60	261.30	740.60	770.90
Acidity	2.23	2.44	2.68	32.17	35.01	37.77	1.00	3.43	9.45	3.07	7.23	7.64
Chloride	1.75	1.96	2.25	5.64	5.81	6.07	1.13	3.95	10.89	3.20	8.95	9.34
Fluoride	0.130	0.153	0.18	0.36	0.38	0.41	0.082	0.379	**1.04**	0.307	0.866	0.90
Sulfate	**312.80**	**371.50**	**438.40**	**1,607.00**	**1,744.00**	**1,844.00**	**140.80**	**978.10**	**2,697.00**	**793.30**	**2,260.00**	**2,350.00**
Aluminum	**0.2911**	**0.3480**	**0.4138**	0.0006	0.0006	0.0006	**0.1843**	**1.0450**	**2.8810**	**0.8473**	**2.4050**	**2.5020**
Antimony	**0.0244**	**0.0292**	**0.034**	**0.065**	**0.070**	**0.073**	**0.0120**	**0.0832**	**0.230**	**0.0675**	**0.1923**	**0.200**
Arsenic	**0.0321**	**0.0385**	**0.045**	**0.100**	**0.109**	**0.113**	**0.0156**	**0.1082**	**0.298**	**0.0878**	**0.2500**	**0.260**
Barium	0.0210	0.0247	0.029	0.099	0.106	0.112	0.0114	0.0627	0.173	0.0509	0.1443	0.150
Beryllium	0.00151	0.00171	0.0019	**0.0064**	**0.0068**	**0.0071**	0.00031	0.00208	**0.0057**	0.00169	**0.00481**	**0.0050**
Bismuth	0.0124	0.0148	0.018	0.056	0.061	0.063	0.0061	0.0416	0.115	0.0338	0.0962	0.100
Boron	0.067	0.080	0.09	0.19	0.21	0.21	0.032	0.217	0.60	0.176	0.500	0.52
Cadmium	**0.00216**	**0.00247**	**0.0028**	**0.0388**	**0.0423**	**0.0455**	**0.00060**	**0.00416**	**0.0115**	**0.00338**	**0.00962**	**0.0100**
Calcium	98.78	117.60	138.00	368.80	394.50	411.80	49.51	320.90	884.90	260.30	740.50	770.20
Chromium	0.00251	0.00299	0.003	0.005	0.006	0.006	0.00141	0.00835	0.023	0.00677	0.01924	0.020
Cobalt	0.00931	0.01075	0.012	**0.168**	**0.183**	**0.197**	0.00304	0.02082	**0.057**	0.01688	0.04808	**0.050**
Copper	**0.0423**	**0.0508**	**0.060**	**0.010**	**0.010**	**0.010**	**0.0224**	**0.1540**	**0.425**	**0.1249**	**0.3558**	**0.370**
Iron	0.239	0.280	0.327	0.002	0.002	0.002	0.232	0.768	**2.118**	0.622	**1.733**	**1.809**
Lead	**0.0065**	**0.0077**	**0.009**	**0.015**	**0.016**	**0.017**	**0.0031**	**0.0208**	**0.057**	**0.0169**	**0.0481**	**0.050**
Magnesium	14.59	16.78	19.61	37.00	37.92	38.53	6.62	41.29	113.90	33.48	95.21	99.04
Manganese	**0.40**	**0.47**	**0.55**	**2.00**	**2.00**	**2.00**	**0.18**	**1.21**	**3.33**	**0.98**	**2.79**	**2.90**
Mercury	**0.000078**	**0.000090**	**0.00011**	**0.00103**	**0.00113**	**0.00122**	**0.000031**	**0.000208**	**0.00057**	**0.000169**	**0.000481**	**0.00050**
Molybdenum	**1.39**	**1.70**	**2.0**	**2.0**	**2.1**	**2.2**	**0.71**	**4.99**	**13.8**	**4.05**	**11.54**	**12.0**
Nickel	0.0094	0.0107	**0.012**	**0.082**	**0.086**	**0.091**	0.0032	**0.0208**	**0.057**	**0.0169**	**0.0481**	**0.050**
Potassium	7.05	8.22	9.71	119.00	133.00	143.90	2.34	15.01	41.38	12.17	34.62	36.01
Selenium	**0.0072**	**0.0086**	**0.010**	**0.026**	**0.028**	**0.029**	0.0034	**0.0229**	**0.063**	**0.0186**	**0.0529**	**0.055**
Silver	**0.00117**	**0.00143**	**0.002**	**0.002**	**0.002**	**0.002**	0.00060	**0.00416**	**0.011**	**0.00338**	**0.00962**	**0.010**
Sodium	21.77	25.16	29.11	207.80	223.50	231.30	9.70	54.35	149.90	44.07	125.00	130.10
Thallium	0.000083	0.000095	0.00011	0.00047	0.00049	0.00051	0.000035	0.000209	0.00058	0.000169	0.000481	0.00050

Table K4.18-11: Predicted Water Quality of WTP Inflows in Closure Phases

Parameters[c,d] (mg/L)	Phase 1[a,b]						Phase 3			Phase 4		
	WTP#2			WTP#3			Bulk TSF Main SCP Stream			Bulk TSF Main SCP Stream		
	10th Percentile[e]	50th Percentile	90th Percentile	10th Percentile	50th Percentile	90th Percentile	10th Percentile	50th Percentile	90th Percentile	10th Percentile	50th Percentile	90th Percentile
Silicon	5.87	6.65	7.47	20.08	22.30	24.01	5.64	13.99	38.58	11.32	30.84	32.33
Tin	0.0236	0.0282	0.033	0.023	0.025	0.026	0.0119	0.0832	0.230	0.0675	0.1923	0.200
Vanadium	0.0041	0.0049	0.006	0.039	0.043	0.046	0.0021	0.0125	0.035	0.0102	0.0289	0.030
Zinc	**0.294**	**0.341**	**0.39**	**1.85**	**1.98**	**2.08**	**0.114**	**0.791**	**2.18**	**0.641**	**1.827**	**1.90**
Nitrate_N	0.05	0.06	0.1	0.8	0.9	1.0	0.00	0.00	0.0	0.00	0.00	0.0
Nitrate (ion)	0.14	0.17	0.20	0.75	0.85	0.96	0.00	0.00	0.00	0.00	0.00	0.00
Nitrite	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Ammonia	0.02	0.02	0.03	1.30	1.47	1.60	0.00	0.00	0.00	0.00	0.00	0.00
Hardness as $CaCO_3$[h]	306.74	362.75	425.34	1,073.26	1,141.22	1,186.93	150.87	971.32	2,678.64	787.84	2,241.10	2,331.04

Notes:
[a] There is no water reporting to the WTP during phase 2, which is after the PAG waste rock/pyritic tailings transfer to the open pit is complete, but before pit lake is full.
[b] Background water quality was assumed during reclamation phase in the bulk TSF.
[c] Tailings pond adjustment values were applied for Al, SO_4, Fe, Cu, and Mn in the Bulk TSF.
[d] Model assumes return of sludge and reject flows from WTP#2 and WTP#3 to the to the open pit.
[e] Percentile results are based on 76 Realizations of model simulations.
[f] pH was not modeled and pH values are based on the range of pH source terms provided by SRK 2018a.
[g] TDS values were calculated by summing alkalinity, Cl, F, SO4, Ca, Mg, K, Na, and Si.
[h] Hardness Values were calculated based on the following: hardness ($CaCO_3$) = calcium Concentration (mg/L)*2.497 + magnesium concentration (mg/L)*4.118.
Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).
$CaCo_3$ = calcium carbonate
mg/L = milligrams/liter
TDS = total dissolved solids
Source: Knight Piesold 2019a



NOTES:

1. BULK TSF BEACHES UNDERGO CAPPING BEGINNING IN CLOSURE YEAR 10.

2. VALUES REPRESENT 50TH PERCENTILE WATER QUALITY PREDICTIONS IN THE BULK TSF SUPERNATENT POND NEAR THE END OF CLOSURE PHASE 3 AND BEGINNING OF CLOSURE PHASE 4.

Source: KP 2018d, Figure 6.1

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BULK TSF POND WATER QUALITY PREDICTIONS - CLOSURE PHASES 3 AND 4

Pit Lake Model

Once mining ceases, partial dewatering of the open pit would be continued to maintain pit wall stability to allow some PAG waste rock to be moved from the pyritic TSF to the open pit until the waste rock buttresses the lower walls of the pit. Transportation of PAG waste rock would be done via mine fleet haul trucks and spread using dozers to build a base for subsequent PAG waste rock and pyritic tailings deposition. An initial layer of PAG waste rock would be placed one year prior to deposition of pyritic tailings (Knight Piésold 2018d). The remaining PAG waste rock would be deposited in the open pit concurrently with the pyritic tailings as it is exposed during reclamation of the pyritic TSF (Knight Piésold 2018b, 2018d). The pyritic tailings would be re-slurried and pumped to the open pit for sub-aqueous disposal via floating dredge pumps. The water level in the open pit would be maintained to allow controlled placement and management of the PAG waste rock while keeping a water cover over the pyritic tailings. Backhauling of the PAG waste rock would end approximately 14 years into closure and the pyritic tailings transfer would end about 15 years into closure. Dewatering of the open pit would cease at the end of Closure Phase 1 once the transfer of these materials is complete.

Once dewatering ceases, groundwater behind the pit walls, along with direct precipitation and surface water runon, would flow into the pit creating a pit lake. The open pit would be allowed to fill to the designated maximum management level of 890 feet above mean sea level so that the pit remains as a hydraulic sink and continues to capture nearby groundwater inflow and mitigates the potential for contaminant release along subsurface pathways. The maximum management level was also designed to allow sufficient storage for the probable maximum flood. General features of the backfilled pit lake are highlighted in Table K4.18-12.

Prior to closure year 15, the pit lake water quality is largely influenced by the pyritic tailings slurry water and PAG waste rock placed in the open pit (Knight Piésold 2018d). After closure year 15, pit water quality is influenced by other water sources including surplus water from the bulk TSF supernatant pond and main SCP which would be pumped to the open pit through closure year 50 (Knight Piésold 2018d), as well as direct precipitation, surface water runon, and groundwater inflow to the pit which could leach metals from oxidized sulfide minerals exposed in the pit walls and metals in unmined mineralized rock adjacent to the pit. As a result, water quality in the pit lake would be expected to be initially acidic but become more alkaline with time, and have elevated concentrations of TDS, sulfate, and some metals (Sb, As, Cd, Cu, Pb, Mn, Hg, Mo, Ni, Se, and Zn) that exceed water quality standards. The predicted water quality in a fully mixed pit lake is provided in Table K4.18-7 and Table K4.18-8 during the period of partial dewatering while backfilling and lake rise in closure phases 1 and 2, respectively. These water quality predictions do not account for thermal and chemical stratification that may develop in the pit lake over time.

The evolution of pit lake water quality during closure was further evaluated by Lorax Environmental (2018) using a numerical one-dimensional hydrodynamic pit lake model called PitMod developed by Dunbar (2013) and Martin et al. (2017). PitMod is capable of predicting the spatial and temporal distribution of temperature, density, dissolved oxygen (DO), and water quality in pit lakes that may lead to thermal and chemical stratification. Lake processes simulated by PitMod include 1) heating and cooling of the lake surface; 2) wind-driven lake circulation; 3) convectional mixing within the lake; 4) ice formation and melting; 5) introduction and mixing of external water sources (e.g., direction precipitation to lake surface, pit wall runoff, mine site drainages, groundwater inflow, and surface water runon); and 6) oxygen consumption. PHREEQC, an industry-standard equilibrium geochemical model developed by the US Geological Survey (USGS) was used to predict pH in the mixed surface layer of the pit lake.

Table K4.18-12: Backfilled Pit Lake General Features

Parameter	Value
Length	6,640 feet
Maximum width	5,550 feet
Depth from top of backfilled tailings	530 feet
Pit lake volume	188,000 acre-feet
Pit lake surface area	198 ha
Time to fill	21.5 years

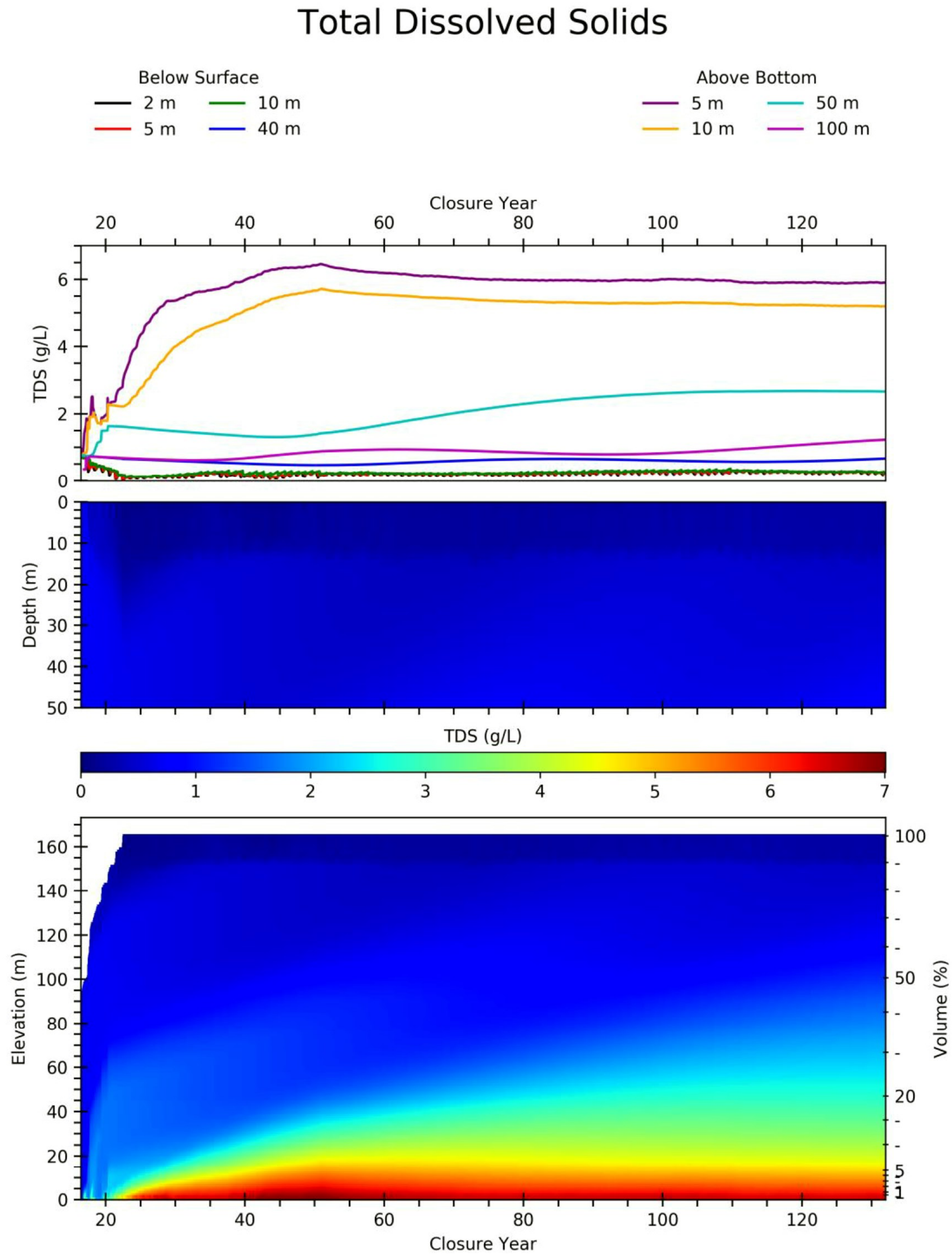
Source: Lorax Environmental 2018

PitMod was used to model pit lake water quality after the open pit is backfilled with PAG waste rock and pyritic tailings, and waters other than tailings slurry water influence pit lake development and quality. Pit lake waters are assumed to be fully mixed (i.e., not stratified) during the backfilling period through closure year 15. PitMod was used to predict pit lake water quality from Closure Years 16 to 131, a 115-year model period. With the exception of dissolved oxygen, water quality constituents are assumed to behave conservatively (i.e., are non-reactive). Biogeochemical processes (e.g., algal assimilation, mineral precipitation, adsorption, and surface complexation) that might lower metal concentrations within the pit lake water column were not simulated. Details regarding PitMod data sources, inputs, and assumptions are provided in Lorax Environmental (2018).

PitMod predicts that the pit lake will become thermally and chemically stratified after about closure years 25 to 30 (Lorax Environmental 2018). The input of higher density WTP sludge and brine to the pit bottom promotes development of chemical stratification in the lower water column as shown by TDS and sulfate concentrations in Figure K4.18-10 and Figure K4.18-11. By closure year 25, TDS and sulfate are expected to be below their respective water quality criteria of 500 and 250 mg/L in lake water above 30 feet. The salinity gradient (pycnocline) migrates upwards over time as the dense sludge and brine inflows progressively fill the pit from the bottom up. Salinity stratification is largely controlled by the concentrations of sulfate, calcium, magnesium, and chloride (Lorax Environmental 2018).

PitMod also predicts that the pit lake will become thermally stratified as shown in Figure K4.18-12. Pit lake surface water temperatures show strong seasonal variability ranging from 2^{o}C to 15^{o}C resulting in a surface layer with seasonal mixing to depths of about 30 to 50 feet. At deeper depths, the pit lake water temperature remains near 4^{o}C, where water is at its maximum density, except at the pit bottom where the input of WTP sludge and brine sustains temperatures of approximately 8^{o}C.

DO also becomes stratified in the pit lake, with well oxygenated, near-surface waters seasonally extending to depths of approximately 50 feet and progressively decreasing dissolved oxygen concentrations below 50 feet as the initially oxygenated waters are isolated from atmospheric influences over time (Figure K4.18-13). However, the fully oxygenated bottom water inputs (e.g., WTP sludge and brine) sustain oxic conditions in the lowermost 130 feet of pit lake water column throughout the simulation period.



Sources: Lorax Environmental 2018

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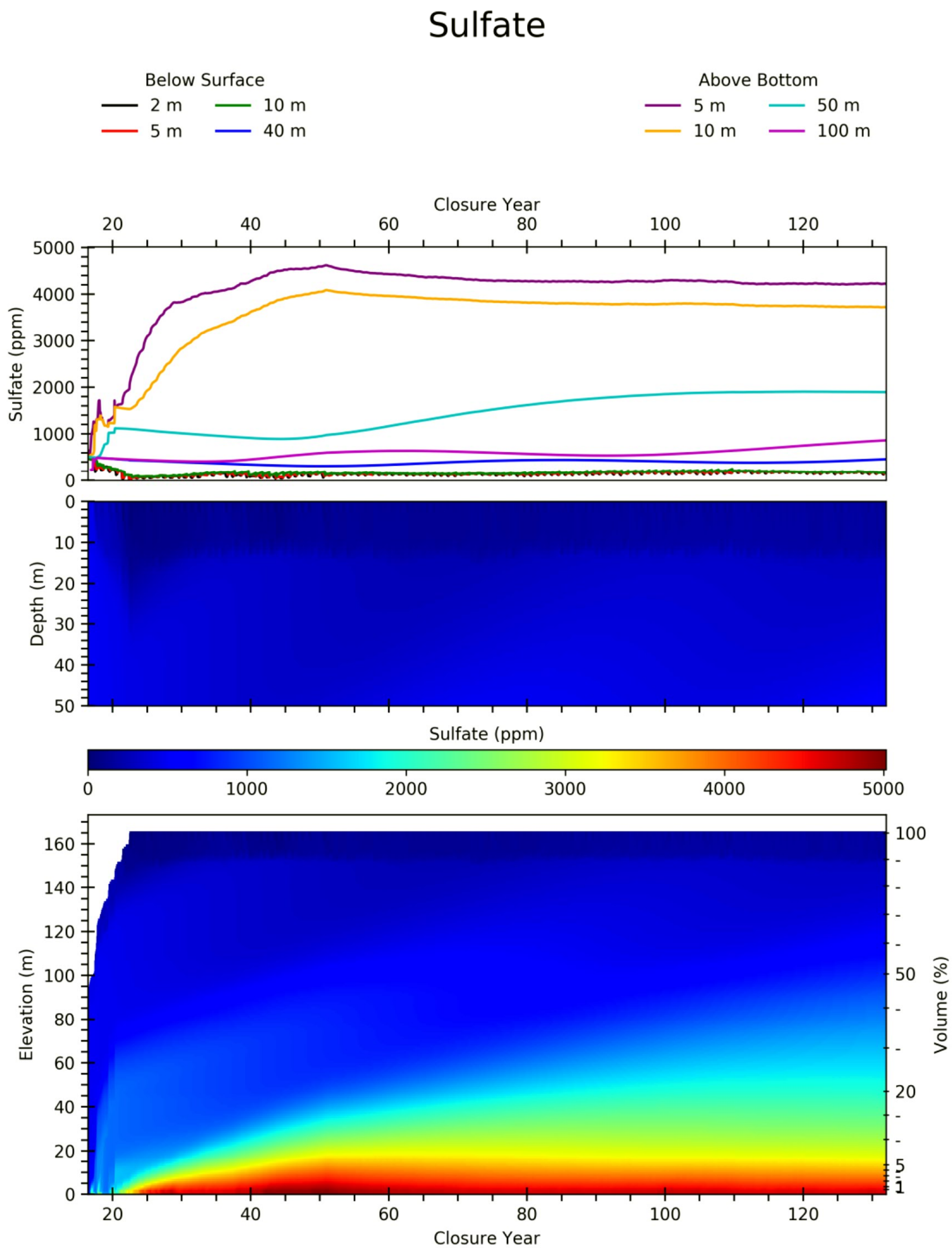
MODELED TDS IN PIT LAKE

PEBBLE PROJECT EIS

FIGURE K4.18-10



Sources: Lorax Environmental 2018

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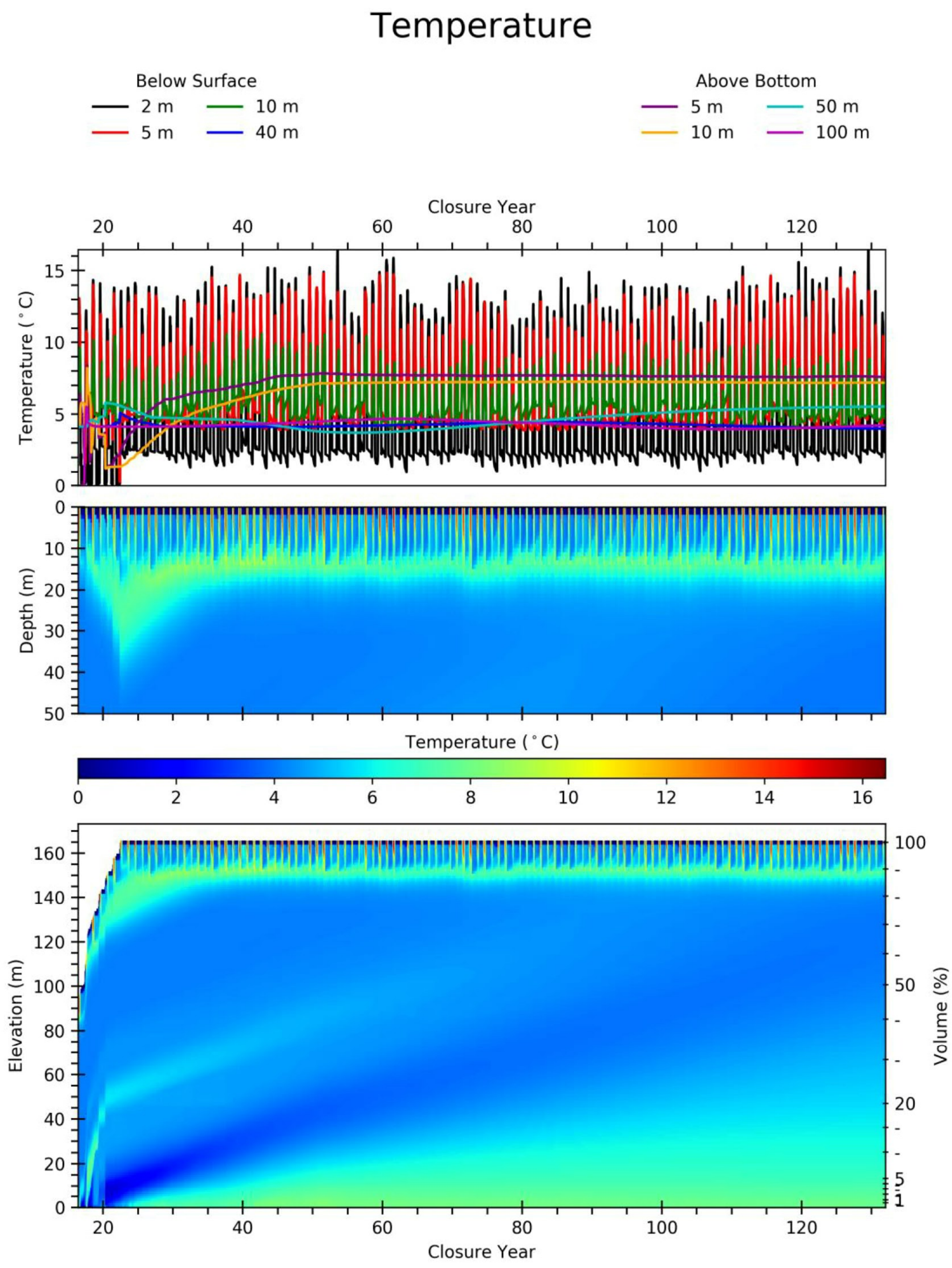
MODELED SULFATE CONCENTRATION IN PIT LAKE

PEBBLE PROJECT EIS

FIGURE K4.18-11



Sources: Lorax Environmental 2018

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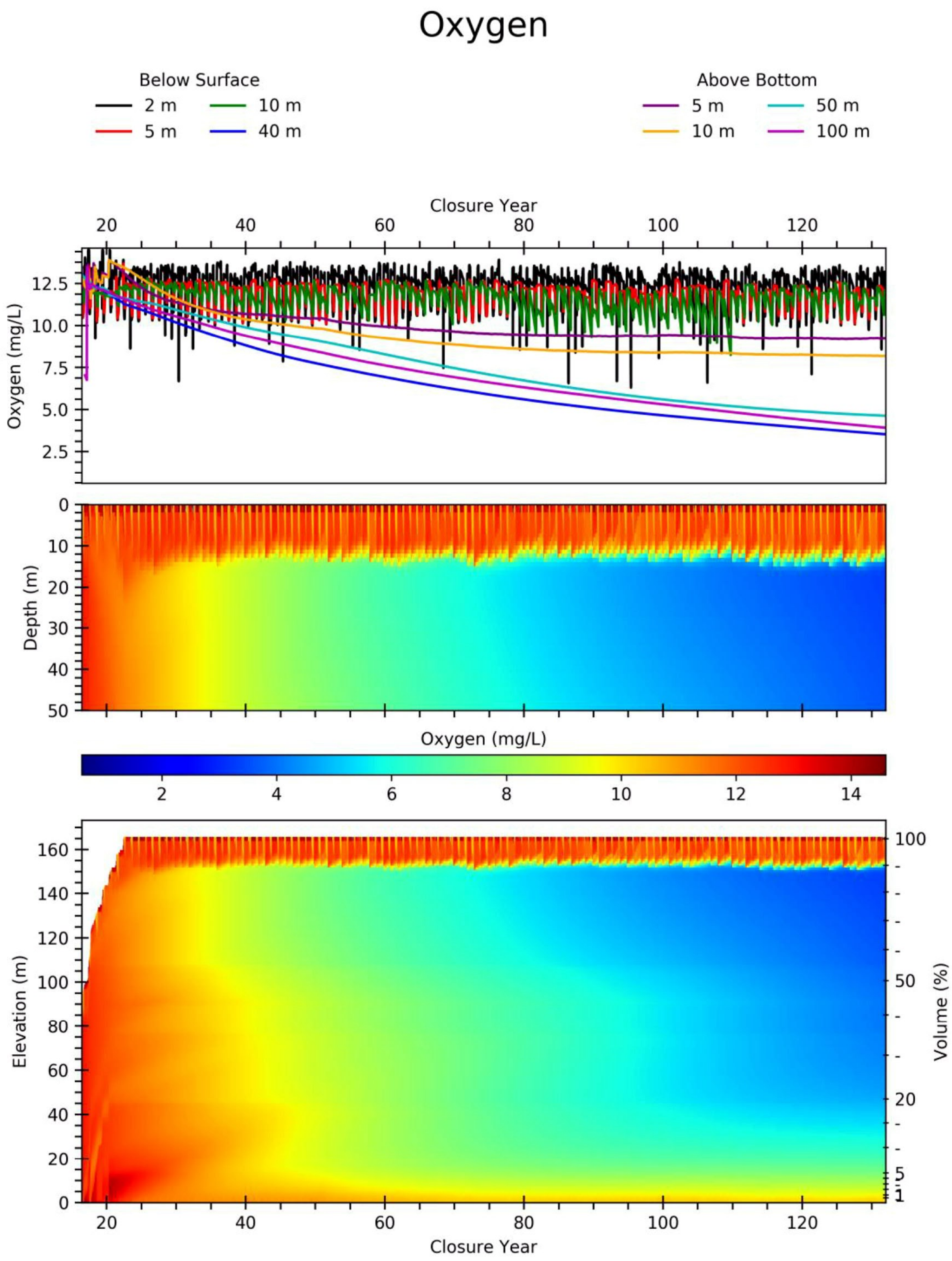
MODELED TEMPERATURE GRADIENT IN PIT LAKE

PEBBLE PROJECT EIS

FIGURE K4.18-12



Sources: Lorax Environmental 2018

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MODELED DISSOLVED OXYGEN CONCENTRATION IN PIT LAKE

Pit lake water quality predictions for all metals are summarized in Table K4.18-7 and Table K4.18-8 for closure phases 1 and 2, respectively. Predictions for copper and zinc specifically are shown on Figure K4.18-14 and Figure K4.18-15 for closure phases beyond year 15 (phase 2 and beyond). PitMod predicts that hardness and trace metals (Al, As, Cd, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, and Zn) in the near-surface (upper 30 feet) pit lake water would exceed discharge limits. For copper (Cu), the highest concentrations are predicted in the pit lake surface layer (Figure K4.18-14), owing to the large influence of runoff from the oxidized pit walls. In contrast to copper, initially higher concentrations of zinc are predicted in the deep pit water during the first few years (Figure K4.18-15) from short-term inputs of the bulk TSF supernatant and SCP waters, which are progressively diluted over time once these inputs cease.

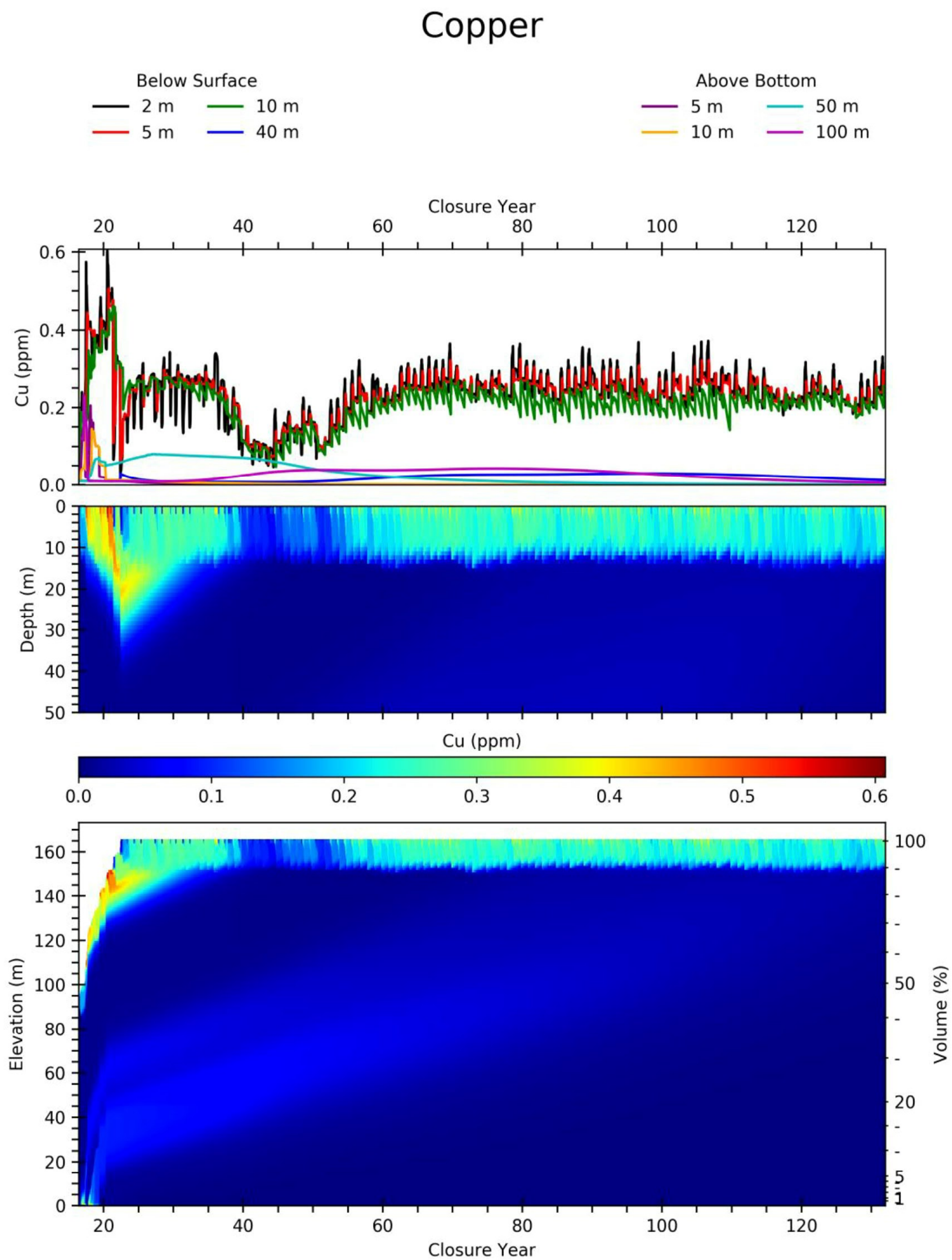
PHREEQC predicts that the pit lake surface water would have slightly basic pH (7.6 to 8.2) within discharge limits. At these pH values, concentrations of some of the metals (Al, Cd, Cu, Fe, Hg, Mn, Ni, Pb, and Zn) may be reduced via precipitation, adsorption (which is not accounted for in PitMod); however, several metals form oxyanions (As, Mo, Sb, and Se) and are likely mobile at these pH values. Thus, it will be important to continue maintain the pit lake as a hydraulic sink in perpetuity to control releases to the environment.

K4.18.2 Water Treatment Methodologies

This section contains technical information on water treatment methodologies for WTPs that would treat contact water at the mine site during operations and closure, along with predictions of WTP effluent concentrations following treatment. WTP processes were developed based on inflows predicted by the water quality modeling in the previous sections. A high-level review of current WTP design was conducted to assess the effectiveness of the planned water treatment approach at meeting water treatment goals. The results of that review are detailed in a memo prepared by AECOM and dated October 18, 2018 (AECOM 2018i), summarized in the discussion below.

Water Treatment during Operations. Two WTPs are planned during operations: WTP#1 and WTP#2. WTP#1 would treat water from the open pit WMP and discharge treated water to the environment, and WTP#2 would treat water from the main WMP and discharge most to the environment, and a limited amount would be used as process water for the power plant and mill site. Water from the bulk TSF and main SCP would be pumped to the main WMP (Knight Piésold 2018a). Proposed discharge locations for treated water include the SFK, NFK, and UTC catchment (Knight Piésold 2018a: Figure 1.1). WTP#1 will discharge treated water into both the SFK catchment/frying pan lake, and the UTC catchment.

Variable water treatment rates would be required to manage surplus water from the mine site under differing climate conditions, with higher treatment rates during extended wet periods and lower treatment rates during extended dry periods. The treatment rates for WTP#1 and WTP#2 would be dictated by the volumes of water stored in the open pit WMP and the main WMP, respectively (Knight Piésold 2018a).



Sources: Lorax Environmental 2018

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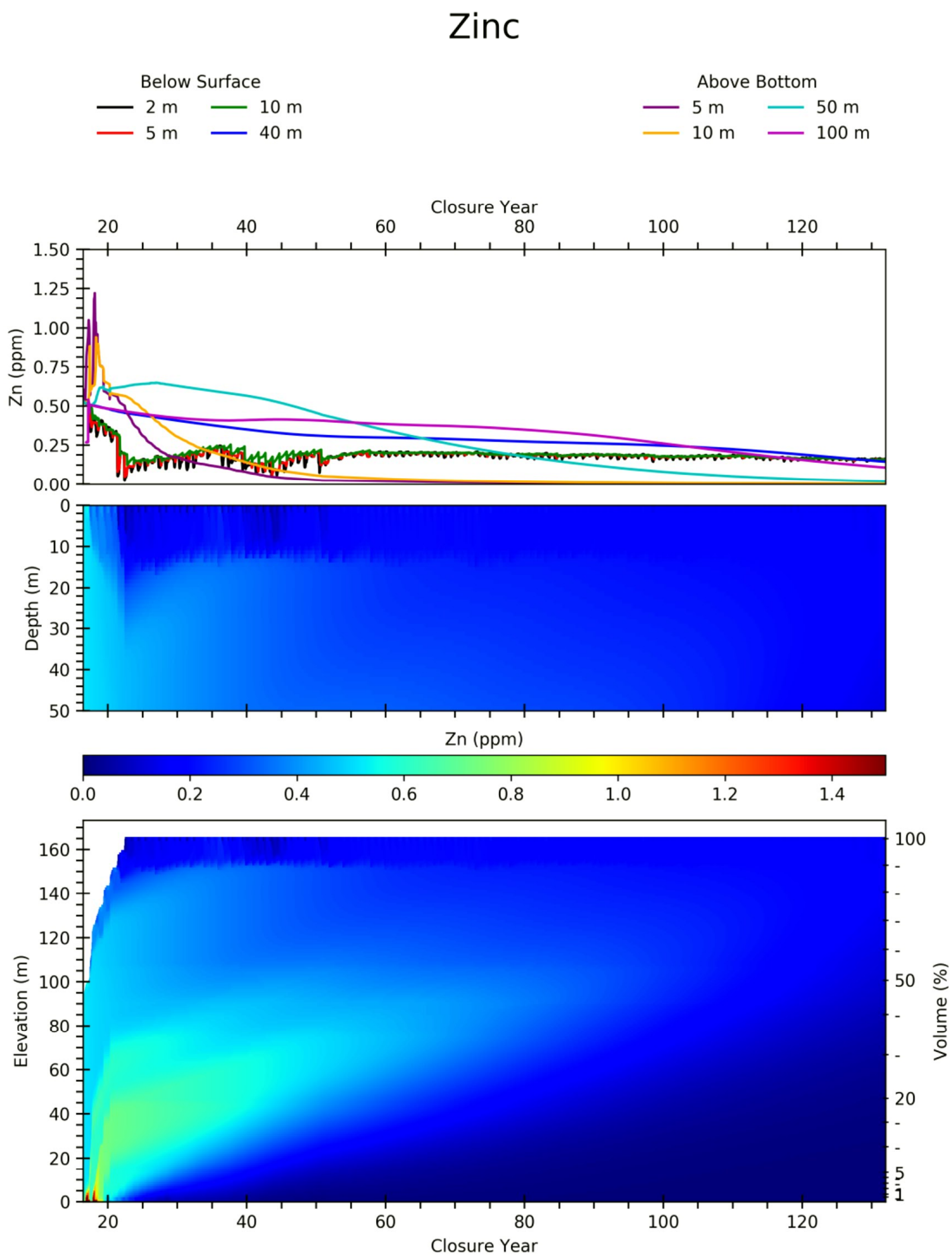
MODELED DISSOLVED COPPER CONCENTRATION IN PIT LAKE

PEBBLE PROJECT EIS

FIGURE K4.18-14



Sources: Lorax Environmental 2018

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MODELED DISSOLVED ZINC CONCENTRATION IN PIT LAKE

Water Treatment during Closure. Two WTPs are planned for operation at various stages during closure: WTP#2, and WTP#3, which would be converted from the open pit WMP (WTP#1). WTP#2 would continue to treat water from the main WMP through phase 1 of closure (years 0 to 15), at which point it would be decommissioned. The treatment rate of WTP#3 would be increased relative to WTP#1 to 49 cfs to meet anticipated treatment and discharge rates (AECOM 2018i; Knight Piésold 2018d), and would use essentially the same processes as WTP#2 (HDR 2019a). WTP#3 would treat surplus water from the open pit while PAG waste rock and pyritic tailings are being transferred (phase 1), and while the surplus water from the bulk TSF supernatant pond and main SCP are transferred to and stored in the open pit between years 20 and 50 (phase 3). WTP#3 would also operate as necessary during phase 4 (year 50 and beyond) to maintain the water level in the open pit below the not-to-exceed level, and to manage any additional surplus water from the bulk TSF main SCP. No water treatment would be necessary during Closure Phase 2 (years 16 to 20) as no discharge to the environment is planned as the open pit fills (Knight Piésold 2018d). Additionally, in closure phases 3 and 4 two additional WTPs will be used for treatment of surplus water from the SCP (Closure SCP WTP) and surplus water from the open pit (Closure Open Pit WTP) (HDR 2019b).

The operation of the WTPs would use an automated control system using supervisory control and data acquisition to monitor and adjust treatment operations to minimize the likelihood of upset conditions and inadvertent discharges above water quality criteria. The supervisory control and data acquisition system would also provide information and alarms to the treatment plant operations staff. Specific details of the operational strategy and control system are not available at this time and would typically be completed in a later phase of project engineering.

Specific details of the operation and treatment process that would be employed by each WTP are discussed in the following sections.

K4.18.2.1 Open Pit Water Treatment Plant (WTP#1)

The open pit WTP (WTP#1) would operate through production to treat water from the open pit WMP, which would receive water primarily from dewatering of the pit. WTP#1 would have two treatment trains to meet the influent flow of 14 cfs and enable ongoing water treatment during mechanical interruption of either train (HDR 2018a). Water in the open pit WMP is expected to be significantly lower in TDS than the main WMP (Knight Piésold 2018d). Key treatment steps would occur in the following sequence:

1. Dissolved metals would be oxidized with potassium permanganate, followed by co-precipitation with ferric chloride. Sodium hydroxide and hydrochloric acid would be added as needed to maintain pH for optimal precipitation. Flocculators/clarifiers would be used to separate out the co-precipitated solids.
2. Clarified water would then be treated with sodium hydrogen sulfide, sodium hydroxide, and ferrous sulfate to further co-precipitate remaining metals under reducing conditions.
3. Water from the sulfide reaction tanks would be filtered to remove precipitated metals. The sulfide reaction will primarily impact dissolved metals and is not expected to significantly alter the other properties of the water, such as pH or alkalinity. The filtered water is expected to be suitable for discharge.
4. Clarifier solids and filter backwash would be thickened (typically in a settling tank) and transferred (typically pumped) to the pyritic TSF.
5. Water from the sulfide reaction tanks would be filtered with ultrafiltration (UF) membranes to remove precipitated metals. Reject from the UF membranes would be thickened and transferred to the pyritic TSF.

6. A portion of the UF membrane filtered water would be treated by RO to remove selenium, and that treated stream will be recombined with the main effluent to achieve acceptable discharge limits.
7. Reject brine from the RO process, which would be high in selenium, would be further treated with a biologic reactor to separate selenium as a solid precipitate. Selenium solids would be separated in flocculators/clarifiers, thickened with other solids, and transferred to the pyritic TSF.

Evaluation of these processes compared to experience at other mines and industries, as well as potential upset conditions, is provided in the following section.

K4.18.2.2 Main Water Treatment Plant (WTP#2)

The main WTP (WTP#2) would operate during operations and through phase 1 of closure, and would treat water from the main WMP, which would receive water from the bulk and pyritic TSF ponds and the bulk TSF main embankment SCP (Knight Piésold 2018d; HDR 2018a). A water balance model diagram in Appendix K4.16, Surface Water Hydrology, depicts where water would be collected, stored, moved, and treated around the mine site. WTP#2 would have four treatment trains to meet the influent flow of 29 cfs and enable ongoing water treatment during mechanical interruption of any one train (HDR 2018a). Key treatment steps would occur in the following sequence (HDR 2018a):

1. Dissolved metals would be oxidized with air, ferric sulfate, and potassium permanganate, followed by co-precipitation with lime. Flocculators/clarifiers would be used to separate out co-precipitated solids. Co-precipitation of metals is a common treatment strategy in mining and is currently used in multiple locations. The process can experience upset if the chemical addition processes are not monitored and adjusted.
2. The clarified water would flow into a membrane feed tank, where sodium hydrogen sulfide or an organosulfide would be added to complete the precipitation process. Supplemental lime and sulfuric acid would be added as needed to maintain pH for optimal precipitation and membrane feed. Organosulfide is a process to precipitate trace metals and has been used in similar applications in other industries. The process can be disrupted due to competition if the upstream co-precipitation process is not properly maintained, leading to excessive metal ions that compete for the sulfide reactant.
3. Ultrafiltration membranes would be used to filter precipitated metals and protect downstream high-pressure membranes. Ultrafiltration is a barrier process for solids that has been used in similar applications at other mining and industrial locations. The process can be disrupted by fouling if the membrane system is not properly monitored and maintained, or if the upstream processes are upset in a manner that results in excessive solids in the influent.
4. High-pressure membranes (nanofiltration [NF]) would provide removal of metals, calcium, magnesium, and sulfate. Filtrate from the high-pressure membranes may require an alkalinity adjustment before discharge. NF is a TDS removal process that has been used in similar applications at other mining and industrial locations. The process can be disrupted if the membrane system is not properly monitored and maintained, or if the upstream processes are upset in a manner that results in excessive TDS in the influent.
5. Reject from the high-pressure membranes would have a high concentration of sulfate and other divalent ions. To prevent overloading the mine water balance with

sulfate, some sulfate must be removed from the reject before its disposal in the TSF. Sulfate would be removed as calcium sulfate process. Precipitated calcium sulfate solids would be disposed of in the pyritic TSF. Water quality modeling has indicated that the conditions in the pyritic TSF should prevent redissolution of the calcium sulfate solids. Lime softening is common method to reduce calcium and sulfate that has been used at other mining and industrial applications. The process can be upset by high levels of TDS.

6. Decant from the calcium sulfate precipitation process would contain high levels of TDS. It would be necessary to split the decant stream as follows:

Approximately three-quarters of the decant stream would be returned to the beginning of the WTP for reprocessing. This approach is common in lime softening and allows for additional precipitation of calcium and sulfate, but it may also result in significant return of TDS that could negatively impact the process. The remainder of the decant stream would be concentrated with an RO system. RO filtrate would be blended with nanofiltration permeate for discharge. Concentrated RO reject water would be sent to an evaporator for further concentration of the TDS. The liquid stream of the concentrated TDS will be transferred to the pyritic TSF. The evaporate will be condensed and the condensate blended with treated water from the nanofiltration membranes (step 4) for discharge. This methodology is not regularly practiced due to the high cost of evaporation. Further, there may be concern that high TDS water return could increase the TDS of decant from the pyritic TSF.

An independent review of the WTP#2 inflows and processes was conducted by AECOM (2018i). While the strategy for treatment and management in WTP#2 considers the major species, it involves highly complex chemistry and is reliant on assumptions that salt mass would be captured in solid form within interstitial voids in the pyritic TSF, and that rejected selenium solids discharged to the bulk TSF would not be remobilized. In the event that these assumptions prove to be invalid, the currently modeled salt and selenium mass balance would not be achieved by the end of operations, and a more rapid increase in salt and selenium mass would occur in the main WMP than currently projected. As these species concentrate, TDS would rise and the treatment strategy for WTP#2 would need to be altered to address these changed conditions. This would also contribute to higher dissolved salt loads, which could result in lower recovery rates in the NF processes, treatment systems not meeting current design capacities, and the potential for higher TDS in the discharge streams in order to close the salt balance. Further, the captured selenium would continue to cycle up in the process and could eventually reach a level where the treatment system is unable to meet discharge limits.

To mitigate the lower recovery rates to meet the hydraulic capacity, the NF system would need to increase pressures as salt load increases to achieve recoveries similar to the current design criteria. While this could allow WTP#2 to meet the hydraulic capacity, salt load would continue to increase, potentially resulting in elevated levels of TDS and selenium in the discharge. This may require further investigation as design progresses and/or as a long-term adaptive management strategy. If necessary to meet both hydraulic capacity and discharge criteria, trains would be installed as needed (PLP 2019-RFI 106).

K4.18.2.3 Closure Water Treatment Plant (WTP#3)

During closure, WTP#1 would be reconfigured and re-designated as WTP#3, with the open pit partially backfilled with materials that were temporarily stored in the pyritic TSF during operations (HDR 2018a). WTP#3 would treat surplus water from the open pit while PAG waste rock and pyritic tailings are being transferred during Closure Phase 1 (closure years 0 through 15). WTP#3 would continue to house separate treatment processes for surplus water from the bulk TSF and main SCP in closure phase 3 (Closure Years 20 and beyond), and from the pit lake in Closure Phase 4 (closure year 50 and beyond) (Knight Piésold 2018d, 2019a; HDR 2019b). The treatment processes for WTP#3 would be similar to WTP#2, and would include the following steps as described in HDR (2019b):

1. Dissolved metals would be oxidized, followed by co-precipitation with iron. Flocculators/clarifiers would be used to separate out co-precipitated solids, some of which would be recycled back to the first reaction tank and the rest wasted to a sludge thickener.
2. The clarified water would flow into a second set of reaction tanks to precipitate metal sulfides and complete precipitation of chromium and molybdenum.
3. UF membranes would be used to filter precipitated metals and protect downstream high-pressure membranes. Reject from UF membranes would be sent to the sludge thickener.
4. NF membranes would provide removal of additional metals, TDS, and sulfate. Permeate from the NF membranes would be habitat-conditioned and discharged to the environment.
5. NF membrane reject would have a high concentration of dissolved sulfate and other divalent ions. To prevent overloading the closure water balance, sulfate would be precipitated from the NF membrane reject before disposal in the open pit. Sulfate from the NF membrane reject would be precipitated as calcium sulfate with a lime softening process and separated with a clarifier. Some of the clarifier solids would be recycled back to the lime softening reaction tank and the rest wasted to the sludge thickener.
6. Decant from the calcium sulfate precipitation clarifier would still contain high levels of TDS and dissolved sulfate, which would be filtered with UF membranes followed by RO membranes. The UF membranes would protect the RO membranes from carryover clarifier solids. Reject from UF membranes would be sent to the sludge thickener. RO membrane permeate would be habitat-conditioned and discharged to the environment.
7. RO membrane reject water, which would occur at high flow rate with high TDS and dissolved sulfate concentrations, would be further processed with a second identical stage of calcium sulfate precipitation by lime softening, clarification, UF membranes, and RO membranes. Some of the second stage clarifier solids would be recycled back to the second stage lime softening reaction tank and the rest wasted to the sludge thickener. Reject from second stage UF membranes would be sent to the sludge thickener. Permeate from the second stage RO membranes would be habitat-conditioned and discharged to the environment. Highly concentrated brine reject from the second stage of RO membranes would be disposed of in the open pit.
8. Decant from the sludge thickener would be returned to the head of the WTP for reprocessing, and thickened sludge would be disposed of in the open pit.

K4.18.2.4 Closure Seepage Collection Pond WTP

In closure phases 3 and 4, the seepage collection pond WTP would operate as a stand-alone treatment plant to treat surplus water from the seepage collection pond. This WTP would not treat water from other streams (i.e., pumped water from the pit lake). The treatment processes would be the same as WTP#3 described above (HDR 2019b).

K4.18.2.5 Closure Open Pit WTP

In closure phases 3 and 4, an open pit WTP would be used as a stand-alone water treatment stream to handle surplus water from the open pit. The open pit WTP would not treat water from other streams. As described above and shown on Figure K4.18-10 and Figure K4.18-11, TDS and sulfate are predicted to be below water quality criteria after about closure year 25. As a result, treatment of TDS and sulfate would not be required, and the process design for this WTP would be limited to metals precipitation, clarification, and filtration as follows (HDR 2019b):

1. Dissolved metals would be oxidized, followed by co-precipitation with iron. Flocculators/clarifiers would be used to separate out the co-precipitated solids.
2. The clarified water would flow into a second set of reaction tanks to precipitate metal sulfides and complete precipitation of remaining metals. Clarifier solids would be sent to a sludge thickener.
3. Water from the sulfide reaction tanks would be filtered with pressure sand filters followed by UF membranes to remove precipitated metals. Permeate from the UF membranes would be habitat-conditioned and discharged to the environment. Backwash from the sand filters and UF membranes would be sent to the sludge thickener.
4. A portion of the sludge from the sludge thickener would be recycled to the first reaction tank, and the balance wasted back to the open pit. Decant water from the sludge thickener would be sent back to the head of the WTP for reprocessing.

K4.18.2.6 Water Quality of WTP Discharge

Operations Phase. The 50th percentile predicted quality of discharge water from both WTPs in operations is provided in Table K4.18-13. Based on a comparison of the data to most stringent discharge limits shown in Appendix K3.18, Table K3.18-1, discharge water is currently expected to meet Alaska Department of Environmental Conservation (ADEC) criteria. However, as described above, there is some concern that during operations, waste products high in selenium and salt placed in the pyritic TSF may, over time, lead to increased TDS concentrations in the main WMP, and thereby affect the inflow conditions to the main WTP (WTP#2) (AECOM 2018i). Such a change in condition of the inflow to the WTPs may warrant additional WTP design consideration, or development of adaptive management strategies to ensure that mine site WTPs are capable of and effective at meeting treatment goals over the duration of time that treatment would be required.

Closure Phases. In closure phase 1, modeled water quality of WTP#3 discharge is expected to be the same or similar to WTP#2 in operations (PLP 2019-RFI 106). No water treatment is anticipated during closure phase 2 as the pit lake fills, and WTP#2 would be decommissioned. In closure phase 3 and beyond, surplus water from the open pit and the bulk TSF main SCP would be treated as two stand-alone water treatment streams, and may be housed in the same WTP building (HDR 2019b). Table K4.18-14 includes water quality information for influent and effluent waste streams for the SCP WTP in closure phase 3 (HDR 2019c). The resultant water quality information from the mass balance model for year 105 of closure phase 4 is included in Table K4.18-15 (HDR 2019d). Water quality of discharge from the open pit WTP is the subject of ongoing engineering analysis (PLP 2019-RFI 106).

Table K4.18-13: Predicted Water Quality of WTP Discharge in Operations

Parameter[a]	Main WTP (WTP#2)				Open Pit WTP (WTP#1)		
	Influent Wastewater	Treated Water Discharge	Waste Water to TSF		Influent Wastewater	Treated Water Discharge	Waste Stream to TSF
mg/L			Sludge	Brine			
Flow (gpm)	12,791	12,690	157	15	6,284	6,277	9
pH (standard units)	7 to 8	7	8	8	7 to 8	7.6	7.5
TDS	**1,677**[b]	232	**2,856**	**218,382**	267	439	438
TSS	**20**	0	**173,600**	0	**30**	0	**70,000**
Alkalinity	252	72	586	16,767	56	60	54
Acidity	3	16	22	0	7.4	50	50
Hardness	853	53	49,211	106,415	147	147	147
Cl	9.6	49	174	**26,832**	1.98	113	102
F	0.3	0.3	0.5	**35.5**	0.21	0.21	0.21
SO_4	973	32	105,589	93,543	109	117	115
Al	**0.25**	0.001	**16.25**	**1.03**	**0.095**	0.015	**56**
Sb	**0.036**	0.001	**2.25**	**0.43**	**0.007**	0.003	**2.8**
As	**0.047**	0.0001	**3.061**	**0.063**	**0.02**	0.004	**11.3**
Ba	0.06	0.001	**3.18**	**5.28**	0.07	0.028	**25.3**
Be	**0.02**	0.0004	**1.248**	**0.091**	0.0002	0.0002	0.0002
B	0.18	0.03	**9.7**	**18**	0.05	0.05	0.05
Cd	**0.00992**	0.00001	**0.64697**	**0.00718**	**0.0073**	0.000005	**5.1**
Ca	228	18	13,028	38,179	45	45	45
Cr, Total	0.0046	0.00001	**0.3017**	0.0031	0.001	0.0001	**0.6**
Co	0.0292	0.0001	**1.89**	**0.09**	0.034	0.008	**18.2**
Cu	**0.042**	0.000007	**2.72**	**0.0024**	**0.042**	<0.000001	**29.6**
Fe	0.21	0.003	**12.87**	**8.89**	0.65	0.01	**279**
Pb	**0.02**	0.000001	**1.19**	**0.00075**	**0.002**	0.000001	**1.4**
Mg	69	2	4,044	2,665	8.3	8.3	8.3
Mn	**1.3**	0.0012	**84**	**3.48**	**1.08**	0.003	**2,041**
Hg	**0.00015**	1E-08	**0.01**	0.00001	**0.00019**	<0.000001	**0.13**
Mo	**2.1**	0.0012	**139**	**1.05**	**0.3**	0.009	**205**
Ni	**0.0613**	0.0003	**3.93**	**0.41**	**0.015**	0.00005	**10.5**
Se	**0.0217**	0.003	**1.12**	**1.04**	**0.008**	0.004	**2.34**
Ag	**0.00185**	1E-07	**0.12**	0.00008	0.0003	<0.00001	**0.2**
Tl	0.0005	0.00001	**0.0286**	**0.0158**	0.0004	<0.00001	**0.25**
V	0.0085	0.000024	**0.55**	0.0142	0.0014	0.0008	**0.43**

Table K4.18-13: Predicted Water Quality of WTP Discharge in Operations

Parameter[a]	Main WTP (WTP#2)				Open Pit WTP (WTP#1)		
	Influent Wastewater	Treated Water Discharge	Waste Water to TSF		Influent Wastewater	Treated Water Discharge	Waste Stream to TSF
mg/L			Sludge	Brine			
Zn	**1.3**	0.000034	**85**	**0.1**	**0.41**	0.00002	**289**
NO_3-N	2.42	2.99	2.01	**109**	--	--	--
NO_2-N	0.19	0.17	0.17	0	--	--	--
NO_3+NO_2	2.61	3.16	2.18	**109**	2.39	2.15	2.4
NH_3-N	0.4	0.39	0.43	**36.8**	0.2	0.18	0.2

Notes:
[a] Units are mg/L unless otherwise noted.
[b] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).
gpm = gallons/minute
mg/L = milligrams/liter
Source: HDR 2018a

Table K4.18-14: Predicted Water Quality of WTP Streams in Closure Phase 3

Parameter	Influent Wastewater	Treated Water Discharge from SCP Water	Waste Streams to Open Pit		
			Sludge		Brine
			Sludge Total	Soluble Sludge	
Flow (gpm)	4,937.13	4,650.12	93.74	79.68	222.25
pH (std units)	7 to 8	7.00	**9.00**	**9.00**	**10.70**
TDS	**4,825.15**	201.51	**2,453.00**	**2,355.45**	**6,808.75**
TSS	**20.00**	0.00	**150,000.00**	0.00	0.00
Alkalinity as $CaCO_3$	888.60	59.30	59.30		1,413.11
Acidity as $CaCO_3$	9.45				
Chloride	10.89	3.85	36.00	36.00	152.41
Fluoride	**1.04**	0.70	**1.01**	0.0034	**2.60**
Sulfate	**2,697.00**	71.20	**150,455.00**	**1,113.78**	**1,412.00**
Aluminum	**2.881**	0.0003	**139.00**	0.0574	0.0106
Antimony	**0.2295**	0.000013	**12.0**	**0.0331**	0.0005
Arsenic	**0.2984**	0.0057	**15.0**	**0.0230**	**0.1701**
Barium	0.173	0.0098	0.1830	0.2377	1.8218
Beryllium	**0.005741**	0.0014	**0.0760**	**0.0092**	**0.0769**
Bismuth	0.1148	0.00005	6.20	0.0819	0.0007
Boron	0.5972	0.53	0.60	0.61	**1.78**
Cadmium	**0.01148**	0.00003	**0.57**	**0.00416**	**0.00084**
Calcium	884.90	36.20	34,795.00	678.78	1,719.43
Chromium, total	0.02303	0.0013	**1.03**	0.0042	0.0125
Cobalt	**0.0574**	0.0004	**3.02**	0.0209	0.01
Copper	**0.4247**	0.00003	**22.00**	**0.09092**	0.00051
Iron	**2.118**	0.0014	**9,549.00**	0.0399	0.0116

Table K4.18-14: Predicted Water Quality of WTP Streams in Closure Phase 3

Parameter	Influent Wastewater	Treated Water Discharge from SCP Water	Waste Streams to Open Pit		
			Sludge		Brine
			Sludge Total	Soluble Sludge	
Lead	**0.05743**	0.000038	**2.820**	**0.0021**	0.00022
Magnesium	113.90	8.96	5,459.00	138.18	26.30
Manganese	**3.331**	0.0016	**196.00**	**0.716**	0.045
Mercury	**0.0005741**	0.0000001	**0.03**	**0.00021**	0.00006
Molybdenum	**13.77**	0.0097	**733**	**0.53**	**0.55**
Nickel	**0.05745**	0.00014	**3.00**	0.0020	0.0043
Potassium	41.38	14.90	62.00	62.62	458.81
Selenium	**0.0632**	0.0048	**0.700**	**0.067**	**0.89**
Silver	**0.0115**	0.00000	**0.71**	0.00001	0.000002
Sodium	149.90	58.30	327.00	282.63	2,112.34
Thallium	0.00058	0.0000006	**0.0315**	0.000043	0.00002
Silicon	38.58	7.40	1,479.00	49.41	59.27
Tin	0.2295	0.000011	12.00	0.0246	0.0006
Vanadium	0.0345	0.002	**1.60**	0.0045	0.02055
Zinc	**2.181**	0.00036	**115.00**	**0.3900**	0.0142
Nitrate-N	0.00	0.00	0.00	0.00	0.00
Nitrite	0.00	0.00	0.00	0.00	0.00
Ammonia	0.00	0.00	0.00	0.00	0.00
Hardness as $CaCO_3$	2,678.64	128.00	87,197.00	2,265.58	4,406.79

Notes:
Units are mg/L (milligrams/liter) unless otherwise noted.
Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).
$CaCO_3$ = calcium carbonate
Source: HDR 2019c

Table K4.18-15: Predicted Water Quality of WTP Streams in Closure Phase 4 (Year 105)

Parameter	Influent Wastewater	Treated Water Discharge	Waste Stream to Open Pit	
			Sludge Total	Soluble Sludge
Flow (gpm)	4,039.20	4,054.74	3.66	3.11
pH (std units)	8.10	7.30	7.30	8.00
TDS	259.00	344.27	347.46	347.46
TSS	**20.00**	0.05	**106,000.00**	
Alkalinity as Ca CO3	40.00	36.00	36.10	36.10
Acidity as CaCO3	0.90	-	-	-
Chloride	2.00	59.61	59.58	59.58
Fluoride	0.12	0.12	0.12	0.12
Sulfate	173.00	173.00	173.00	173.00
Aluminum	**1.00**	0.0483	1047	0.0482

Table K4.18-15: Predicted Water Quality of WTP Streams in Closure Phase 4 (Year 105)

Parameter	Influent Wastewater	Treated Water Discharge	Waste Stream to Open Pit	
			Sludge Total	Soluble Sludge
Antimony	**0.011**	0.0019	**9.8**	0.002
Arsenic	0.016	0.0007	**16.8**	0.0007
Barium	0.015	0.015	0.015	0.015
Berylium	0.0010	0.00004	**1.057**	0.00004
Bismuth	0.0070	0.0011	6.5	0.0011
Boron	0.034	0.034	0.034	0.034
Cadmium	**0.0017**	0.00003	**1.8**	0.00003
Calcium	59.00	66.01	66.19	66.19
Chromium, total	0.0020	0.00004	**2.2**	0.00004
Cobalt	0.014	0.000008	**15.5**	0.0001
Copper	**0.270**	0.00010	**298**	0.0004
Iron	**1.70**	0.058	**208,434**	0.00005
Lead	**0.0038**	0.000001	**4**	0.000001
Magnesium	7.7	7.6	7.6	7.6
Manganese	**0.89**	0.01	**968**	0.01
Mercury	**0.00004**	0.00000001	**0.04418**	0.00000002
Molybdenum	**0.70**	0.0061	**766**	0.006
Nickel	0.0120	0.0009	**12**	0.0009
Potassium	2.8	12.8	3.3	3.3
Selenium	**0.0096**	0.0042	**6.4**	0.0042
Silver	0.00066	0.0000002	**0.73**	0.0000000003
Sodium	10.0	10.2	10.2	10.2
Thallium	0.00013	0.00004	**0.12**	0.00004
Silicon	2.3	2.3	2.3	2.3
Tin	0.0130	0.00001	14.3	0.00004
Vanadium	0.0020	0.00005	**2.15**	0.00005
Zinc	**0.180**	0.0005	**198**	0.0005
Nitrate-N	0.018	0.018	0.018	0.018
Nitrite	0.001	0.001	0.001	0.001
Ammonia	0.002	0.002	0.002	0.002
Hardness as $CaCo_3$	179	196	197	197

Notes:
Units are mg/L (milligrams/liter) unless otherwise noted.
Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).
$CaCO_3$ = calcium carbonateSource: HDR 2019d

K4.18.3 Dust Deposition Methodologies

This section describes the methodology used to calculate potential increases in surface water from both direct deposition to waterbodies and runoff from dust in soil. The methodology for calculating incremental increases in the top inch of soil from dust deposition is provided in Appendix K4.14, Soils.

K4.18.3.1 Sediment/Substrate Quality

Baseline sediment quality data are presented in Appendix K3.18, Water and Sediment Quality. Dust deposition impacts to sediment/substrate quality at the mine site were calculated following the same approach as for soils, outlined in Section 4.14, Soils. Baseline dry weight sediment quality data for the mine site (Appendix K3.18) was used for this analysis, as well as the same default parameters for sediment bulk density and mixing zone. Table K4.18-16 provides the results of dust deposition impacts to sediment quality, including the percent increase in metals concentration and total estimated concentration of metals in sediment after the 20-year life of mining operations.

Air deposition represents the primary source of site-related contamination to waterbodies, with metals partitioning to both sediment and surface water. The equation used below conservatively assumes all of the metals from air deposition partition to sediment. Although this modeling does not account for overland runoff, metals' contributions from this pathway to nearby waterbodies are expected to be minor, as most of the site is covered with vegetation (not paved or bare soil), minimizing the potential for overland transport. Furthermore, baseline metals concentrations in soil and sediment are similar; therefore, any soil particles washing off into the waterbody would not likely introduce higher metals concentrations than are already present in the waterbody (i.e., mixing of similar concentrations would result in similar concentrations).

K4.18.3.2 Surface Water Quality

Table K4.18-17 provides the results of the estimated increase in metals concentrations in surface water from dust deposition at the mine site. The 20-year total and dissolved concentrations due to dust deposition were calculated as follows:

$$Total\ SW_{20yr} = \frac{SD_{20yr}}{R_{total}};\ Dissolved\ SW_{20yr} = \frac{SD_{20yr}}{R_{dissolved}}$$

(Equation K4.18-1)

where SW_{20yr} is the surface water concentration (total and dissolved respectively) after 20 years of operations, SD_{20yr} is the sediment concentration after 20 years of operations, and R is a site-specific relationship representing the ratio of sediment to surface water. R is defined as follows:

$$R_{total} = \frac{SD_{BL}}{SW_{BL(total)}};\ R_{dissolved} = \frac{SD_{BL}}{SW_{BL(dissolved)}}$$

(Equation K4.18-2)

where SD_{BL} is the baseline sediment concentration and SW_{BL} is the baseline surface water concentration. This approach allows the estimation of impacts to surface water quality for the length of mining operations. This methodology was applied to mine site related surface water sources including the NFK, SFK, UTC, and Frying Pan Lake. Mean values of sediment and surface water metals concentrations were used for this analysis. This approach was developed as a semi-quantitative approach to be analogous to the EPA surface water pathway approach using chemical-specific soil-water partition coefficients (K_d) (Allison and Allison 2005).

Table K4.18-16: Predicted Change in Sediment Quality from Dust Deposition

Analyte	Baseline Concentration[a]	Deposition from Dust			Sediment % Increase	Soil/Sediment Criteria[d]		
	Mean[b] (mg/kg)	Yearly Deposition Rate (g/m^2-year)	Incremental Increase over 20 Years[c] (mg/kg)	Baseline + 20 Years Dust Deposition (mg/kg)		ADEC Soil Human Health (mg/kg)	TEL (mg/kg)	PEL (mg/kg)
Antimony	0.23	0.0000113	0.0075	0.24	3.17%	33	--	--
Arsenic	**14.2**[e]	0.0000884	0.059	**14.3**	0.41%	7.2 (inorganic)	5.90	17.0
Beryllium	0.35	0.0000032	0.0021	0.35	0.61%	170	--	--
Cadmium	0.26	0.0000026	0.0017	0.26	0.66%	76 (diet)	0.596	3.53
Chromium	15.4	0.00011	0.073	15.5	0.47%	1.0×10^5 (CrIII)	37.3	90
Cobalt[f]	7.86	0.0000293	0.020	7.88	0.25%	--	--	--
Lead	6.9	0.0000307	0.020	6.92	0.30%	400	35	91.3
Manganese[f]	623	0.00104	0.69	624	0.11%	--	--	--
Mercury	0.04	1.92E-07	0.00013	0.040	0.32%	3.1 (elemental)	0.174	0.486
Nickel	8.95	0.0000264	0.018	8.97	0.20%	1,700 (soluble salts)	18	36
Selenium	1.15	0.0000113	0.008	1.16	0.65%	410	--	--

Notes:
[a] Source: SLR 2011a.
[b] All sediment data is presented on a dry weight basis.
[c] Since sediment data presented in dry weight, the same soil equation and default parameters were used for sediment (i.e., bulk density & mixing zone) (EPA 2005).
[d] Source: Buchman 2008; ADEC 2017
[e] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).
[g] No available reference value per ADEC 18 Alaska Administrative Code (AAC) 75. Additional human health evaluation of all hazardous air pollutant (HAP) metals is provided in Section 4.10 (Health and Safety) based on published US Environmental Protection Agency (EPA) Regional Screening Levels (RSLs). Additional human health evaluation of all HAP metals based on published EPA RSLs is provided in Section 4.10 (Health & Safety), and includes metals for which no ADEC reference value is shown in Table 4.14-1.

Table K4.18-17: Predicted Change in Surface Water Quality from Dust Deposition

Location	Analyte	Baseline Concentration			20-Yr Sediment Concentration[c] (mg/kg)	20-Yr Surface Water Concentration[d]			ADEC Most Stringent Water Quality[e] (mg/L)
		Sediment Mean[a] (mg/kg)	Surface Water-Total Mean[b] (mg/L)	Surface Water-Dissolved Mean[b] (mg/L)		Total (mg/L)	Dissolved (mg/L)	% Increase (Total)	
NFK	Antimony	0.23	--	--	0.24	--	--	--	0.006
	Arsenic	**14.2**[f]	0.00034	0.00031	**14.3**	0.00034	0.00031	0.41%	0.01
	Beryllium	0.35	--	--	0.35	--	--	--	0.004
	Cadmium	0.26	0.000020	0.000020	0.26	0.000020	0.000020	0.66%	0.00008
	Chromium	15.4	0.00029	0.00028	15.5	0.00029	0.00028	0.47%	0.1 (total)
	Cobalt	7.86	--	--	7.88	--	--	--	0.05
	Lead	6.9	0.00012	0.000070	6.92	0.00012	0.000070	0.30%	0.00039
	Manganese	623	0.013	0.0082	624	0.013	0.0082	0.11%	0.05
	Mercury	0.04	--	--	0.040	--	--	--	0.000012
	Nickel	8.95	0.00025	0.00033	8.97	0.00025	0.00033	0.20%	0.01287
	Selenium	1.15	0.00027	0.00028	1.16	0.00027	0.00028	0.65%	0.005
SFK	Antimony	0.23	--	--	0.24	--	--		0.006
	Arsenic	**14.2**	0.00033	0.00031	**14.3**	0.00033	0.00031	0.41%	0.01
	Beryllium	0.35	--	--	0.35	--	--		0.004
	Cadmium	0.26	0.000019	0.000019	0.26	0.000019	0.000019	0.66%	0.00008
	Chromium	15.4	0.00027	0.00025	15.5	0.00027	0.00025	0.47%	0.1 (total)
	Cobalt	7.86	--	--	7.88	--	--		0.05
	Lead	6.9	0.00011	0.000072	6.92	0.00011	0.000072	0.30%	0.00039
	Manganese	623	0.024	0.019	624	0.024	0.0189	0.11%	0.05
	Mercury	0.04	--	--	0.040	--	--		0.000012
	Nickel	8.95	0.00033	0.00042	8.97	0.00033	0.00042	0.20%	0.01287
	Selenium	1.15	0.00029	0.00029	1.16	0.00029	0.00030	0.65%	0.005
UTC	Antimony	0.23	--	--	0.24	--	--		0.006
	Arsenic	**14.2**	0.00095	0.00082	**14.3**	0.00096	0.00082	0.41%	0.01
	Beryllium	0.35	--	--	0.35	--	--		0.004

Table K4.18-17: Predicted Change in Surface Water Quality from Dust Deposition

Location	Analyte	Baseline Concentration			20-Yr Sediment Concentration[c] (mg/kg)	20-Yr Surface Water Concentration[d]			ADEC Most Stringent Water Quality[e] (mg/L)
		Sediment Mean[a] (mg/kg)	Surface Water-Total Mean[b] (mg/L)	Surface Water-Dissolved Mean[b] (mg/L)		Total (mg/L)	Dissolved (mg/L)	% Increase (Total)	
UTC	Cadmium	0.26	0.000017	0.000017	0.26	0.000017	0.000017	0.66%	0.00008
	Chromium	15.4	0.00036	0.00031	15.5	0.00036	0.00031	0.47%	0.1 (total)
	Cobalt	7.86	--	--	7.88	--	--		0.05
	Lead	6.9	0.000089	0.000057	6.92	0.00009	0.000058	0.30%	0.00039
	Manganese	623	0.026	0.020	624	0.026	0.0199	0.11%	0.05
	Mercury	0.04	--	--	0.040	--	--		0.000012
	Nickel	8.95	0.00061	0.00068	8.97	0.00061	0.00068	0.20%	0.01287
	Selenium	1.15	0.00030	0.00030	1.16	0.00030	0.00030	0.65%	0.005
Frying Pan Lake	Antimony	0.23	--	--	0.24	--	--		0.006
	Arsenic	**14.2**	0.00048	0.00036	**14.3**	0.00048	0.00036	0.41%	0.01
	Beryllium	0.35	--	--	0.35	--	--		0.004
	Cadmium	0.26	0.000018	0.000018	0.26	0.000018	0.000018	0.66%	0.00008
	Chromium	15.4	--	--	15.5	--	--	--	0.1 (total)
	Cobalt	7.86	--	--	7.88	--	--		0.05
	Lead	6.9	0.00011	0.00016	6.92	0.00011	0.000165	0.30%	0.00039
	Manganese	623	0.035	0.017	624	0.036	0.0171	0.11%	0.05
	Mercury	0.04	--	--	0.040	--	--		0.000012
	Nickel	8.95	0.00022	0.00036	8.97	0.00022	0.00037	0.20%	0.01287
	Selenium	1.15	--	--	1.16	--	--	--	0.005

Notes:
[a] Sediment data (in dry weight) obtained from Appendix K3.18, Table K3.18-18.
[b] Surface water data from Appendix K3.18, Tables K3.18-6 through K3.18-9.
[c] 20-yr sediment concentration = baseline + incremental increase over 20 years (Table K4.18-11).
[d] 20-yr surface water concentration = 20-yr sediment concentration / site-specific baseline sediment-baseline surface water relationship factor.
[e] Surface water quality criteria from Appendix K3.18, Table K3.18-1; most stringent criteria (e.g., of human health, aquatic life, drinking water) for total metals, unless specified as dissolved.
[f] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).

K4.18.3.3 Groundwater Quality

Table K4.18-18 displays baseline and predicted soil concentrations of hazardous air pollutant (HAPs) metals due to dust compared to ADEC migration to groundwater levels. The ADEC levels represent soil concentrations at which there is potential risk for substances to leach to groundwater and potentially result in a completed human health exposure pathway (ADEC 2017b). This approach was used to examine potential impacts to groundwater from dust deposition.

Table K4.18-18: Predicted Change in Groundwater Quality from Dust Deposition

Analyte	Baseline[a]	Soil Concentration Post-Dust Deposition			Comparative Action Levels[d]
	Soil Concentration Mean (mg/kg)	Incremental Increase over 20 Years (mg/kg)[b,c]	Baseline + 20 Years Dust Deposition	% Increase after 20 years	Migration to Groundwater (mg/kg)
Antimony	0.24	0.00753	0.248	3.04%	4.6
Arsenic	**10.2**[e]	0.0589	**10.26**	0.57%	0.2
Beryllium	0.41	0.00213	0.412	0.52%	260
Cadmium	0.24	0.00173	0.242	0.72%	9.1
Chromium	17.7	0.0733	17.8	0.41%	1.0 x 10^5 (Cr^3)
Cobalt	6.55	0.0195	6.57	0.30%	N/A
Lead	8.74	0.0205	8.76	0.23%	N/A
Manganese	388	0.693	389	0.18%	N/A
Mercury	0.12	0.000128	0.120	0.11%	0.36
Nickel	9.16	0.0176	9.18	0.19%	340
Selenium	2.76	0.00753	2.77	0.27%	6.9

Notes:
[a] Source: SLR et al. 2011b
[b] Based on PLP 2018-RFI 009 total HAPs concentration in dust and EPA 2005
[c] Calculation assumes time period of deposition be the operational life of the mine (20 years), a soil mixing zone depth of 2 cm, and soil bulk density of 1.5 g/cm3 (EPA 2005)
[d] ADEC 2017b
[e] Bold values indicate exceedances of the most stringent water quality criteria (Appendix K3.18, Table K3.18-1).

K4.20 AIR QUALITY

This Technical Appendix supports discussion and explanation of an analysis of project impacts to air quality presented in Section 4.20, Air Quality, of the Environmental Impact Statement (EIS). This appendix presents the approach and results of the assessment of emissions and impacts for select project components and variants (mine site, transportation corridor, Amakdedori port, and pipeline corridor) and phases (construction, operations, and closure) for which direct impacts were predicted using modeling. Components and phases selected for modeling were those anticipated to produce impacts with the highest magnitude, largest geographic extent, and longest duration. Impacts from other components and phases are smaller than those modeled and are assessed by proxy. In addition to the model impacts for the project, a cumulative impact assessment was completed for the combined impacts of the project and Reasonably Foreseeable Future Actions (RFFAs). The cumulative impact assessment is based on the analysis of the direct impacts that were predicted using modeling of the project components and phases.

K4.20.1 Comparison of Model-Predicted Direct Impacts to Applicable Thresholds

Project direct impacts are compared to applicable thresholds using near-field dispersion models for Class II areas and far-field modeling assessments tools for Federal Class I areas. Federal Class I area status is assigned to federally protected wilderness areas, and allows the lowest amount of permissible deterioration. All other areas are Class II, allowing for a moderate amount of air quality deterioration.

K4.20.1.1 Near-Field Class II Area Impact Assessments

The Clean Air Act (CAA) of 1970 (42 United States Code [USC] 7401 et seq.), as amended in 1977 and 1990, is the primary federal statute that regulates air pollution. The CAA provides states with the authority to regulate air quality within state boundaries. The State of Alaska has enacted the Alaska Ambient Air Quality Standards (AAAQS). The AAAQS establishes maximum acceptable concentrations for criteria pollutants, including nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), particulate matter with an aerodynamic diameter of 10 microns or less (PM_{10}), particulate matter with an aerodynamic diameter of 2.5 microns or less ($PM_{2.5}$), ozone, ammonia, and lead. The AAAQS represent the maximum allowable atmospheric concentrations that may occur to protect public health and welfare, and include a reasonable margin of safety to protect the more sensitive individuals in the population. Table K4.20-1 lists AAAQS criteria used to evaluate project plus background impacts, based on the results of dispersion modeling. Note that lead and ammonia emissions are either negligible or not emitted at all from project components; therefore, they were not addressed as part of the impact analysis.

In addition to the AAAQS, New Source Review Prevention of Significant Deterioration (PSD) regulations are a CAA provision that is relevant to the project's impact assessment. PSD regulations, which restrict the degree of ambient air quality deterioration allowed in areas that meet the AAAQS, apply to proposed new or modified major stationary sources that have the potential to emit criteria pollutants in excess of predetermined de minimis values (40 Code of Federal Regulations [CFR] Part 51). Allowable deterioration to air quality can be expressed as the incremental increase to ambient concentrations of criteria pollutants, also referred to as a "PSD increment." The PSD increments for criteria pollutants are based on the PSD classification of the area. Class I areas allow the lowest amount of air quality increment consumption, while Class II designations allow higher increment consumption. The project is in a Class II area. Therefore, the project-only impacts based on near-field modeling are assessed using the PSD

Class II increments as listed in Table K4.20-1. The comparison of impacts using PSD Class II increments has been provided for informational purposes only, and does not represent a regulatory PSD increment consumption analysis. PSD increment consumption would be assessed as part of a formal increment consumption analysis during the permitting process, if required. Evaluation of PSD Class I increments are not included, because it is anticipated that the closest Federal Class I areas are too far from the project to be impacted by the project. Also, for the purpose of this assessment, not all ambient standards and increments are addressed. The modeled project and project-only impacts are compared to the ambient standards and increments based on likely air quality permits requirements once the project is operational.

Table K4.20-1: Prevention of Significant Deterioration Increments and Alaska Ambient Air Quality Standards

Pollutant	Averaging Period	PSD Class II Increment		AAAQS	
		Value ($\mu g/m^3$)	Form	Value ($\mu g/m^3$)	Form
CO	8-hour	N/A	N/A	10,000	Not to be exceeded more than once per year
	1-hour	N/A	N/A	40,000	Not to be exceeded more than once per year
NO_2	Annual	25	Annual mean	100	Annual mean
	1-hour	N/A	N/A	188	98th percentile of annual distribution of the maximum daily 1-hour concentrations averaged over 3 years
$PM_{2.5}$	Annual	4	Annual mean	15	Annual mean, averaged over 3 years
	24-hour	9	Not to be exceeded more than once per year	35	98th percentile, averaged over 3 years
PM_{10}	Annual	17	Annual mean	N/A	Annual mean
	24-hour	30	Not to be exceeded more than once per year	150	Not to be exceeded more than once per year on average over 3 years
SO_2	Annual	20	Annual mean	80	Never to be exceeded
	24-hour	91	Not to be exceeded more than once per year	365	Not to be exceeded more than once per year
	3-hour	512	Not to be exceeded more than once per year	1,300	Not to be exceeded more than once per year
	1-hour	N/A	N/A	196	99th percentile of the annual distribution of the maximum daily 1-hour concentrations averaged over 3 years
Lead	Rolling 3-month average	N/A	N/A	0.15	Not to be exceeded

Table K4.20-1: Prevention of Significant Deterioration Increments and Alaska Ambient Air Quality Standards

Pollutant	Averaging Period	PSD Class II Increment		AAAQS	
		Value ($\mu g/m^3$)	Form	Value ($\mu g/m^3$)	Form
Ammonia	8-hour	N/A	N/A	2.1 mg/m^3	Not to be exceeded more than once per year

Notes:
$\mu g/m^3$ = micrograms per cubic meter
mg/m^3 = milligrams per cubic meter
AAAQS = Alaska Ambient Air Quality Standards
CO = carbon monoxide
N/A = not applicable
NO_2 = nitrogen dioxide
$PM_{2.5}$ and PM_{10} = particulate matter with an aerodynamic diameter less than or equal to 2.5 and 10 micrometers, respectively
PSD = prevention of significant deterioration
SO_2 = sulfur dioxide
Source: Alaska Administrative Code Title 18, Section 50.010

Because of the lack of large nearby sources, modeling was conducted only to predict project-only concentrations. Therefore, project total ambient impact concentrations were developed by summing the project-only concentrations with a representative background concentration. Project-only impacts can be inferred from the modeling results tables presented in the following sections by eliminating the background concentrations. The background concentrations presented in the modeling results tables are concentrations representative of the ambient environment, and include the contributions from nearby and other background sources. Therefore, the background concentrations vary depending on the project component because the ambient environment of each component is different. Additionally, because there are no RFFA within 31 miles of project area that would overlap in time with the project's construction and operations, the background values added to the project total are representative of the cumulative project impact.

K4.20.1.2 Far-Field Class I Area Impact Assessments

Given that there is a large distance (greater than 100 miles) between the project and Class I areas and that project near-field criteria pollutant impacts are minimal, it is anticipated that the far-field impacts at Class I areas would be even smaller. Therefore, the far-field impact assessment focuses on impacts to air quality-related values (AQRVs). The US Forest Service, National Park Service, and US Fish and Wildlife Service (USFWS), collectively the Federal Land Managers (FLM), define an AQRV as "a resource, as identified by the FLM for one or more federal areas that may be adversely affected by a change in air quality. The resource may include visibility or a specific scenic, cultural, physical, biological, ecological or recreational resource identified by the FLM for a particular area" (Federal Land Managers' Air Quality Related Values Workgroup [FLAG] 2010). The AQRV analysis is typically limited to either a plume blight or regional haze analysis depending on impact magnitude and an acidic deposition analysis. The FLAG 2010 document provides guidance on methods used to assess the potential AQRV impacts.

For similar projects that have relatively low emissions and are far from the Federal Class I areas, FLAG 2010 offers a Q/D[1] screening approach to potentially avoid the need to quantify

[1] Q/D = sum of certain pollutant emissions (tons per year) divided by distance (kilometer) from Class I area

impacts for direct comparison to AQRVs. The Q/D value is calculated by dividing the sum of potential oxides of nitrogen (NO_x), total suspended particulate matter (PM), and SO_2 emissions by the distance to closest boundary of a Class I area. A Q/D value of greater than or equal to 10 would indicate possible AQRV impacts to the Federal Class I from the project: below 10, and the project is considered to have negligible impacts to AQRVs in the Class I area.

Critical load values for Federal Class I areas are used to assess acidic deposition, if such analysis is needed. To assess the magnitude of acidic nitrogen deposition, the National Park Service has developed nitrogen deposition critical load values for Federal Class I areas based on the amount of deposition that could lead to harmful changes in an ecosystem. As presented in Section 3.20, Air Quality, the nitrogen deposition critical loads for Denali National Park and other nearby Federal Class I areas are between 1.2 and 17 kilograms per hectare per year (kg/ha/yr). Cumulative project impacts below this threshold are acceptable.

K4.20.2 Discussion of Model-Predicted Criteria Pollutant Impacts for Alternative 1 – Applicant's Proposed Alternative

The approach and results of the assessment of emissions and impacts of Alternative 1 are addressed for select project components (mine site, transportation corridor, Amakdedori port, and natural gas pipeline corridor) and phases (construction, operations, and closure) for which direct impacts were predicted using modeling. Components and phases selected for modeling were those anticipated to produce impacts with the highest magnitude, largest geographic extent, and longest duration. Impacts from all other phases would be less impactful, and are assessed by proxy to phases modeled.

The federal action consists of the discharge fill material into waters and wetlands, and authorization to work in and place structures in wetlands and other waters. For the project, the federal action that could cause an air impact includes the construction and operations of the Amakdedori port, construction and operations of the ferry terminals at Iliamna Lake, and construction and operations of the offshore pipeline across Iliamna Lake and Cook Inlet. Discussion of the assessed magnitude, duration, extent, and probability for each of these components is provided in the sections below. Based on the modeling assessments described below, for those project activities directly related to the federal action, impacts would be minimal and localized, and are likely to occur while the components are being constructed and/or operated. The area would return to baseline conditions once the activity ceases.

K4.20.2.1 Mine Site

Potential direct impacts from the mine site were developed by completing a project impacts assessment using dispersion modeling. For the dispersion modeling of the mine site, the ambient air boundary is based on the boundary of the safety zone established around the mine site from which the public would be precluded. This safety zone would be established to ensure that the public would not be exposed to work site safety risks. Therefore, model receptors were placed only along and outside of the safety zone to capture those areas to which the public would have access. The assessment was conducted based on the emissions presented in Section 4.20, Air Quality, and an analysis of modeling needs based on likely air quality permits required once the mine is operational, which results in only select pollutants being modeled. The full permit applicability analysis is provided in PLP 2018-RFI 007. In the future, the mine site would undergo a complete permitting analysis.

Construction

The concentration of PM attributed to the increase in emissions from construction activities of a new permitted source lasting less than 24 months is excluded from PSD increment consumption analysis under 18 Alaska Administrative Code (AAC) 50.306(b)(2). Therefore, PM_{10} and $PM_{2.5}$ PSD increments were not part of the dispersion modeling assessment. However, in accordance with the requirements for potential future air permit authorizing the construction and operations of a stationary source, dispersion modeling was conducted to demonstrate compliance with the NO_2, PM_{10} and $PM_{2.5}$ AAAQS; and NO_2 PSD Class II increment. Table K4.20-2 and Table K4.20-3 present the modeling results relative to AAAQS and PSD Class II increment, respectively. The maximum modeled near-field impacts are presented for modeled AAAQS in Figure K4.20-1, and the modeled PSD Class II increments are presented in Figure K4.20-2. The star points in the figures represent the locations of the maximum modeled impact, which all occur along the ambient air boundary based on mine site safety zone. Additional details regarding the near-field modeling configuration, emissions, and assessments are provided in PLP 2018-RFI 009. Minimal and localized impacts would only occur during the construction of the mine site. Impacts would dissipate once the construction was complete (PLP 2018-RFI 009). Compliance with modeled concentrations compared to the air quality standards and PSD Class II increment is demonstrated by showing that the standards are not exceeded.

Far-field modeling was not conducted or warranted because the impacts would be temporary, and only occur when the construction activities are ongoing. Furthermore, because the construction impacts are temporary, the potential impacts would be lower than those during the operational phase, for which far-field impacts are analyzed in the following section.

Table K4.20-2: Mine Site Construction Maximum Modeled Project Impacts Compared to the AAAQS

Pollut-ant	Averag-ing Period	Maximum Project-only Predicted Concentration (μg/m^3)	Background Concentration (μg/m^3)	Maximum Concentration (μg/m^3)	AAAQS (μg/m^3)	Percent of the AAAQS
NO_2	1-Hour	77.9	2.3	80.2	188	43%
	Annual	0.3	0	0.3	100	0.3%
PM_{10}	24-Hour	23.2	12.4	35.6	150	24%
$PM_{2.5}$	24-Hour	2.2	4.1	6.3	35	18%
	Annual	0.3	0.9	1.2	12	10%

Notes:
μg/m^3 = micrograms per cubic meter
AAAQS = Alaska Ambient Air Quality Standards
NO_2 = nitrogen dioxide
$PM_{2.5}$ and PM_{10} = Particulate matter with an aerodynamic diameter less than or equal to 2.5 and 10 micrometers, respectively
Source: PLP 2018-RFI 009

Table K4.20-3: Mine Site Construction Maximum Modeled Project-only Impacts Compared to Class II PSD Increment Limit

Pollutant	Averaging Period	Maximum Project-only Predicted Concentration (μg/m^3)	Class II PSD Increment (μg/m^3)	Percent of the Class II PSD Increment
NO_2	Annual	0.3	25	1.2%

Notes:
μg/m^3 = micrograms per cubic meter
NO_2 = nitrogen dioxide
PSD = prevention of significant deterioration
Source: PLP 2018-RFI 009

Figure K4.20-1: Mine Site Construction Maximum Modeled Project Impacts

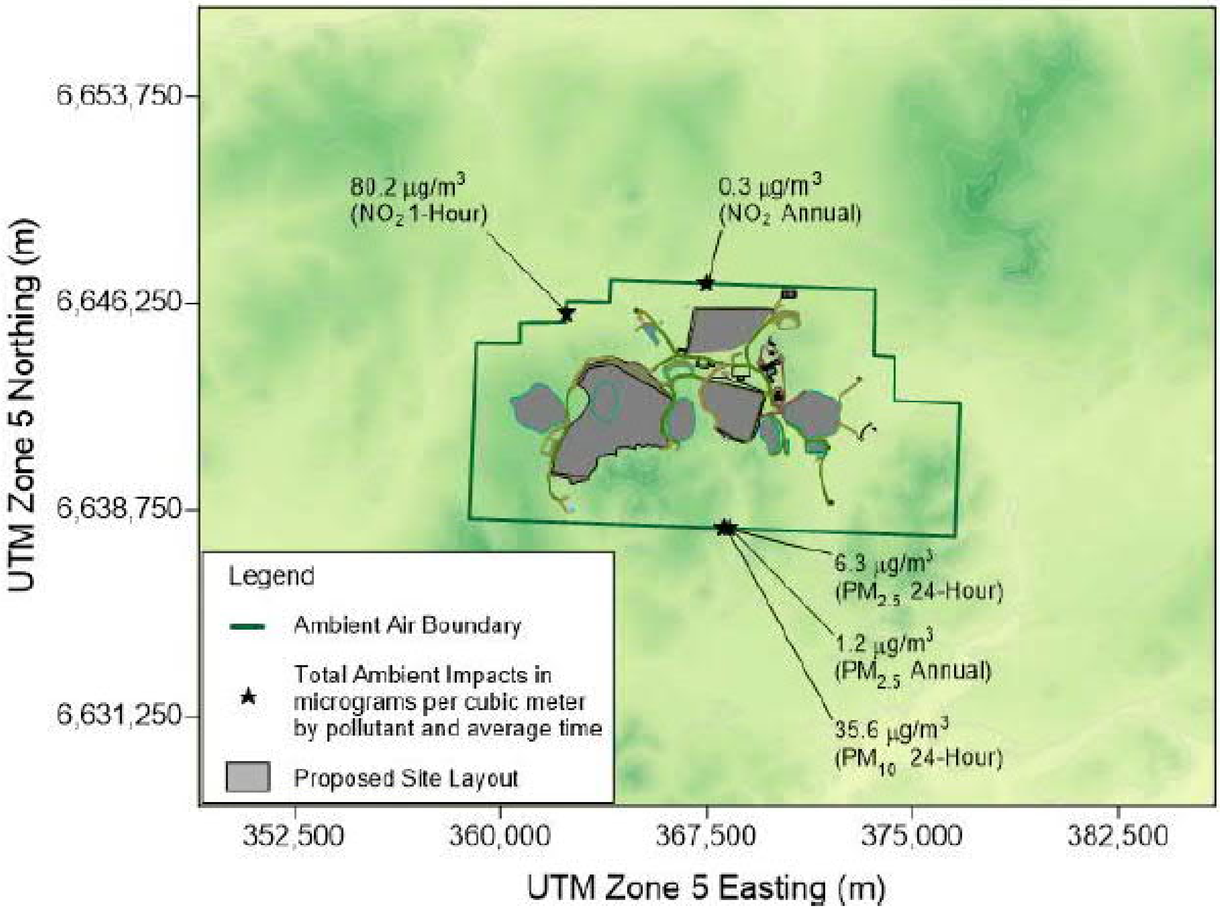
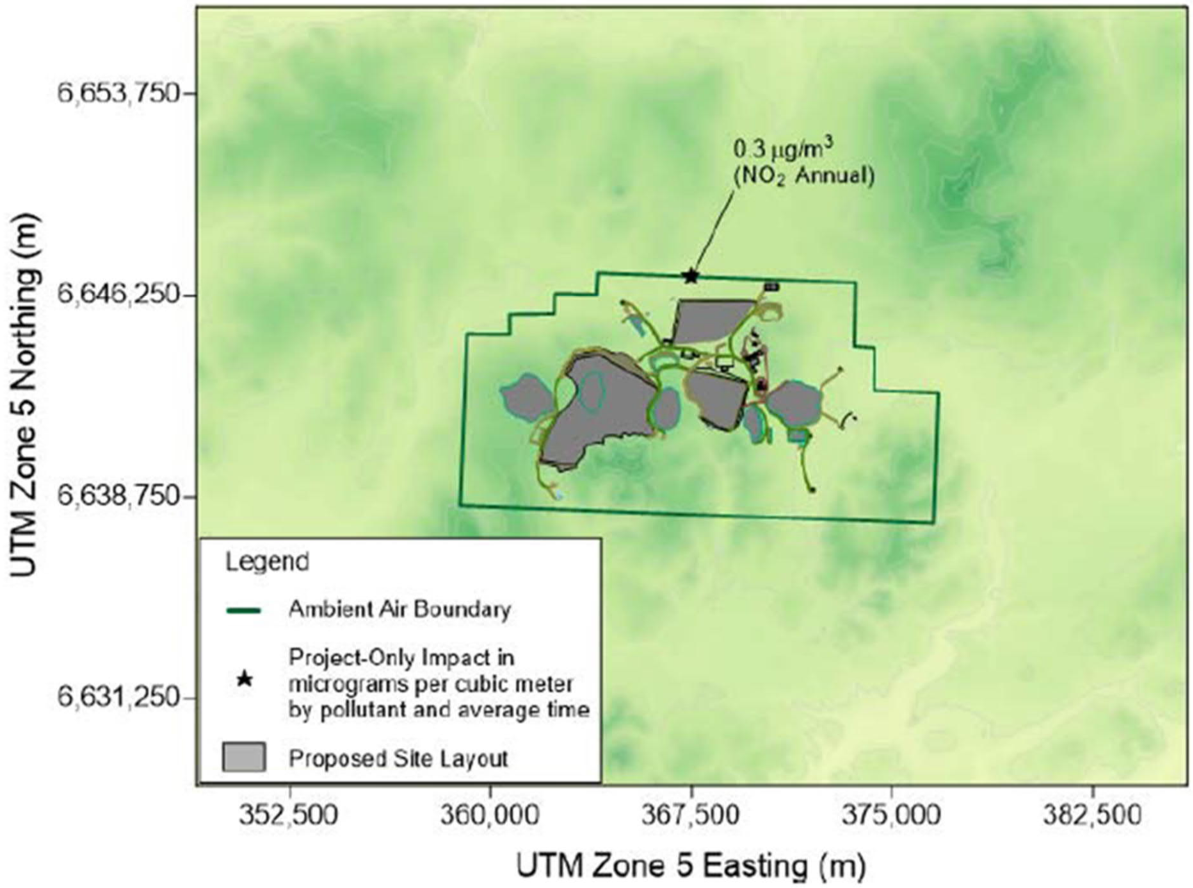


Figure K4.20-2: Mine Site Construction Maximum Modeled Project-Only Impacts



Operations

A near-field modeling assessment was completed, consistent with Alaska Department of Environmental Conservation (ADEC) air quality permitting requirements, which require a permit to construct and operate a stationary source. The modeling assessment was prepared to address the potential air quality impacts related to the operation of the mine site. Table K4.20-4 and Table K4.20-5 present the modeling results relative to the AAAQS and PSD Class II increments, respectively, that are likely to be required for an air quality permit. The maximum modeled impacts are presented for modeled pollutants compared to AAAQS in Figure K4.20-3; and the modeled pollutants compared to the PSD Class II increments are presented in Figure K4.20-4. The star points in the figures represent the locations of the maximum modeled impact, which all occur along the ambient air boundary based on the mine site safety zone, which would preclude public access. Additional details regarding the near-field modeling configuration, emissions, and assessments are provided in PLP 2018-RFI 009. Compliance with modeled air quality standards and PSD Class II increments is demonstrated. Minimal and localized impacts would occur only during operations at the mine site. Impacts would return to the baseline once the operations phase has concluded (PLP 2018-RFI 009).

Table K4.20-4: Mine Site Operations Maximum Modeled Project Impacts Compared to the AAAQS

Pollutant	Averaging Period	Maximum Project-Only Predicted Concentration (μg/m^3)	Background Concentration (μg/m^3)	Maximum Concentration (μg/m^3)	AAAQS (μg/m^3)	Percent of the AAAQS
NO_2	1-Hour	99.1	2.3	101.4	188	54%
	Annual	0.1	0	0.1	100	0.1%
PM_{10}	24-Hour	26.3	12.4	38.7	150	25%
$PM_{2.5}$	24-Hour	3.2	4.1	7.3	35	21%
	Annual	0.5	0.9	1.4	12	12%

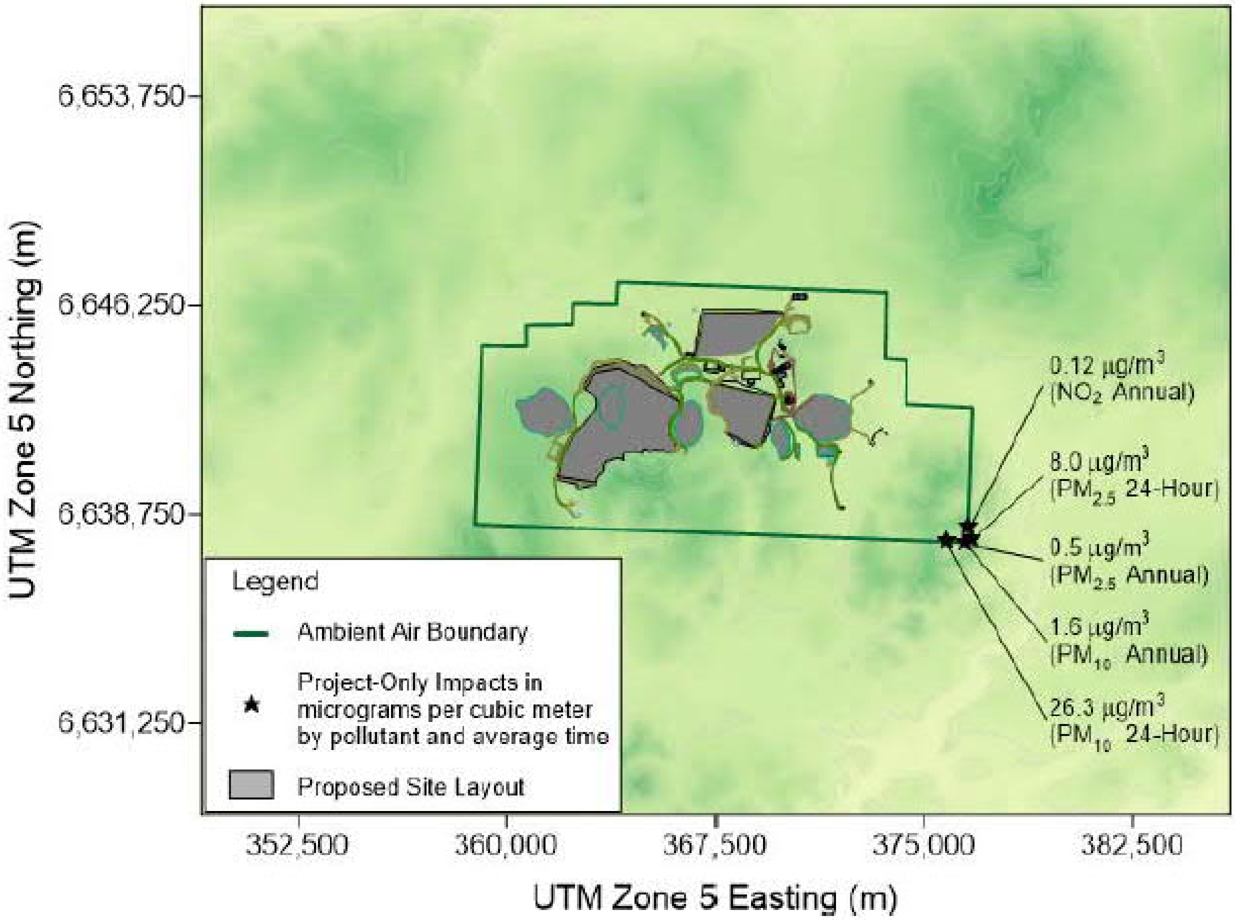
Notes:
μg/m^3 = micrograms per cubic meter
AAAQS = Alaska Ambient Air Quality Standards
NO_2 = nitrogen dioxide
$PM_{2.5}$ and PM_{10} = Particulate matter with an aerodynamic diameter less than or equal to 2.5 and 10 micrometers, respectively
Source: PLP 2018-RFI 009

Table K4.20-5: Mine Site Operations Maximum Modeled Project-only Impacts Compared to Class II PSD Increment Limit

Pollut-ant	Averaging Period	Maximum Project-only Predicted Concentration (μg/m^3)	Class II PSD Increment (μg/m^3)	Percent of the Class II PSD Increment
NO_2	Annual	0.1	25	0.4%
PM_{10}	24-Hour	26.3	30	88%
	Annual	1.6	17	9%
$PM_{2.5}$	24-Hour	8	9	89%
	Annual	1.4	4	35%

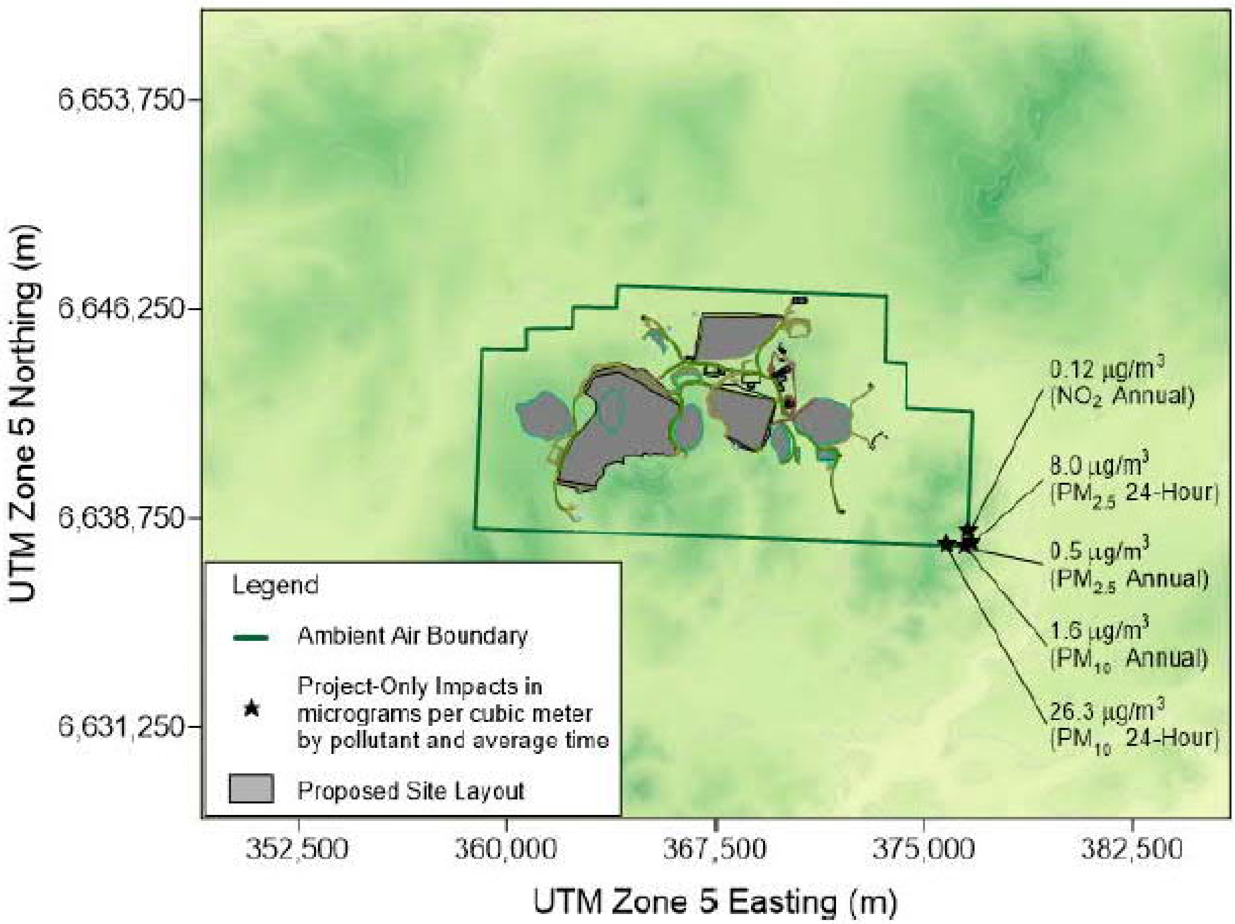
Notes:
μg/m^3 = micrograms per cubic meter
NO_2 = nitrogen dioxide
PSD = prevention of significant deterioration
$PM_{2.5}$ and PM_{10} = Particulate matter with an aerodynamic diameter less than or equal to 2.5 and 10 micrometers, respectively
Source: PLP 2018-RFI 009

Figure K4.20-3: Mine Site Operations Maximum Modeled Project Impacts



Source: PLP 2018-RFI 009

Figure K4.20-4: Mine Site Operations Maximum Modeled Project-Only Impacts



Source: PLP 2018-RFI 009

To assess the far-field impacts, the Plume Visual Impact Screening Model (VISCREEN) was used to determine whether air pollutant emissions from the mine site would cause visibility impacts at Federal Class I areas in the general vicinity of the mine site. Based on the combination of inputs, distances modeled, and conservative model assumptions, the model-predicted impacts show that the visibility screening criteria established for Federal Class I areas would not be exceeded at any Federal Class I area, obviating the need for a cumulative impact analysis to demonstrate this project would not adversely contribute to regional haze. Further details of this assessment are provided in PLP 2018-RFI 012.

Although far-field deposition impacts from the mine site operations were not evaluated in PLP 2018-RFI 012, conservative estimates of potential far-field deposition impacts can be inferred from predicted near-field annual NO_x and SO_2 impacts using a screening technique detailed in the Level I Analysis of Long Range Transport and Depositional Impacts (EPA 1993), and conservatively assuming total conversion of NO_x and SO_2 emissions to depositional nitrogen and sulfur. NO_x and SO_2 contribute to deposition when these compounds are converted into other compounds that are readily removed from the atmosphere, and deposited to soils, vegetation, and waterbodies. SO_2 emissions from the mine site operations are below the modeling requirement, based on likely permitting needs. Therefore, the SO_2 impacts were not modeled for the mine site, and it is unlikely that the SO_2 emissions from the mine site operations would be large enough to contribute to sulfur deposition impacts. Unlike SO_2, annual NO_2 concentrations were predicted, as shown in Table K4.20-5, and were used to estimate acidic nitrogen deposition. Using the maximum project-only concentration as input to the screening approach discussed above yields a conservatively high nitrogen deposition impact of 0.5 kg/ha/yr.

As discussed in Section 3.20, Air Quality the nitrogen deposition critical loads for Denali National Park and other nearby Federal Class I areas range from 1.2 kilograms of nitrogen per hectare per year (kgN/ha/yr) for lichens and bryophytes, to 17.0 kgN/ha/yr for forests and nitrate leaching (National Park Service 2018e). The critical loads are for total (wet plus dry) deposition, while the project nitrogen deposition impact is representative of dry deposition for the project-only. Measured wet and dry deposition values at Denali National Park can be added to the project-only nitrogen deposition impact to provide an estimated total deposition, which can be compared to criteria loads to assess the mine site operation's deposition impact. As presented in Table 3-20-4, for 2015, the measured nitrogen dry deposition value at the park was 0.3 kg/ha/yr, while the wet deposition was 0.4 kg/ha/yr (1.5 micro-equivalent per liter). When added to the project-only deposition, the total deposition is 1.2 kg/ha/yr. This estimated total deposition is equal to the lowest critical load for lichens and bryophytes, which is an ecosystem found in Denali National Park and other nearby Federal Class I areas. Although the calculated total nitrogen deposition value is a conservatively high estimate, the analysis still shows impacts equal to the lowest critical load value, and below the other criteria loads at a distance of 1 kilometer from the source. Therefore, because Denali National Park and other nearby Federal Class I areas are more than 62 miles from the source, negligible impacts are expected.

Closure

The closure phase of the mine site was not explicitly modeled, because the impacts are expected to be similar to the construction phase. The duration of the closure phase at the mine site is expected to be approximately 20 years, compared to less than 5 years of construction. However, the closure and construction activities and emissions in a given year would be similar. Assuming impacts would be similar to those from the construction phase, near-field impacts may be possible, but far-field impacts are unlikely to occur. Impacts are limited to the duration of mine site closure. Impacts would return to the baseline conditions at the end of closure.

K4.20.2.2 Transportation Corridor

For analysis of impacts to air quality, the transportation corridor includes all-season gravel roads, ferry terminals on Iliamna Lake, port, and spur roads, and the onshore pipeline segment at the port, because the pipeline and road would be constructed jointly. The transportation corridor would be operational through the life of the project.

The emissions are presented in Section 4.20, Air Quality. Due to lower level of activity and emissions at the transportation corridor relative to the mine site, it is anticipated that the construction, operations, and closure of the transportation corridor would have lower near-field and far-field impacts than those predicted for the mine site. Therefore, modeling was not conducted for this project component phase, and impacts are assessed by proxy to those predicted for the mine site.

K4.20.2.3 Amakdedori Port

Potential direct impacts from the port were developed by completing a project impacts assessment using dispersion modeling. The assessment was conducted based on the emissions presented in Section 4.20, Air Quality, and an analysis of modeling needs based on likely air quality permits required once the port is operational. The permit applicability analysis is provided in PLP 2018-RFI 007. In the future, the port would undergo a complete permitting analysis.

<u>Construction</u>

Because of the lower level of construction activity and emissions at the port relative to the mine site, it is anticipated that the construction of the Amakdedori port would have lower near-field and far-field impacts than those predicted for the mine site; therefore, modeling was not conducted for this project component phase, and impacts are assessed by proxy to those predicted for the mine.

<u>Operations</u>

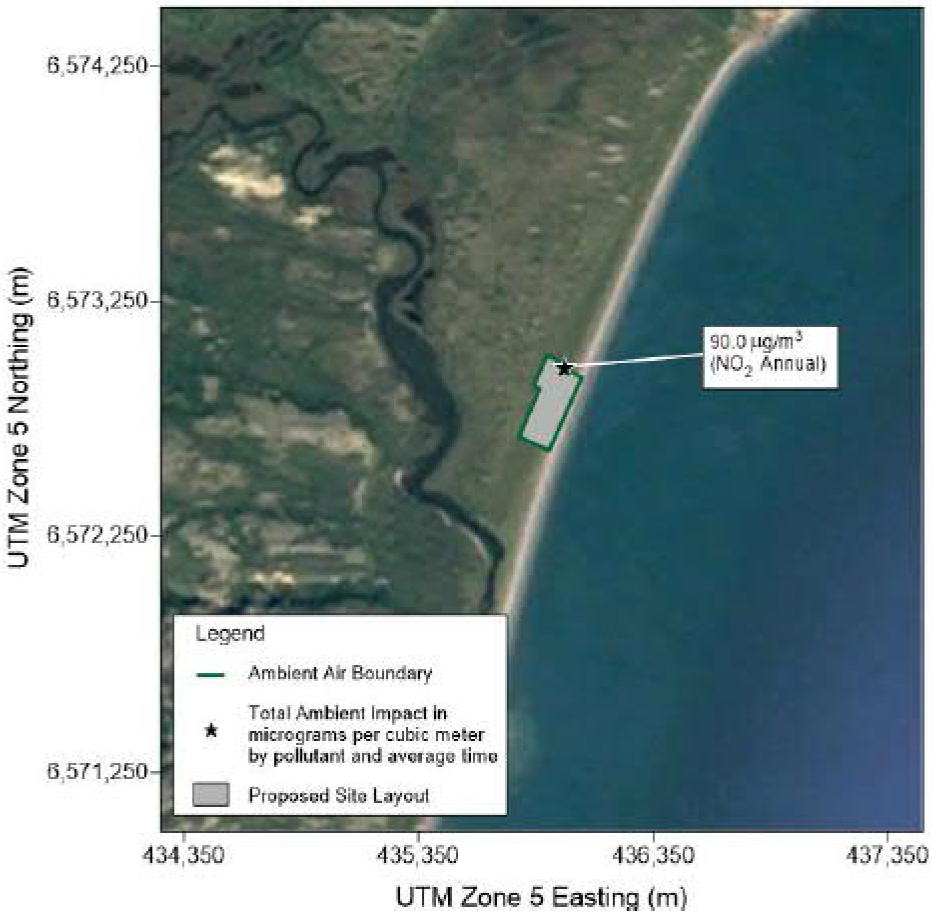
Based on the air quality permitting assessment, a minor source permit to construct and operate a stationary source could be required for NO_x emissions, and not the other pollutants. A near-field modeling assessment was completed, consistent with ADEC minor air quality permitting requirements, which uses dispersion modeling to determine the annual NO_2 impact of the NO_x that would occur from the Amakdedori port. Table K4.20-6 presents the modeling results relative to the pollutant modeled in the form of the AAAQS. Figure K4.20-5 presents the maximum modeled impacts for NO_2 in the form of the annual NO_2 AAAQS. The star points in the figures represent the locations of the maximum modeled impact, which occur along the ambient air boundary. Additional details regarding the near-field modeling configuration, emissions, and assessments are provided in PLP 2018-RFI 009. Results of this modeling show that AAAQS would not be exceeded under the port operations, and operations would result in minimal impacts, which would be localized, and remain only while the port is operational.

Table K4.20-6: Amakdedori Port Operations – Maximum Modeled Project Impacts Compared to the AAAQS

Pollutant	Averaging Period	Maximum Project-Only Predicted Concentration (μg/m³)	Background Concentration (μg/m³)	Maximum Concentration (μg/m³)	AAAQS (μg/m³)	Percent of AAAQS
NO_2	Annual	89.98	0	90	100	90%

Notes:
μg/m³=micrograms per cubic meter
AAAQS = Alaska Ambient Air Quality Standards
NO_2 = nitrogen dioxide
Source: PLP 2018-RFI 009

Figure K4.20-5: Amakdedori Port Operations Maximum Modeled Project Impacts



Source: PLP 2018-RFI 009

To assess the far-field impacts, per the FLAG 2010 guidance, a Q/D screening assessment was conducted to determine if the emissions from the port would affect the AQRVs in the nearest Federal Class I area. The Q/D value for the port is less than 1. As a result, AQRVs would not likely be affected at any of the Federal Class I areas as a result of the port operations.

Closure

Although near-field and far-field air quality impacts from port closure were not explicitly modeled, the impacts are expected to be similar to those outlined for the port construction, because the activities that would occur in a given year are similar. Near-field impacts may be possible, but far-field impacts are unlikely to occur. If the near-field impacts occur, they would be localized, minimal, and only occur during port closure.

K4.20.2.4 Natural Gas Pipeline Corridor

Potential direct impacts from the pipeline corridor were developed by completing a project impacts assessment using dispersion modeling. The assessment was conducted based on the emissions presented in Section 4.20, Air Quality, and an analysis of modeling needs based on likely air quality permits required once the pipeline is operational. The full permit applicability analysis is provided in PLP 2018-RFI 007. In the future, emissions sources associated with the pipeline would undergo a complete permitting analysis.

Construction

It is anticipated that the construction associated with the pipeline corridor and compressor station would have lower near-field and far-field impacts than those predicted for the mine site, because the construction of pipeline and compressor station would have less activities and lower emissions than the mine site. Therefore, modeling was not conducted for this project component phase, and impacts are assessed by proxy to those predicted for the mine.

Operations

During the operations of the pipeline, the emissions and associated impacts from the onshore and offshore pipeline segments would be negligible. The Kenai compressor station would have emissions and possible air impacts. Therefore, for the operations phase, only the potential emissions from the compressor station were modeled.

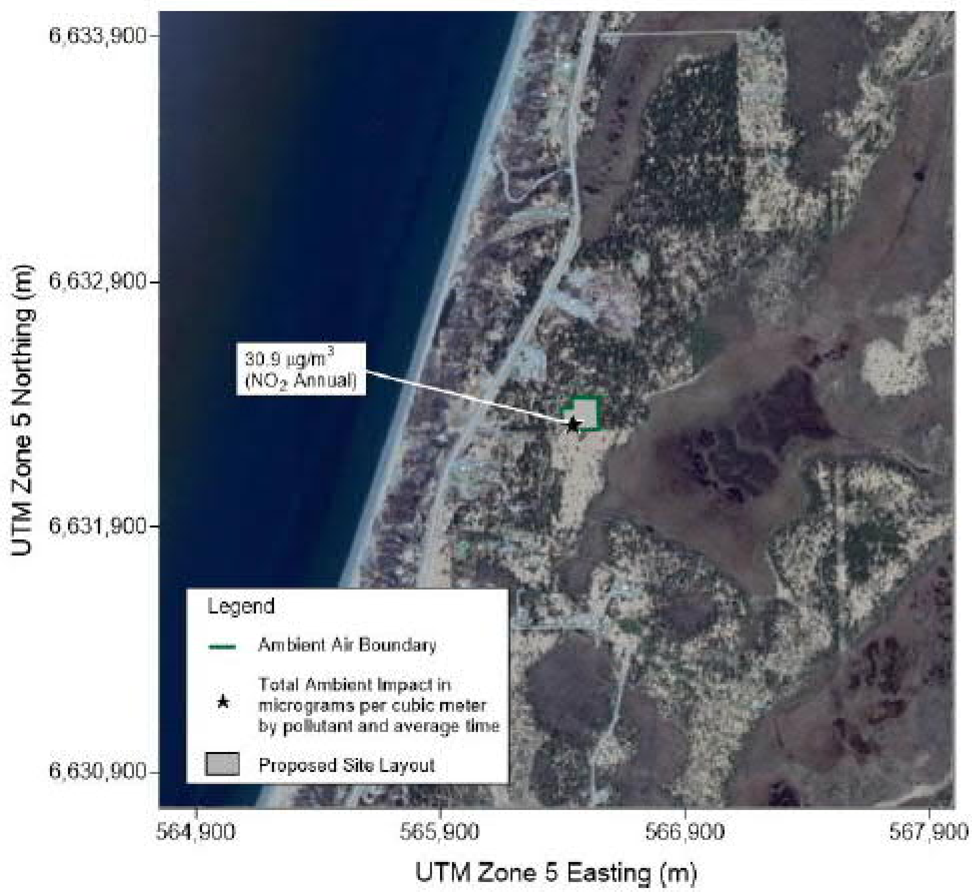
A near-field modeling assessment for the operation of the compressor station was completed to address possible air quality impacts. Because a requirement to obtain a minor air quality permit might be triggered, a dispersion modeling assessment consistent with ADEC minor air quality permitting requirements was prepared. Based on the estimated emissions, only NO_X emissions would require modeling. Per permit requirements, dispersion modeling was used to determine the annual NO_2 impact of the NO_X emissions that would occur from the Kenai compressor station. Table K4.20-7 presents the modeling results relative to the AAAQS. Figure K4.20-6 presents the maximum modeled impacts for NO_2 in the form of the annual NO_2 AAAQS. The star points in the figures represent the locations of the maximum modeled impact, which occur along the ambient air boundary of the compressor station. Additional details regarding the near-field modeling configuration, emissions, and assessments are provided in PLP 2018-RFI 009. This modeling shows that AAAQS would not be exceeded under compressor station operations. If near-field impacts occur from the compressor station, those impacts would be minimal, localized, and would only occur when the compressor station is operating.

Table K4.20-7: Kenai Compressor Station Operations – Maximum Modeled Project Impacts Compared to the AAAQS

Pollutant	Averaging Period	Maximum Project-only Concentration (μg/m^3)[1]	Background Concentration (μg/m^3)	Maximum Concentration (μg/m^3)	AAAQS (μg/m^3)	Percent of AAAQS
NO_2	Annual	17.7	13.2	30.9	100	30%

Notes:
AAAQS = Alaska Ambient Air Quality Standards
μg/m^3 = micrograms per cubic meter
NO_2 = nitrogen dioxide

Figure K4.20-6: Compressor Station Operations Maximum Modeled Project Impacts



To assess the far-field impacts, per the FLAG 2010 guidance, a screening assessment was conducted to determine if the emissions from the compressor station would affect the AQRVs in the nearest Federal Class I area. The Q/D value for the compressor station is less than 2. As a result, AQRVs would not likely be impacted at any of the Federal Class I areas as a result of the compressor station operations.

Closure

Although the air quality near-field and far-field impacts from the closure activities were not explicitly modeled, the impacts are anticipated to be similar to those presented for the construction phase, because the activities are similar in a given year. Near-field impacts may be possible, but far-field impacts are unlikely to occur. If the near-field impacts occur, they would be localized, minimal, and only occur during closure.

K4.20.3 Discussion of Cumulative Impact Analysis for Alternative 1 – Applicant's Proposed Alternative

Past, present, and RFFAs in the cumulative impact study area have the potential to contribute cumulatively to impacts on air quality. Section 4.1, Introduction to Environmental Consequences,details the past, present, and RFFAs that may impact air quality. The potential future actions are similar to the proposed project in how they impact air quality by emitting combustion-related air pollutant emissions from fuel-burning equipment; and fugitive emissions from blasting, drilling, vehicle traffic on unpaved roads, and material handling.

There is no indication that development of the nearby RFFA within roughly 30 miles of the Pebble Project (e.g., Pebble South/PED, Big Chunk South, Groundhog) would occur in the operations phase of the proposed Pebble Project. It is likely some exploration activities from the nearby RFFAs would occur during the project operations, which could cause a small increase of emissions in the area. The exploration activities could likely result in a slight increase of emissions in and near the Pebble Project's transportation corridor, because it could be used as a transportation corridor for other projects, as well. Beyond a slight increase of traffic through the transportation corridor, it is unlikely that the exploration activities would generate enough emissions to result in a change the Pebble Project's near-field impact, as presented in Section K4.20.2. Therefore, the near-field impacts assessed for the Pebble Project would be representative of the near-field cumulative impacts.

There are several RFFAs (e.g., Shotgun, Donlin Gold Mine, Alaska Liquefied Natural Gas [LNG]) that could be undergoing development and operations during the operations timeframe of the proposed Pebble Project. However, all these RFFAs are beyond 30 miles from the Pebble Project, and would not influence the near-field impacts. The proposed Donlin Gold Mine would be situated roughly 174 miles northwest of the proposed Pebble mine site, and the proposed Alaska LNG facility would be roughly 137 miles east of the proposed Pebble mine site. These RFFAs would have their own impact at Federal Class I areas that could overlap with Pebble mine site operations. However, given the distance from the Pebble Project and prevailing wind, it is unlikely these RFFAs would contribute to a far-field cumulative impact resulting from project emissions. Additionally, the low Q/D value for the Pebble Project components indicates that its emissions are too small and too far away from Federal Class I areas to contribute to an adverse cumulative impact without conducting cumulative dispersion modeling explicitly involving RFFAs. Therefore, it is concluded that the magnitude of cumulative impacts associated with project emissions would be minimal.

K4.20.3.1 Pebble Project Ambient Ozone

The entire project and all of its components are in an ozone unclassified area, with measurement showing no evidence of attainment issues. Additionally, there are minimal nearby anthropogenic sources of NO_x and volatile organic compounds (VOCs), which are ozone precursors. The area surrounding the mine site has naturally occurring VOCs. As demonstrated in Section 3.20, Air Quality, the ambient NO_x concentrations are low surrounding the mine site. This results in an NO_x-limited ozone environment, meaning ozone formation is capped, because the reactions that result in ozone are limited by the amount of available NO_x. Because the project NO_x sources are dispersed over a large area and the potential to emit NO_x from the project components would be low, and are unlikely to accumulate to any large degree under stagnant atmospheric conditions, project air pollutant emissions would result in minimal ozone formation, if any formation would occur as a result of the project. Therefore, project impacts to ambient ozone concentrations would be negligible.