APPENDIX H:

Analysis of Mine Site Geochemistry

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APPENDIX H: Analysis of Mine Site Geochemistry

This appendix contains additional background and detail related to geochemical effects at the Mine Site for Alternative 2, and is provided in support of the water quality analysis, water management decisions, and water treatment needs discussed in Section 3.7, Water Quality.

1. Infrastructure and Processes

Under Alternative 2, geochemical environmental consequences are tied to several components of the Donlin Gold Project, specifically:

- The Waste Rock Facility (WRF);
- The North Overburden (NOB) and South Overburden (SOB) Stockpiles;
- Low-grade Ore Stockpile and Ore Stockpile Berm
- Lower and Upper Contact Water Dam (CWD);
- Haul roads built with waste rock;
- The Tailings Storage Facility (TSF); and
- Open Pit and Pit Lake.

With the exception of haul roads, each of these components is considered in general in this section of the appendix, and described in more detail for each project stage in Sections 2 (Construction), 3 (Operations and Maintenance), and 4 (Closure, Reclamation, and Monitoring). The haul roads are discussed in the main EIS in Section 3.7.3.2.2, Surface Water Quality, and Section 3.7.3.2.3, Groundwater Quality.

1.1 Waste Rock Facility

Alternative 2 would generate approximately 3 billion tons of waste rock, of which approximately 2.5 billion tons are planned to be placed in a proposed WRF that would ultimately cover an area of 3.5 square miles (SRK 2012a). As discussed in EIS Section 3.7.2.4.1, Geochemical Characterization – Waste Rock, Donlin Gold has conducted an extensive geochemical characterization of the waste rock that would be generated by the proposed mining. The results indicated that most of the waste rock has metal leaching potential, especially for arsenic, selenium, and antimony, which are soluble in the neutral to basic solutions likely to be generated by the non-acid generating (NAG) rocks (SRK 2007; SRK 2011). The characterization also indicated that about 7 to 8 percent of the waste rock is potentially acid generating (PAG) (Table H-1). Both metal leaching (ML) fluids and acid rock drainage (ARD) could react with local soils and rocks and negatively impact surface and groundwater in the vicinity of the site if not controlled and managed.

Table H-1: Waste Rock Tonnage Estimates

Material Type	Total Waste Rock[1] (thousand tons)		Waste Rock Tonnage by Facility[2] (thousand toms)			
	Total Tonnage	**Percent of Total**	**ACMA Backfill**	**Waste Rock Facility**	**Isolated Cells in WRF**	**Tailings Dam**
NAG 1-4	2,873,600	93	442,900	2,335,900	--	95,100
OVB	46,400[3]		45	46,400	--	--
PAG 5	87.2	2.7	12,000	75,200	--	--
PAG 6	135.3	4. 3	12,000	--	123,320	--
PAG 7	2.6	0.08	47	2500[4]	--	--
Total Waste Rock	**3,145,000**	**100**	**467,000**	**2,460,600**	**123,320**	**95,100**

1 Source: SRK 2016d, Table 3-4

2 Source: SRK 2016d, Table 4-1

3 Not considered waste rock

4 This tonnage reflects the total PAG 7 waste rock that would be temporarily placed in the low-grade ore stockpile at the toe of the WRF and relocated to the ACMA pit backfill once space is available.

Management of the waste rock is planned to be based on identification and classification of the various waste rock categories discussed below (SRK 2012e, 2016d).

- *Overburden*. Overburden is planned to be used in Construction, as cover for the isolated cells of PAG 6 waste rock, and for final site reclamation. Excess overburden is planned to be placed in the American Creek drainage WRF. Geochemical testing of 33 overburden samples (see EIS Section 3.7.2.4.2, Water Quality) suggests that the overburden tends to be pH-inert, with essentially no neutralizing potential or acid generating potential. However, there may be a potential for leaching of arsenic and other metals from overburden taken from directly above the pit area (BGC 2011g), and possible ARD formation from the same overburden taken from lower depths.
- *NAG 1-4*. Much of the NAG 1-4 rock would be placed in the unlined American Creek drainage WRF (Table H-1, SRK 2016d). Rocks of these classifications would also be used as construction material for unlined portions of the TSF as rockfill, filter zones, riprap, and underdrain rockfill. The NAG rocks were found to have no potential to generate ARD (EIS Table 3.7-16, Water Quality). However, they do have the potential to generate drainage with concentrations of arsenic above applicable water quality criteria (AWQC) (SRK 2007, 2016d). Because antimony and mercury were found to be positively correlated with arsenic and typically show geochemical coherence with arsenic, these constituents could also potentially leach from these rocks.
- *PAG 5*. The PAG 5 rock has the potential to generate ARD after one to several decades (SRK 2016g). Modeling of drainage chemistry suggests that approximately 81 percent of the PAG 5 rock can be blended with the NAG rock in the WRF, provided that the blending is managed to result in adequate contact between the rock types (SRK 2012e, 2016d). The remaining 19 percent would be used as pit backfill. According to SRK (2017**e)**, PAG 5 rock would be about seven percent of the total waste rock in the NAG

WRF (about 75.9 million tons, using the tonnage values in Table H-1). Based on this estimate, the tonnage of NAG waste rock in the WRF would be approximately 1.084 billion tons. Further discussion of the design of the American Creek WRF is given in EIS Section 2.3.2.1.9, Chapter 2, Alternatives.

- *PAG 6*. The PAG 6 rock has the potential to generate acid over a relatively short time period (possibly less than a decade) (SRK 2007, 2011, 2016d). This rock is to be placed in isolated cells in Rob's Gulch and Unnamed Gulch, between the main American Creek drainage WRF and the open pit (BGC 2011b, 2016d). An intermediate cover of approximately 3 feet of low-permeability terrace gravel and/or colluvium would be placed over each 100-foot lift to direct runoff and reduce infiltration (BGC 2011a; SRK 2012e, 2016d). The design of the PAG cells is discussed further in Chapter 2, Section 2.3.2.1. The PAG 6 rock mined near the end of mine life would be used as backfill into the ACMA Pit.
- *PAG 7*. The PAG 7 rock has the potential to generate acid in a few years or less (SRK 2007, 2012b, 2016d). It is not planned to be put into the WRF, but would be stored temporarily in the low-grade ore stockpile until it can be transferred as backfill into the ACMA Pit (SRK 2012e, 2016d).

1.2 Tailings Storage Facility

The tailings formed from proposed ore processing are planned to be deposited as slurry in a conventional TSF with a fully lined impoundment (SRK 2012a, 2016a). The TSF is planned to be located in the Anaconda Creek valley south of the American Creek WRF (Figure 2.3-7, Chapter 2, Alternatives). The TSF design is discussed more fully in Section 2.3.2.1.8, Chapter 2, Alternatives.

According to the Tailings Management Plan (SRK 2016f), tailings from the mine site would be comprised of about 64 percent water and 36 percent solids by weight, comprised of approximately 85 percent flotation tails and 15 percent CIL tailings. Three phases of metallurgical testing were conducted. A blend of detoxified CIL tailings and neutralized autoclave acidic liquor was used to create the final tailings in order to provide samples that were reasonably representative of both the ore and the complete metallurgical process (SRK 2012b, 2017e). The chemistry of the solids portion of the pilot final tailings product is given in Table H-2; while the liquor chemistry is given in Tables H-3 and H-4.

As discussed in Section 3.7.2.4.4, Water Quality, Tailings, the tailings from the Phase 2 pilot testing are more representative of the combined ore types that would be processed through the process facilities. Comparison of the Phase 2 results with the prior tests show the variation across ore samples. Based on the three sets of testing, the tailings solids tend to be elevated with respect to arsenic and antimony compared with their average concentrations in the rhyodacite rocks to be mined. The tailings liquor pH is circumneutral (7.6 to 7.7), but could have concentrations of sulfate in the range of 2,500 to 4,600 mg/L and arsenic concentrations in the range of 0.43 to 1.1 mg/L. Compared with the most stringent AWQC, the tailings liquor is elevated for cobalt, mercury, manganese, molybdenum, antimony, and selenium (SRK 2012b, 2017e). Due to high mercury levels, the process plant design would include a dosage facility to allow chemical addition to precipitate mercury as a stable mercury sulfide compound that would remain with the tailings solids in the TSF (SRK 2012b, 2017e).

The Donlin Gold Project is expected to have a water surplus during Operations under average precipitation conditions. Surplus water would be stored in the TSF pond until Closure, when it will be pumped to the open pit. Originally, the project was conceived to have a no-discharge TSF. However, because of the water surplus, an advanced water treatment (AWT) scheme was developed by Hatch (2015, 2017). (The water treatment plant (WTP) design under the AWT scheme is discussed in Section 3.7.3.2.2 of the EIS.) Based on the AWT, a water management system was designed to minimize the amount of contact water and to treat and discharge various mine water sources, as needed, to minimize build-up of water in the TSF pond (BGC 2015f; SRK 2017e). Under this system, the concentrations of constituents in the TSF pond and pore water are predicted to increase beyond the results shown in Tables H-3 and H-4 by as much as a factor of three over the mine life, due to re-circulation of tailings water into the flotation and hydrometallurgical processes. The predicted chemistry of these waters is discussed further in Section 3.6 of this appendix (Operations—Tailings Storage Facility).

Table H-2: Final Plant Tailings Solids Analysis of the Pre-Feasibility, Phase 1 Feasibility, and Phase 2 Feasibility Pilot Tests

Parameter	Unit	Feasibility Pilot (Phase 2) Final Tailings Filtrate 2007	Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007	Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006
Chloride	%	<0.01	<0.01	<0.01
Fluoride	%	0.01	0.01	0.01
Aluminum	mg/Kg	63,000	69,000	71,000
Antimony	mg/Kg	120	230	250
Arsenic	mg/Kg	910	2,900	3,400
Barium	mg/Kg	640	520	520
Beryllium	mg/Kg	2.2	2	2.1
Bismuth	mg/Kg	0.13	0.16	0.22
Boron	mg/Kg	2	<3	5
Cadmium	mg/Kg	0.2	0.6	0.24
Calcium	mg/Kg	12,000	8,200	11,000
Cerium	mg/Kg	33	52	41
Cesium	mg/Kg	7	7.5	7.9
Chromium	mg/Kg	180	210	300
Cobalt	mg/Kg	3.7	8	8.2
Copper	mg/Kg	60	60	77
Gallium	mg/Kg	18	18	21
Germanium	mg/Kg	<0.4	<2	<0.5
Hafnium	mg/Kg	2.5	5.1	2.7

Table H-2: Final Plant Tailings Solids Analysis of the Pre-Feasibility, Phase 1 Feasibility, and Phase 2 Feasibility Pilot Tests

Parameter	Unit	Feasibility Pilot (Phase 2) Final Tailings Filtrate 2007	Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007	Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006
Indium	mg/Kg	<0.01	0.06	0.05
Iron	mg/Kg	16,000	20,000	23,000
Lanthanum	mg/Kg	16	25	20
Lead	mg/Kg	15	15	26
Lithium	mg/Kg	56	38	35
Magnesium	mg/Kg	6,000	3,800	5,000
Manganese	mg/Kg	380	380	450
Mercury	mg/Kg	0.7	1	2
Molybdenum	mg/Kg	2.4	7.1	14
Nickle	mg/Kg	21	70	170
Niobium	mg/Kg	6.7	5.6	4
Potassium	mg/Kg	23,000	23,000	22,000
Rhenium	mg/Kg	<0.02	<0.02	0.04
Rubidium	mg/Kg	98	140	130
Selenium	mg/Kg	<0.7	1	<1
Silicon	mg/Kg	309,000	330,000	-
Silver	mg/Kg	0.68	0.95	1.1
Sodium	mg/Kg	2,600	1,900	1,500
Strontium	mg/Kg	98	62	64
Tantalum	mg/Kg	0.72	0.71	0.86
Tellurium	mg/Kg	<0.4	<0.4	<0.4
Thallium	mg/Kg	0.9	0.9	1
Thorium	mg/Kg	11	23	10
Tin	mg/Kg	3.1	12	3
Titanium	mg/Kg	1,000	790	390
Tungsten	mg/Kg	5.8	12	6
Uranium	mg/Kg	2.7	2.7	2.7
Vanadium	mg/Kg	49	42	46
Ytterbium	mg/Kg	8.4	10	8.6
Zinc	mg/Kg	100	96	66
Zirconium	mg/Kg	-	71	44

Source: SRK 2017e, Appendix C, Table C-2.

Table H-3: Final Plant Tailings Liquor - Major Components Analysis

Parameter	Unit	AWQC	Feasibility Pilot (Phase 2) Final Tailings Filtrate Oct 2007	Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007	Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006
Total Suspended Solids	mg/L		1	10	7
Total Dissolved Solids	mg/L	500[1]	3,850	6,950	6,070
pH	Units	6.5-8.5[1]	7.62	7.69	7.63
Alkalinity	mg/L as $CaCO_3$	20 (min)[2]	44	47	52
Conductivity	µS/cm		3,860	5,970	5,390
Carbonate	mg/L as $CaCO_3$		<2	<2	<2
Bicarbonate	mg/L as $CaCO_3$		44	47	52
Hydroxide	mg/L as $CaCO_3$		<0.6	<2	<2
Fluoride	mg/L	1[2e]	0.91	0.5	0.77
Sulfate	mg/L	250[1]	2,500	4,600	4,000
Nitrite	as N mg/L	1[2d]	<0.6	<0.6	<0.6
Nitrate	as N mg/L	10[2d]	<0.5	<0.5	<0.5
Ammonia	as N mg/L	2.99[2g]	9.6	21	32.6
Cyanide Speciation					
Total Cyanide	µg/L		--	110	40
WAD Cyanide	µg/L	5.2[2b]	--	80	<10
Free Cyanide	µg/L	5.2[2b]	--	80	<20
Cyanate	µg/L		--	17,000	27,000
Thiocyanate	µg/L		--	2,100	8,000

Notes: – Shaded values exceed applicable water quality criteria (AWQC).

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L; otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present. Standard for ammonia is based on 85th percentile of pH (7.85) and temperature (6.83°C) measured at Crooked Creek Station CCBO 1996-2015 (Donlin Gold 2017d).

Source: SRK 2012b, Table 5-3.

Table H-4: Final Plant Tailings Liquor - Metals Analysis

Parameter	Unit	AWQC	Feasibility Pilot (Phase 2) Final Tailings Filtrate Oct 2007		Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007		Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006	
			Total	Dissolved	Total	Dissolved	Total	Dissolved
Major Constituents								
Calcium	mg/L	--	449	500	427	437	531	516
Magnesium	mg/L	--	150	160	820	833	682	659
Potassium	mg/L	--	40.4	45.3	63.8	62.5	50.1	48.7
Silicon	mg/L	--	2.34	2.56	3.07	2.92	--	--
Sodium	mg/L	--	376	275	93	95.9	120	116
Strontium	mg/L	--	2.63	2.34	3.83	3.69	2.46	2.54
Metals								
Aluminum	µg/L	750[2b]	20	10	32.4	4.6	60	10
Antimony	µg/L	6[2d]	45.9	44.9	31.9	34.3	38.6	34.1
Arsenic	µg/L	10[2d]	1110	1090	467	483	454	432
Barium	µg/L	2,000[2d]	22.9	22.4	27.8	25.6	23.1	22.7
Beryllium	µg/L	4[2d]	<0.02	<0.02	<0.04	<0.04	<0.04	<0.04
Bismuth	µg/L	--	<0.01	<0.01	<0.02	<0.02	--	--
Boron	µg/L	750[2e]	198	190	1170	1310	428	445
Cadmium	µg/L	0.64[2a,b]	0.242	0.241	0.11	0.18	0.39	0.42
Cerium	µg/L	--	<0.07	<0.07	<0.09	<0.09	0.12	<0.09
Cesium	µg/L	--	<0.4	<0.4	5.2	5.72	5.23	4.7
Chromium, total	µg/L	100[2e]	3.9	3.5	1.4	1	1.5	1.8
Cobalt	µg/L	50[2e]	6.44	7.2	114	141	25.1	26.6
Copper	µg/L	29[2a,b]	7.7	7.2	115	135	102	116
Gallium	µg/L	--	<0.01	0.11	0.33	0.33	1.04	1.1
Germanium	µg/L	--	0.27	0.25	0.5	1.7	<0.1	0.9
Hafnium	µg/L	---	0.548	0.05	0.22	0.07	1.03	0.64
Indium	µg/L	--	<0.01	<0.01	<0.04	<0.04	<0.04	0.1
Iron	µg/L	1,000[2b]	270	170	200	50	190	<10
Lanthanum	µg/L	--	<0.04	<0.04	0.07	0.04	0.08	0.07
Lead	µg/L	11[2a,b]	1	0.3	3.02	0.48	0.57	<0.02
Lithium	µg/L	2,500[2e]	<2	5	16	16	747	743
Manganese	µg/L	50[2f]	676	677	18,100	18,400	15,700	13,200
Molybdenum	µg/L	10[2e]	78.1	73.6	106	114	302	259

Table H-4: Final Plant Tailings Liquor - Metals Analysis

Parameter	Unit	AWQC	Feasibility Pilot (Phase 2) Final Tailings Filtrate Oct 2007		Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007		Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006	
			Total	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**
Nickel	µg/L	100[2d]	20.8	12.4	57.4	64.1	47.7	56.7
Niobium	µg/L	--	0.02	<0.001	<0.1	<0.1	0.6	<0.1
Rhenium	µg/L	--	<0.2	<0.2	0.12	0.18	0.46	0.46
Rubidium	µg/L	--	29	28.8	119	130	185	103
Selenium	µg/L	4.6[2b]	14	16	42	44	28	33
Silver	µg/L	34.9[2a,b]	0.03	<0.01	0.56	0.55	0.42	0.27
Tantalum	µg/L	--	0.02	<0.001	<0.03	<0.03	0.24	<0.03
Tellurium	µg/L	-	0.03	<0.03	<0.4	<0.4	<0.4	<0.4
Thallium	µg/L	1.7[2f]	0.136	0.147	0.5	0.5	-	-
Thorium	µg/L	-	2.82	0.038	2.2	1.2	0.2	0.2
Tin	µg/L	--	0.11	0.15	1	0.8	--	--
Titanium	µg/L	-	0.6	0.4	1.4	69.6	0.9	1.1
Tungsten	µg/L	-	1.61	1.54	0.35	0.23	-	-
Uranium	µg/L	-	3.81	3.74	0.4	0.43	1.69	0.80
Vanadium	µg/L	100[2e]	0.47	0.47	0.63	0.5	0.35	0.41
Ytterbium	µg/L	-	0.029	0.023	0.198	0.11	0.089	0.034
Zinc	µg/L	379[2a,c]	11	23	15	15.9	42.1	15.1
Zirconium	µg/L	-	0.59	0.18	3.61	0.11	2.22	0.60
Mercury	ng/L	12[2b]	40	20	28	--	24,200	--

Notes:–Shaded values exceed applicable water quality criteria (AWQC).

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations. For aluminum, if
pH≥7.0 and hardness ≥50, then 750 µg/L; otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.

Source: SRK 2012b, Table 5-4.

1.3 Open Pit and Pit Lake

The resource to be mined is located in two main areas, ACMA and Lewis, which would be mined as two open pits (SRK 2012a, 2016a). As ore and waste rock are mined, the open pits would grow and partially coalesce later in the mine life (Figure 2.3-2, Chapter 2, Alternatives). The ultimate pit footprint is planned to be approximately 2.2 miles long by 1 mile wide. The ultimate depths of the Lewis and ACMA pits would be 1,653 feet and 1,850 feet, respectively, from the upper highwall to the final pit bottom (SRK 2012a, 2016a).

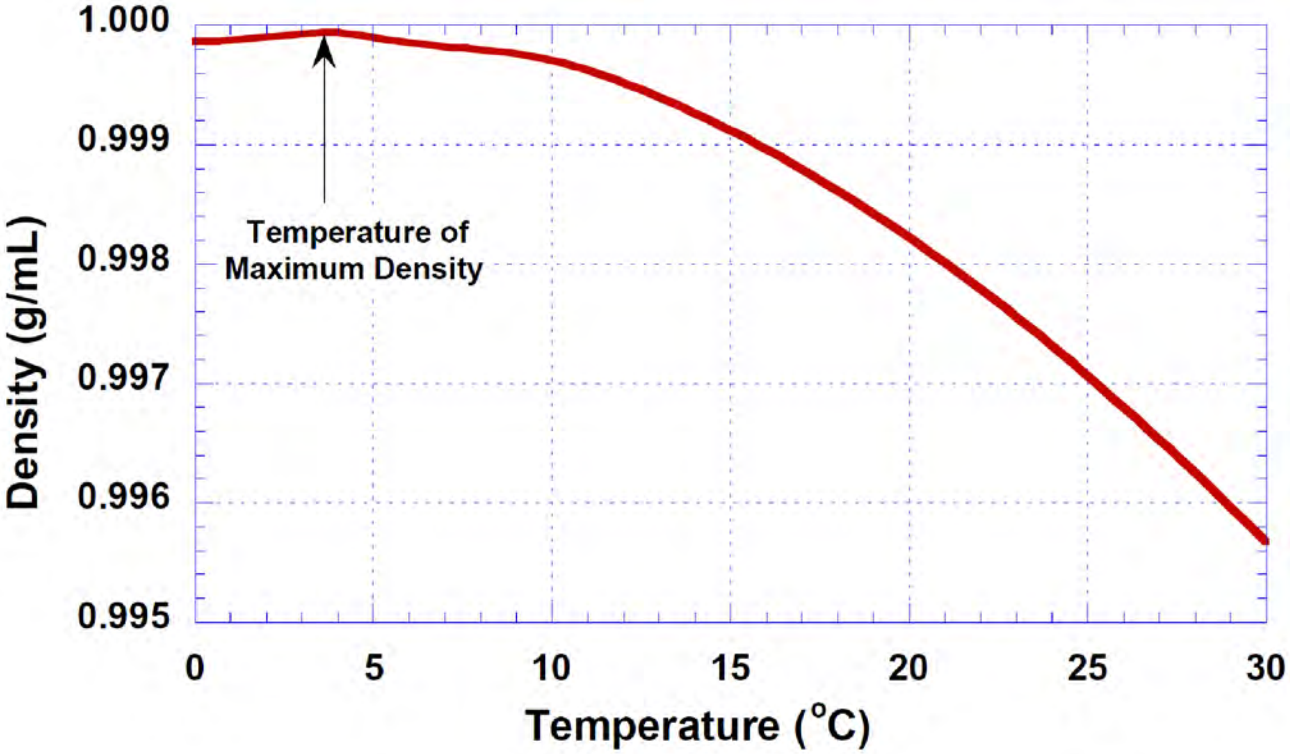
In the mining process, rock that would eventually become ore or waste rock would be progressively exposed to oxidizing atmospheric conditions. These newly exposed rocks include all the NAG and PAG rock categories discussed previously in the WRF section. Runoff from the pit walls and groundwater seeping into the pit would likely react with the rocks and is thus considered contact water. This water would be pumped out of the pit during Construction and Operations, but would be allowed to remain in the pit after Closure (SRK 2012b, 2017e).

A major component of the post-Closure contact water management strategy is also to pump low quality water from various other mine sources to a deep layer of the pit lake. This would be done in order to form a permanently stratified pit lake with high total dissolved solids (TDS), low-quality, denser water near the bottom, and lower-metal-content, lower-TDS water at the surface (Lorax 2012a, 2015). The surface water would then require less treatment before discharge. It is estimated that approximately 53 years after mine Closure the pit will have filled to near its controlled discharge elevation of 316 feet above mean sea level (AMSL), at which time water will be treated and discharged to Crooked Creek. The controlled discharge elevation is planned to be approximately 33 feet below the spillway elevation of 349 feet AMSL.

1.3.1 Lake Stratification Processes

The behavior of lake water with regard to stratification has important implications for pit surface water quality in the post-Closure period. The existence of stratified pit lakes has been widely documented (Filipek et al. 2004; Castendyk and Eary 2009). The process of vertical stratification in lakes is due to variations in the density of the water at different depths, and may be seasonal or permanent. If waters from different sources with different densities enter a lake, they can and will adjust themselves vertically until they reach a stable—or stratified—density configuration, with the highest density water at depth and the lowest density at the surface.

The density of water is a function of both its temperature and salinity, or total dissolved solids (TDS) content. Freshwater is densest at a temperature of about 40°F (4°C on Figure H-1). Above this temperature, the density decreases with increasing temperature. Below this temperature, the density decreases with decreasing temperature until it reaches its freezing point. At a given temperature, water density increases with increasing TDS. As its TDS increases, the temperature of maximum density of water also decreases.



Data Source: Lorax 2012

DONLIN GOLD
PROJECT EIS

WATER DENSITY AS A
FUNCTION OF TEMPERATURE

JUNE 2017

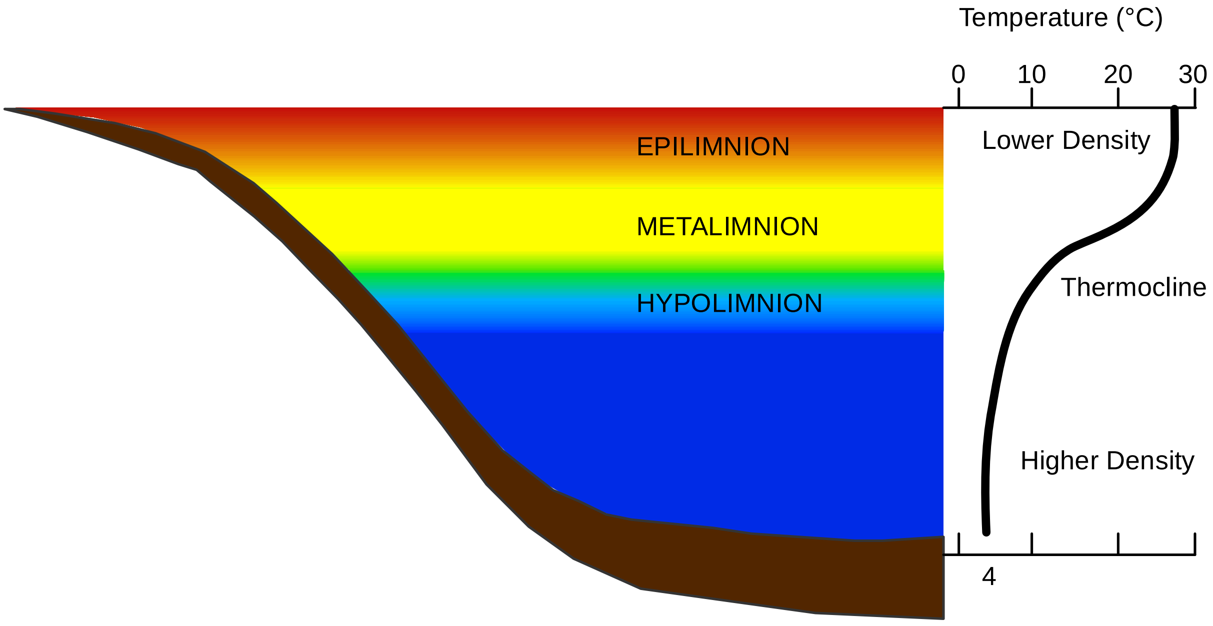
APPENDIX H FIGURE 1

1.3.2 Seasonal Effects on Stratification

Thermally induced seasonal density stratification is the norm in temperate to high latitude lakes of uniform chemistry (i.e., uniform TDS), and is due to the following processes.

- As air temperature and solar radiation increase in spring and summer, the surface water heats from above. This heating causes the density of the surface layer to decrease. The lake then has a surface layer (*epilimnion*) of uniform lower density and higher temperature, and an underlying layer (*hypolimnion*) of higher density and lower temperature. These layers are separated by a zone called the *thermocline* (or *metalimnion)* in which the temperature decreases rapidly with depth (Figure H-2). Above the thermocline, the surface water is mixed by wind and is typically in equilibrium with atmospheric oxygen. The epilimnion is typically less than about 20 to 30 feet deep, because wind-induced mixing in mid- to high-latitude pit lakes seldom reaches beyond this depth. Below the thermocline, oxygen may gradually become depleted by oxidation of organic matter that falls into the hypolimnion from the surface.
- At some point in the late autumn or early winter, the surface water temperature drops below that of the underlying water and reaches a point at which the surface water density is greater than that of the underlying water, which is an unstable situation. The surface water sinks until it reaches the level of its new density. Eventually, the entire water column may overturn, depending on the temperature structure of the lower layer and the amount of cooling at the surface. Overturn through the water column could take less than a day or occur over several weeks, and causes mixing which replenishes the oxygen throughout the depth of overturn, potentially to the bottom of the lake.
- When ice forms in early winter, the water below the ice may gradually lose its oxygen by the same processes that occur in the lower layer in summer. Below the ice, the water may become temperature-stratified with 40°F water at the bottom or it could remain well-mixed due to heating from the sides and bottom of the pit. Which process occurs depends on the relative temperatures of the air, water, and ground and the thermal conductivity of the ground.
- In spring, the air temperature increases. Ice gradually melts and the water temperature increases from the surface downward, as well as from the bottom up. When the surface water temperature reaches 40°F, the lake may again overturn and re-oxygenate due to the denser surface water.

Thermal Stratification



Data Source: Herbert 2012

DONLIN GOLD
PROJECT EIS

THERMAL STRATIFICATION DURING SUMMER IN FRESHWATER LAKES

JUNE 2017

APPENDIX H FIGURE 2

1.3.3 Chemical Effects on Stratification

This seasonal cycle is based on a pit lake with either no TDS or constant TDS with depth. Long-term (multi-year) or permanent density stratification can occur due to the following processes.

- A lake can develop a large vertical variation in TDS due to differences in the TDS of various source waters to the lake and/or to processes in the lake that increase the TDS, and thus the density, of the deeper water. For example, if the lake contains enough organic matter to deplete oxygen in the hypolimnion during the summer, any ferric hydroxide that precipitates at the surface and falls to the lake bottom may become reduced and dissolved in the anoxic bottom water, raising the TDS content and the density of the bottom water.
- Typically, a chemically stratified lake (i.e., one with vertical variations in TDS) has an upper epilimnion layer of lower TDS water overlying a hypolimnion layer of higher TDS water. The two layers are separated by a zone called the *pycnocline* in which the TDS and the water density increase rapidly with depth. If the bottom layer is sufficiently deep (well below the depth of summer wind mixing), a seasonal middle layer (*metalimnion*) may form below the summer thermocline and above the denser hypolimnion. Overturn in the fall/winter usually occurs throughout the metalimnion, but not the hypolimnion. Thus, once the hypolimnion becomes anoxic, it may remain so and may continuously dissolve any ferric hydroxide precipitates falling into it from above and release any metals sorbed onto the ferric hydroxide. This process further increases the TDS of the hypolimnion and strengthens the density gradient between it and the overlying layer, perpetuating the stratification. The larger the density difference between vertical layers of the lake, the more stable the stratification and the less prone the lake is to overturn and mix.

1.3.4 Physical Effects on Stratification

Physical processes such as precipitation, evaporation, ice formation, melting, wind, and molecular diffusion can also increase or decrease vertical density differences.

- For example, if precipitation, spring snowmelt, or runoff have lower TDS than the lake-water TDS, their addition could induce stratification near the lake surface, even when no temperature differences exist.
- Ice formation excludes dissolved salts and causes the water underlying the ice to become more concentrated. The underlying unfrozen water also may become reducing over the winter due to the lack of exposure to oxygen under ice cover. If a substantial thickness of ice forms in winter in such a lake (on the order of 5 feet estimated for the ACMA pit lake [Lorax 2012b]) then the initial melt water from ice and overlying snow could be more dilute than the water underlying the previous ice. If water to be treated and discharged is pumped from the pit lake surface soon after ice melts, then it may remove only the dilute ice-melt water and concentrate the remaining water. Later in summer, the surface water may then become even more concentrated because runoff from the pit walls forms a larger portion of the water. If each spring the water pumped and treated consists mainly of ice melt and that process continues year after year, the remaining surface water may become increasingly concentrated over time, never reaching a "steady state." Thus, in order to maintain the surface water concentrations within a relatively narrow band of water quality over the long term, it may be necessary to seasonally adjust the

depth from which water is pumped, for example, to pump water from below the ice-melt layer each spring. Countering density stratification are the slow processes of thermal and molecular diffusion, which tend to homogenize the water in terms of temperature and salinity. Thermal diffusivity in water is on the order of 10^{-5} m^2/sec, or about one m^2/day; while molecular diffusivity in water is several orders of magnitude slower.

2. Construction

Construction at the mine site is planned to take place over a 3-year period. The American Creek drainage into the CWDs, pit dewatering, overburden stockpiles, and TSF (Anaconda Creek runoff) are the primary geochemical components of the mine site that could potentially impact surface water quality during the Construction phase. Management objectives during Construction include minimizing build-up of contact water in the Lower CWD and eliminating the need to store water in the TSF until immediately before mine start-up. A detailed discussion of water treatment objectives during Construction is given in Section 3.7.3.2.2, Water Quality of the EIS.

2.1 Overburden Stockpiles

Overburden removed from the pit and TSF that is planned for later use in reclamation would be stored in the overburden stockpiles located near Crooked Creek (EIS Figures 2.3-6 and 2.3-7). The stockpiles would be protected from erosion and sedimentation through Best Management Practices (BMPs) and design features such as berms, diversion channels, and sedimentation ponds (EIS Section 3.2.3.2.3, Soils). Runoff from the stockpiles would be directed toward sediment ponds. Materials in the North Overburden Stockpile (NOB) are not considered to pose an ARD or M/L risk, so runoff and seepage are considered suitable for discharge from the sediment ponds. The South Overburden Stockpile (SOB) would contain terrace gravel and colluvium from the open pit. As described above (Infrastructure and Processes, WRF), there is the possibility for arsenic and other metals leaching, as well as ARD, from the mineralized zone of the open pits. Accordingly, runoff collected the SOB sediment pond is planned to be pumped to the Lower CWD (SRK 2012b, 2017e). Three overburden stockpiles are also planned to be located downstream of the TSF.

2.2 Waste Rock Facility

Details of the American Creek WRF construction are given in Section 2.3.2.1.9, Chapter 2, Alternatives, of the EIS. The foundation is planned to be built of coarse waste rock to allow drainage from the facility as well as discharging springs in the valley bottoms. The NAG 1-4 rock would be blended with PAG 5 rock in the interior of the WRF. The last 80 feet of the dump crest of any lift would be limited to only NAG 1-4 rock to minimize the potential for ARD formation (SRK 2012e, 2016g). The Lower and Upper CWD ponds are planned to be built in American Creek for the purpose of managing runoff from the WRF and pit, and preventing mine contact water from release to the environment (SRK 2012b, 2017e). NAG waste rock with metal leaching potential could be used for construction of the Lower CWD. Runoff and seepage from the Lower CWD would be collected either in the ACMA pit dewatering system, or at the proposed ore stockpile berm designed to minimize surface runoff to the pit. The ACMA pit would intersect American Creek downstream of the dam during Construction, so that runoff and seepage from the Lower CWD would not migrate off site.

Seepage from the WRF is planned to be contained by the Lower CWD and monitored quarterly (SRK 2012d, 2016h). The water quality of seepage from both the NAG and PAG portions of the WRF during Construction could exceed AWQS for certain constituents. This water would be stored during Construction for later use as process water during Operations or treated, as needed, by using the AWT.

2.3 Low-Grade Ore Stockpile and Ore Stockpile Berm

The low-grade ore stockpile is the area set aside to hold PAG 7 rock, which is highly mineralized rock of too low grade to process. It is assumed to be part of the long-term ore stockpile to be located between the Lower CWD and the ACMA pit (EIS Figure 2.3-6, Chapter 2, Alternatives). During the early years of Construction, a berm is planned to be constructed on American Creek, immediately downstream of the ore stockpile area to collect runoff downgradient from the Lower CWD. Contact water collected above the berm would be pumped to the Lower CWD. Any water overtopping the berm would flow to the ACMA pit and be collected by the pit dewatering system.

2.4 Tailings Storage Facility

The TSF is planned to be a fully lined facility constructed in six stages over the 27.5-year mine life. A seepage recovery system (SRS) is planned immediately downstream of the main tailings dam, which would collect groundwater and any seepage from the lined TSF. This water would be pumped to the TSF or treated using AWT, as needed, for water management.

Reclaim water from the tailings pond would be recycled back to the process facility from a floating barge via a pipeline (SRK 2012a, 2016a). NAG 1-4 waste rock is planned to be placed in lined portions of the TSF for use in construction (SRK 2016d). Two freshwater diversion dams upstream of the TSF in Anaconda Creek are planned to be maintained during Construction and the first 3 years of Operations. During Construction, these dams would divert non-contact water around the TSF and facilitate construction of the facility (SRK 2012a, 2016a). In year 3 of Construction, the dams would be decommissioned to allow for additional tailings storage. No tailings would be generated until the mine begins Operations. On the north and south sides of the TSF, freshwater diversions would continue to be constructed in stages until Year 17.

2.5 Open Pit

It is anticipated that only non-contact water perimeter wells, but not in-pit (contact water) dewatering wells, would be required during the Construction period (SRK 2012b, 2017e). Water collected from perimeter wells is predicted to exceed AWQC for several constituents including dissolved antimony, arsenic, iron, and manganese, and total concentrations of aluminum, antimony, arsenic, copper, iron, lead, and manganese (BGC 2014b; Hatch 2015, 2017). Accordingly, during Construction, the water is planned to be treated using the AWT. A water treatment plant (WTP) is planned to treat this water, as necessary, before being discharged to Crooked Creek (SGS 2012). A more detailed discussion is provided in Section 3.7.3.2.2, Water Quality.

3. Operations and Maintenance

Alternative 2 would involve operation of mine site facilities located in the American Creek and Anaconda Creek drainages. These include the overburden stockpiles, WRF, low-grade ore stockpile, the CWDs, TSF and associated SRS, and the mine pit. A set of operational rules has been designed to maintain maximum operational pond volumes of 811 acre-feet for the Lower CWD and 2,432 acre-feet for the Upper CWD (BGC 2015f). The rules determine which combination of water sources would be treated using the AWT at the WTP (SRK 2017e). The potential sources include: the pit perimeter and in-pit dewatering wells, inflows to the SRS, CWD water, and TSF water. Each of these sources is discussed in the following sections, except the pit perimeter and in-pit dewatering wells, which are discussed in Section 3.7.3.2.2, Water Quality.

3.1 Overburden Stockpiles

As discussed previously, the materials in the SOB stockpile have the potential to leach metals. Therefore, seepage and surface runoff from the SOB is planned to be captured and pumped to the Lower CWD for use in process or for treatment and discharge, as needed. In addition, the stockpile will be progressively reclaimed to minimize infiltration and entrainment. However, the potential exists for seepage underground to flow toward Crooked Creek. This issue is discussed in more detail in EIS Section 3.6, Groundwater Hydrology and potential mitigation measures are discussed in Chapter 5 of the EIS, Impact Avoidance, Minimization, and Mitigation. Over the course of mine Operations, all materials placed in the SOB will eventually be moved to the WRF and placed as waste or as internal capping material for the PAG cells (SRK 2012b).

3.2 Waste Rock Facility

During project operations, the WRF is planned to be progressively reclaimed by placing a cover of a minimum of 14 inches of growth medium over a minimum 12 inches of lower permeability terrace gravel and/or colluvium to reduce infiltration and seepage. The seepage from the WRF is planned to be collected and used as process water or treated, as needed.

Predicted water quality of the WRF pore water seepage is given in Tables H-5a through H-5c at the 50th, 75th, and 95th percentiles, respectively, for selected years of mining for the NAG and the isolated PAG cells in the WRF. Life of mine (LOM) Year 19 is the year that the NAG WRF is projected to reach its maximum areal extent. LOM Year 10 is the year that the PAG cells are projected to reach their maximum areal extent. After LOM Year 22, all newly mined PAG 6 rock would be placed in the final pit bottom rather than in PAG cells.

Table H-5a: Waste Rock Pore Water Concentration Estimates, 50th Percentile

Dump Sector			**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**PAG**	**PAG**	**PAG**	**PAG**
LOM Year			**Year 13**	**Year 13**	**Year 19**	**Year 19**	**Year 22**	**Year 22**	**Year 10**	**Year 10**	**Closure**	**Closure**
Case		**AWQS**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**
Major Constituents												
pH		6.5-8.5[1]	7.7	7.7	7.7	7.7	7.7	7.6	7.7	7.6	6.4	3.5
Sulfate	mg/L	250 [1]	2,000	1,900	2,000	2,000	2,000	3,900	2,000	2,600	42,000	180,000
Acidity	mg/L		0.17	0.17	0.17	0.17	0.17	8.8	0.009	0.17	0.028	190000
Alkalinity	mg/L		23	23	23	22	24	17	24	20	2.8	0.78
Calcium	mg/L		710	680	710	690	710	610	710	660	390	400
Magnesium	mg/L		64	70	64	86	64	610	64	240	7,500	1,500
Potassium	mg/L		27	27	27	27	27	200	27	27	590	1.4E-06
Sodium	mg/L		0	0	0	0	0	0	0	0	4400	0.01
Fluoride	mg/L	1[2e]	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Phosphorus	mg/L		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Silica	mg/L		31	31	31	31	31	31	31	31	31	31
Strontium	mg/L		6.2	5.9	6.2	6	6.2	5.3	6.2	5.8	3.4	3.5
Total Dissolved Solids	mg/L	500 [1]	2,800	2,700	2,800	2,800	2,800	5,100	2,800	3,500	55,000	220,000
Metals												
Aluminum	µg/L	750[2a,b]	29	29	29	29	29	1,600	0.6	0.48	0.72	3.2E+07
Antimony	µg/L	6[2d]	3,100	3,100	3,100	3,100	3,100	3,000	3,100	3,100	3,100	2,800
Arsenic	µg/L	10[2d]	21,000	10,000	21,000	19,000	21,000	21,000	21,000	20,000	21,000	27,000
Barium	µg/L	2,000[2d]	4.7	4.6	4.7	4.6	4.7	4.3	4.7	4.5	3.3	3.2
Beryllium	µg/L	4[2d]	0.68	0.68	0.68	0.68	0.68	21	0.68	0.68	0.68	74
Boron	µg/L	750[2e]	200	200	200	200	200	200	200	200	200	200
Cadmium	µg/L	0.64[2a,b]	1.3	1.3	1.3	1.3	1.3	4.7	1.3	1.3	0.5	65
Chromium	µg/L	100[2e]	31	31	31	31	31	58	31	31	31	130
Cobalt	µg/L	50[2e]	240	210	240	240	240	240	240	240	240	1100
Copper	µg/L	29.3 [2a,b]	25	25	25	25	25	24	25	26	13,000	33,000
Iron	µg/L	1,000[2b]	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.2	8.9	710,000
Lead	µg/L	10.9 [2a,b]	300	300	810	790	960	920	900	4,500	1,000	360
Lithium	µg/L	2,500[2e]	70	70	70	70	70	520	70	70	1,500	3.7E-06
Manganese	µg/L	50[2f]	7,500	7,300	8,800	9,000	8,800	8,500	8,800	9,600	370,000	170,000
Molybdenum	µg/L	10[2e]	820	820	820	820	820	790	820	820	820	720

Table H-5a: Waste Rock Pore Water Concentration Estimates, 50th Percentile

Dump Sector			**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**PAG**	**PAG**	**PAG**	**PAG**
LOM Year			**Year 13**	**Year 13**	**Year 19**	**Year 19**	**Year 22**	**Year 22**	**Year 10**	**Year 10**	**Closure**	**Closure**
Case		**AWQS**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**
Nickel	µg/L	100[2a]	1,600	1,400	1,600	1,500	1,600	1,600	1,600	1,600	1,600	2,300
Selenium	µg/L	4.6[2b]	860	850	860	880	860	1,700	860	1,100	18,000	80,000
Silver	µg/L	34.9[2a,c]	2	2	2	2	2	2	2	2	2	2
Thallium	µg/L	1.7[2f]	1	1	1	1	1	1	1	1	1	1
Vanadium	µg/L	100[2e]	3	3	3	3	3	3	3	3	3	3
Zinc	µg/L	379[2a,c]	1,900	1,800	5,100	4,900	6,000	5,800	5,900	28,000	400,000	190,000
Mercury	ng/L	12[2b,3]	190	190	190	190	190	180	190	190	190	180

Notes:

Values exceeding discharge criteria are highlighted.
1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels
2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations.
For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L; otherwise, 87 µg/L.
2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.
2c Aquatic life for fresh water (acute) criteria.
2d Drinking water primary maximum contaminant levels.
2e Irrigation water criteria.
2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.
Standard for ammonia is based on 85th percentile of pH (7.85) and temperature (6.83oC) measured at Crooked Creek Station CCBO 1996-2015 (Donlin Gold 2017d).
Source: SRK 2012h, 2017e

Table H-5b: Waste Rock Pore Water Concentration Estimates, 75th Percentile

Dump Sector			**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**PAG**	**PAG**	**PAG**	**PAG**
LOM Year			**Year 13**	**Year 13**	**Year 19**	**Year 19**	**Year 22**	**Year 22**	**Year 10**	**Year 10**	**Closure**	**Closure**
Case		**AWQS**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**
Major Constituents												
pH		6.5-8.5^{1}	7.7	7.6	7.7	7.6	7.7	7.5	7.7	7.6	6.7	3.5
Sulfate	mg/L	250 ^{1}	2,000	2,000	2,000	2,700	2,000	5,300	2,000	2,500	52,000	180,000
Acidity	mg/L		0.17	0.17	0.17	0.17	0.17	23	0.17	0.17	0.18	190,000
Alkalinity	mg/L		23	20	24	18	24	17	23	19	5.1	0.78
Calcium	mg/L		710	670	710	650	710	570	710	660	370	400
Magnesium	mg/L		64	150	64	290	64	990	64	220	8,600	1,500
Potassium	mg/L		27	27	27	27	27	200	27	27	27	1.40E-06
Sodium	mg/L		0	0	0	0	0	0	0	0	7500	0.01
Fluoride	mg/L	1^{2e}	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Phosphorus	mg/L		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Silica	mg/L		31	31	31	31	31	31	31	31	31	31
Strontium	mg/L		6.2	5.8	6.2	5.7	6.2	5	6.2	5.8	3.2	3.5
Total Dissolved Solids	mg/L	500 ^{1}	2,800	2,900	2,800	3,700	2,800	6,900	2,800	3,400	61,000	210,000
Metals												
Aluminum	µg/L	750^{2a,b}	29	29	29	29	29	4,200	29	29	29	3.00E+07
Antimony	µg/L	6^{2d}	3,100	3,100	3,100	3,100	3,100	3,000	3,100	3,100	3,100	2,800
Arsenic	µg/L	10^{2d}	21,000	15,000	21,000	20,000	21,000	22,000	21,000	20,000	21,000	27,000
Barium	µg/L	2,000^{2d}	4.7	4.5	4.7	4.5	4.7	4.1	4.7	4.5	3.1	3.2
Beryllium	µg/L	4^{2d}	0.68	0.68	0.68	0.68	0.68	21	0.68	0.68	0.68	74
Boron	µg/L	750^{2e}	200	200	200	200	200	200	200	200	200	200
Cadmium	µg/L	0.64^{2a,b}	1.3	1.3	1.3	1.3	1.3	6.9	1.3	1.3	0.5	65
Chromium	µg/L	100^{2e}	31	31	31	31	31	58	31	31	31	130
Cobalt	µg/L	50^{2e}	240	240	240	240	240	280	240	240	240	1,100
Copper	µg/L	29.3 ^{2a,b}	25	28	25	29	25	31	25	29	3,200	33,000
Iron	µg/L	1,000^{2b}	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	5.1	710,000
Lead	µg/L	10.9 ^{2a,b}	420	410	1,100	1,100	1,300	1,300	640	700	2,800	460
Lithium	µg/L	2,500^{2e}	70	70	70	70	70	530	70	70	70	3.70E-06
Manganese	µg/L	50^{2f}	8,800	8,900	8,800	11,000	8,800	11,000	8,800	9,800	370,000	170,000
Molybdenum	µg/L	10^{2e}	820	820	820	820	820	790	820	820	820	720

Table H-5b: Waste Rock Pore Water Concentration Estimates, 75th Percentile

Dump Sector			**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**PAG**	**PAG**	**PAG**	**PAG**
LOM Year			**Year 13**	**Year 13**	**Year 19**	**Year 19**	**Year 22**	**Year 22**	**Year 10**	**Year 10**	**Closure**	**Closure**
Case		**AWQS**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**
Nickel	µg/L	168[2a]	1,600	1,500	1,600	1,600	1,600	1,700	1,600	1,600	1,600	2,300
Selenium	µg/L	4.6[2b]	860	900	860	1,200	860	2,300	860	1,100	23,000	80,000
Silver	µg/L	34.9[2a,c]	2	2	2	2	2	2	2	2	2	2
Thallium	µg/L	1.7[2f]	1	1	1	1	1	1	1	1	1	1
Vanadium	µg/L	100[2e]	3	3	3	3	3	3	3	3	3	3
Zinc	µg/L	379[2a,c]	2,400	2,300	6,400	6,200	7,600	7,300	3,600	4,100	400,000	190,000
Mercury	ng/L	12[2b,3]	190	190	190	190	190	180	190	190	190	180

Notes:
Values exceeding discharge criteria are highlighted.
1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels
2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations.
For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L; otherwise, 87 µg/L.
2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.
2c Aquatic life for fresh water (acute) criteria.
2d Drinking water primary maximum contaminant levels.
2e Irrigation water criteria.
2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.
Standard for ammonia is based on 85th percentile of pH (7.85) and temperature (6.83oC) measured at Crooked Creek Station CCBO 1996-2015 (Donlin Gold 2017d).
Source: SRK 2012h, 2017e

Table H-5c: Waste Rock Pore Water Concentration Estimates, 95th Percentile

Dump Sector			NAG	NAG	NAG	NAG	NAG	NAG	PAG	PAG	PAG	PAG
LOM Year			Year 13	Year 13	Year 19	Year 19	Year 22	Year 22	Year 10	Year 10	Closure	Closure
Case		AWQS	Well Mixed	Poorly Mixed	Well Mixed	Poorly Mixed	Well Mixed	Poorly Mixed	Well Mixed	Poorly Mixed	Well Mixed	Poorly Mixed
Major Constituents												
pH		6.5-8.5[1]	7.7	7.6	7.7	7.5	7.7	7.5	7.7	7.5	6.8	3.4
Sulfate	mg/L	250 [1]	2,000	2,800	2,000	4,400	2,000	7,800	2,000	4,500	65,000	40,000
Acidity	mg/L		0.17	0.17	0.17	0.17	0.17	260	0.17	0.17	0.013	42,000
Alkalinity	mg/L		23	18	24	17	24	17	23	17	6.3	0.95
Calcium	mg/L		710	650	710	590	710	530	710	590	360	500
Magnesium	mg/L		64	300	64	750	64	1,600	64	760	11,000	1,900
Potassium	mg/L		27	27	27	27	27	300	27	27	27	1.70E-06
Sodium	mg/L		0	0	0	0	0	0	0	0	9,900	0.01
Fluoride	mg/L	1[2e]	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Phosphorus	mg/L		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Silica	mg/L		31	31	31	31	31	31	31	31	31	31
Strontium	mg/L		6.2	5.6	6.2	5.1	6.2	4.6	6.2	5.1	3.1	4.3
Total Dissolved Solids	mg/L	500 [1]	2,800	3,800	2,800	5,800	2,800	10,000	2,800	5,900	76,000	49,000
Metals												
Aluminum	µg/L	750[2a,b]	29	29	29	29	29	46,000	29	29	0	5.E+06
Antimony	µg/L	6[2d]	3,100	3,100	3,100	3,100	3,100	3,000	3,100	3,100	3,100	2,800
Arsenic	µg/L	10[2d]	21,000	20,000	21,000	20,000	21,000	22,000	21,000	20,000	21,000	27,000
Barium	µg/L	2,000[2d]	4.7	4.4	4.7	4.2	4.7	3.9	4.7	4.2	3	3.8
Beryllium	µg/L	4[2d]	0.68	0.68	0.68	0.68	0.68	21	0.68	0.68	0.68	74
Boron	µg/L	750[2e]	200	200	200	200	200	200	200	200	200	200
Cadmium	µg/L	0.64[2a,b]	1.3	1.3	1.3	1.3	1.3	13	1.3	1.3	0.5	65
Chromium	µg/L	100[2e]	31	31	31	31	31	58	31	31	31	130
Cobalt	µg/L	50[2e]	240	240	240	240	240	420	240	240	240	1,100
Copper	µg/L	29.3 [2a,b]	25	28	25	32	25	34	25	36	2,000	36,000
Iron	µg/L	1,000[2b]	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	4.3	890,000
Lead	µg/L	10.9 [2a,b]	510	500	1,400	1,400	1,700	1,600	780	850	2,800	500
Lithium	µg/L	2,500[2e]	70	70	70	70	70	780	70	70	70	4.40E-06
Manganese	µg/L	50[2f]	8,800	11,000	8,800	15,000	8,800	17,000	8,800	16,000	390,000	190,000

Table H-5c: Waste Rock Pore Water Concentration Estimates, 95th Percentile

Dump Sector			**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**NAG**	**PAG**	**PAG**	**PAG**	**PAG**
LOM Year			**Year 13**	**Year 13**	**Year 19**	**Year 19**	**Year 22**	**Year 22**	**Year 10**	**Year 10**	**Closure**	**Closure**
Case		**AWQS**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**	**Well Mixed**	**Poorly Mixed**
Molybdenum	µg/L	10[2e]	820	820	820	820	820	790	820	820	820	720
Nickel	µg/L	168 [2a]	1,600	1,600	1,600	1,600	1,600	1,800	1,600	1,600	1,600	2,300
Selenium	µg/L	4.6[2b]	860	1,200	860	1,900	870	3,400	860	2,000	28,000	18,000
Silver	µg/L	34.9[2a,c]	2	2	2	2	2	2	2	2	2	2
Thallium	µg/L	1.7[2f]	1	1	1	1	1	1	1	1	1	1
Vanadium	µg/L	100[2e]	3	3	3	3	3	3	3	3	3	3
Zinc	µg/L	379[2a,c]	3,000	2,900	8,100	7,900	9,600	9,200	4,600	15,000	400,000	200,000
Mercury	ng/L	12[2b,3]	190	190	190	190	190	180	190	190	190	180

Notes:
Values exceeding discharge criteria are highlighted.
1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels
2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations.
For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L; otherwise, 87 µg/L.
2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.
2c Aquatic life for fresh water (acute) criteria.
2d Drinking water primary maximum contaminant levels.
2e Irrigation water criteria.
2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.
Standard for ammonia is based on 85th percentile of pH (7.85) and temperature (6.83oC) measured at Crooked Creek Station CCBO 1996-2015 (Donlin Gold 2017d).
Source: SRK 2012h, 2017e

ARD water quality prediction is an evolving science and needs to be corroborated with many decades of mine-site data. All predictions of future water quality are estimates based on a number of assumptions, as discussed in SRK (2007, 2012h, 2017e), and likely represent order-of-magnitude approximations at best. If the NAG and PAG 5 rock are well blended within the WRF, then the chemistry of seepage is predicted to remain relatively constant over time using the mixing approach for NAG and PAG 5 rock discussed in SRK (2016d). Even if the rocks are not well mixed, no major change is expected for the first 20 or so years of Operations (SRK 2007, 2016g). The mixing approach discussed in SRK (2016g) is state-of-the-art, and no evidence is available that mixing adequate to minimize mobilization of acid and/or metals has been achieved at prior mine sites. SRK (2007, Section 2.4.4 Waste Rock Mixing, pp. 40-43) discusses the problems of intimate or adequate blending in depth.

If the blending is incomplete, then SRK predicts that the pH will decrease slightly near the end of mine life to about pH 7.5, with sulfate concentrations increasing from approximately 2,000 mg/L to about 7,800 mg/L. In either case, a number of constituents are predicted to exceed AWQC throughout the mine life. For example, in drainage from a well-mixed NAG WRF, arsenic concentrations are predicted to be approximately 21,000 µg/L, antimony 3,100 µg/L, selenium about 860 µg/L, and mercury 190 ng/L.

SRK (2012h) predictions for the isolated PAG cell pore water were based on an earlier waste rock management plan that assumed PAG 6 and PAG 7 would both be included in the isolated PAG cells. PAG 7 is now planned to be held in the low-grade ore stockpile until it is either processed or eventually goes to the pit in about LOM Year 22 (SRK 2016g). The quality of water from the PAG 6 seepage is predicted to degrade over time during Operations. It could be similar to that for well-mixed PAG at Closure in Tables H-5a through H-5c. However, PAG 6 rock is predicted to produce ARD in less than roughly 10 years (SRK 2007, 2016g). For that reason, it is possible that the predictions shown for the poorly-mixed PAG at Closure could be indicative of just PAG 6 rock in the later part of the mine life. The intermediate cover of terrace gravel and colluvium within a year of isolated PAG cell placement is predicted to reduce long-term percolation rates by about 36 percent from the rates predicted for bare PAG waste rock (O'Kane Consultants Inc. 2009). This water is planned to report to the Lower CWD.

Based on this assessment, the PAG cells could eventually have seepage with pH as low as 3.4, with manganese concentrations of approximately 190,000 µg/L; zinc approximately 190,000 µg/L; and selenium approximately 80,000 µg/L. Surface and groundwater potentially containing seepage from this area would be intercepted and pumped back into the Lower CWD.

During Operations, the WRF would be inspected and monitored as follows (SRK 2012d, e, 2016g, h):

- Each area of the WRF that is undergoing active development or concurrent reclamation is planned to be visually inspected weekly, and non-active areas inspected monthly;
- Complete annual inspections would be carried out for reclaimed portions of the WRF until Closure, and the results recorded in a document storage system developed for the site;
- During Operations, the toe of the WRF would be checked for seepage on a monthly basis, and as soon as practicable after major precipitation events. If seepage is observed,

the location and flow rate would be recorded, and a sample collected for water quality analysis; and the seepage would be pumped to the Lower CWD.

- During Closure, seepage from the WRF would be monitored quarterly for water quality and flow until analyses indicate a stable condition.

While seepage monitoring plans do not provide specific sample locations, it is recommended that flow and water quality monitoring from each source (NAG and PAG) be collected at least twice a year in spring and fall in order to test and improve (if necessary) water quality predictions.

3.3 Low-Grade Ore Stockpile and Ore Stockpile Berm

The long-term ore stockpile is planned to be downstream of the Lower CWD (SRK 2017e). A small berm is to be built on American Creek immediately downstream of the stockpile to prevent runoff from the stockpile from discharging into the open pit. The low-grade ore stockpile is an area of the ore stockpile set aside to hold PAG 7 rock, which is highly mineralized but of too low grade to process as ore at the time of mining. The PAG 7 rock has the potential to generate acid over a relatively short period (possibly in less than a few years). The PAG 7 rock is planned to be eventually moved to the ACMA pit once the final limits of the pit are reached, which is expected to be in Year 22 of the mine life (SRK 2016g). Stormwater and drainage from the ore stockpile, including runoff from the PAG 7 rock, would be collected by the berm and pumped to the Lower CWD. Any overflow from the berm would drain to the pit and be collected by the pit dewatering system. Any seepage that enters groundwater would be intercepted below the Lower CWD for mill make-up water or pumped to the Upper CWD (SRK 2016g).

Almost 70 percent of the PAG 7 rock is expected to be mined by the end of LOM Year 5 (Enos 2013c). By that time, the low-grade ore stockpile could have reached peak oxidation and could continue at that level over time as more PAG 7 is added each year through LOM Year 22, when it is expected to be placed in the final pit bottom. Separate water quality predictions have not been made for PAG 7 rock drainage or for that of stockpiled ore, which would report to the Lower CWD. Because PAG 7 rock is predicted to generate acid within a few years, it is assumed that the poorly-mixed PAG water quality at Closure is also indicative of PAG 7 rock drainage during LOM.

Ore rock is expected to have relatively high concentrations of pyrite and arsenopyrite, because the gold mineralization at the Mine Site occurs mainly within these sulfide minerals. A four-block model was developed of the NP/AP ratio of ore samples: NP/AP is 0.15 (equivalent to PAG 7) in Block 1, 0.53 (PAG 6) in Block 2, 0.82 (PAG 6) in Block 3, and 5.8 (NAG) in Block 4 (Enos 2013c). The average total sulfur in the ore is expected to be about 1.1 percent. Because most PAG 7 low-grade ore is planned to be mined early in LOM, it is possible that the ore-grade rock during this period is at least a mixture of PAG 6 and PAG 7 rock. Thus, the water quality predicted for poorly mixed PAG rock at Closure is assumed to be indicative of the remainder of the ore stockpile drainage for at least the latter part of the mine life, because little of the ore in the stockpile is planned to be moved to the crusher and processed until starting in about LOM year 14 (SRK 2016g, Appendix A).

It is recommended that surface water flow and quality be monitored at least twice a year (spring and fall) from drainage in the long-term and the low-grade ore stockpile areas in order to test and improve water quality predictions of CWD water.

3.4 Lower CWD

The Lower CWD is planned to hold runoff and seepage from several sources (BGC 2014b, 2015f; SRK 2017e). This water would be stored during Construction for later use as process water during Operations, as needed, and would continue to receive water throughout the life of the mine. It would be monitored quarterly (SRK 2016e) and sent to the Upper CWD, then on to the WTP for treatment, as needed. The major flows include surface water from the pit and the ore stockpile berm, and runoff from undisturbed areas of American Creek watershed,. Lesser inflows include surface runoff and seepage from both active and reclaimed portions of the NAG and PAG WRF, as well as input from the SOB sediment pond.

During Construction, surface water inflow is estimated at 156 gpm from the pit; 11 gpm from the ore stockpile; 1,157 gpm from undisturbed ground; 194 gpm from undisturbed ground below the Lower CWD; 15 gpm from the active WRF; and 104 gpm from the SOB; whereas seepage from the WRF is estimated at 42 gpm (all assuming average precipitation). Additionally, 440 gpm may be added as brine if SRS water needs to be treated (SRK 2017e, Appendix B, Figure B-1a).

During Operations, average surface water inflow is estimated at 999 gpm from the pit and the ore stockpile berm; 703 gpm from undisturbed ground; 49 gpm from active portions and 123 gpm from reclaimed portions of the WRF; and 92 gpm from the SOB sediment pond; whereas seepage inflow is estimated at 157 gpm from active portions and 85 gpm from reclaimed portions of the WRF (Figure 3.5-22).

The water quality of the Lower CWD would likely be variable, due to the variation in input sources, both seasonally and over time throughout the LOM. The quality of some of the source waters would be expected to decrease over time. First, the exposed pit wall surface area will increase, and waste rock will fill larger and larger portions of the WRF, so a smaller percentage of the drainage would be from undisturbed areas. Additionally, the PAG 7 and ore stockpile areas and the waste rock is expected to weather over time. Order-of-magnitude estimates of the water quality of the Lower CWD for different mining periods are given in Table H-6. These estimates were developed using two approaches, as described below.

Table H-6: Predicted Lower CWD Pond Concentrations (maximum by period)--Comparative Analysis

			1. WTP Source Water Prediction 95th Percentile Estimates (SRK 2017e, Appendix D, Table 6)			2. Independent Analysis[6] (AECOM 2018)				
	Units	AWQC[1]	APDES Years 1- 5	APDES Years 6 - 10	APDES Years 11 - 26.25	APDES Years 1- 5		APDES Years 6 - 10	APDES Years 11 - 26.25	
						No Brine	Brine		Ore Stockpile same as PAG WRF	Ore Stockpile same as PAG 7
Major Constituents										
pH	S.U.	6.5-8.5[2]	8.1	8.1	8.1	8.1	8.2	7.0	6.4	5.0
Alkalinity as CaCO3	mg/L		107	105	98	110	120	88	74	76
Calcium	mg/L		168	218	218	68	140	130	440	250
Magnesium	mg/L		24	29	29	14	63	25	390	270
Potassium	mg/L		25	29	31	5.8	4.6	15	22	22
Sodium	mg/L		25	26	30	14	11	19	21	21
Chloride	mg/L	230 [2]	2.1	2.1	2.3	2.1	4.8	1.8	1.5	1.5
Sulfate	mg/L	250 [2]	513	659	670	190	520	470	2,800	6,500
Total Dissolved Solids (est)	mg/L	500 [2]	861	1,053	1,073	350	800	690	3,700	8,000
Metals										
Aluminum	µg/L	87 (T)	100	130	180	8,200	6,600	16,000	18,000	890,000
Antimony	µg/L	6 [2]	740	960	970	180	150	510	760	750
Arsenic	µg/L	10 [2]	2,900	4,400	4,400	1,100	920	3,200	4,400	4,600
Barium	µg/L	2000 [2]	190	190	200	190	150	130	89	89
Beryllium	µg/L	4 [2]	0.48	0.55	0.57	0.48	0.38	0.67	0.56	2.7
Boron	µg/L	750 [5]	140	160	170	50	40	96	130	130
Cadmium	µg/L	0.64 [1]	0.86	1.0	1.1	0.50	0.46	0.85	0.86	2.7
Chromium	µg/L	100 [2]	19	23	24	4.9	3.9	13	18	21
Cobalt	µg/L	50 [5]	44	62	61	16	12	36	49	74
Copper	µg/L	29.3 [1]	8.2	10	10	18	14	29	170	1,000
Iron	µg/L	1000 [4]	350	360	430	760	600	910	740	21,000
Lead	µg/L	10.9 [1]	68	99	98	22	21	59	260	190
Manganese	µg/L	50 [3]	1,800	2,500	2,500	690	560	1,600	18,000	12,000
Molybdenum	µg/L	10 [5]	170	230	240	46	46	120	190	180
Nickel	µg/L	168 [1]	270	380	380	78	62	210	300	320
Selenium	µg/L	4.6 [4]	200	270	270	73	67	190	1,200	2,900
Silver	µg/L	34.9 [1]	1.2	1.4	1.4	0.51	0.41	0.90	1.2	1.2
Thallium	µg/L	1.7 [3]	0.71	0.82	0.85	0.32	0.25	0.54	0.70	0.71
Zinc	µg/L	379 [1]	390	570	570	190	150	460	18,000	12,000

Table H-6: Predicted Lower CWD Pond Concentrations (maximum by period)--Comparative Analysis

			1. WTP Source Water Prediction 95th Percentile Estimates (SRK 2017e, Appendix D, Table 6)			2. Independent Analysis[6] (AECOM 2018)				
	Units	AWQC[1]	APDES Years 1- 5	APDES Years 6 - 10	APDES Years 11 - 26.25	APDES Years 1- 5		APDES Years 6 - 10	APDES Years 11 - 26.25	
						No Brine	Brine		Ore Stockpile same as PAG WRF	Ore Stockpile same as PAG 7
Mercury	ng/L	12 [3]	120	150	150	34	87	81	120	120

Notes:
Shaded cells exceed most stringent water quality standard.
Most stringent Alaska water quality criteria (AWQC), based on hardness values, where applicable. AWQC are in terms of dissolved, unless otherwise noted by (T) for total concentration.
Drinking water primary max. contaminant levels
Human health criteria for non-carcinogens (for consumption of water + aquatic organisms)4
Aquatic life criteria for fresh waters (chronic)
Alaska criteria for irrigation and stock water.
Source: AECOM (2018). For all chemistry calculations:
a) Undisturbed American Creek watershed, SOB, and individual highwall rock category water qualities were taken from SRK 2017e, App. A, Table 5;
b) The surface water drainage from the WRF has the concentrations used in PitMod (Lorax 2015);
b) Ratios of rock categories for the pit (averages over the time period), the NAG and PAG portions of the WRF (cumulative over the time period), and the ore stockpile were developed from the AP and NP schedule in Enos 2013c;
d) Average percentages for each modeled period of mined-pit area to total planned pit area and of ground covered, respectively, by active and reclaimed NAG and PAG WRF to the total planned WRF were estimated from BGC 2011, Appendix A end-of-period maps.
e) The third period ore stockpile drainage was assumed to be either well-mixed or poorly-mixed PAG drainage at closure.

3.4.1 Donlin Gold WTP Source Water Predictions for Lower CWD

The first approach was developed by the Applicant in SRK 2017e, Appendix D, to predict source water concentrations for the design of the Operations WTP. It consisted of using 75th percentile values of source terms, as given in Table 5 of SRK (2017e, Appendix D). SRK modeled the combined stream requiring water treatment for three APDES periods. (According to SRK 2017e [Appendix D, Figure 2], APDES year 1 begins at the end of the third quarter of LOM year -2.) These periods include:

- The first five-year permitting cycle, representing Construction and initial Operations (APDES years 1 through 5);
- The second five-year permitting cycle, representing early Operations (APDES years 6 through 10); and
- LOM expected maximum contaminant loading and water quantity (APDES years 11 through 26.25).

According to SRK (2017e, Appendix D, Table 5), the same water quality estimates for the NAG and PAG waste rocks and for pit runoff were used for all three time periods. In addition, the combined open pit runoff was based on average areas exposed over the LOM, with an assumption of zero percent runoff from PAG 7 rock.

The predicted results of the SRK approach do not vary substantially for the three periods (see Table H-6, columns under “1. WTP Source Water Prediction”). Maximum during APDES Years 11 through 26.25 tend to be slightly higher than for the preceding years.

3.4.2 Independent Analysis of Lower CWD Water Quality

The second approach, an independent analysis completed by AECOM (2018), used a somewhat different method than that of SRK (2017e, Appendix D). In this approach, SRK (2017e, Appendix A, Table 5) was used to estimate water quality of SOB flows, clean runoff from undisturbed areas, and individual rock categories for pit runoff. However, the second approach did not use averages of rock categories in pit runoff over LOM, as did the SRK approach. Instead, for each modeled time period, different ratios of rock categories for the pit (averages over the time period) and the NAG and PAG portions of the WRF (cumulative over the time period) were developed from the mine AP and NP schedule (see EIS Figure 3.7-15, Tonnage-weighted Annual Average NP/AP for Waste Rock Categories) (Enos 2013c). In doing so, the second approach assumes that ore in the pit walls constitutes the same average percent during the modeled time period as that of the mined ore of the same time period, using the mine production schedule in SRK (2016g, Appendix A). Surface water from the ore stockpile assumes the stockpiled ore and PAG 7 rock are the averages estimated from the same mine production schedule (SRK 2016g, Appendix A).

The second approach mixed the predicted water chemistries of the various water sources to the Lower CWD using their annual average relative flows, based on interpolation of SRK (2017e, Figures 3-2 and 3-5); i.e. for each of the same three modeling periods used by SRK (2017e), the second approach used different percentages of each of the flows predicted to be affected by the pit or waste rock. In addition, BGC (2011b, Appendix A) end-of-period maps were used to estimate the average ratio (for each modeled period) of mined-pit area to total planned pit area, and of ground covered by active and reclaimed NAG and PAG WRF to the total planned WRF. The surface water runoff from reclaimed portions of the WRF was assumed to have the concentrations used in PitMod (Lorax 2012a, 2015); whereas runoff from active portions of the PAG and NAG WRF is assumed to be the same as their seepage chemistries. Those areas not yet mined (for the pit) and not yet covered in waste rock (for the WRF) were assumed to have the drainage chemistries of undisturbed land. The modeling was also based on the "what if" scenario that PAG rocks in the ore stockpile would produce acidic drainage during the third modeling period in the later LOM.

As mentioned previously, no drainage information exists on the equivalent category for ore. SRK (2017e) assumed it is similar to PAG 6 in the highwall "based on the relatively short length of time that the material would be exposed in the pit highwall." However, the text also states: "WRMC 7 material was conservatively assumed to be leaching at the peak acidic rate during Operations as this material category oxidizes rapidly." To be conservative, the second approach investigates two scenarios for the ore in the stockpile during the latest APDES modeling period, because the ore block model shows a mixture of ore categories from NAG to PAG 7 (see Appendix H, Section 3.3). The first scenario assumes that ore drainage in the (long-term) ore stockpile is equivalent to that of well-mixed PAG rock at Closure; the second assumes it is equivalent to poorly-mixed PAG rock at Closure (Table H-6).

Two scenarios were also investigated for the first time period under the second approach. The first assumes no brine would be added to the Lower CWD. The second assumes 440 gpm of brine would be added, using a composition based on Hatch (2017, Tables 4-6 and 4-11, with the metals in Table 4-11 concentrated by a factor of 3.9).

The mixing in the second approach used PHREEQC, a public domain geochemical computer code developed by the U.S. Geological Survey (Parkhurst and Appelo 2013.) The code allows both conservative mixing, which adjusts the final pH based on the acidities/alkalinities of the input waters, and mixing with mineral precipitation, when the mineral is saturated and forming in the mixture. Whether and which minerals are allowed to precipitate is at the user's discretion, because precipitation of many minerals is kinetically hindered under certain environmental conditions. This type of modeling is based on known thermodynamic data and is the standard method of estimating geochemical mixing and mineral precipitation across a spectrum of aqueous environments.

As for the first approach, no minerals were allowed to precipitate. The results of the second approach are given in Table H-6 (columns under "2. Independent Analysis).

3.4.3 Comparison of Results

As shown in Table H-6, the two approaches to predicting the water chemistry of the Lower CWD give similar results for several constituents for all three time periods, but deviate substantially for others, especially for the last time period, in which use of Closure PAG WRF values for the ore stockpile in the second approach produces more acidic water than what is used in the first approach. The high concentrations of aluminum and iron in those waters from the second approach is due to not allowing precipitation of aluminum and iron sulfate-oxyhydroxide minerals. If they were allowed to precipitate at saturation, assuming equilibrium with atmospheric oxygen and carbon dioxide, one or both of their values would decrease substantially. However, even if iron oxyhydroxide (ferrihydrite) precipitated, very little of the other constituents would adsorb onto the mineral surface, due to the relatively low pH values. This was confirmed by additional modeling not shown in the table (AECOM 2018).

The results of both approaches suggest that several constituents would exceed the most stringent AWQC for most or all modeled scenarios. These include sulfate, TDS, aluminum, antimony, arsenic, cadmium, lead, manganese, molybdenum, nickel, selenium, and mercury. Cobalt, copper, and zinc also exceed standards for some scenarios. The pH is also outside the standard for the latest time period using the "what if" assumption in the second approach, as is iron if not allowed to precipitate.

The major difference between the two approaches is that the "what if" scenario in the second approach predicted that the water would likely eventually turn acidic as the PAG rock in the ore stockpile oxidized, and the acid would trigger higher concentrations of sulfate, TDS, aluminum, iron, and certain metals. These results indicate the importance of monitoring the water quality of the various source areas over time. They also suggest that preferential processing of the PAG ore would likely result in better water quality for the Lower CWD over time.

3.5 Upper CWD

The Upper CWD would receive water from the Lower CWD and runoff from undisturbed areas above the WRF. The relative volumes of the two types of water are predicted to be about 66 percent Lower CWD water and 34 percent runoff from undisturbed areas (SRK 2017e). Parallel to the Lower CWD, the same two approaches were used to predict the range of water chemistries for the Upper CWD. The results for both approaches are given in Table H-7. Sulfate, TDS, antimony, arsenic, cadmium, lead, manganese, molybdenum, nickel, selenium, and mercury are predicted to exceed the most stringent AWQC standards for both approaches. Aluminum, copper, iron, zinc, and pH are also predicted to not meet AWQC in the third period in the "what if" scenario that assumes the ore stockpile produces acidic drainage.

Table H-7: Predicted Upper CWD Pond Concentrations (maximum by period) - Comparative Analysis

			95th Percentile Estimates (SRK 2017e, Appendix D, Table 7)			(AECOM 2018)				
						APDES Years 1- 5		APDES Years 6 - 10	APDES Years 11 - 26.25	
	Units	1AWQC	APDES Years 1- 5	APDES Years 6 - 10	APDES Years 11 - 26.25	No Brine	Brine		Ore Stockpile same as PAG WRF	Ore Stockpile same as PAG 7
Major Constituents										
pH	S.U.	6.5-8.5[2]	8.4	8.2	8.5	8.2	8.3	7.8	7.5	5.1
Alkalinity as CaCO3	mg/L		113	97	118	110	120	99	89	91
Calcium	mg/L		128	147	151	57	100	100	300	180
Magnesium	mg/L		21	23	23	14	47	21	260	180
Potassium	mg/L		18	18	22	4.0	3.2	10	15	14
Sodium	mg/L		20	18	22	10	7.8	13	15	15
Chloride	mg/L	230[2]	1.9	1.3	1.3	1.6	3.4	1.4	1.3	1.3
Sulfate	mg/L	250[2]	365	423	437	140	360	320	1,800	4,300
Total Dissolved Solids (est)	mg/L	500[2]	651	728	746	290	590	510	2,500	5,300
Metals										
Aluminum	µg/L	87 (T)	85	43	49	5,400	4,300	10,000	12,000	590,000
Antimony	µg/L	6[2]	520	600	620	120	100	340	501	490
Arsenic	µg/L	10[2]	2,000	2,600	2,700	760	610	2,100	2,900	3,000
Barium	µg/L	2000[2]	160	88	89	140	120	110	77	77
Beryllium	µg/L	4[2]	0.36	0.38	0.43	0.34	0.27	0.46	0.39	1.8
Boron	µg/L	750[5]	100	100	120	36	29	66	89	89
Cadmium	µg/L	0.64[1]	0.63	0.66	0.76	0.36	0.33	0.59	0.59	1.8
Chromium	µg/L	100[2]	14	15	17	3.6	2.9	8.6	12	14
Cobalt	µg/L	50[5]	31	38	39	11	8.4	24	32	49
Copper	µg/L	29.3[1]	6.3	6.6	6.8	12	10	19	110	680
Iron	µg/L	1000[4]	290	140	140	500	400	600	490	14,000
Lead	µg/L	10.9[1]	47	59	61	14	14	39	170	120
Manganese	µg/L	50[3]	1,300	1,500	1,600	460	370	1,000	12,000	7,700
Molybdenum	µg/L	10[5]	120	150	150	31	31	82	120	120
Nickel	µg/L	168[1]	190	230	240	52	41	140	200	210

Table H-7: Predicted Upper CWD Pond Concentrations (maximum by period) - Comparative Analysis

			95th Percentile Estimates (SRK 2017e, Appendix D, Table 7)			(AECOM 2018)				
						APDES Years 1- 5		APDES Years 6 - 10	APDES Years 11 - 26.25	
	Units	1AWQC	APDES Years 1- 5	APDES Years 6 - 10	APDES Years 11 - 26.25	No Brine	Brine		Ore Stockpile same as PAG WRF	Ore Stockpile same as PAG 7
Selenium	µg/L	4.6[4]	140	170	170	48	44	120	800	1,900
Silver	µg/L	34.9[1]	0.90	0.90	1.00	0.39	0.32	0.65	0.84	0.84
Thallium	µg/L	1.7[3]	0.55	0.58	0.64	0.26	0.22	0.41	0.52	0.52
Zinc	µg/L	379[1]	280	340	350	130	110	300	12,000	7,900
Mercury	ng/L	12[3]	89	93	110	23	58	53	77	77

Notes:

Shaded cells exceed most stringent water quality standard.

1 Most stringent Alaska water quality criteria (AWQC), based on hardness values, where applicable. AWQC are in terms of dissolved, unless otherwise noted by (T) for total concentration.
2 Drinking water primary max. contaminant levels
3 Human health criteria for non-carcinogens (for consumption of water + aquatic organisms)4
4 Aquatic life criteria for fresh waters (chronic)
5 Alaska criteria for irrigation and stock water.
6 Source: AECOM (2018). For all chemistry calculations:
  a) Undisturbed American Creek watershed, SOB, and individual highwall rock category water qualities were taken from SRK 2017e, App. A, Table 5;
  b) b) The surface water drainage from the WRF has the concentrations used in PitMod (Lorax 2015);
  c) Ratios of rock categories for the pit (averages over the time period), the NAG and PAG portions of the WRF (cumulative over the time period), and the ore stockpile were developed from the AP and NP schedule in Enos 2013c;
  d) Average percentages for each modeled period of mined-pit area to total planned pit area and of ground covered, respectively, by active and reclaimed NAG and PAG WRF to the total planned WRF were estimated from BGC 2011, Appendix A end-of-period maps.
  e) The third period ore stockpile drainage was assumed to be either well-mixed or poorly-mixed PAG drainage at closure.

3.6 Tailings Storage Facility

Tailings pond water is formed by recirculation as process water. It is assumed to have a concentration factor of three from initial tailings liquor (Tables H-3 and H-4) due to the recirculation (SRK 2015b). SRK (2015b, 2017e) predicted the water chemistry of the recirculated TSF pond water using Geochemist's Workbench, a thermodynamic equilibrium code, and allowed precipitation of certain minerals if they had reached saturation in the concentrated water. The results are shown in Table H-8. The "Solubility Constrained" column is checked for those constituents whose concentrations were lowered due to mineral precipitation.

Along with the tailings pond water, two other types of water are likely to exist in the TSF during mine Operations. One is pore water in contact with buried tailings. The other is surficial runoff of snowmelt and rainfall from the beach area.

The pore water in contact with buried tailings is expected to equilibrate with the prevailing conditions of the tailings. In the surficial layers, the tailings were assumed to be in equilibrium with atmospheric (non-reducing) conditions. In this case, the pore water may remain similar to the overlying tailings pond water.

Deeper in the tailings, it was assumed that reducing conditions develop that result in reduction of ferric iron to ferrous, and release of tailings components such as arsenic associated with iron. Thermodynamic equilibrium calculations were conducted using dissolved organic carbon (DOC) in the form of residual cyanide and flotation reagents in the process water ("Process DOC" in Table H-8). The model results suggest that reduction by DOC decreases pH and increases iron and antimony by several orders of magnitude, as well as arsenic by almost a factor of five (Table H-8).

Several constituents are predicted to exceed AWQC for both near-surface and deeper tailings pore water, including fluoride, sulfate, TDS, antimony, arsenic, cadmium, manganese, molybdenum, selenium, and mercury. Iron and pH are predicted to not meet AWQC for the deeper tailings pore water.

Table H-8: Tailings Pond Water and Pore-Water Quality in Buried Tailings

Parameter	Units	AWQC	Solubility Constrained	Tailings Pond Water[4]	Buried Tailings – Process DOC[4]	WTP Design Basis – TSF Reclaim Water, Steady State[5]
Major Constituents						
Redox Potential	mV			-	300	-
pH	S. U.	6.5-8.5[1]	X	7.7	5.5	7.7
Calcium	mg/L		X	610	1,000	610
Magnesium	mg/L		X	440	1,000	1,733
Potassium	mg/L		X	120	120	120

Table H-8: Tailings Pond Water and Pore-Water Quality in Buried Tailings

Parameter	Units	AWQC	Solubility Constrained	Tailings Pond Water[4]	Buried Tailings – Process DOC[4]	WTP Design Basis – TSF Reclaim Water, Steady State[5]
Sodium	mg/L			1,100	1,100	1,100
Strontium	mg/L			7.9	7.9	7.9
Chloride	mg/L	230[2b]		26	25	26
Fluoride	mg/L	1[2e]	X	2	2	2
Sulfate	mg/L	250[1]	X	5,800	4,400	8,605
Silicon	mg/L			7	7	7
Alkalinity	mg/L	20 (min)[2b]		25	530	25
TDS	mg/L	500[1]		-	7,779	11,550
Ammonia	mg/L	2.99[2g]		29	29	29
Cyanide						
WAD Cyanide	µg/L	5.2[2h]				1.6[6]
Metals						
Aluminum	µg/L	87[2a]	X	13	5.6	13
Antimony	µg/L	6[2d]	X	22	1,100	22
Arsenic	µg/L	10[2d]	X	3,300	15,000	3,300
Barium	µg/L	2,000[2d]	X	11	11	11
Beryllium	µg/L	4[2d]		<0.06	<0.06	0.03
Boron	µg/L	750[2e]		590	590	590
Cadmium	µg/L	0.64[2a,b]		0.73	0.73	0.73
Chromium	µg/L	100[2d]		12	12	12
Cobalt	µg/L	50[2e]		19	19	19
Copper	µg/L	29[2a,b]	X	18	18	18
Iron	µg/L	1,000[2b]	X	4.4	98,000	4.4
Lead	µg/L	11[2a,b]		3	3	3
Lithium	µg/L	2,500[2e]		<6	<6	3
Manganese	µg/L	50[2f]	X	2,000	2,000	2,000
Molybdenum	µg/L	10[2e]		230	230	230
Nickel	µg/L	100[2a,b]		62	62	62
Selenium	µg/L	4.6[2b]		42	42	42
Thallium	µg/L	1.7[2f]		0.41	0.41	0.41

Table H-8: Tailings Pond Water and Pore-Water Quality in Buried Tailings

Parameter	Units	AWQC	Solubility Constrained	Tailings Pond Water[4]	Buried Tailings – Process DOC[4]	WTP Design Basis – TSF Reclaim Water, Steady State[5]
Vanadium	µg/L	1,000[e]		4.8	4.8	4.8
Zinc	µg/L	379[2a,c]		33	33	33
Mercury	ng/L	12[2a]		10,000[3]	10,000[3]	10,000[3]

Notes:

All tailings pond water and pore-water concentrations are "dissolved" and should be used as "average" annual.
Shaded cells exceed most stringent water quality standard.
AWQC:
1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.
2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L.
2b Aquatic life for fresh water (chronic) criteria.
2c Aquatic life for fresh water (acute) criteria.
2d Drinking water primary maximum contaminant levels.
2e Irrigation water criteria.
2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present. Standard for ammonia is based on 85th percentile of pH (7.85) and temperature (6.83°C) measured at Crooked Creek Station CCBO 1996-2015 (Donlin Gold 2017d).
2h Aquatic life criteria (chronic) for free cyanide, measured as weak acid dissociable (WAD) cyanide.
3 Hatch 2015; Donlin 2015 (personal communication, RE: Hg in TSF pond water, email from Gene Weglinski to Nancy Darigo, Aug 26, 2015); SRK 2017e (based on reduction observed at a Barrick facility using UNR reagent).
4 Source: SRK 2017e, Appendix C, Table C-8.
5 Source: SRK 2017e, Table 4-4; Hatch 2017, Table 4-2.

6. Source: SRK 2017e, Appendix D, Table 8.

Tailings beach runoff water was estimated assuming that the humidity cell discussed in Section 3.7.2.4.4, Water Quality, could be used as an analog for beach runoff, in combination with average annual net precipitation data for the site (SRK 2007). The beach runoff is predicted to be relatively dilute due to exposure of the water to only a thin layer of tailings, as shown in Table H-9. However, several constituents are predicted to exceed AWQC, including sulfate, antimony, arsenic, manganese, molybdenum, selenium, and mercury. Alkalinity is expected to be lower than required by AWQC.

Table H-9: Beach Runoff Water Quality at Tailings Storage Facility

Parameter	Units	AWQC	Concentration
Major Constituents			
Sulfate	mg/L	250[1]	520
Alkalinity	mg/L	20 (min)[2b]	11
Calcium	mg/L	-	140
Sodium	mg/L	--	4.2
Magnesium	mg/L	-	32
Metals			
Aluminum	µg/L	750[2a,b]	290
Antimony	µg/L	6[2d]	81
Arsenic	µg/L	10[2d]	290
Barium	µg/L	2,000[2d]	11
Beryllium	µg/L	4[2d]	0.15
Cadmium	µg/L	0.64[2a,b]	0.22
Chromium	µg/L	100[2e]	1.1
Cobalt	µg/L	50[2e]	2.7
Copper	µg/L	29[2a,b]	2.7
Iron	µg/L	1,000[2b]	39
Lead	µg/L	11[2,ba]	0.1
Manganese	µg/L	50[2f]	1,100
Molybdenum	µg/L	10[2e]	38
Nickel	µg/L	100[2d]	9.2
Selenium	µg/L	4.6[2b]	11
Silver	µg/L	34.9[2a,c]	0.11
Thallium	µg/L	1.7[2f]	0.37
Zinc	µg/L	379[2a,c]	11
Mercury	ng/L	12[2b]	51

Notes:

All beach runoff concentrations are “dissolved” and should be used as “average” annual. Shaded cells exceed most stringent water quality standard.

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column.
2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L; otherwise 87 µg/L.
2b Aquatic life for fresh water (chronic) criteria.
2c Aquatic life for fresh water (acute) criteria.
2d Drinking water primary maximum contaminant levels.
2e Irrigation water criteria.
2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

Source: SRK 2012b, Table 5-5.

3.7 TSF Seepage Recovery System

A Seepage Recovery System (SRS) would be built at the downstream toe of the TSF that consists of a collection pond, groundwater monitoring and collection wells, and pumping system. It is designed to capture two sources of water: 1) potential seepage through the TSF liner and 2) surface water and groundwater that enters the rock underdrains (BGC 2011a). The SRS water may be treated at the WTP and discharged to Crooked Creek, when needed, for water management.

Due to the TSF liner, the seepage is expected to be minimal, ranging from about 1.4 gpm in Year 1 to about 17.6 gpm in Year 27 (BGC 2016c). Flows from surface water and groundwater are expected to vary seasonally, with higher flow rates in summer than in winter. Flows are expected to increase over the first few years, and then taper off again slowly by the end of mine life. Summer flows are predicted to range between about 550 gpm (at end of mine life) to about 1,030 gpm (around Year 4); whereas winter flows are predicted to range between about 380 to 690 gpm.

SRS water chemistry (Table H-10) is predicted to be neutral pH. WAD cyanide, antimony, arsenic, iron, manganese, and mercury concentrations are expected to exceed AWQC (Hatch 2017; SRK 2017e).

Table H-10: Predicted TSF Seepage Recovery System Water Quality (95th Percentile Values)

Parameter	Units	AWQC	Estimated Water Quality		
			APDES Years 1- 5	APDES Years 6 - 10	APDES Years 11 - 26.25
Major Constituents					
pH		6.5-8.5[1]	7.8	7.8	7.8
Calcium	mg/L		38	46	90
Magnesium	mg/L		15	23	67
Potassium	mg/L		2.4	3.4	9
Sodium	mg/L		14	23	72
Chloride	mg/L	230[2b]	1.8	2	3
Fluoride	mg/L	1[2e]	0.1	0.12	0.2
Sulfate	mg/L	250[1]	33	69	266
Ammonia	mg/L	2.99[2g]	1.2	1.4	2.6
Total Dissolved Solids	mg/L	500[1]	210	273	615
Cyanide					
WAD Cyanide	µg/L	5.2[2b]	6.3	12	45
Metals					
Aluminum	µg/L	750[2a,b]	33	33	32
Antimony	µg/L	6[2d]	7.3	16	66
Arsenic	µg/L	10[2d]	99	220	890
Barium	µg/L	2,000[2d]	150	150	150
Beryllium	µg/L	4[2d]	0.065	0.065	0.065

Table H-10: Predicted TSF Seepage Recovery System Water Quality (95th Percentile Values)

Parameter	Units	AWQC	Estimated Water Quality		
			APDES Years 1- 5	APDES Years 6 - 10	APDES Years 11 - 26.25
Boron	µg/L	750[2e]	11	16	42
Cadmium	µg/L	0.64[2a,b]	0.079	0.085	0.11
Chromium	µg/L	100[2e]	0.63	0.73	1.2
Cobalt	µg/L	50[2e]	0.72	0.87	1.7
Copper	µg/L	29[2a,b]	1	1.2	1.9
Iron	µg/L	1,000[2b]	840	1,600	6,000
Lead	µg/L	11[2a,b]	0.23	0.25	0.38
Lithium	µg/L	2,500[2e]	1.6	1.6	1.6
Manganese	µg/L	50[2f]	440	450	520
Molybdenum	µg/L	10[2e]	3	4.9	15
Nickel	µg/L	100[2a]	1	1.5	4.3
Selenium	µg/L	4.6[2b]	1	1.4	3.2
Silver	µg/L	34.9[2a,c]	0.17	0.19	0.31
Thallium	µg/L	1.7[2f]	0.16	0.16	0.17
Vanadium	µg/L	100[2e]	3.1	3.1	3.2
Zinc	µg/L	379[2a,c]	10	11	12
Mercury	ng/L	12[2b,3]	84	170	610

18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels

Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations.
For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L; otherwise, 87 µg/L.
2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.
2c Aquatic life for fresh water (acute) criteria.
2d Drinking water primary maximum contaminant levels.
2e Irrigation water criteria.
2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.
Standard for ammonia is based on 85th percentile of pH (7.85) and temperature (6.83oC) measured at Crooked Creek Station CCBO 1996-2015 (Donlin Gold 2017d).

3.8 Open Pit

During Operations, water collected from pit dewatering would report to the Lower CWD for storage. When the combined pond volume of the Lower and Upper CWD exceeds 1,216 acre-feet, this water would be treated, as needed, and discharged to Crooked Creek (BGC 2015f; SRK 2017e). The predicted chemistry of the pit dewatering wells is given in EIS Table 3.7-38, Water Quality.

4. Closure

According to the mine plan, in Year 22 of the mine life, the final limits of the pit would be reached. At this point, all PAG 6 and PAG 7 waste rock mined in the Lewis Pit would be placed as backfill into the ACMA Pit. At least some rock classified as NAG 1-4 and PAG 5 rock would also be backfilled into the ACMA Pit as it is mined from the Lewis Pit (SRK 2012e, 2016g). Closure of the overburden stockpiles, WRF, low grade ore stockpile, and the TSF and formation of the Closure pit lake that includes collection of drainage from the closed WRF and TSF are discussed in the following sections.

4.1 Waste Rock Facility

The WRF is planned to be progressively reclaimed during Operations by placing a cover designed to reduce infiltration and provide natural drainage toward the south margin of the WRF (SRK 2012e, 2016g). At mine Closure, seepage from the both NAG and PAG portions of the WRF is expected to continue to exceed AWQC for several constituents (Table H-11). Sulfate, antimony, arsenic, cadmium, lead, manganese, nickel, selenium, zinc, and mercury concentrations are predicted to exceed AWQC for both NAG and PAG seepage. Additionally, aluminum, copper, and chromium concentrations exceed AWQC for PAG seepage.

The seepage from the WRF would flow to a collection area, and be gravity-piped to a deep layer of the pit lake. Over time, it is expected that the quality of seepage from the PAG 6 cells will improve. However, piping of the combined WRF seepage to the pit lake may need to continue indefinitely because PAG 5 rock in the WRF is predicted to have the potential to generate ARD only after several decades (SRK 2007).

Table H-11: Water Quality of Major Inflows to Pit at Closure

Parameter	Units	AWQC	NAG WRF Seepage[3]	PAG Cell Seepage[4]	Initial Pit Lake Water[5]	Tailings Pore-water Seepage[6]	Groundwater[7]	Undisturbed Reclamation Runoff[8]
pH	Units	6.5-8.5[1]	7.7	3.5	7.7	7.7	7.3	6.4
Sulfate	mg/L	250[1]	2,000	180,000	3,811	4,400	9	20
Aluminum	µg/L	87/750[2a,b]	29	30,000,000	221	5.6	81	1,100
Antimony	µg/L	6[2d]	3,100	2,800	1,630	1,100	0.5	3
Arsenic	µg/L	10[2d]	21,000	27,000	12,600	15,000	100	12
Boron	µg/L	750[2e]	200	200	390	590	30	20
Cadmium	µg/L	0.64[2a,b]	1.3	65	1	7.3	0.25	0.25
Copper	µg/L	29[2a,b]	25	33,000	22	18	1.5	1
Chromium	µg/L	100[2e]	31	130	22	12	1	2
Lead	µg/L	50[2a,b]	1,300	460	680	3	0.1	1.2
Manganese	µg/L	50[2f]	8,800	170,000	5,600	2,000	220	260
Nickel	µg/L	100[2d]	1,600	2,300	870	62	1	2.9
Selenium	µg/L	4.6[2b]	860	80,000	470	42	2.5	2.5
Zinc	µg/L	379[2a,c]	7,600	190,000	4,000	33	3	9

Table H-11: Water Quality of Major Inflows to Pit at Closure

Parameter	Units	AWQC	NAG WRF Seepage[3]	PAG Cell Seepage[4]	Initial Pit Lake Water[5]	Tailings Pore-water Seepage[6]	Groundwater[7]	Undisturbed Reclamation Runoff[8]
Cyanide, WAD	µg/L	5.2[2b]	0	0	60	100	0	0
Mercury	ng/L	12[2b]	190	180	34,900	73,000	2.2	14

Notes:

Shaded cells exceed most stringent water quality standard.

AWQC

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L,
otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.

3 75th Percentile chemistry for well mixed NAG at year 2036 based on scaling of humidity cell leachate data (SRK 2015c).

4 75th Percentile chemistry for poorly mixed PAG at year 2050 2036 based on scaling of humidity cell leachate data (SRK 2012h2015c).

5 Conservative mixture of 8,920 acre-feet of backfill runoff and 24,000 acre-feet of tailings supernatant water.

6 Predicted concentrations of tailings pore water (SRK 2015a).

7 Denotes mean background groundwater quality in the mineralized area of the pit shell. Data collected from site monitoring wells MW03-1, MW03-2, MW03-4, MW03-14, MW03-15, MW03-16, and MW05-23 during the period from March 2004 until December 2010.

8 95th Percentile chemistry for background surface water quality in American Creek (2004 to 2010).

Source: Lorax 2015, Table 2-1.

4.2 Low-Grade Ore Stockpile

At or before Closure, all materials remaining in the low-grade ore stockpile would be transferred as backfill into the ACMA Pit (SRK 2012e, 2016g).

4.3 Tailings Storage Facility

In preparation for Closure, the operating pond would gradually be shifted to the southeast corner of the TSF by modifying the direction of tailings deposition. At Closure, the tailings water is expected to continue to exceed water-quality standards (EIS Table 3.7-33, Water Quality) and the pond water would be pumped to a deep layer of the pit lake. The TSF would be covered with a coarse NAG waste rock drain layer overlain by colluvium/terrace gravel, in turn overlain by a growth media mix with a slope to promote controlled surface runoff and reduce infiltration into the tailings. It is predicted that over the 5-year Closure period, the cover would induce consolidation of the underlying tailings.

The expelled tailings water, along with infiltration through the overlying cover, would flow through the coarse rock layer to the (then) small lined impoundment located on the southeast corner of the TSF. The water would continue to be pumped from the small impoundment to the pit rim, where it would be combined with WRF drainage. From there, it would be gravity-piped to the pit lake bottom until AWQC are met. Thereafter, flow from the TSF would be discharged to Crevice Creek (SRK 2012f, 2017c). The consolidation water is predicted to decrease exponentially from approximately 1,000 acre-feet/year to 400 acre-feet/year during the first 10 years after Closure, and to approximately 100 acre-feet/year by Year 51 (BGC 2014b). It is expected that the water quality would improve rapidly with time as consolidation reaches completion and the rate of consolidation decreases, such that, by approximately Year 52 post-Closure, the flow would be essentially all infiltrated precipitation. At that time it is predicted that water quality standards would be met, and that the consolidation water would no longer be routed to the pit lake (final volume approximately 380,000 acre-feet [BGC 2012c]), but rather discharged directly to Crevice Creek. (For flow-rate comparisons, the annual average Crooked Creek flow at Crevice Creek is on the order of 70,000 acre-feet/year [BGC 2014i].)

4.4 Pit Lake

4.4.1 Lake Depth, Inflow Sources, and Gradient

Starting in Year-22 of the mine life, all Lewis Pit PAG 6 and PAG 7 waste rock, as well as some NAG 1-4 and PAG 5 rock would be placed as backfill into the ACMA Pit (SRK 2012e). The backfill would be such that the maximum depth of the deepest part of the post-Closure pit lake would be approximately 1,020 to 1,050 feet. Other portions of the pit would be backfilled to maintain a shallower lake depth of approximately 205 to 216 feet (SRK 2012b, e).

After Closure, pit dewatering would stop and the pit would fill with water from several sources (Lorax 2012a), including:

- Groundwater inflows;
- Highwall precipitation runoff;
- Direct precipitation on the surface of the pit lake;
- Excess tailings water in the impoundment at the end of Operations;
- Tailings consolidation water and cover infiltration water;
- Tailings seepage recovery system (SRS) water consisting of natural groundwater and a small component of tailings pore water;
- NAG seepage water from the WRF;
- PAG seepage water from the isolated cells of the WRF; and
- Undisturbed runoff from American Creek watershed and runoff from the WRF reclamation cover.

According to the numerical hydrogeologic model developed by BGC (2011d, 2015g), for about 8 years after pit dewatering is stopped, water would flow into the pit from the groundwater at higher elevations and from the pit into the pore space of the waste rock placed as backfill and into the localized bedrock outside of and surrounding the pit from which bedrock water had been removed during mining. Once the localized bedrock had refilled with water, the direction of flow would reverse and groundwater would move towards the pit (pit lake). Thereafter, the seepage rate from the lake to groundwater would gradually decrease to zero as the lake reaches its managed final elevation approximately 10 to 30 feet below the designed spillway overflow elevation of 349 feet AMSL (BGC 2015g). Additional description of the temporary localized flow reversal into bedrock as the pit fills is given in EIS Section 3.6, Groundwater Hydrology. The pit outflow may result in an elevated input of sulfate and metals and decreased pH to the deep bedrock portion of the aquifer for the first few years. Pit lake levels would be managed in post-Closure to maintain a net inward groundwater gradient to the pit by pumping from the lake surface and treating it at the WTP for discharge to Crooked Creek (SRK 2012b, f, 2017c, e; BGC 2014b).

Treatment and discharge of pit lake surface water are predicted to begin approximately 53 years after Closure, based on the most likely pit filling rate obtained in the BGC (2015g) hydrogeological model. Hydrogeologic sensitivity runs suggested that the timing of pit lake filling could be as little as 30 years, assuming a future wet climate due to climate change or a higher hydraulic conductivity, or as long as 60 years. The uncertainty in the pit filling rate is discussed in more detail in EIS Section 3.6, Groundwater Hydrology.

Most WRF seepage would report to the WRF underdrain, and from there, would flow by gravity to the pit rim. Pumping would be required to get TSF and SRS water to the pit rim, where it would be combined with the WRF seepage, then flow via a gravity-fed pipe to the bottom of the pit lake. Groundwater seepage through the pit walls could possibly contain a small fraction of WRF seepage that leaks below the WRF underdrain, but this is expected to be a very minor contribution to the pit lake in comparison to the piped flows and overall groundwater seepage from around the pit. The denser TSF/WRF water piped to the bottom of the pit lake would likely stay below the pycnocline. Groundwater seepage into the pit lake through the walls would likely be less dense than the TSF/WRF water. EIS Section 3.6, Groundwater Hydrology further describes the inflows and water balance in relation to the pit lake.

4.4.2 Pit Lake Modeling

Lorax (2012a, 2015) modeled the evolution of the post-Closure pit lake to assess the physics and geochemistry of the pit filling process, confirm the assumption that the pit lake would stratify, and predict the quality of the water that would eventually be discharged from the lake (SRK 2012b, 2017e). The model was originally run for 100 model years, starting at Year 0 at Closure. The initial modeling and sensitivity runs were done under assumptions of an Operations water management plan that allowed no discharge of process or seepage waters. These runs were also done with an early version of water quality estimates for each of the NAG and PAG categories. This early dataset was developed while humidity cell tests (HCTs) were still ongoing (SRK 2007).

When the AWT option was introduced as part of Alternative 2, a revised model was developed (Lorax 2015). In this model, an updated set of predictions from SRK (2012g, h) was used for the water quality to be expected from each of the NAG and PAG categories. In 2017, the revised AWT model was run for an additional 100 years, for a total of 200 years. The 200-year run is discussed below in Section 4.4.2.6, Temporal Changes in Surface Water Quality and Pycnocline Depth.

4.4.2.1 Methods and Assumptions

A one-dimensional (vertical) model, PitMod, was developed by Lorax to model pit lake chemistry development. The model assumes uniformity in both horizontal dimensions and the water column divided into a vertical stack of 3.3 feet (1 meter) thick homogeneous layers. The assumption of horizontal homogeneity is based on the high depth to surface area ratio and the absence of horizontal mixing, as well as knowledge of other pit lakes, in which major chemical and physical variations are in the vertical. It has been validated for the Island Copper Mine in British Columbia (BC), Canada, and in a three-year Canadian government-funded study of water properties in the two Equity Mine pit lakes in north Central BC (Lorax 2012a).

The physical and hydrodynamic processes simulated by the model include: solar heating of the lake surface; ice formation and decay; surface and groundwater inflows and outflows; wind mixing; and vertical mixing as a function of the density structure of the water column due to heating and cooling of the lake water and differences in the TDS and chemical-constituent content of the water at different depths.

Model physical inputs include pit morphometry, the site water balance, and high-temporal-resolution meteorological data. The meteorological data, including wind speed and direction, precipitation, evaporation, relative humidity, incoming and out-going radiation, and percent cloud cover, were used to create a 200-year synthetic meteorological database. Model geochemical/water-quality inputs include the Donlin Gold baseline water-quality database, SRK's assessment of various impacted water sources, and mapping of exposed pit-wall geology.

PitMod has the ability to couple the hydrodynamic model with a customized version of PHREEQC (Parkhurst and Appelo 1999). PHREEQC allows geochemical equilibrium calculations such as element speciation and mineral precipitation and dissolution. However, the PHREEQC component was not used for the initial intensive modeling effort. Instead, constituent concentrations were calculated based on conservative mixing with no reactions, which thus yielded higher surface-water concentrations (Lorax 2012a). Later modeling included a run allowing common low-temperature minerals, such as ferric hydroxide, to precipitate if supersaturated. The pit lake is assumed to be oligotrophic with no interaction between bottom waters and backfill (Lorax 2012a).

4.4.2.2 Model Input Chemistries

The predicted water quality of the various major inflows into the pit lake varies several orders of magnitude from direct precipitation and snowmelt with essentially no TDS, to low-TDS runoff from reclaimed areas and groundwater, to highly saline PAG seepage from the isolated cells of the WRF. Table H-12 shows the predicted (75th percentile) annual average concentrations from major inflows, assuming AWT during Operations. This table provides a comparison between the chemistries used under AWT, and those under the assumption of the initial no-discharge water management plan (labeled "base case"), for sources whose predicted chemistries changed under the different assumptions.

Table H-12: Water Quality of Major Inflows to Pit at Closure, Comparison of AWT and Base Case Inputs

Parameter	Units	AWQC	PAG Cell Seepage		Initial Pit Lake Water		Tailings Pore-water Seepage	
			AWT[3]	Base Case[4]	AWT[5]	Base Case[6]	AWT[7]	Base Case[8]
pH	Units	6.5-8.5[1]	3.5	4.1	7.7	7.7	7.7	5.5
Sulfate	mg/L	250[1]	180,000	42,450	3,811	10,537	4,400	15,900
Total Dissolved Solids (est.)	mg/L	500[1]	210,000	160,000	5,500	14,000	8,300	23,000
Aluminum	µg/L	87/750[2a,b]	30,000,000	30,4700,000	221	18.14	5.6	1.9
Antimony	µg/L	6[2d]	2,800	2,800	1,630	920	1,100	1,160
Arsenic	µg/L	10[2d]	27,000	27,000	12,600	6,600	15,000	15,700
Cadmium	µg/L	0.64[2a,b]	65	65	1	0.7	7.3	0.93
Copper	µg/L	29[2a,b]	33,000	35,600	22	310	18	674
Chromium		100[2e]	130	130	22	11	12	7.23
Lead	µg/L	11[2a,b]	460	99	680	350	3	82.5
Manganese	µg/L	50[2f]	170,000	370,300	5,600	43,200	2,000	45,600
Selenium	µg/L	4.6[2b]	80,000	18,790	470	330	42	220
Zinc	µg/L	379[2a,c]	190,000	3,991,000	4,000	2,100	33	79
Mercury	ng/L	12[2b]	180	150	34,900	720	73,000	1,440

Notes:

Shaded cells exceed most stringent water quality standard.

AWQC

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L, otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.

3 75th Percentile chemistry for poorly mixed PAG at year 2050 based on scaling of humidity cell leachate data (SRK 2015c).

4 75th Percentile chemistry for poorly mixed PAG at year 2050 based on scaling of humidity cell leachate data (SRK 2012h).

5 Conservative mixture of 8,920 acre-feet of backfill runoff and 24,000 acre-feet of tailings supernatant water (Lorax 2015).

6 Conservative mixture of 8,920 acre-feet of backfill runoff and 24,000 acre-feet of tailings supernatant water (Lorax 2012a).

7 Predicted concentrations of tailings pore water (SRK 2015a).

8 Predicted concentrations of tailings pore water (Lorax 2012a).

4.4.2.3 Effect of Pit Highwall Runoff

Tables H-11 and H-12 do not include the predicted chemistries of pit highwall runoff for the various categories of rock. As shown in Figure H-3, at least six categories of rock in terms of acid generating potential are expected to be exposed on the pit highwalls at Closure. As discussed above, two sets of predictions were developed by SRK of the water quality to be expected from each of the NAG and PAG categories. The first set was developed while humidity cell tests (HCTs) were still ongoing. This set was used for the initial base case pit lake model (Lorax 2012a). The first set was updated following more humidity cell testing (SRK 2012g, 2017e). Table H-13 gives the 75th percentile values of this update. In the updated dataset, the values for the PAG rock categories were divided into early (neutral), peak, and leached or exhausted stages of oxidation. The stage labeled Neutral is the water quality expected from pit wall runoff before major oxidation occurs. The next, labeled Peak, is the water quality expected during peak oxidation of the PAG rocks. The third, labeled Exhausted, is the water quality expected once the PAG rocks have essentially exhausted their sulfide content and produce only dilute water chemistry, which is of higher quality than NAG rock runoff for most constituents. As shown in Table H-14, the actual water quality used for the initial base case pit lake modeling predictions and sensitivity runs for PAG rocks is more similar to the Exhausted PAG chemistry than the Peak PAG chemistry, and contains lower concentrations than the water quality used for the AWT model. Highwall rock with the PAG rock chemistry used for the base case and the sensitivity runs is hereafter referred to as exhausted PAG rock.

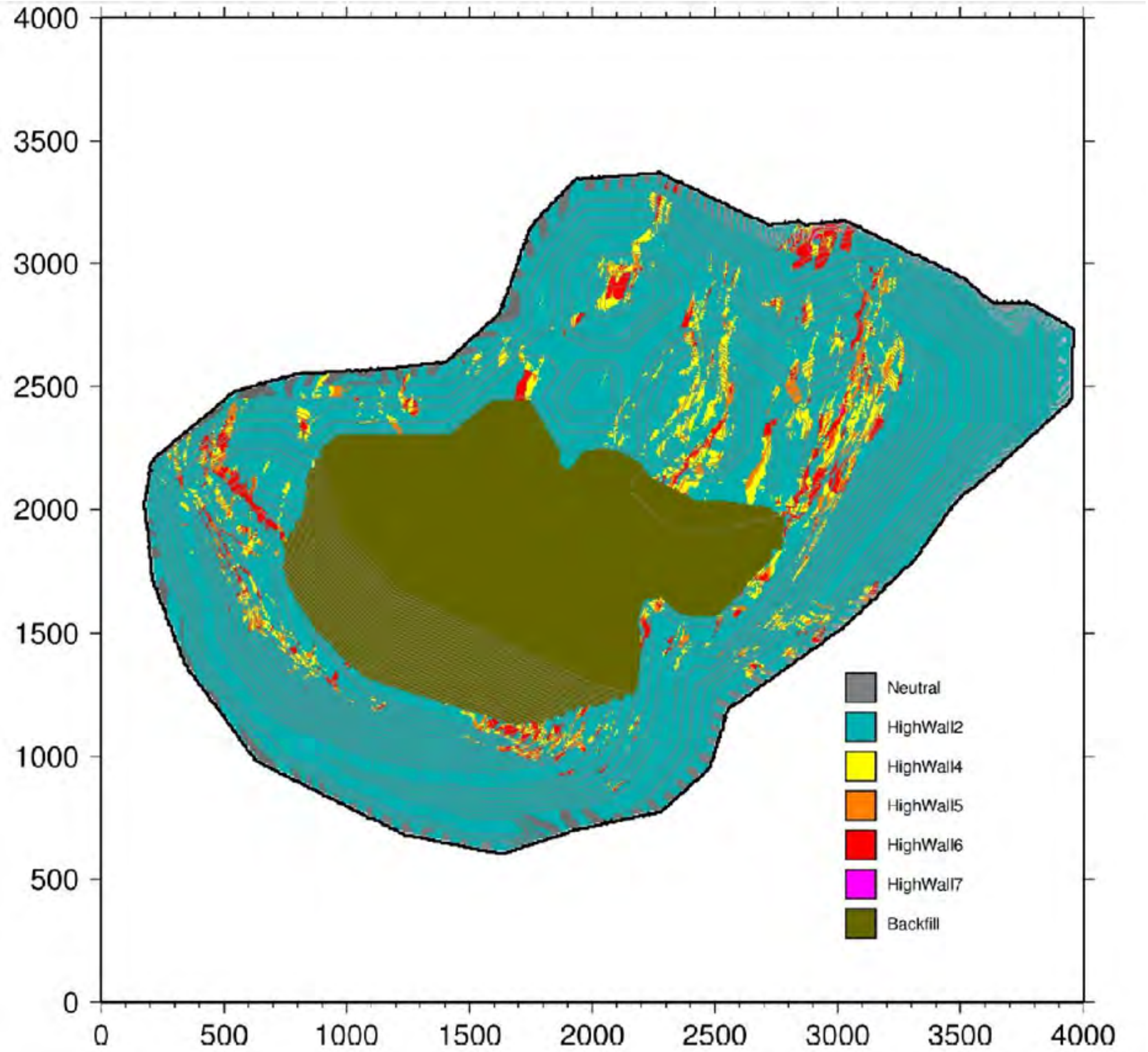
Table H-13: Water Quality of Pit Highwall Runoff (75th Percentile Values)

Parameter	Units	[1]AWQS	HIGHWALL						HIGHWALL			HIGHWALL		
			1	2	3	4	5	6	5	6	7	5	6	7
			Neutral						Peak			Exhausted		
Major Constituents														
pH		6.5-8.5[2]	8.2	8.3	7.7	7.7	7.7	7.8	3.5	3.4	3.4	4	3.7	3.7
Calcium	mg/L		18	29	280	450	270	280	150	540	540	0.0097	0.0097	0.0097
Magnesium	mg/L		11	2.8	110	130	170	44	91	440	470	0.0097	0.0097	0.0097
Potassium	mg/L		50	41	56	48	55	40	2.80E-05	3.50E-06	3.20E-06	2.2	1.2	1.2
Sodium	mg/L		43	37	49	44	78	51	110	520	550	0.0097	0.0097	0.0097
Sulfate	mg/L	250[2]	180	150	1,200	1,700	1,500	960	2,700	13,000	13,000	11	6.1	6.1
Total Dissolved Solids	mg/L	500[2]	304	263	1,730	2,380	2,080	1,390	3,470	16,400	16,600	16	38	38
Metals														
Aluminum	µg/L	87 (T)	1.5	1.7	0.6	0.55	0.6	0.7	260,000	1,300,000	1,400,000	9.7	9.7	9.7
Antimony	µg/L	6[2]	730	600	3100	710	300	660	280	280	280	1.1	0.13	0.13
Arsenic	µg/L	10[2]	250	510	28,000	5,900	5,800	8,800	18,000	15,000	15,000	5.1	24,000	24,000
Barium	µg/L	2000[2]	1.0	0.7	5.1	4.8	4.8	5.4	4.7	4.0	4.0	66	130	130
Beryllium	µg/L	4[2]	0.68	0.68	0.68	0.68	0.68	0.68	98	480	580	0.40	0.23	0.27
Boron	µg/L	750[5]	200	200	200	200	200	200	200	200	200	0.82	0.10	0.092
Cadmium	µg/L	0.64[1]	1.2	1.3	1.3	1.1	1.3	1.3	25	120	510	0.10	0.059	0.24
Chromium	µg/L	100[2]	12	31	14	11	23	31	120	590	820	0.49	0.29	0.38
Cobalt	µg/L	50[5]	6.1	18	9.1	18	15	27	850	4,200	7,100	3.5	2.0	3.3
Copper	µg/L	29.3[1]	4.5	3.6	5.5	4.9	14	16	1,900	9,500	10,000	9.7	9.7	9.7
Iron	µg/L	1000[4]	2.0	1.9	2.1	2.1	2.1	2.1	110,000	510,000	540,000	2,400	6,600	6,600
Lead	µg/L	10.9[4]	1.7	18	3.7	1.7	4.7	21.0	62	300	330	9.7	9.7	9.7
Manganese	µg/L	50[3]	410	310	630	390	320	4,200	11,000	54,000	57,000	10	10	10
Molybdenum	µg/L	10[5]	180	140	48	67	190	63	9.4	9.4	9.4	0.038	0.0046	0.0043
Nickel	µg/L	168[1]	21	90	32	86	47	100	2,800	7,300	7,300	11	3.5	3.4
Selenium	µg/L	4.6[4]	67	180	30	22	150	180	200	780	780	0.80	0.38	0.36
Silver	µg/L	34.9[1]	0.22	1.8	0.28	0.2	0.44	1.80	0.62	0.62	0.62	0.0025	0.0003	0.0003
Thallium	µg/L	1.7[3]	1.0	1.0	1.0	1.0	1.0	1.0	1.9	1.9	1.9	0.0078	0.0009	0.0009
Zinc	µg/L	379[1]	27	92	78	41	68	170	8,700	42,000	45,000	10	10	10
Mercury	ng/L	12[3]	190	190	190	190	190	190	150	150	150	0.62	0.074	0.071

Notes:

Shaded cells exceed most stringent water quality standard.

1 Most stringent Alaska water quality criteria (AWQC), based on hardness values, where applicable. AWQC are in terms of dissolved, unless otherwise noted by (T) for total concentration.
2 Drinking water primary max. contaminant levels
3 Human health criteria for non-carcinogens (for consumption of water + aquatic organisms)4
4 Aquatic life criteria for fresh waters (chronic)
5 Alaska criteria for irrigation and stock water.
Source: SRK 2017e



Data Sources: Lorax 2012

DONLIN GOLD PROJECT EIS

HIGHWALL GEOLOGY ON EXPOSED PIT WALLS AT CLOSURE

JUNE 2017

APPENDIX H FIGURE 3

Table H-14: Water Quality of Runoff from Backfill and Highwall Waste Rock Used in Base Case Pit Lake Model for Constituents Expected to Exceed AWQS (Exhausted-PAG Wall Rock)

Parameter	Units	AWQC	Category Backfill	Category 2	Category 4	Category 5	Category 6	Category 7
pH	Units	6.5-8.5[1]	7.7	8.0	7.7	4.0	3.7	3.7
Sulfate	mg/L	250[1]	1,964	150	1,700	11	6	6
Antimony	µg/L	6[2d]	3,100	600	710	1	0.1	0.1
Arsenic	µg/L	10[2d]	20,800	510	5,900	5.1	24,000	24,000
Cadmium	µg/L	0.64[2a,b]	1.25	1.3	1.1	0.1	0.06	0.06
Copper	µg/L	29[2a,b]	25	4	5	9.7	9.7	9.7
Iron	µg/L	1,000[2b]	2.1	2	2	2,400	6,600	6,600
Lead	µg/L	11[2a,b]	1,300	18	1.7	9.7	9.7	9.7
Manganese	µg/L	50[2f]	8,770	310	390	9.7	9.7	9.7
Selenium	µg/L	4.6[2b]	864	180	22	0.8	0.4	0.4
Thallium	µg/L	1.7[2f]	1	1	1	<0.1	<0.1	<0.1
Zinc	µg/L	379[2a,c]	7,600	92	41	10	10	10
Mercury	ng/L	12[2b]	180	190	190	1	0.1	0.1

Notes:

Categories 2 through 7 refer to waste rock NAG and PAG classifications in Table 3.7-16 of the EIS.
Shaded cells exceed most stringent water quality standard.

AWQC

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L, otherwise, 87 µg/L.
2b Aquatic life for fresh water (chronic) criteria.
2c Aquatic life for fresh water (acute) criteria.
2d Drinking water primary maximum contaminant levels.
2e Irrigation water criteria.
2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

Source: Lorax 2012a.

4.4.2.4 Sensitivity Analyses

The base case assumes the expected climatic conditions and the input water quality shown in Tables H-11 through H-14. It also assumes that initial groundwater inflows have the same chemistry as that of the highwalls, but that the groundwater chemistry would change linearly with time and eventually return to background groundwater quality. Table H-15 shows the predicted surface water quality for several sensitivity runs.

The groundwater sensitivity scenario in Table H-15 is similar to the base case, except that the groundwater quality is predicted to remain at the chemistry of the highwall runoff throughout the entire modeling period. In general, the predicted concentrations in surface water increase somewhat from that of the base case. The increase varies from essentially no increase for aluminum to an increase of between 75 and 80 percent for antimony, arsenic, boron, and selenium.

Table H-15: Surface Water Quality Estimates for Pit Lake at Closure Year 99—Sensitivity Analysis (assuming Exhausted PAG Pit-Wall Runoff and No-Discharge Water Management)

Parameter[1]	Units	Most Stringent Applicable Water Quality Criteria	Base Case	Groundwater Sensitivity	Complete Mixing[3]		Extreme Winds Sensitivity[4]	Decreased Salinity Sensitivity
					Year 55	Year 65		
Sulfate	mg/L	250[1]	31	48	1,607	658	31	30
Total Dissolved Solids	mg/L	500[1]	135	142	2,370	918	137	112
Aluminum	µg/L	87[2a,b]	310	311	31,900	12,700	316	311
Antimony	µg/L	6[2d]	67	120	382	216	68	67
Arsenic	µg/L	10[2d]	112	198	2,440	1,060	116	112
Boron	µg/L	750[2f]	202	356	1,740	880	205	199
Cadmium	µg/L	0.18[2a,b]	0.24	0.33	0.54	0.4	0.24	0.24
Chromium	µg/L	100[2e]	4	6.7	9.7	7.5	4	4
Copper	µg/L	6.2[2a,b]	1.4	1.7	90	32	1.4	1.4
Lead	µg/L	1.6[2a,b]	2.3	3.8	91	38	2.3	2.2
Manganese	µg/L	50[2f]	128	136	5,770	2,350	131	128
Nickel	µg/L	36[2a,b]	11	19	153	70	12	11
Selenium	µg/L	4.6[2b]	20	36	128	70	21	20
Zinc	µg/L	81[2a,c]	13	21	745	304	14	13
Mercury	ng/L	12[2b]	25	42	183	100	25	26

Notes:

Values are for dissolved metals, and represent depths between 0 and 33 feet in lake. Shaded cells exceed most stringent water quality standard. The pH was not modeled, but estimated to be between 5 and 6, based on input pH values.

AWQC:

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A value of 65 mg/L as CaCO3 was used for hardness, based on model predictions for calcium and magnesium (not shown). For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L, otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

3 Represents Years 55 and 65 (complete mixing induced in Year 55).

4 Represents Year 56 (hurricane winds induced in Years 55 and 56).

Source: Lorax 2012a (Table 4-2)

Another factor affecting the stability is the salinity of the water pumped to the bottom of the pit lake. This salinity is controlled mainly by the >20,000 mg/L TDS chemistry of the base-case TSF water (Table H-12) and secondarily by the substantially lower-volume, but higher-TDS PAG seepage from the WRF. The decreased salinity scenario assumes that the TSF seepage is similar to the lower-salinity NAG seepage from the WRF, at a TDS content of 3,000 mg/L. (The TSF seepage used for the AWT model, with a TDS at 8,300 mg/L, is between the base case and low-salinity models, but closer to the low-salinity model.) For the decreased salinity case, TDS is predicted to decrease somewhat from the base case, although the metals and sulfate concentrations remain essentially unchanged.

The prior scenarios predicted a permanently stratified lake for the 100-year duration of the model. Comparison of results from Model Year 53 (Lorax 2012a, Table 4-1) and Year 99 indicate little change in surface-water chemistry over the first 50 or so years once the pit lake fills. In the complete mixing scenario (Table H-15), a catastrophic mixing event is assumed to occur at one point in the lake history that causes complete overturn and mixing of the lake in Year 55, a few years after complete pit filling. This scenario provides an upper bound assessment of the concentrations of constituents predicted in the surface waters of the lake for that time period. The chemistry of overturned lake water is expected to vary depending on how many years after filling the lake overturns, because the volume of water beneath the pycnocline is predicted to increase over time due to filling from the bottom, as discussed in Section 4.4.2.5, Temporal Changes in Surface Water Quality and Pycnocline Depth.

Following the complete mixing event, salinity would begin to decrease in surface water due to precipitation and undisturbed runoff, and a new pycnocline would form that would vary in concentration seasonally, from a low during spring snow and ice melt, to a seasonal high in winter. Following an overturn event in Year 55, sulfate concentrations are predicted to decrease to less than 400 mg/L by Year 99 (Lorax 2012a).

The complete mixing event would require strong physical forcing to overcome the stability of the density gradient predicted by expected conditions. Wind forcing is one possibility, so an extreme wind event scenario was conducted by specifying a steady 125 mph wind over a two-day interval during the summer of year 55. The resulting surface water concentrations are predicted to remain essentially unchanged from the base case scenario, due to the depth of the pycnocline in that early year.

Neither the decreased salinity nor the extreme wind scenarios prevent formation of a stratified lake during the modeling period. Thus, the results of the sensitivity analyses suggest that the pit lake would develop a density stratification with poor quality, highly saline bottom waters, overlain by low TDS (112 to 142 mg/L) surface water, under all likely scenarios (Table H-15) for the first 99 years post-Closure.

In the base case, as well as all the sensitivity cases except complete mixing, antimony, arsenic, cadmium, lead, manganese, mercury, and selenium concentrations are predicted to exceed AWQC. The complete mixing sensitivity run forces the lake to mix completely in Year 55. In that year, the TDS is calculated to be 2,350 mg/L throughout the water column. By Year 65, stratification is predicted to re-establish, and surface water TDS decreases to 918 mg/L (Table H-15 Complete Mixing). Model Limitations

The initial Lorax (2012a) modeling has some limitations that may have resulted in an under-estimate of predicted surface water concentrations. It assumes exhausted PAG runoff concentrations for PAG wall rock over the long term. However, pit walls are known to undergo periodic sloughing that expose fresh rock to weathering processes (Filipek 2004). Accordingly, the PAG runoff is more likely to have concentrations over time that range between those used in the model and those given in Table H-13 for peak oxidation rates. To test the effects of using peak PAG concentrations for runoff, Lorax (2014b, c) conducted two additional PAG model runs for their "decreased salinity" case: 1) the conservative case, in which no reactions were allowed but PHREEQC was used to calculate pH of the mixed solutions; and 2) a reactive case allowing precipitation of low-temperature saturated aluminum, iron, and manganese oxyhydroxide minerals (Table H-16).

In both peak PAG, decreased salinity cases, the results are similar to the base case (within a factor of two for most constituents). Lake surface water concentrations of aluminum, antimony, arsenic, cadmium, lead, molybdenum, selenium, and mercury exceeded AWQC for all three cases. Copper exceeds AWQC in both peak PAG cases, but not in the base case. Manganese concentrations exceed AWQC when not allowed to precipitate. The predicted pH in both peak-PAG cases is outside regulatory limits: The modeled pH is 5.2 for the no-reaction peak PAG case, and 5.1 with mineral precipitation.

When the AWT water management option was added to Alternative 2, Lorax (2015) developed another pit lake model using the revised water quality values from Table H-12 for the major inflow sources. The resulting predicted water quality for the uppermost 33 feet of the pit lake, shown in Table H-16, is similar to those predicted for the original water management plan. Aluminum, antimony, arsenic, cadmium, copper, iron, lead, manganese, molybdenum, selenium, and mercury concentrations exceed AWQC. Although not modeled, pH is less than the lower AWQC limit (estimated to be between 5.0 and 6.0).

Table H-16: Comparison of Surface Water Quality Estimates for Pit Lake-- at Closure Year 100 for Exhausted-PAG (Base Case) and Peak-PAG Pit-Wall Runoff (Decreased Salinity Case), and for Closure Years 100 and 200 for the AWT Model

Parameter[1]	Units	AWQC[2]	Base Case	Peak-PAG Case		AWT Year 100	AWT Year 200[6,7]
			No Reaction	No Reaction[3]	Mineral Precipitation[4]	No Reaction[5]	
pH	Units	6.5 – 8.5[1]	6 (est.)	5.2	5.1	5.0 – 6.0	
Sulfate	mg/L	250[1]	31	48	48	41	183
Total Dissolved Solids	mg/L	500[1]	139	143	97	125	340[7]
Aluminum	µg/L	87[2a,b]	310	590	97	1,570	5,080
Antimony	µg/L	6[2d]	67	75	76	67	148
Arsenic	µg/L	10[2d]	112	190	190	114	656
Boron	µg/L	750[2f]	200	230	200	31	50
Cadmium	µg/L	0.18[2a,b]	0.24	0.31	0.31	0.35	0.49
Chromium	µg/L	100[2e]	4.0	4.3	4.3	4.6	6
Cobalt	µg/L	50[2e]	3.0	5	5	6.5	
Copper	µg/L	6.2[2a,b]	1.4	7.1	6.7	10.5	20
Iron	µg/L	1000[2b]	830	960	180	1,200	
Lead	µg/L	1.6[2a,b]	2.3	2.7	2.7	2.6	21
Manganese	µg/L	50[2f]	128	170	15	176	439
Molybdenum	µg/L	10[2e]	17	19	18	17	
Nickel	µg/L	36[2a,b]	11	20	20	19	59
Selenium	µg/L	4.6[2b]	20	23	23	20	50
Zinc	µg/L	81[2a,c]	13	45	47	53	238
Mercury	ng/L	12[2b]	25	28	28	25	1,000

Notes:

Values are for dissolved metals, and represent depths between 0 and 33 feet in lake. Shaded cells exceed most stringent water quality standard.

AWQC:
1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.
2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
  2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 65 mg/L as $CaCO_3$ was used for hardness, based on model predictions for hardness. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L, otherwise, 87 µg/L.
  2b Aquatic life for fresh water (chronic) criteria.
  2c Aquatic life for fresh water (acute) criteria.
  2d Drinking water primary maximum contaminant levels.
  2e Irrigation water criteria.
  2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
3 Lorax. 2014b. PitMod_conservative_monthly_means.xls
4 Lorax. 2014c. PitMod_mean monthly_PHREEQC.xls. Aluminum, iron, and manganese low-temperature oxyhydroxide minerals were allowed to precipitate if saturated.
5 Lorax 2015; PitMod_AWT2015.xlsx; and Lorax 2017a.
6 Lorax 2017a
7 Lorax 2017b

Another limitation is that the model does not address the role of ice melt in seasonal stratification, and the potential for continued concentration of surface waters over time if more dilute ice melt is preferentially withdrawn for treatment and discharged each spring. However, the relatively low calculated TDS (on the order of 112 to 142 mg/L) for all but the complete mixing case suggest that the concentration effect due to ice formation would be minor.

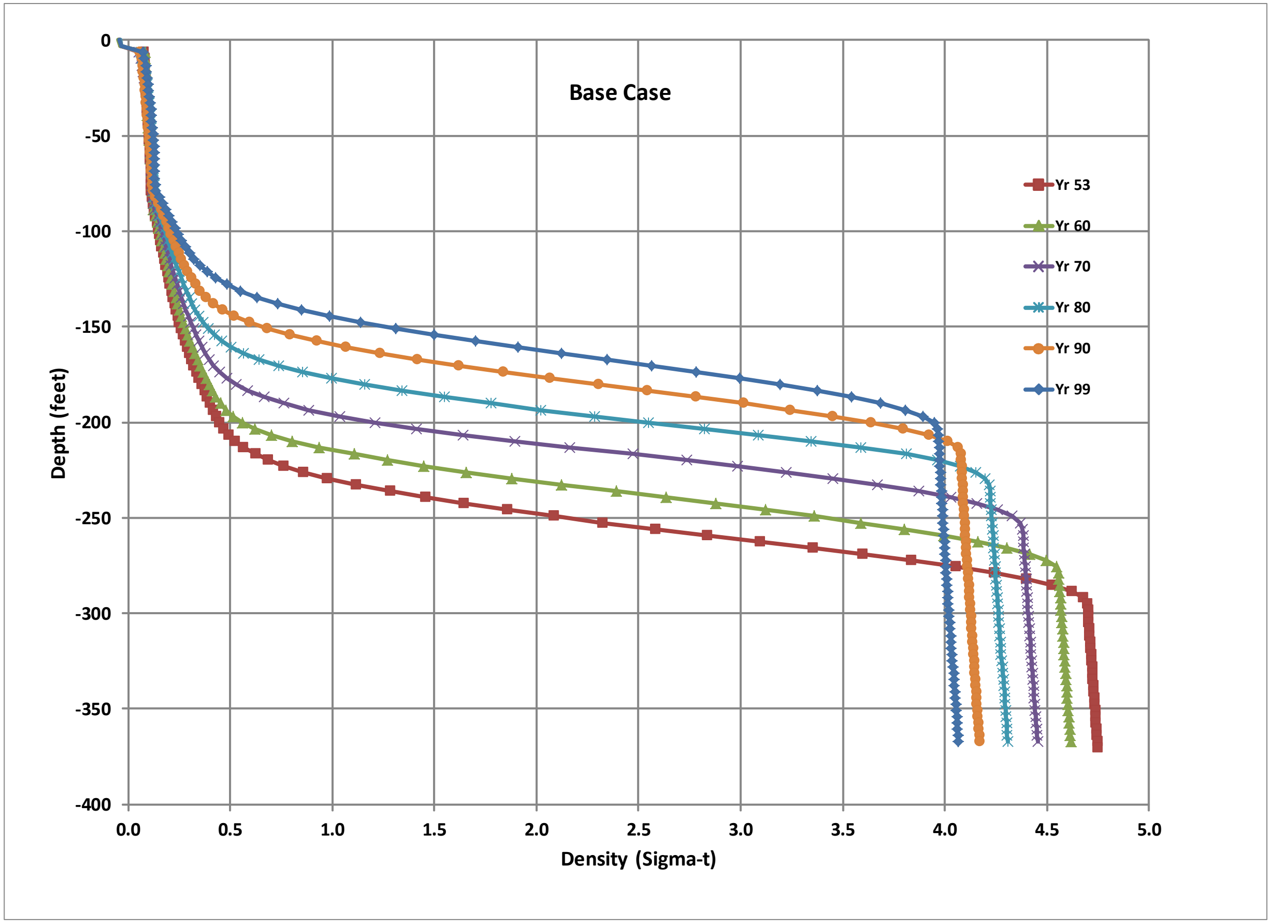
4.4.2.5 Temporal Changes in Surface Water Quality and Pycnocline Depth

In all the modeled cases, pit lake surface-water concentrations appear to remain relatively constant for the first 50 or so years after the lake reached its maximum allowed elevation, so that the results for all but the Complete Mixing case for Year 53 are essentially identical to those shown in Table H-15 for Year 99. In contrast, the depth to the top of the pycnocline was found to decrease (i.e., the pycnocline would rise) over time in all cases (Figures H-4 through H-6; note change in scale of the density [sigma-t] axis between figures). As the pycnocline depth decreases over time, so does the concentration difference between the waters above and below the pycnocline.

The relative strengths of the pycnoclines for the base case; peak PAG, decreased salinity case; and the AWT case can be seen in Figure H-7. For the base case, a gradual increase in density is predicted to occur between about 80 and 120 feet below the lake surface, with a rapid density increase (the pycnocline proper) starting at about 130 feet and continuing to about 200 feet below the surface. For the peak PAG, decreased salinity case, the total pycnocline zone is predicted to be similar in thickness (starting at about 80 feet and ending at about 200 feet). However, the gradient is less sharp (i.e., the pycnocline is weaker), due to the smaller density difference between the waters above and below the pycnocline, suggesting that a decreased-salinity system could be more vulnerable to overturn and mixing throughout the water column than the base case. The strength of the pycnocline for the AWT case falls between the other two cases, due mainly to the lower TDS in the TSF seepage for the AWT water management plan than the original water management plan (Table H-12). The PAG cell seepage is also predicted to change; however, that seepage is only about one percent of the tailings pore water while the pit lake is filling.

The modeled pycnocline is predicted to move up through the water column with time in all cases. This result is likely because each year additional water is added below the pycnocline, due to ongoing groundwater influx below the pycnocline and the location of the feed pipe near the lake bottom. These inputs increase the volume of water in the hypolimnion (i.e., below the pycnocline), while the only water being removed and treated is from above the pycnocline. Therefore, simple mass balance considerations suggest that eventually the pycnocline would be close enough to the surface that wind and/or winter overturn would cause the lake to completely mix to the surface. In all three modeled cases shown in Figures H-4 through H-6, the depth of the pycnocline decreases by about 100 feet between Years 53 and 99, or about 100 feet per 50 years. In Year 99, the top of the pycnocline is at about 100 feet below the surface, and its base is at about 200 feet below the surface. Because the pit is essentially an inverted truncated cone, it would be expected that the rate of rise in the pycnocline elevation would slow over time, but not stop, as the pycnocline elevation increases within the pit lake.

To test whether the modeled pycnocline would continue to move up the water column over time, Lorax made an additional run (Lorax 2017a, b, c). Figure H-8 shows that this trend continues through the modeled year 200. (No complete mixing or wind forcing scenario was done for the 200-year predicted pit lake.) Based on the complete mixing sensitivity run, after the lake overturns, the pit lake would likely eventually re-establish a pycnocline, but with higher constituent concentrations in the surficial layer, as occurred for the complete mixing case. At some future time beyond model Year 200, the base of the pycnocline would reach the pit lake surface. At that point, the pit lake would be completely mixed. A shallow seasonal pycnocline would likely form due to snow and ice melt, with lower surface-water concentrations in late-spring and summer, and higher concentrations in fall and winter. The actual concentrations of constituents in the resulting surface water would be mainly a function of the amount of sulfides remaining in the WRF and their oxidation rate at that time.



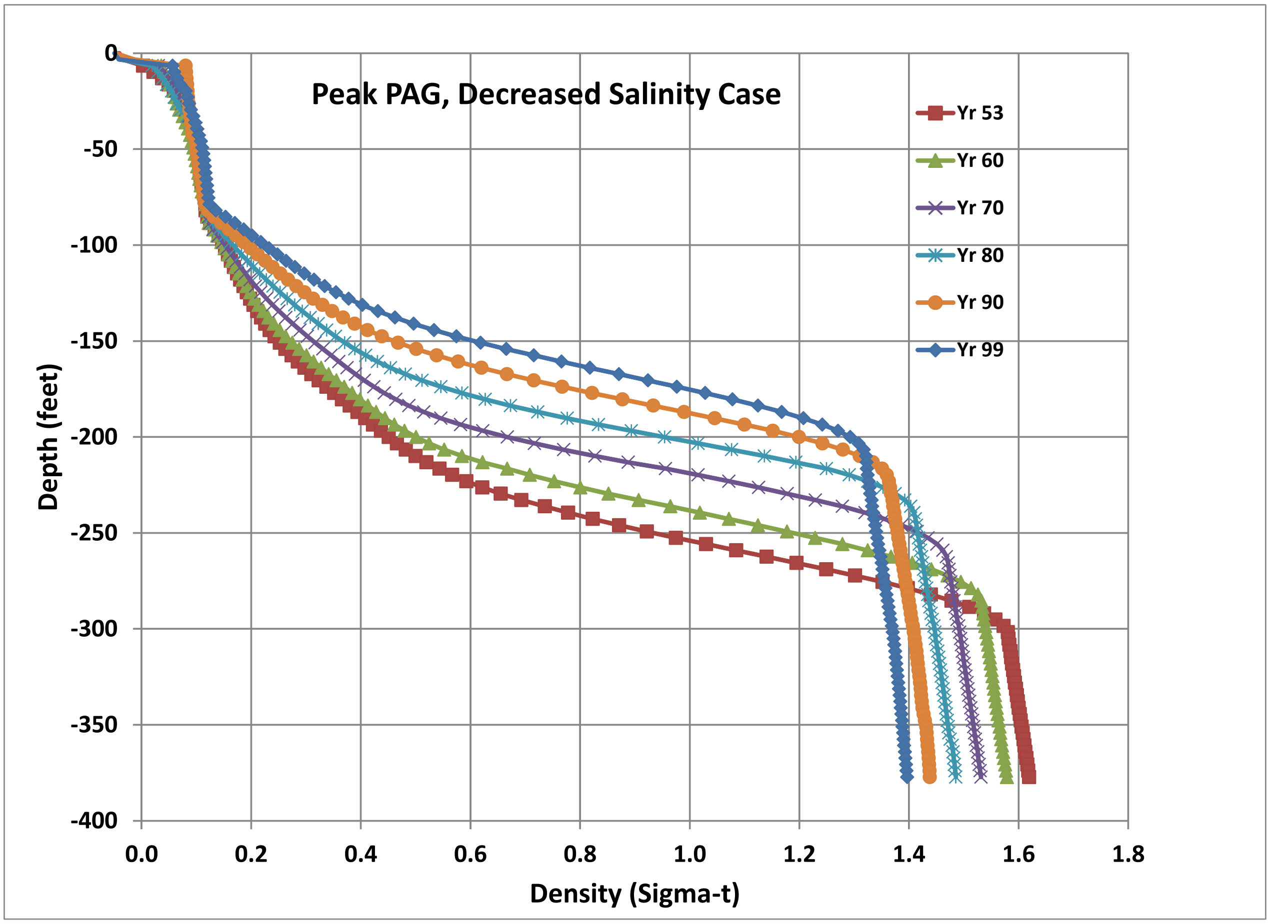
Data Source: Lorax 2015

DONLIN GOLD
PROJECT EIS

Variation of Pycnocline Depth with Age of Pit Lake (53-99 Years) – Base Case

JUNE 2017

APPENDIX H FIGURE 4



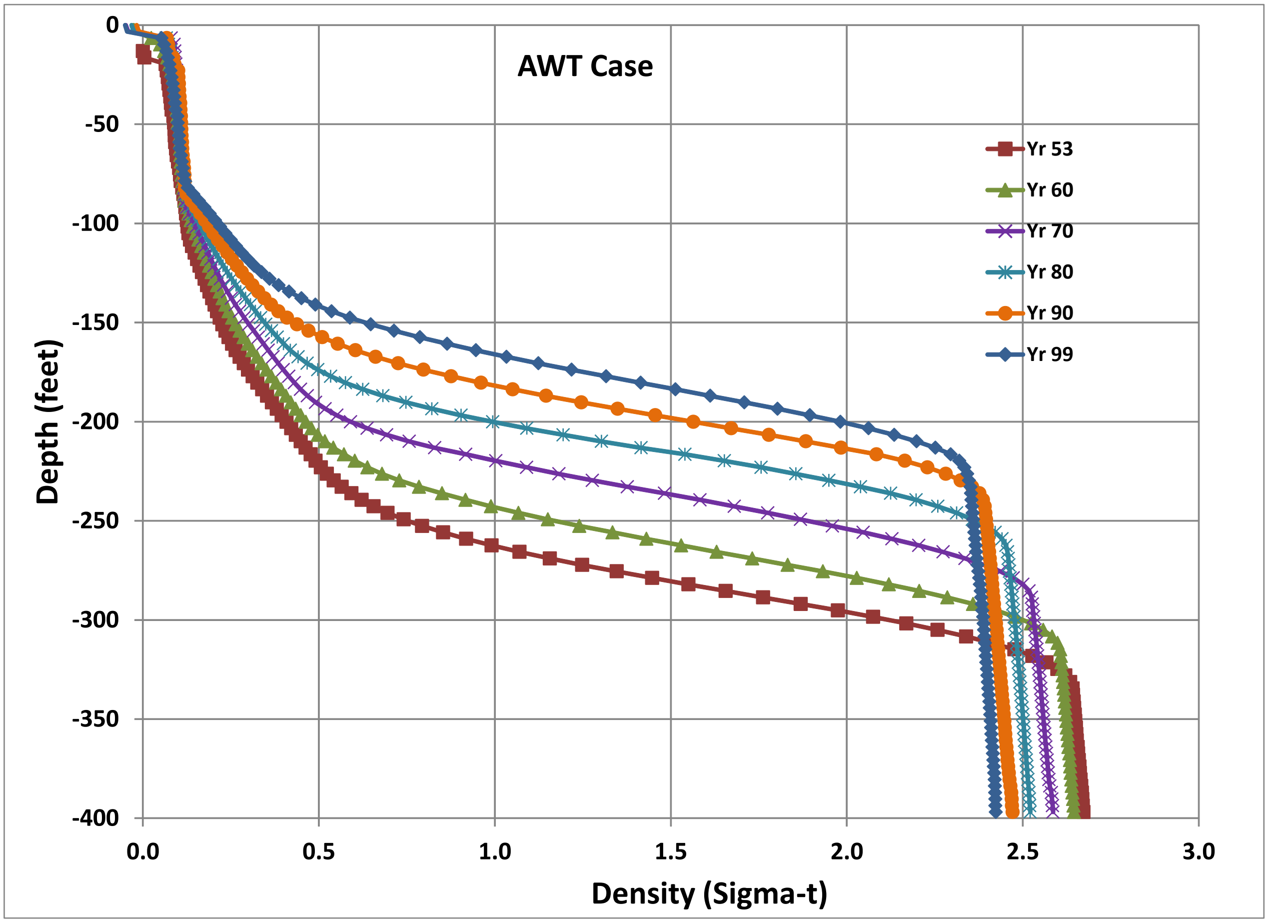
Data Source: Lorax 2015

DONLIN GOLD PROJECT EIS

Variation of Pycnocline Depth with Age of Pit Lake (53-99 Years) – Peak PAG, Decreased Salinity Case

JUNE 2017

APPENDIX H FIGURE 5



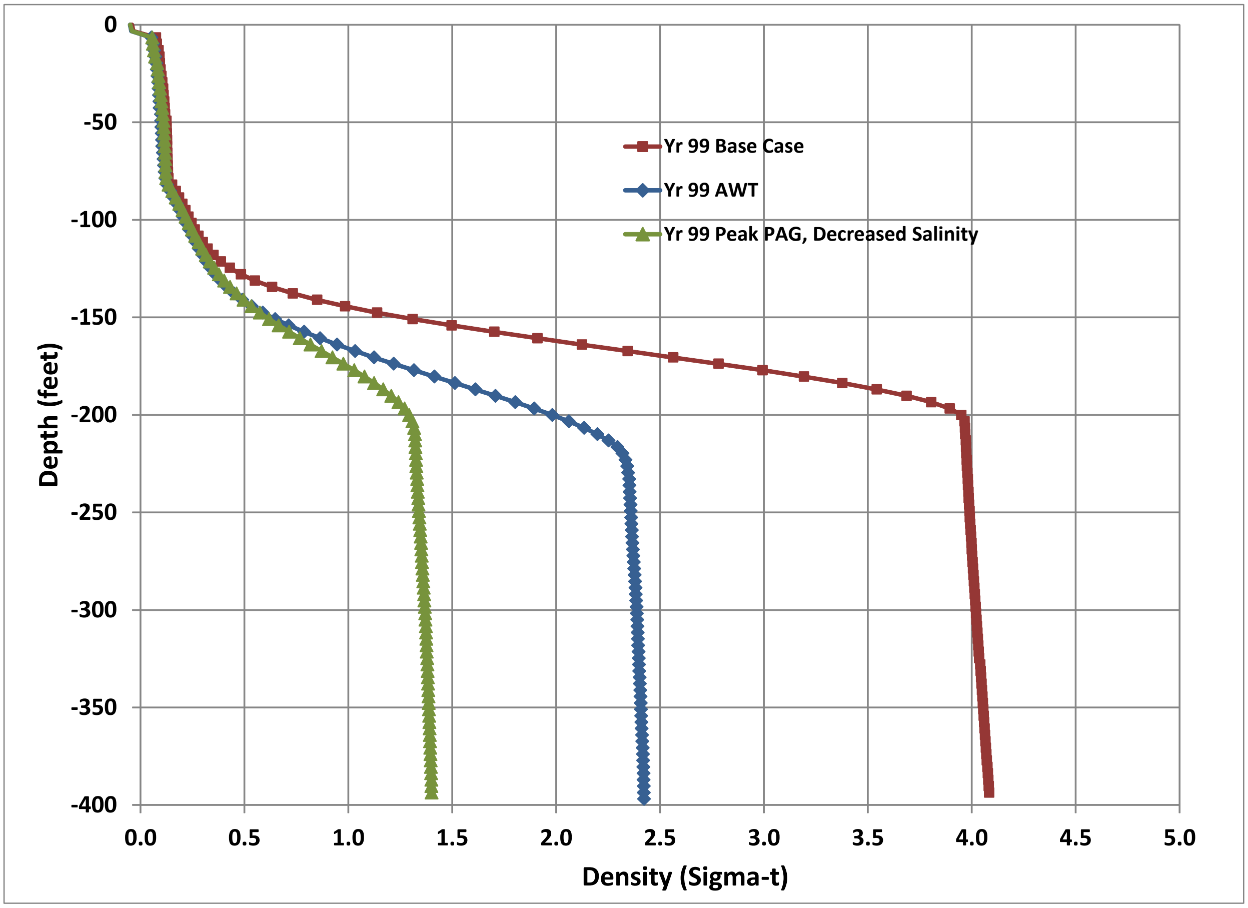
Data Source: Lorax 2015

DONLIN GOLD
PROJECT EIS

Variation of Pycnocline Depth with Age of Pit Lake (55 to 99 Years) – AWT Water Management Plan

JUNE 2017

APPENDIX H FIGURE 6



Data Source: Lorax 2015

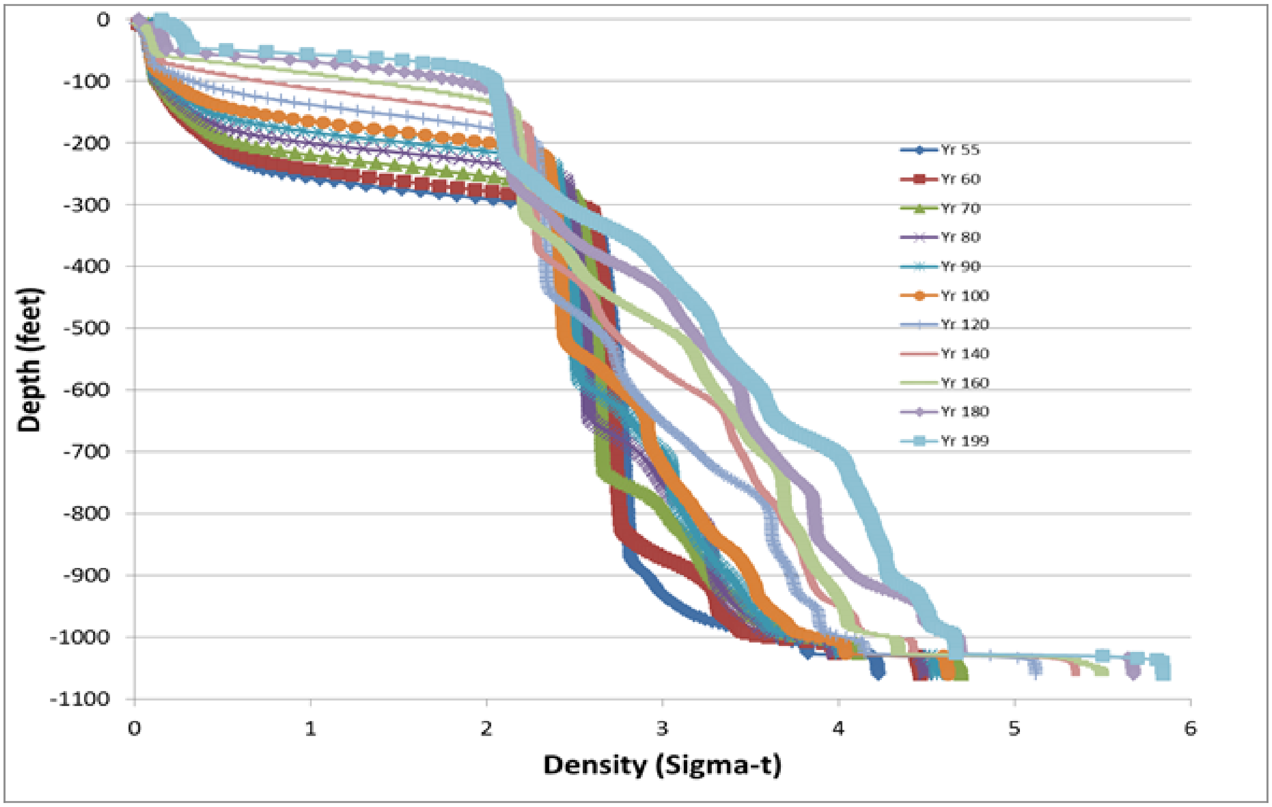
DONLIN GOLD

DONLIN GOLD PROJECT EIS

COMPARISON OF PYCNOCLINE DEPTH AND STRENGTH FOR THE BASE CASE, PEAK-PAG, DECREASED SALINITY CASE, AND AWT CASE (YEAR 99)

JUNE 2017

APPENDIX H FIGURE 7



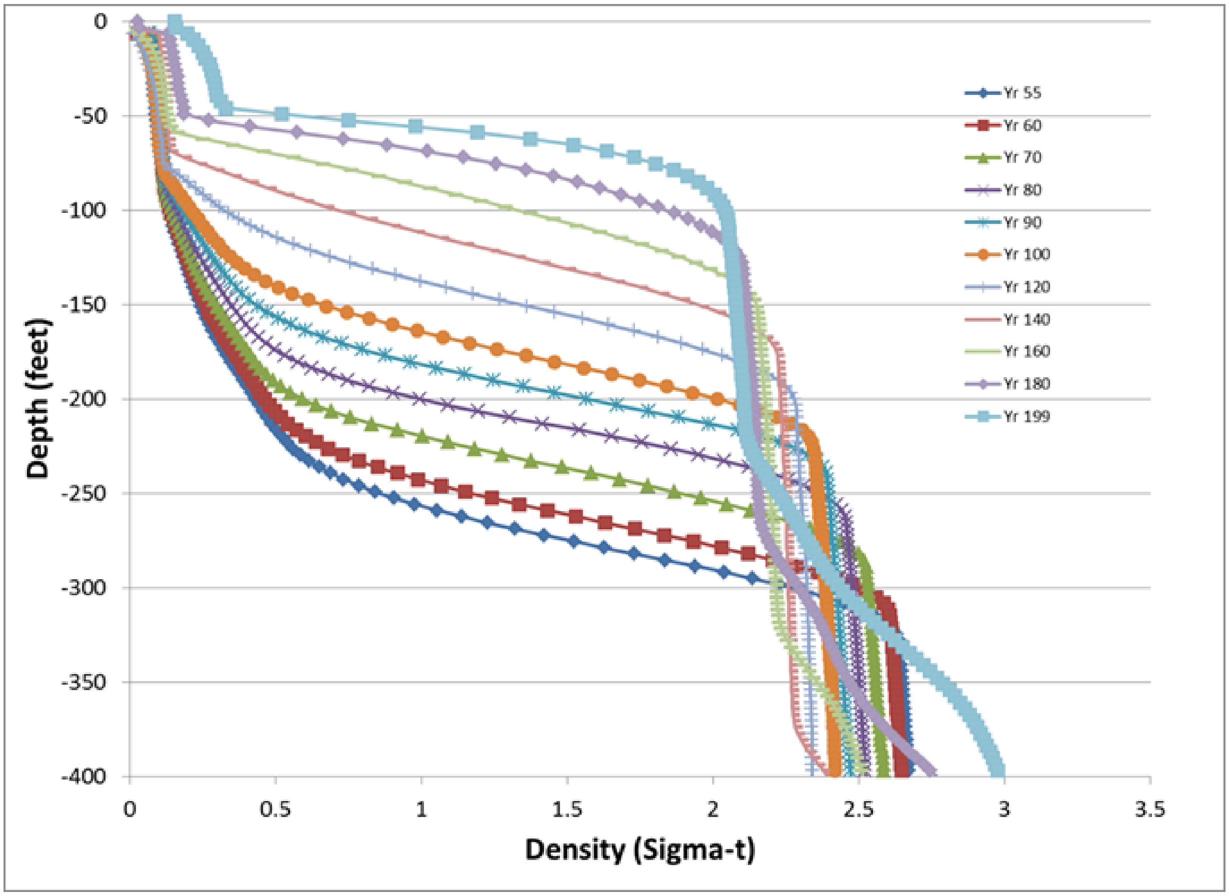
Data Source: Lorax 2017c

DONLIN GOLD PROJECT EIS

Variation of Pycnocline Depth with Age of Pit Lake (55-199 Years) – Base Case (200-yr run)

JANUARY 2018

APPENDIX H FIGURE 8A



Data Source: Lorax 2017c

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Variation of Pycnocline Depth with Age of Pit Lake (55-199 Years) – Detail of Upper 400 feet

JANUARY 2018

APPENDIX H FIGURE 8B

4.4.2.6 Summary of Pit Lake Modeling

The results of the various modeling efforts of the predicted pit lake suggest that the concentrations of several constituents in surface waters would exceed the most stringent AWQC throughout the 200-year modeling period. Additionally, the pycnocline is predicted to move upward toward the surface and become less intense over time, eventually reaching the surface at some point beyond the modeling period. Even before this time, as the pycnocline moves closer to the surface and becomes less intense, mixing by wind events becomes more likely. These conclusions are based both on the Lorax modeling and on simple mass balance considerations, because, each year, most of the water entering the pit is being added below the pycnocline from the WRF and inflowing groundwater, and being removed above the pycnocline. The actual concentrations of constituents in the resulting mixed surface water would be mainly a function of the amount of sulfides remaining in the WRF and their oxidation rate at that time. Pit-lake modeling contains a number of assumptions that can only be tested in real time after Closure. For these reasons, additional mitigation measures that would help manage lake stratification, surface water quality, and water treatment in post-Closure are provided in Chapter 5, Impact Avoidance, Minimization, and Mitigation.

5. Summary of Impacts for Alternative 2 – Geochemistry

Geochemistry describes the distribution, movement, and chemical reactions of elements in the environment, as well as processes affecting distribution, movement, and reactivity leading to effects on water quality. Because the changes that would occur from geochemical processes are reflected in water quality, the mitigation and cumulative effects associated with these changes are discussed in the EIS under Sections 3.7.3.2.2 and 3.7.3.2.3, Water Quality.