3.6 GROUNDWATER HYDROLOGY

SYNOPSIS

This section examines the subsurface hydrology, or groundwater, of the Project Area. While all three project components interact with groundwater to some degree, the Mine Site would alter groundwater hydrology in and around the mine. The section looks at applicable laws, hydrogeology (literally, water in the earth), and existing uses of groundwater, before turning to expected effects. Discussion and analysis of groundwater quality can be found in Section 3.7, Water Quality.

EXISTING CONDITION SUMMARY

A number of federal and state regulations, including the Safe Drinking Water Act, and portions of Alaska Administrative Code, including Temporary Use Authorizations, pertain to groundwater for the project.

The mine and processing facilities would be located in a region of localized discontinuous permafrost. In this region, groundwater occurs both above and beneath the permafrost, and in permafrost-free areas. Groundwater feeds area streams during dry conditions and in winter months, and is recharged through snowmelt, rainfall, and stream flow. Mine Site groundwater occurs in three main units: an alluvial aquifer associated with Crooked Creek; a thin, colluvial layer associated with valley slopes and bottoms; and, in fractured bedrock aquifers. Analysis of stream discharge records from Crooked Creek indicate that the creek generally gains water from groundwater in the area of the Mine Site.

Along the Kuskokwim River, considerable groundwater is found in alluvial deposits amid alternating layers of sand and gravel and silty deposits up to hundreds of feet thick. Permafrost can be up to 400 feet thick in places along the river, with groundwater sometimes present above and below. Wells provide water to many households in villages along the Kuskokwim. In Bethel, well water is drawn from below permafrost, while other communities use shallower aquifers. On a regional scale, groundwater flow systems in the Kuskokwim River corridor tend to flow to the southwest. The year-round flow of the Kuskokwim River and its major tributaries is attributable to groundwater discharge to the rivers throughout the winter months.

Along the Pipeline corridor, groundwater occurs: in the Cook Inlet aquifer system; in alluvial, colluvial, and glacial deposits, and bedrock of the Alaska Range; and, west of the Alaska Range, in alluvial deposits and above permafrost. Approximately 35 percent of the pipeline route is estimated to be underlain by shallow groundwater (within 3 feet of the land surface) during summer, or by substantial wet organic deposits.

Groundwater Flow and Modeling: A three-dimensional, mathematical model of roughly 85 square miles surrounding the Mine Site (to a depth of 1,500 feet below the deepest Mine Area) was constructed based on the location of major surface and groundwater divides in the vicinity, using field measurements and field-based estimates for water inputs, outputs, and underground structure. This modeling is the basis of estimates of the effects of the project on groundwater hydrology. In a process of calibration, the model was tested against past data, yielding results within accepted groundwater modeling industry standards.

EXPECTED EFFECTS SUMMARY

Alternative 1 - No Action

Groundwater systems would remain in their natural state (where not utilized by other parties), and there would be no impacts on groundwater from the project.

Alternative 2 - Donlin Gold's Proposed Action

The mine would lower the water table in the area of and around the pit in order to establish stable pit walls and dry working conditions. This *dewatering* would be accomplished by pumping groundwater from wells and drains in the pit area for use in the processing mill and for treatment and return to Crooked Creek. The deepening and lowering of the water table would form a *cone of depression*, which would continue through the life of the mine. Water levels in the bedrock aquifer would be lowered and groundwater would no longer flow into Crooked Creek adjacent to the Mine Site, nor into adjacent creek beds east of Crooked Creek. Rather, groundwater would flow toward the pit. Also, some surface water in Crooked Creek would seep into the ground and flow to the pit. Related reductions in Crooked Creek stream flows are discussed in detail in Section 3.5, Surface Water Hydrology.

Mine pit dewatering (at a maximum planned groundwater pumping rate of about 2,900 gpm) would create up to 1,600 feet of drawdown in the local groundwater flow system. The areal extent of the cone of depression would be 9,000 acres during operations and 2,000 acres during post-Closure. The Tailings Storage Facility (TSF) would be lined to mitigate contact water seepage to groundwater, and would be backed up by an underdrain and downgradient seepage recovery system. The Waste Rock Facility (WRF) would be unlined, and could be a source of contact water that could infiltrate to the groundwater. During operations, modeling shows that the WRF contact water would be captured by pit dewatering; after closure, it would flow into the pit lake.

The pit would take about 52 years to fill after the mine closes and dewatering ceases. During the pit filling period, some water would flow out of the pit lake into localized temporary storage in fractured bedrock and pit backfill pore spaces, and would flow back towards the pit lake once the pore spaces were filled, the pit lake level rises to the maximum managed stage, and the local water table recovers. A strong hydraulic gradient driven by regional topographic highs well beyond the temporary bedrock storage area, would direct overall groundwater flow towards the pit lake, maintain hydraulic containment of all contact groundwater, and block pathways for escape of contaminated water. After pit filling, the pit lake would continue to be a destination for groundwater flow, and Crooked Creek would continue to lose water to the groundwater system flowing to the pit. Because of ongoing pumping and treating of lake water to keep water levels below surrounding water levels, hydraulic containment would be maintained through the full depth of the pit lake throughout post-Closure. Groundwater levels and flow would be monitored throughout operations and closure to confirm that these processes are occurring.

The highest intensity groundwater impacts associated with the Mine Site would occur during the period of active mining. Mitigation recommendations in Chapter 5, Impact Avoidance, Minimization, and Mitigation, could potentially reduce effects; however, some effects to the groundwater flow system would result in chronic effects and the resource would not be anticipated to return to previous conditions.

The Transportation Corridor would have minimal effects on groundwater, limited to potable water supply wells for new port facilities. Groundwater exists in the pipeline corridor within burial depths for the pipeline. However, the potential for disruption of springs and groundwater flow is low, either because the pipeline does not encounter groundwater (and misses disrupting the flowpath), or because foam trench breakers keyed into the sides and bottom of the trench would be installed to minimize the potential for the pipeline trench to create a preferred pathway and alter the natural flow of groundwater. The Alternative 2-North Option would likely have a decreased length of shallow groundwater that would be affected along the pipeline, about 3 miles less than Alternative 2.

OTHER ALTERNATIVES - This section discusses differences of note between Alternative 2 and the following alternatives, but does not include a comprehensive discussion of each alternative's impacts if they are the same as or similar to Alternative 2 impacts.

Alternative 3B - Diesel Pipeline

Alternative 3B would have an increased potential for diesel spill impacting groundwater, and an increased length of shallow groundwater that would be affected along the pipeline, about 9 to 10 miles more than Alternative 2.

Alternative 5A - Dry Stack Tailings

Under the Alternative 5A, the liner underneath the dry stack would result in seepage rates comparable to Alternative 2 at closure. After 200 years, the quantity of seepage from the unlined dry stack would be similar to the amount of seepage through the liner in Alternative 2 or the Alternative 5A-Lined Option. Under both options in Alternative 5A, seepage flow would be captured by a seepage recovery system comparable to that of Alternative 2, and the time until the seepage pump system can be decommissioned would be no different than under Alternative 2. The estimated time for the pit lake to fill after closure would be about 42 years for the Unlined Option and 47 years for the Lined Option, compared to 52 years for Alternative 2.

3.6.1 AFFECTED ENVIRONMENT

3.6.1.1 APPLICABLE REGULATIONS

Groundwater resources are governed by several applicable regulatory programs. Table 3.6-1 summarizes the federal and State of Alaska regulations affecting groundwater. While drinking water sources are regulated by federal laws and regulations, chiefly the Safe Drinking Water Act, Alaska has received primacy as a result of having adopted regulations that are at least as stringent as federal regulations. Nationally, except for federal reserve water rights, statutes and regulations governing water diversion, water use, and water rights are customarily left to the states. Temporary or long-term permits are required for practically any diversion of water or pumping of groundwater above minimum thresholds as defined by regulations (11 AAC

93.035). Alaska also has in-stream flow water rights regulations designed to protect certain in-stream flow quantities or lake levels for aquatic habitat, recreation, navigation, or water quality. Although these regulations are primarily related to surface water bodies, they are potentially applicable in situations where potential changes to groundwater resources may have impacts on surface waters. Additional state and federal regulations affect groundwater quality and are addressed in Section 3.7, Water Quality.

Table 3.6-1: Federal and State Regulations Affecting Groundwater Quantity

Agency and Regulatory Program	Regulation	Description
Federal		
EPA Safe Drinking Water Act (SDWA) and Sole Source Aquifer Protection	Section 1424(e) of the SDWA of 1974 (Public Law 93-523, 42 U.S.C. 300 et seq.).	Under the SDWA, EPA sets standards for drinking water quality. and implements various technical and financial programs to ensure drinking water safety. The SSA designation is a tool to protect drinking water supplies in areas where few or no alternative sources to the groundwater resource exist and where, if contamination occurred, using an alternative source would be extremely expensive. The designation protects an area's groundwater resource by requiring EPA to review certain proposed projects within the designated area. The SSA designation does not currently apply to the Mine Site.
Federal and State of Alaska		
ADEC Public Drinking Water Systems and protection areas	18 AAC 80 (and federal 40 CFR Part 141, 40 CFR Part 142, and 40 CFR Part 143**)**	Alaska has primacy on regulating public drinking water systems with many references to federal regulations. Regulations also contain references to Drinking Water Protection areas that have been mapped for many public drinking water systems.
State of Alaska		
ADNR Temporary Water Use Authorization or Water Appropriation	11 AAC 93	Temporary water use authorizations and/or water rights permits and certificates are needed for use of a significant amount of water, including groundwater, as water rights can be issued for both surface and subsurface water. This may apply to the mine and process facility's water use, camp water use, dust control, pipeline construction or testing, ice roads, mine dewatering, dewatering of pipeline trenches, water extraction, treatment, and discharge, and all other water diversions.
ADNR In-stream flow reservations	11 AAC 93.141-147	In-stream flow reservations may be filed with ADNR by interested parties for maintaining stage or discharges in streams or rivers or maintaining minimum levels in lakes.

Notes:

ADEC – Alaska Department of Environmental Conservation
ADNR – Alaska Department of Natural Resources
EPA – Environmental Protection Agency
SSA – Sole Source Aquifer

3.6.1.2 HYDROGEOLOGICAL SETTING AND DATA SOURCES

The Project Area encompasses seven physiographic sub-provinces spread across Southwest and Southcentral Alaska and the Aleutian Island Chain with diverse hydrogeological settings. These are described in the following subsections for each of the three project components (Mine Site, Transportation Corridor, Pipeline), along with a summary of available data sources used in the analysis.

3.6.1.2.1 MINE SITE

Groundwater data and data analyses for the Mine Site are contained in reports by BGC (2011d, g, h, i; 2014c, f, g) and SRK (2017b). Groundwater data for the mine and process facilities area have been collected from 217 monitoring locations, including 150 monitoring and test pumping wells and 67 vibrating wire piezometers. To measure vertical groundwater gradients, 29 nested well or piezometer pairs were installed. To measure hydraulic conductivities of aquifers, 40 tests were performed in non-lithified materials (including 35 slug tests and five estimates of hydraulic conductivity from three pumping tests; one of which was at a larger scale than the rest) and 396 tests were performed in bedrock (not influenced by permafrost) in more than 130 boreholes. To measure hydraulic conductivity on a larger scale than near a single borehole, 13 aquifer tests using pumping wells were also conducted (including 12 in bedrock and the one larger scale test in non-lithified materials noted above). Geological information, including information about the distribution of permafrost and the geological formations found in the area, were also collected as part of the groundwater data collection program.

Hydraulic head and hydraulic conductivity data are less abundant at the full depth of the pit compared to shallower data. This is related to the high cost and logistical difficulty of obtaining data at such depths. The relevance of this lesser abundance of data is relatively low, however, for the following reasons:

- Geological sampling at the full depth of the pit has shown that there is no "new" uncharacterized geological unit or formation at depth; thus, shallower data are applicable for the characterization provided that suitable accommodation is made for depth- and pressure-related effects, which has been done.
- Packer test data are shown to be adequate to characterize larger-scale pumping test results (BGC 2014c, Drawing 12), and 38 packer tests were conducted at depths greater than 660 ft (BGC 2014c), yielding an adequate understanding of conditions at depth for the analysis.
- Of the 198 permanent stations where water-level data have been collected, 21 were deeper than 330 ft and 5 were deeper than 800 feet. Importantly, vertical hydraulic gradients were measured at 29 monitoring well or piezometer nests (BGC 2014g) and were consistent with the conceptual and numerical models showing downward flow in upland areas and upward flow in valley bottom locations. Additional, deeper or more abundant water level data would not be expected to materially change this condition.
- Regional groundwater modeling results (BGC 2017e) confirm that regional flows systems that have been hypothesized to exist at depth have been evaluated to depths beyond which the project is likely or certain to have effects, and found no indication that such regional flow systems exist at relevant depths as a result of high topographic relief and the dominance of local groundwater flow systems. The modeling confirms that it is unlikely that additional or deeper water level or packer or pumping test data would materially change the characterizations or assessments made or the reliability of the model predictions.

Nevertheless, additional boreholes (i.e., exploration and geotechnical) would be drilled and hydrogeologic testing (e.g., dewatering well testing) would be conducted as the project develops. There would be opportunity at that time to collect additional deep hydrogeologic data and to modify / refine interpretations and analyses as required (see Chapter 5, Table 5.7-1: Monitoring and Adaptive Management being Considered by the Corps).

The mine and process facilities would be located in a region of localized discontinuous permafrost where groundwater occurs throughout the area, both in permafrost-free areas and above and beneath permafrost. Groundwater is found in alluvial, colluvial, terrace gravel, and loess deposits as well as in fractured bedrock. Most recharge to groundwater occurs in the non-freezing months from snowmelt, rainfall, or recharge from streams. Local permafrost can impede groundwater recharge or confine groundwater in some areas; however on a basin-wide scale, permafrost is considered too sporadic to substantially impede recharge or discharge. Natural groundwater discharge occurs in most of the main stream and river bottomlands throughout the year. Wintertime surface water flows, for example, are sustained almost entirely by groundwater discharge.

3.6.1.2.2 TRANSPORTATION CORRIDOR

The Transportation Corridor includes the port at Dutch Harbor, the Kuskokwim River lowlands (including a fuel storage and transfer facility at Bethel, a connected action), a river port facility on the Kuskokwim River, and road corridor from the river port to the Mine Site. Data on groundwater for the transportation corridor includes: about 130 geotechnical borings at the potential Angyaruaq (Jungjuk) and BTC Port sites and along the road alignments (DMA 2007a, 2007b; RECON 2011a); well log data from Bethel and other river communities (ADNR 2013c); and data from the Alaska Department of Environmental Conservation (ADEC) Public Water System and Contaminated Sites databases (ADEC 2013a, 2013c).

The Kuskokwim River lowlands (including Bethel) contain coarse-grained alluvial deposits that are capable of yielding large quantities of water to wells where permafrost is thin or absent - usually very close to the Kuskokwim River. At Bethel, where over 400 feet of permafrost has been encountered, yields from wells of approximately 400 gallons per minute (gpm) have been obtained from alluvial deposits below permafrost (ADNR 2013c). Most households in the villages along the Kuskokwim River obtain water from wells. Some wells tap relatively shallow and thawed alluvial deposits while others, such as those in Bethel, tap deeper aquifers below permafrost, or aquifers that appear to be between permafrost layers (ADEC 2013c; ADNR 2013c).

Groundwater has also been encountered in several of the test holes drilled along the road alignments from the Angyaruaq (Jungjuk) and BTC port sites to the Mine Site. In general, the hydrogeologic setting in this area is similar to that described for the Mine Site, with most groundwater found in unconsolidated alluvial material in drainages and weathered bedrock. Permafrost, mostly in low-lying areas, provides local confinement of groundwater (DMA 2007a, 2007b; RECON 2011a).

3.6.1.2.3 PIPELINE

Subsurface data on groundwater for the Pipeline corridor under Alternative 2, Alternative 2-North Option, and Alternative 6A were obtained from over 500 boreholes and 50 test pit sites. Additionally, 15 test holes were drilled at five different river crossings (BGC 2013c; CH2MHill 2011b). Information on groundwater in the Cook Inlet region along Alternative 3B and its two route options (Port MacKenzie Option and Tyonek / Collocated Natural Gas and Diesel Pipeline

Option) is available from public sources and online literature (ADEC 2013c, 2017; Kikuchi 2013; STB 2011).

The pipeline alternative routes include the Cook Inlet lowlands on the east, crossing the Alaska Range, and interior lowlands and uplands to the Mine Site. Southeast of the Alaska Range, groundwater is mostly found in permafrost-free environments. At the eastern end of the Pipeline corridor, groundwater occurs in the Cook Inlet aquifer system, consisting of predominantly glacially-related silt, sand, gravel, clay, cobbles, and boulders, with some estuarine deposits in the Susitna Valley area. Groundwater can occur under confined or unconfined conditions.

In the Alaska Range, groundwater occurs in alluvial, colluvial, and glacial deposits as well as in bedrock. West of the Alaska Range, permafrost is commonly present in the Pipeline corridor and groundwater occurs as suprapermafrost groundwater, or is associated with the larger alluvial fans and drainages. Suprapermafrost groundwater is water found seasonally in saturated soils above permafrost.

3.6.1.3 GROUNDWATER OCCURRENCE AND AQUIFER CHARACTERISTICS

3.6.1.3.1 HYDROGEOLOGIC UNITS

Mine Site

Groundwater in the area of the Mine Site occurs in three main hydrogeologic environments: 1) an alluvial aquifer associated with Crooked Creek; 2) a thin colluvial layer that covers most of the valley side slopes and valley bottoms; and 3) bedrock aquifers where groundwater is also found in fractures, faults, joints, and weathering voids in intruded sedimentary rocks. The alluvial aquifer consists primarily of sand and gravel with varying amounts of silt in the floodplain and adjacent low terraces of Crooked Creek, and is generally less than 30 feet thick. The colluvial deposits are relatively thin (up to about 7 feet thick on ridgetops and valley walls), but are up to 20 feet thick in valley bottoms. A few monitoring wells have also been completed in loess and terrace gravels; however, these are considered to be very minor hydrogeologic units (BGC 2011d).

In the vicinity of the Mine Site, bedrock consists of faulted and folded greywacke, shale, and siltstone intruded by felsic and mafic igneous rocks (Section 3.1.2.1.2). Bedrock geology at the Mine Site consists of sedimentary rocks of the Kuskokwim Group, with younger, late Cretaceous to early Tertiary, intrusions of igneous rocks of the Kuskokwim Mountains Group (Decker et al. 1994; Bundtzen and Miller 1997; Szumigala et al. 2000; Miller et al. 2008; Goldfarb et al. 2010). The Kuskokwim Group rocks consist of a deep marine sequence of greenish-gray colored, fine- to coarse-grained, thinly cross-bedded graywacke sandstone, with interbeds of dark gray siltstone and shale that have experienced low-grade regional metamorphism and deformation (Cady et al. 1955; Dusel-Bacon et al. 1996; Szumigala et al. 2000).

Bedrock at the Mine Site reflects a complex history of folding, faulting, and intrusion. An east-west trending fold deforms the Kuskokwim Group rocks, with strike-slip fault expressions of the Donlin and Crooked Creek faults trending northeast-southwest at the northwest edge of the Mine Site and the ACMA fault trending northwest-southeast. Numerous thrust and reverse fault expressions exist throughout the site, generally trending northwest-southeast (Figure 3.1-

3). After folding and faulting, molten igneous rocks intruded along the north-northeast and west-northwest trending structural weaknesses, creating numerous dikes and sills (Figure 3.1-4). This was followed by cross-cutting high-angle faulting along northeast and northwest trends (Figure 3.1-3). Finally, extensional fractures cross-cut all previous structures, and are concentrated within the igneous and coarse-grained sedimentary rocks (Goldfarb et al. 2004).

Permafrost is discontinuous in the area (Section 3.2.2.1.2) and generally causes conditions of lower hydraulic conductivity where it occurs (Figure 3.2-2). Permafrost is more prevalent on north- and east-facing slopes. Permafrost also tends to be more prevalent in lower topographic features such as valley bottoms, drainages, and toeslopes. In the Mine Site area, vegetation tends to decrease with increasing elevation, reducing surface insulation. Consequently, these higher elevations tend to have thinner permafrost.

Permafrost may function as a local confining unit or as a barrier to infiltration and recharge. Regionally, however, because it is discontinuous and evidence of any major effect on groundwater flow systems is lacking, it is not considered to be a substantial hydrogeologic unit or barrier to flow (BGC 2011d).

Transportation Corridor

Dutch Harbor

A number of ADEC-designated contaminated sites, related to historical spills from existing tank farms and fuel handling (unrelated to this project), have been documented in the Dutch Harbor area (Sections 3.2.2.2.4 and 3.7.1.2). Local groundwater information available as a result of site characterization and cleanup activities at these sites indicates the presence of groundwater in shallow soils in low-lying areas like near the Delta Western fuel dock at depths of 10 feet or less, and in volcanic bedrock in hilly areas like Rocky Point at depths ranging from 20 feet to over 100 feet (Stantec 2010).

Kuskokwim River

Along the Kuskokwim River, alluvial deposits contain alternating layers of sand and gravel, silty overbank deposits, or slack water deposits; and can be up to hundreds of feet thick. Shallow groundwater in unconsolidated deposits along the banks flows into and out of the river in response to changing river levels (Section 3.7.2.2.2, Figure 3.7-7). Permafrost is present intermittently in many places in the Kuskokwim River valley, and in some places reaches depths of up to 400 feet. Wells in Bethel tap an alluvial aquifer beneath 400 feet of permafrost. Wells in other communities obtain water from water table aquifers at a depth of approximately 50 feet that lack effective confining layers of silt or frozen material (Dorava 1994).

Angyaruaq (Jungjuk) and Birch Tree Crossing (BTC) Roads and Ports

Groundwater occurs in sand and gravel alluvium in several drainages crossed by the Angyaruaq (Jungjuk) and BTC road alternatives. These include the drainages of Getmuna and Jungjuk creeks on the Alternative 2 mine access road (RECON 2011a); and the Iditarod and Owhat rivers, and drainages of Cobalt, Tyrel, Kaina, and Ones creeks along the BTC Road (DMA 2007a). No groundwater was encountered in boreholes drilled in intervening upland areas and smaller drainages; however, boreholes were drilled for geotechnical data collection and likely not drilled deep enough to encounter groundwater in bedrock. In general, groundwater conditions in bedrock are expected to be similar to those encountered in the mine and facilities area as a result of similar geology and topography. In a number of the larger drainages, groundwater was present in units below relatively thick (5 to 30 feet) sections of permafrost or unfrozen silt.

Discontinuous groundwater was present in less than half of boreholes drilled in a benched area above the Kuskokwim River at the Angyaruaq (Jungjuk) Port site (DMA 2007b). No groundwater was encountered in boreholes drilled up to 27 feet deep through frozen and unfrozen silt at the BTC Port site (DMA 2007a).

Pipeline

Along the Pipeline corridor, groundwater is commonly found in alluvial and glacial deposits and wetland areas. Alluvial and alluvial fan deposits are typically very permeable and saturated with groundwater to within a few feet of the land surface. Glacial till, outwash, and moraine deposits may contain coarser gravel mixtures with variable fines, and local areas of fine-grained lake sediment and peat. Locally, the alluvial and glacial deposits may contain large quantities of groundwater.

Figure 3.6-1 shows the distribution of shallow groundwater (within 3 feet of the land surface) along the alternative pipeline routes based on borehole and terrain mapping data (SRK 2012i, 2013b; BGC 2013c) and inferred from topography and wetlands maps. Depth-to-groundwater data for Alternative 2 are also listed by milepost in Appendix F, the Soil and Permafrost Data, and detailed wetlands mapping is provided in Appendix L, Wetlands Pipeline Mapbook. Approximately 112 miles or 36 percent of the pipeline route is estimated to be underlain by shallow groundwater during summer, or by major wet organic deposits. Additional seasonal occurrences of thin discontinuous shallow groundwater could occur in the active layer in permafrost areas (shown in Figure 2.3-34, Chapter 2, Alternatives); these are indicated as “frozen” in the geotechnical data and not included on Figure 3.6-1.

Groundwater occurrence along Alternative 6A in the Alaska Range is expected to be similar to that of Alternative 2 in this area, as the routes traverse similar types of alluvial, alluvial fan, and glacial deposits. Similarly, groundwater occurrence is expected to be similar between Alternative 2-North Option and Alternative 2, where shallow groundwater is expected to occur interspersed with deeper groundwater in glacial deposits along both sides of Happy Valley (Wilson et al. 2012; SRK 2013b).

Depth to groundwater increases in the Cook Inlet area south and east of Mount Susitna, where Alternatives 2 and 6A reach their terminus (Figure 3.6-1) and the Alternative 3B options extend south and east to Tyonek and Susitna Valley, respectively. Quaternary aquifer materials in this area include poorly sorted glacial moraine and meltwater lake deposits, finer estuarine sediments, and Holocene outwash alluvium. The water table in this area can be more than 100 feet deep and the base of the aquifers several hundred feet deep (Leslie 1981; Moran and Solin 2006; Kikuchi 2013). Local areas of shallow groundwater are common in wetlands along these routes.

3.6.1.3.2 GROUNDWATER FLOW SYSTEMS

Mine Site

The upper surface of groundwater at the Mine Site is generally known as the water table or potentiometric surface. Figure 3.6-2 shows the configuration of the potentiometric surface in the vicinity of the mine and process facilities. This map is termed a potentiometric surface map, because most of the water level data used to construct it were obtained from wells that tap deeper portions of the aquifer, rather than the water table surface. Groundwater level data are available for 29 monitoring well pairs and piezometer nests at the site. Many nested piezometers are installed near creeks. Several of these piezometer pairs indicate artesian conditions, and have upward gradients indicating upward groundwater flow towards creeks and groundwater discharge to the creeks. In other piezometer pairs near creeks, gradients are near zero (i.e., essentially there is no vertical gradient).

At other piezometer nests located on Lewis Ridge, along the slopes of American Creek valley, in upper Crevice Creek valley, and on the American Creek ridge, vertical gradients are typically near zero or downward (i.e., downwards flow of groundwater), indicating recharge at these locations. The difference in water levels between shallow and deep wells at all but four of the sites was less than 10 ft. At ridge locations, four of the nested pairs showed water elevation differences between deep and shallow wells ranging between 17 and 41 feet (BGC 2014g). These data show that both shallow and deeper water-level data are useful for contouring the potentiometric surface as a result of the relatively small differences in water levels compared to the 1000-foot head drop across the study area (BGC 2014g, Drawing 2).

The potentiometric surface occurs at or near the land surface near creeks and streams and at depths of up to approximately 300 feet below the land surface at ridgetops (BGC 2011d, 2011h). The configuration of the potentiometric surface generally follows the configuration of land surface contours, so in areas near the perimeter of the facilities where data are too sparse to effectively draw contours of the surface (such as in the vicinity of the Snow Gulch reservoir), the approximate shape of the potentiometric surface and groundwater flow directions can be inferred. Fractures in the bedrock aquifer are considered to be fully saturated with groundwater from the water table to depths greater than the depth of the open pit.

Groundwater flows under natural gradients driven by gravity from highlands to lowlands, generally at right angles to the potentiometric surface contours, discharging to the lower reaches of streams. In some cases, permeable faults or rock fractures can locally cause flow paths to deviate from this right-angle relationship, but the overall directions of flow from highland areas to lowland areas is driven by larger-scale topographic/gravity forces. Analysis of stream discharge records from Crooked Creek indicate that the creek generally gains water in the area of the Mine Site. A detailed examination of water levels in wells near Crooked Creek (BGC 2014g, Drawing 19) shows that shallow groundwater elevations are higher than nearby creek levels, confirming gradients of groundwater flow towards Crooked Creek.

In general, groundwater (while below ground) does not freeze during the winter months, and is capable of providing year-round flows to larger streams and rivers. Groundwater flows from aquifer storage during the winter months (and during summer dry spells) thus causing water levels in the aquifer to fall. Water levels rise and groundwater is replenished during spring snowmelt and also during summer and fall rain events. Groundwater levels generally fluctuate less in lowland settings along creeks at the Mine Site (up to about 16 feet in any given year) than in upland settings, where levels generally vary by 10 to 66 feet over the course of a year (BGC 2011d).

Groundwater fluctuations and discharge to creeks are driven by groundwater recharge. Recharge at the Mine Site occurs from rainfall, snowmelt, and to a lesser extent from infiltration from losing reaches of creeks. Recharge rates are likely to vary across the site based on topography, geology, soil development, vegetation, permafrost, time of year, and precipitation distribution. Typically, recharge would be expected to be higher on hill tops as soils are less developed, there is less vegetation, less area with potential permafrost, and the saturated soil levels are deeper below the ground surface, as compared to valley areas (Donlin Gold 2017a). Recharge is expected to occur during the approximate six-month thawed season between April and October. An estimate of the quantity of groundwater recharge determined from Mine Site groundwater flow and surface water balance models (Section 3.6.1.3.1) is 5.5 inches per year, or approximately 28 percent of average annual precipitation (BGC 2011b).

Groundwater recharge was also evaluated by interpretation of data collected for isotopes of hydrogen and oxygen in molecules of groundwater and dissolved helium gas (BGC 2014h). Samples were obtained and analyzed from 18 wells. Ratios of stable isotopes of oxygen and hydrogen were used to conclude that groundwater recharge appears to occur widely throughout the Mine Site area. Tritium and helium isotopes were used to estimate groundwater ages based on elevated tritium levels that were emplaced into the earth's atmosphere since the early 1950s from thermonuclear testing. The study found that the estimated age of groundwater in the Project Area varies from approximately 21 to 56 years of age (in 2013) and that the conceptual model of older water being found in deeper wells and at places further down the groundwater flow path is substantiated.

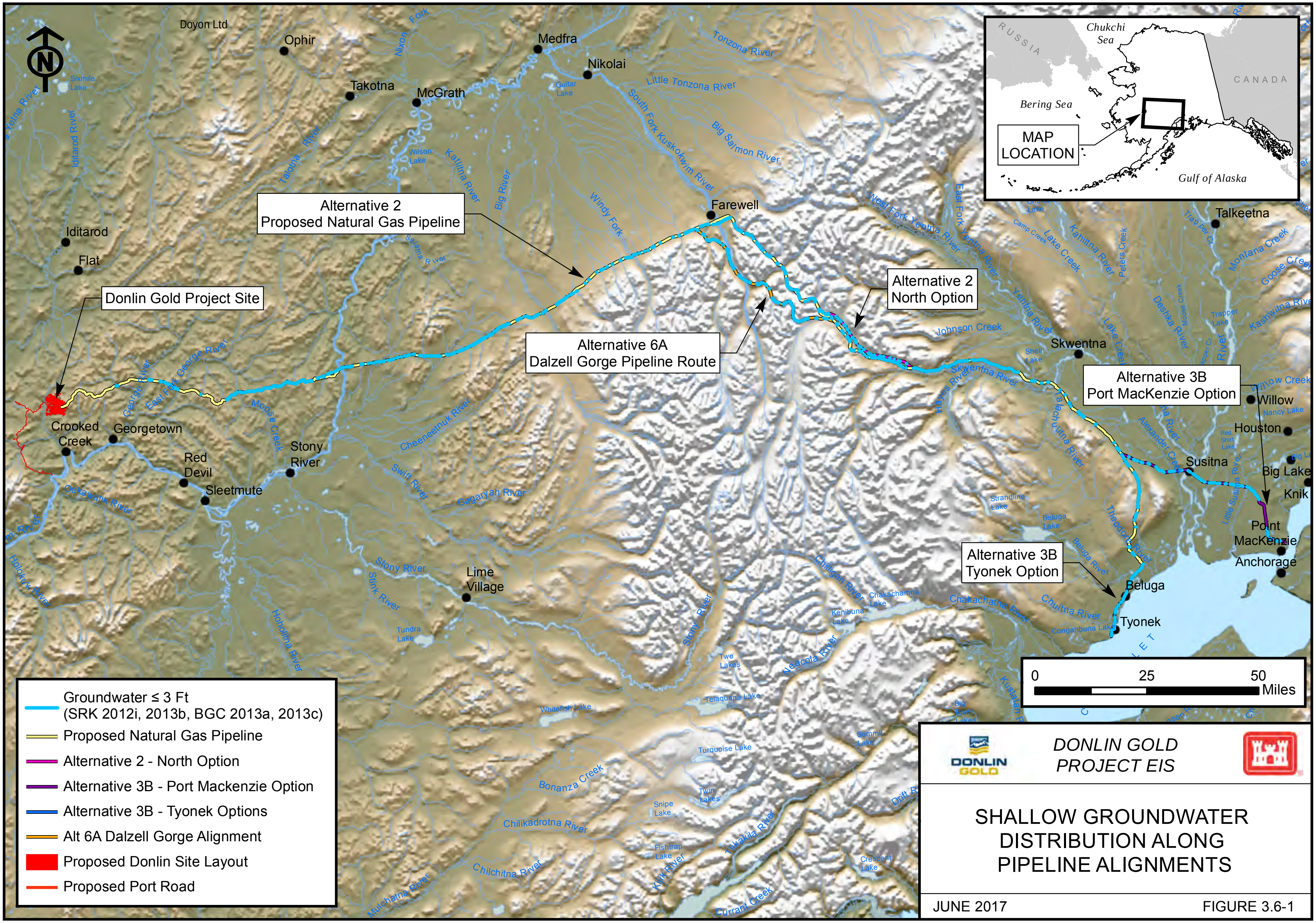
Transportation Corridor

On a regional scale, groundwater flow systems in the Kuskokwim river corridor tend to flow to the southwest, generally paralleling surface water flow directions (Dorava 1994). Locally, shallow groundwater in unconsolidated deposits along the banks flows into and out of the river in response to changing river levels (Section 3.7.2.2.2, Figure 3.7-7). The year-round flow of the Kuskokwim River and its major tributaries is attributable to groundwater discharge to the rivers throughout the winter months.

Groundwater flow in Dutch Harbor generally mimics topography. Flow is directed radially away from Rocky Point; northwest towards Delta Western fuel dock and Dutch Harbor, southeast towards Iliuliuk Bay, and southwest towards Ilulaq Lake (Stantec 2010).

Pipeline

Groundwater flow directions along the Pipeline corridor in alluvial fans and stream alluvium are likely to be generally parallel to the direction of flow of the associated stream or river. Where alluvial fans exit mountain valleys, it is expected that streams may generally lose water to groundwater systems. Springs and seeps commonly occur at the toe of alluvial fans where groundwater discharges to the surface. Groundwater flow in the Cook Inlet area is generally towards the inlet and parallel to the direction of flow in rivers that drain to the inlet. Groundwater is recharged by flow loss from major rivers such as the Susitna River, and by rainfall and snowmelt that percolates downward before reaching surface water bodies (Kikuchi 2013).

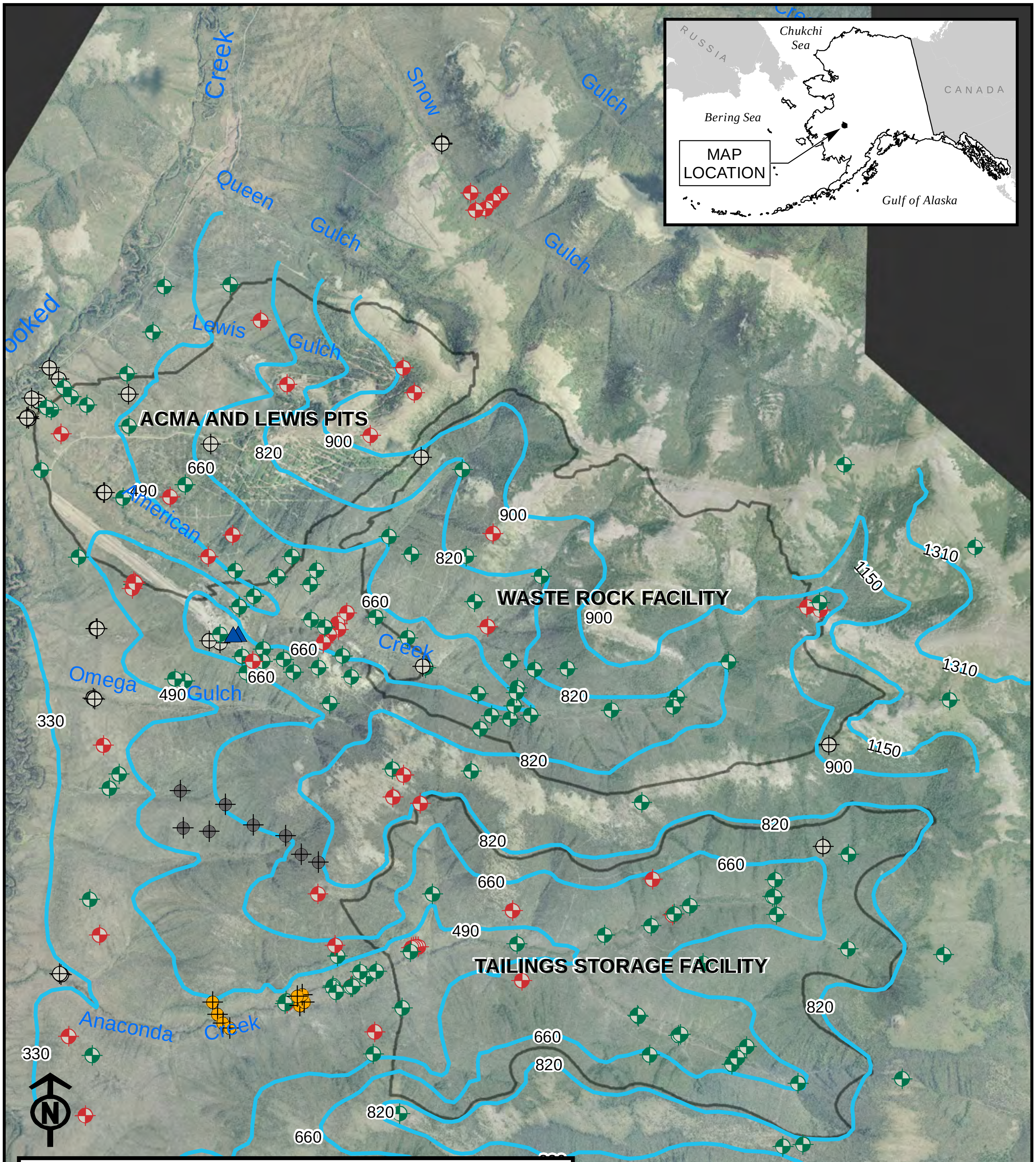


DONLIN GOLD PROJECT EIS

SHALLOW GROUNDWATER DISTRIBUTION ALONG PIPELINE ALIGNMENTS

JUNE 2017

FIGURE 3.6-1



▲ Existing Exploration Camp Drinking Water Wells

— Potentiometric Groundwater Surface Elevation and Contours in Feet

Groundwater Monitoring Program, 2004-2013:

- ⊕ Monitoring Well
- ⊕ Piezometer
- ⊕ Standpipe

Proposed Sites:

- ⊕ Proposed Construction Camp and Plant Drinking Water Wells
- ⊕ Proposed TSF Monitoring Wells

Source: BGC (2014f)

0 5,000 10,000 Feet

DONLIN GOLD PROJECT EIS

POTENTIOMETRIC GROUNDWATER SURFACE, MONITORING AND DRINKING WATER WELLS

JANUARY 2018

FIGURE 3.6-2

3.6.1.3.3 AQUIFER PARAMETERS: HYDRAULIC CONDUCTIVITY AND SPECIFIC STORAGE

Hydraulic conductivity is a measure of the ease with which water moves through the subsurface; it is used to understand rates of and quantities of groundwater movement. As described in Section 3.6.1.3.1, both sedimentary and intrusive igneous bedrock units in the project area have been subjected to extensive fracturing, folding, and faulting. These deformations have resulted in observed brecciation, fault gouge, slickensides, and disintegrated or decomposed rock zones identified in cores (BGC 2017c). Additional observations of interconnected jointing, weathering, and bedding plane fracturing are also evident from surface exposures in the area (BGC 2014c). Both sedimentary and igneous rock types exhibit very low primary permeability (intergranular or intercrystalline permeability), and practically all water flow is considered to occur through secondary fractures in the rock mass.

Table 3.6-2 summarizes the results of hydraulic testing to determine estimates of hydraulic conductivity in wells tapping colluvial, alluvial, and bedrock aquifers in the area of the Mine Site. Some well tests were affected by permafrost and were excluded from the analysis. Not included in Table 3.6-2 were four tests that were also conducted in wells tapping the minor hydrogeologic units loess and terrace gravels (two tests each), resulting in estimated hydraulic conductivity values of 0.06 and 0.1 feet per day (ft/d) for these units, respectively.

Many of the single-well tests used to construct Table 3.6-2 were conducted in separate, discrete intervals in deep bedrock-aquifer wells, thus providing information on how bedrock aquifer characteristics vary with depth. The testing has shown that the bedrock aquifer is generally less permeable with greater depth. This finding is consistent with the concept that increasing confining pressure with depth resulting from the overlying rock mass tends to reduce rock fracture apertures, thereby reducing hydraulic conductivity. Even the very low values of hydraulic conductivity reported are considered to represent fractured media, just with a lower frequency or interconnectedness of fractures than at other locations. The data suggest that there is a continuum of fracture densities, from very low to moderate, and that the occurrence of aquifer fractures is generally random within each identified depth zone. The geometric mean is a well-accepted method to characterize the variability of such an aquifer for modeling purposes (Anderson and Woessner, 2002).

Because the edge of the open pit would be less than 1,000 feet from Crooked Creek, detailed aquifer testing adjacent to Crooked Creek was conducted to investigate the relationships between groundwater and surface water in that area (BGC 2014f). The testing found that recharge from Crooked Creek to the alluvial aquifer under pumping conditions was evident. Testing of the bedrock aquifer also found that, while hydraulic conductivities of the bedrock aquifer were much lower than the alluvium, recharge from Crooked Creek to the bedrock aquifer under pumping conditions was also evident. Crooked Creek appeared to be better connected to the alluvial aquifer than to the bedrock aquifer.

In general, fractured rock aquifers are known to have irregular distributions of permeable zones, correlating with the variable distribution of faults and fracture zones of locally higher hydraulic conductivity. Mapped faults in the area of the pit are shown in BGC (2017c, Slide 54). The variability of fracture zones at the Mine Site is illustrated by the observed range of hydraulic conductivity measurements, at any given depth interval, of approximately three orders of magnitude (Table 3.6-2). Analysis of data at the Mine Site has not resulted in the identification of any drastically higher or lower hydraulic conductivities associated with faults or water level discontinuities associated with any of the known faults (BGC 2014g). Thus, at the regional or pit-area scale, faults have not been defined as distinct hydrogeologic features. Detailed examination of the available data has also not revealed any significant correlation between bedrock hydraulic conductivity and rock type or formation.

Table 3.6-2: Summary of Hydraulic Conductivity Estimates from Hydraulic Tests Not Influenced by Permafrost

Aquifer	Upper (less than 330 ft aquifer depth)		Middle (330 to 660 ft aquifer depth)		Lower (greater than 660 ft aquifer depth)	
	Geometric Mean (ft/d) (number of tests)	Range (ft/d)	Geometric Mean (ft/d) (number of tests)	Range (ft/d)	Geometric Mean (ft/d) (number of tests)	Range (ft/d)
Alluvium	11 (20)	0.3 to 850	na	na	na	na
Colluvium	0.06 (11)	0.003 to 1	na	na	na	na
Bedrock	0.3 (301)	0.006 to 14	0.03 (57)	0.0009-0.9	0.006 (38)	0.0003-0.2

Notes:

Includes only tests not affected by permafrost
ft/day = feet per day na = not applicable

Source: BGC 2014c

For these reasons, and because both the sedimentary and igneous rock types have been subjected to extensive faulting and fracturing stresses, the bedrock aquifer outside of the open pit area is characterized as a single hydrogeologic unit with a representative hydraulic conductivity that decreases with depth (BGC 2014g). Within the pit area, more detailed hydrogeological information is available and hydraulic conductivity variations associated with different rock types was mapped and incorporated into the model. Locally, both within and surrounding the pit area, zones of hydraulic conductivity higher than regional or local averages (by factors of 10 or more) may be present and could influence local groundwater flow fields and groundwater pumping rates from wells.

Specific storage is a measure of the volume of water that an aquifer releases from storage, per volume of aquifer, per unit decline in hydraulic head (or groundwater surface elevation). It is expressed on a unit basis per foot (ft^{-1}) of head change. Specific storage is generally used to understand rates of groundwater withdrawal that can be sustained over the long-term. At the Mine Site, however, specific storage is used to determine the amount of groundwater that would need to be pumped in order to achieve desired reductions of water levels around the pit and the recovery rate of groundwater levels after pumping stops.

Because slug tests and packer tests are generally unsuitable for determining the specific storage of the aquifers, limited data are available. Estimates determined from aquifer tests at the site indicate that the specific storage of the bedrock aquifer at the Mine Site ranges from 1×10^{-7} ft^{-1} to 6×10^{-5} ft^{-1}. These volumes of water apply to the "per foot" of water level, or head, change (typically a decline). The alluvial aquifer occurs mostly as an unconfined aquifer and the storage characteristic of the aquifer is known as the specific yield. The geometric mean specific yield of the alluvial aquifer from aquifer testing conducted near Crooked Creek was determined to be 0.03, although the value determined may have been affected by aquifer recharge from Crooked

Creek or rainfall or both during the test. No aquifer testing data are available for storage coefficient or specific yield from the colluvium.

3.6.1.4 MINE SITE GROUNDWATER MODEL

A three-dimensional mathematical model of the groundwater flow system in the vicinity of the mine pit and process facilities area has been constructed by BGC (2011d, h, i, 2014g, c) in order to accomplish the following primary goals:

- Better understand pre-mining groundwater flow through the region;
- Plan mine dewatering facilities;
- Estimate the potential effects of the mine on flow in local surface water, in particular Crooked Creek;
- Estimate the effects of tailings storage on groundwater flow;
- Estimate the amount of groundwater that would be collected by the tailings storage facility (TSF) underdrain and seepage collection systems; and
- Estimate the amount of time it would take for the pit lake to fill after mining.

The flow model was developed using MODFLOW-SURFACT, which is based on a groundwater modeling industry-standard three-dimensional finite-difference flow model (MODFLOW) developed by the U.S. Geological Survey (Harbaugh et al. 2000; McDonald and Harbaugh 1988). MODFLOW-SURFACT is a proprietary code developed by HydroGeoLogic, Inc. (1996) that provides advanced features and solver options for MODFLOW.

The model employs equations governing groundwater flow, using site-specific estimates of aquifer parameters and boundary conditions derived from field data. The model is capable of simulating groundwater flow for periods of tens of decades or more. Initially, the model is used to simulate natural conditions, followed by simulation of aquifer tests conducted in the area, allowing calibration of the model against real data. The model is then used to simulate various development scenarios. Finally, an important part of the modeling effort is to test the robustness of the model by performing various sensitivity analyses by varying input parameters within reasonable ranges. Groundwater models of this type are widely used to simulate complex groundwater flow systems, provide assessments of potential future conditions, and provide information about the reliability of those assessments.

3.6.1.4.1 MODEL SETUP AND CALIBRATION

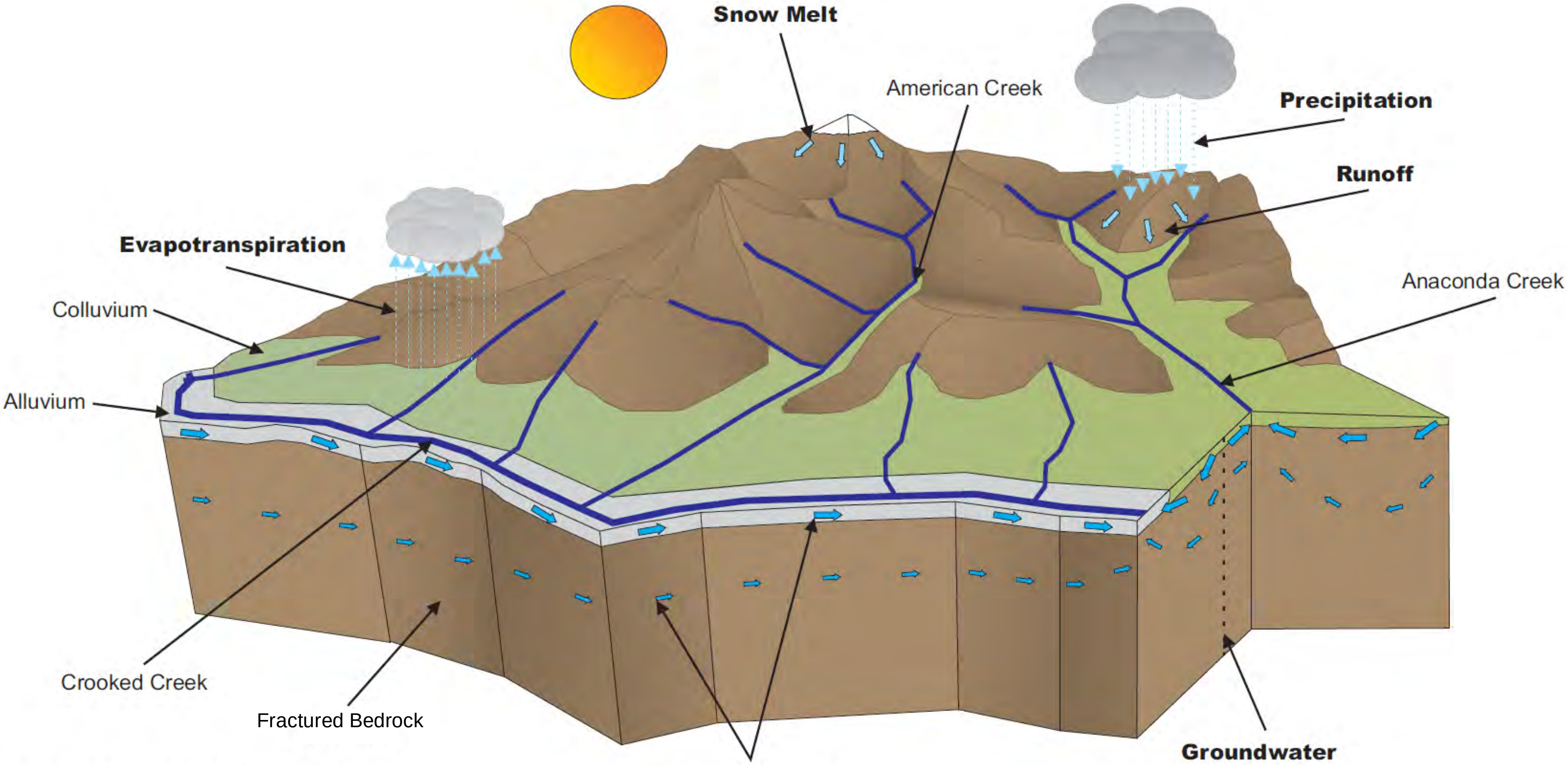
The model domain is a roughly 85-square mile area including and surrounding the Mine Site. The lateral boundaries of the model generally coincide with inferred groundwater divides, which are simulated as no-flow boundaries representing the outer limits of the pre-development groundwater flow system containing the pit. For the most part (as explained further in subsequent sections of this analysis), these boundaries also extend beyond the expected effects of the mine dewatering, indicating that the modeled area is of adequate size. In the southeast portion of the modeled area, the projected drawdown in the groundwater system extends to the model boundary; however, the potential inaccuracies on the overall flow system modeling are considered minor and the use of the 85-square mile area is considered adequate for the purposes of the EIS.

The bottom of the modeled area is 1,500 feet below the deepest planned depth of the mine, which is also considered to be an adequate depth of simulation. The model is broken into the following hydrogeologic units (Section 3.6.1.3.1, Figure 3.6-3): alluvium, colluvium, and bedrock, which are further categorized spatially (valleys vs. ridges) and by depth (upper, middle, lower) consistent with the aquifer test results (Table 3.6-2). In the pit area where more detailed hydrogeologic data are available, individual rock units were assigned hydraulic conductivity and storage properties. The model subdivides the flow domain through the hydrogeologic units into 347 columns, 222 rows, and 9 layers, resulting in approximately 693,000 blocks. Layer 1 was used to define relatively thin alluvium and colluvium deposits, and the remaining layers were used to represent the fractured bedrock aquifer (BGC 2014c).

Some of the blocks around the periphery were deactivated to match flow system boundaries. The actual thickness of the shallow aquifer may vary from that assumed in the model. Model flows are calculated to be the result of both layer thickness and hydraulic conductivity, and initial model inputs for hydraulic conductivity are likely to be more uncertain than shallow aquifer thickness. The model results, however, are produced after the model calibration process, which adjusts model inputs to match aquifer water levels, stream flow, and water-level fluctuations, so the effects on the model results of initial shallow aquifer thickness uncertainties are expected to be small.

The model uses field measurements and field-based estimates for determining initial input parameters for the following: hydraulic conductivity of earth materials; precipitation; evapotranspiration; sublimation/evaporation; runoff; groundwater recharge; stream depths and stages; and well-pumping rates (during aquifer tests). The model output consists of simulated values of hydraulic head throughout the model domain, and quantities of water discharging to streams from groundwater or being recharged to groundwater from streams. These model outputs are then compared to field measurements of the potentiometric surface, seasonal groundwater level trends, aquifer tests, and streamflow. Model input parameters are then changed (calibrated) until a satisfactory fit with field measurements is obtained. Sensitivity analyses were then performed to determine the sensitivity of the model results to reasonable variations in input parameters.

The model was run as a transient model to simulate both winter and summer conditions. Initial condition used as input to the transient model was a steady state simulation. The transient simulations were run for a simulated 20-year "spin-up" period using an eight-year period of hydrograph records coinciding with the available data (BGC 2017d). First-stage calibration was measured by comparing annual average simulated heads with annual average water-level data. In second-stage calibration, the model simulated pumping test results by simulating pumping rates and durations as observed in the field (BGC 2017d). Calibration of the model to pumping was completed using manual parameter adjustment of both hydraulic conductivity and storage properties, and visual comparison to the pumping test results.



Note: Conceptual diagram only. Drawing not to scale.

Data Sources: BGC 2014g

DONLIN GOLD PROJECT EIS

CONCEPTUAL HYDROGEOLOGIC MODEL

DECEMBER 2017

FIGURE 3.6-3

Fracture Flow Analysis

The model treats the aquifer domain as continuous porous media even though, in reality, for the bedrock portions of the model, groundwater flows through discrete individual fractures with variable spacing, orientation, and connectivity. The variability of the fracture system is evident in the variable hydraulic conductivity values (heterogeneity) determined from wells tapping the bedrock aquifer during the field testing program. While evidence of large individual fractures that distort the flow field or dominate flow are lacking, they may be present and undetected and may influence the accuracy of model projections. Such inaccuracies are reflected in imperfect matches of model simulations with aquifer test results and seasonal hydrographs (discussed below in this section); however, aquifer fractures appear to have minimal effects on the broad trends of the groundwater flow system's recharge and discharge areas. In order to further evaluate these potential phenomena, sensitivity analyses were performed to examine the potential effects of fractures on groundwater flow (see Section 3.6.2.2.1 - Model Robustness and Accuracy).

Simulated Potentiometric Surface and Comparison to Field Data

Figure 3.6-4 shows the model-generated potentiometric surface in the vicinity of the Mine Site. A qualitative comparison to the potentiometric surface map based on field data for the drainages of American and Anaconda creeks (Figure 3.6-2) shows broad similarity with modeled peak water levels under the ridges and Crooked Creek serving as a discharge area from the model flow system. Quantitatively, Figure 3.6-5 shows a comparison of model-generated head values (groundwater elevation) with field-measured head values in wells on a point-by-point basis. The goodness-of-fit of a model such as this with field data is commonly evaluated by calculation of the root mean square (RMS) error (Anderson and Woessner 2002). When normalized by dividing by the total head drop across the flow field, the normalized RMS, or NRMS, is calculated. This number should be "small," generally less than 10 percent (BLM 2008c). In this case, the NRMS is 5.9 percent, which is considered, in the context of the groundwater modeling industry as a whole, to be an acceptable match between the model results and field data.

The model was also used to simulate seasonal water-level trends at 33 wells where sufficient data were available for comparison. The model divides each simulated year into two time steps, winter (November to April) and summer (May to October). Simulations of summer conditions included groundwater recharge at a uniform rate of 5.5 inches per year, and simulations of winter conditions were conducted with recharge set equal to zero. The plots show overall groundwater elevation offsets ranging from 0 to 150 feet between the observed and simulated values (results which are captured by the NRMS analysis described above). Of the 33 sites, 18 locations show offsets within ±16 ft, six are within 16 to 33 ft, five are within 33 to 82 ft, and four are greater than 82 ft. A qualitative comparison of simulated and measured fluctuations in the timing and magnitude of seasonal water-level fluctuations shows that the calibrated model simulates the long-term seasonal fluctuations in measured water levels reasonably closely (BGC, 2014c, Appendix A).

Where actual seasonal fluctuations are small (less than about 5 feet, which generally occurs in lower elevation wells), the modeled results show little to no seasonal fluctuation. Where actual seasonal fluctuations are more pronounced (e.g., on the order of tens of feet, usually in higher elevation wells), the simulated fluctuations are generally within the same order of magnitude (BGC 2011i).

Simulation of Baseflow to Creeks

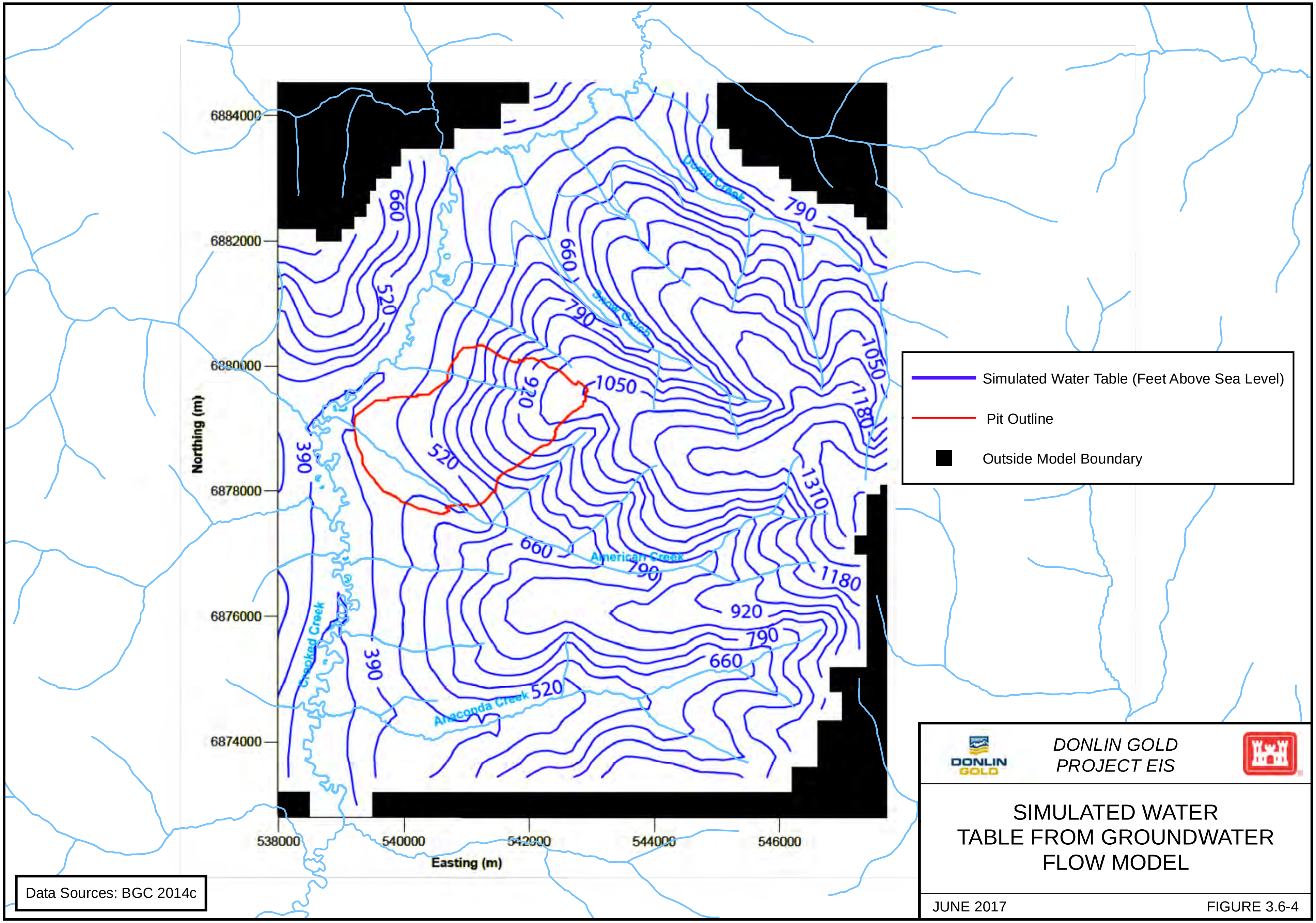
A comparison of groundwater model-predicted streamflow at five streams with summertime gaged streamflow measurements yielded a NRMS value of 3.3 percent.

Simulation of Aquifer Tests and Stream Leakage

Comparison of simulated and measured drawdowns from aquifer tests show variable-quality matches. Some matches are reasonably close; however, other matches are not close. This is likely attributable to several factors, including the scale of the model grid versus the scale of a well bore and aquifer heterogeneity. The grid spacing of the model reduces to five meters around the test wells, but considering the size, spacing, and expected variability of typical fractures, this is still rather coarse to expect close matches of all the aquifer testing responses. The inexactness of the matches provides context that illustrates the irresolvable residual uncertainty of the model and the importance of considering a variety of monitoring and adaptive management measures (see Chapter 5) to adjust project features as needed during the life of the mine and closure period, as data are collected and the groundwater system is better understood.

Evaluation of Regional Groundwater Flow and Model Boundaries

Part of the evaluation of the groundwater flow model is an analysis of the extent to which the selected model boundaries accurately reflect the possible presence of regional groundwater flow systems. Regional and intermediate-scale flow modeling to simulated depths of 9,951 feet below sea level (BGC 2017e) shows that the high topographic relief in the area confirms that the boundaries used for the Mine Site model are appropriate. The vertical boundaries in the base-case model closely match the topographic and groundwater divides present in the vicinity of the mine, while the bottom no-flow boundary is more complicated. Regional modeling shows that some flow does cross this boundary of the base-case model; however, the amount of water is relatively small and hydraulic containment of the pit lake water is maintained throughout lake filling, closure, and post-Closure time (see Section 3.6.2.2.1, Closure, Pit Lake). Regional-scale modeling (BGC 2017e) has failed to show conditions, either under base case or sensitivity analysis scenarios, that regional flow systems capable of transporting contaminants to distant locations could exist. This is because of the high-relief local topographically-driven flow cells present. The results of regional flow analysis and modeling (BGC 2017e) confirms that regional flow systems are not expected to occur at the pit at any depth of relevance to the project under any reasonably foreseeable hydrogeologic scenario.



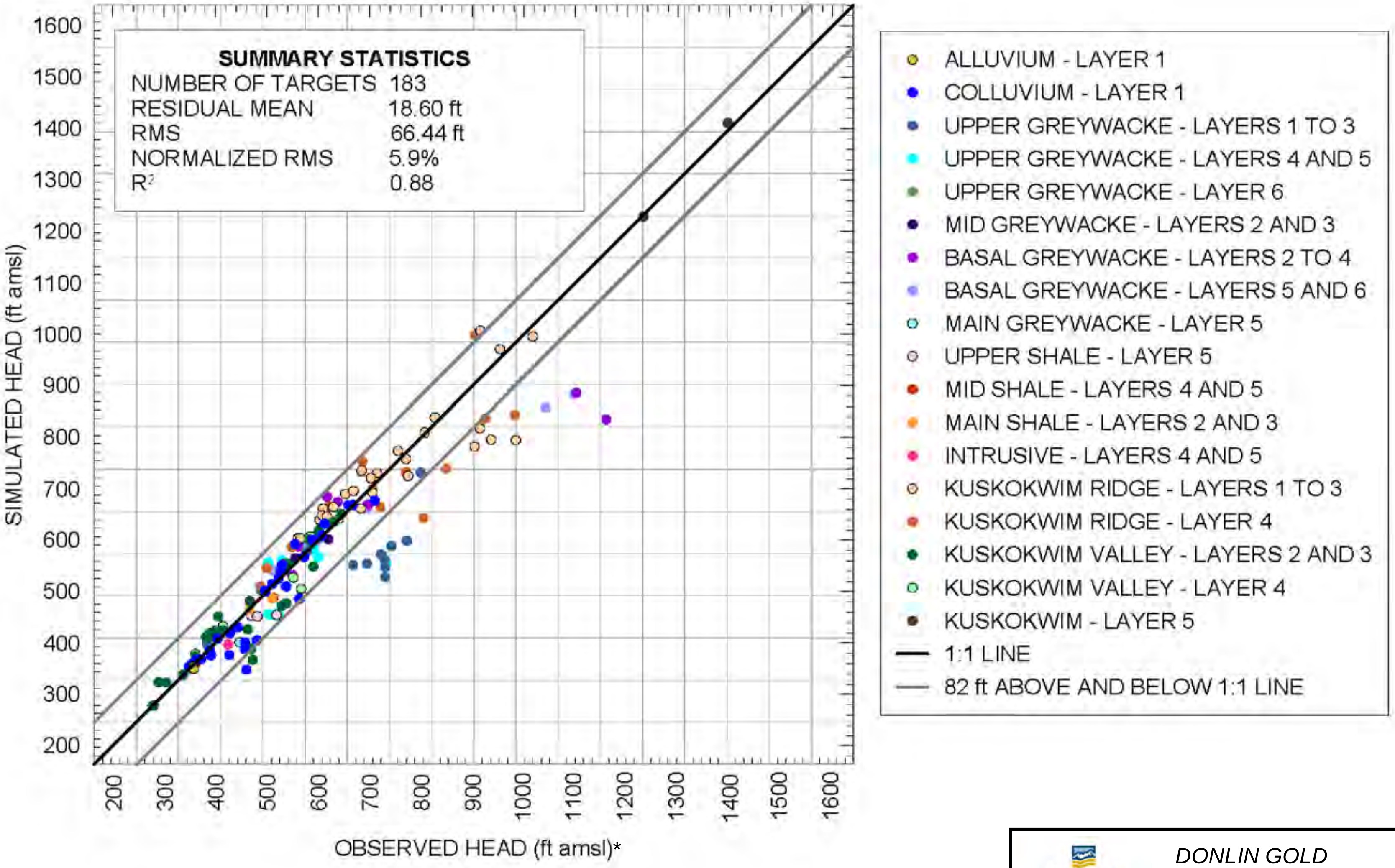
Data Sources: BGC 2014c

DONLIN GOLD
PROJECT EIS

SIMULATED WATER TABLE FROM GROUNDWATER FLOW MODEL

JUNE 2017

FIGURE 3.6-4



Data Sources: BGC 2014c

* Feet Above Mean Sea Level

DONLIN GOLD PROJECT EIS

RESULTS OF MODEL CALIBRATION: SIMULATED VS. OBSERVED MEAN ANNUAL HYDRAULIC HEAD

DECEMBER 2017

FIGURE 3.6-5

Summary of Model Calibration and Simulation of Future Conditions

The results of the model calibration show that the match between model output and field observations is well within accepted groundwater modeling industry standards, indicating that the numerical model provides a reasonable representation at the project scale of the existing physical hydrogeologic system at the Mine Site. It was also observed that there is a high degree of heterogeneity with respect to the bedrock hydraulic conductivity at the scale of the aquifer testing.

As is common with models of this type, however, the model is used to simulate conditions (such as dewatering the mine pit) that do not currently exist (Anderson and Woessner 2002). The amount and uncertainty of inaccuracies of these simulations are difficult to gauge. Therefore, sensitivity analysis simulations of mine pit dewatering are used to assess model uncertainty and robustness. These assessments are subsequently used to justify possible mitigation conditions such as additional data collection and periodic model revision as dewatering of the pit progresses. These concepts are further developed in Section 3.6.2.2, and Chapter 5, Impact Avoidance, Minimization, and Mitigation.

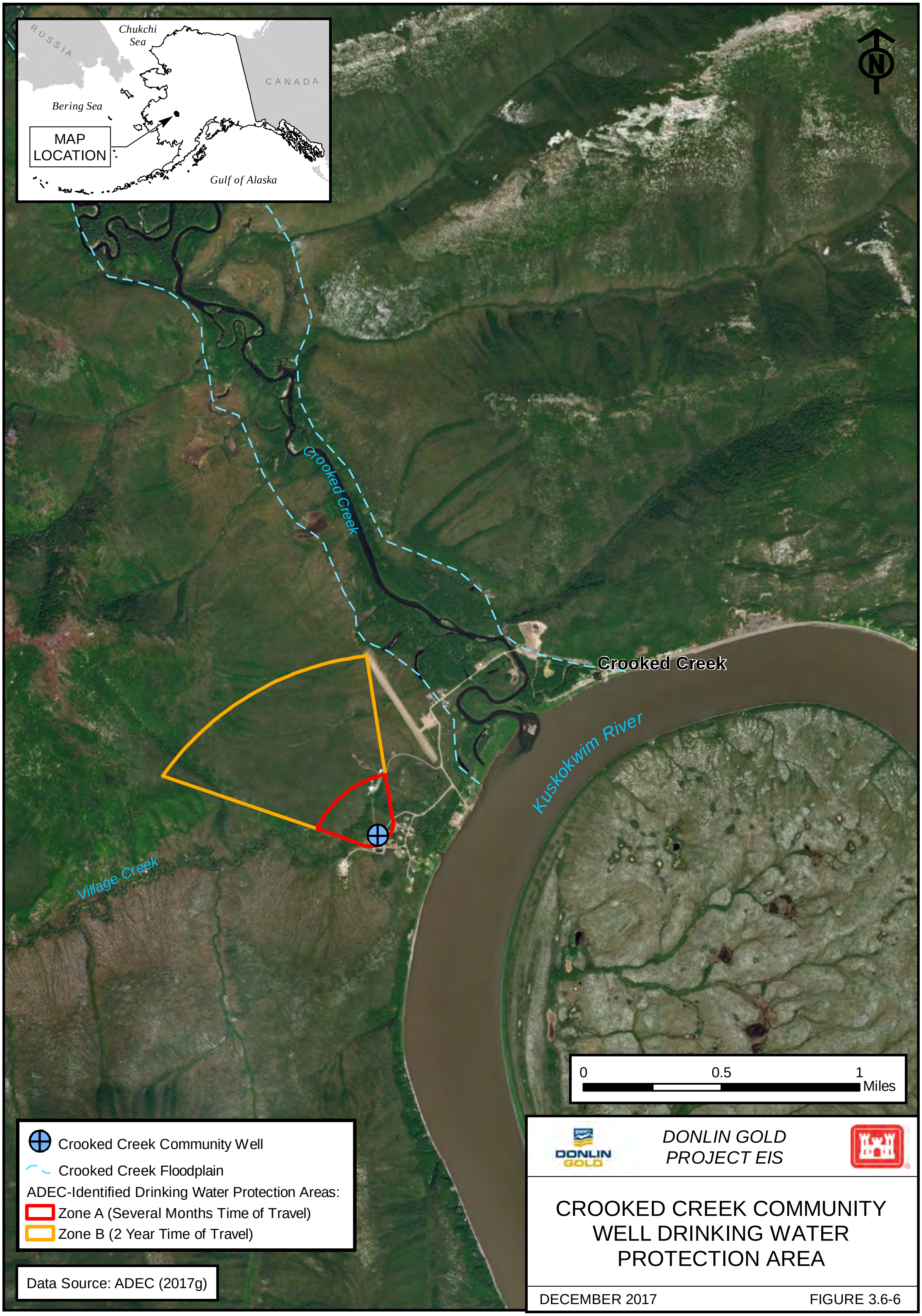
3.6.1.5 GROUNDWATER USE

3.6.1.5.1 MINE SITE AND PIPELINE

Two wells are reported to serve the existing Donlin Camp as a domestic water supply, a main well and a backup well, located at the southeast end of the current airstrip (Figure 3.6-2). These wells were drilled in 1996 and 2007. Together with a treatment plant, storage, and distribution components, these comprise a transient non-community water system. The camp wells were temporarily closed in March 2015, but are noted as seasonally active in the ADEC (2017f) Drinking Water Watch system as of Summer 2017. The wells were completed to depths of 520 to 600 feet, and yield about 7 gpm each from the fractured bedrock aquifer. The wells are located along the ridge between the American Creek and Omega Gulch drainages (Figure 3.6-2). The drinking water source protection area identified for these wells extends southeast beneath this ridge, along a groundwater table high that mimics surface topography in this area (ADEC 2017g).

A community water supply well is located in the village of Crooked Creek about 10 miles downstream of the Mine Site and ½-mile southwest of the confluence with the Kuskokwim River. Subsurface water rights are held here by Crooked Creek Traditional Council. The well and associated treatment, storage, and distribution system is listed as active as of 1993 by ADEC (2017f). The drinking water source protection area identified by ADEC (2017g) for the well extends northwest and upslope of the hill west of the airstrip (Figure 3.6-6).

Available ADEC (2013c, 2017a) and ADNR (2013c) records show that existing use of groundwater for water supply occurs near each end of the pipeline alternative routes. In the Beluga, Tyonek, and Port MacKenzie areas, there are a number of public water system wells located within approximately 1 mile of the diesel pipeline alternative alignments, and several of these may be located within 500 feet of the alignment (e.g., at the Beluga Power Plant). Many residential and commercial users of water appear to have their own wells in these areas.



Data Source: ADEC (2017g)

DONLIN GOLD PROJECT EIS

CROOKED CREEK COMMUNITY WELL DRINKING WATER PROTECTION AREA

DECEMBER 2017

FIGURE 3.6-6

Between Cook Inlet and the Mine Site, there are few known wells within the pipeline corridors, although there may be groundwater sources (wells or springs) that are in use associated with residences or camps. One private well is located several miles west of the Susitna River crossing along the Port MacKenzie Option route (ADEC 2017). In many areas near streams, groundwater is shallow enough to be accessed with small-diameter driven point wells that would be unlikely to be registered in public databases.

3.6.1.5.2 TRANSPORTATION CORRIDOR

Nine villages (Kwethluk, Akiachak, Akiak, Tuluksak, Lower Kalskag, Upper Kalskag, Aniak, Chuathbaluk, and Napaimute) are located between Bethel and Crooked Creek along the Kuskokwim River and adjacent sloughs. Each village except Napaimute has records of one or more wells drilled for water supply. While most well records are for public water systems, there are also some records of privately owned wells. Bethel has the most numerous wells, with approximately 17 known public water systems served by wells, although a few are inactive. Wells have been in use in Bethel for several decades, so there is also the possibility that there are some formerly-used wells that are not part of current public water systems. There are records of a few other wells in Bethel that may be privately owned and used for residential or other purposes (ADEC 2013c; ADNR 2013c).

3.6.1.6 CLIMATE CHANGE

Climate change is affecting resources in the Project Area and trends associated with climate change are projected to continue into the future. Section 3.26.3 discusses climate change trends and impacts to key resources in the physical environment including atmosphere, water resources, and permafrost. Current and future effects to subsurface hydrology are tied to changes in water resources (discussed in Section 3.26.3.2).

3.6.2 ENVIRONMENTAL CONSEQUENCES

Criteria for determining the groundwater hydrology impacts are based on intensity, duration, extent, and context, as shown in Table 3.6-3. As described in Section 3.6.1.1, groundwater diversion and use is primarily governed by State of Alaska statutes and regulations, which are considered in determining the context of groundwater in this section.

Groundwater is an abundant resource throughout most areas of Alaska, and is not currently considered a depleted resource in the Project Area. Groundwater diversions proposed as part of the Donlin Gold Project, however, are governed by state regulations for even small amounts, at least partly because the diversions could potentially have effects on other resources, notably biological resources associated with Crook Creek. Groundwater is considered a shared resource when it applies to a specific purpose such as recharging fish habitat or providing a drinking water supply, however where such values are absent, the context of the groundwater resource is characterized as usual or ordinary.

In evaluating negative and positive impacts to groundwater resources, relevant factors for this project include:

- Impacts to groundwater that have an identifiable beneficial use such as drinking water or are important for maintaining fish habitat;

- The size of area impacted; for example, potable water well impacts would be more localized than pit dewatering; and
- The degree to which changes are long-term or reversible, such as the recovery of groundwater levels after pumping wells cease (long-term but reversible) versus changes in directions of groundwater flow systems created by permanent lowering of pit lake water levels.

Table 3.6-3: Impact Methodology for Groundwater Resources

Type of Effect	Impact Factor	Effects Summary		
Changes to Water Quantity	Magnitude or Intensity	Groundwater flow systems are maintained. Changes in water quantity within historic seasonal or minimal variation.	Changes in groundwater flow system, with alterations in flow quantity and location. Effects exceed historic seasonal variations, but nearby uses and environments are maintained.	Substantial flow diversions and changes in flow systems affecting nearby uses or environments.
	Duration	Resource would be reduced infrequently but not longer than the span of the Construction Phase and would be expected to return to pre-activity levels at the completion of the activity.	Resource quantities would be changed throughout the life of the mine for up to 100 years after the end of the Construction Phase; however, they would return to pre-activity levels sometime during that period.	Chronic effects; resource would not be anticipated to return to previous conditions or would take longer than 100 years to do so.
	Extent or Scope	Impacts limited geographically; discrete portions of the Project Area affected. Hydraulically connected waters beyond the Project Area are not affected.	Affects hydraulically connected waters beyond a local area, potentially throughout the EIS Analysis Area.	Affects hydraulically connected waters beyond the region or EIS Analysis Area.
	Context	Affects usual, ordinary, or abundant resources; not depleted or protected by legislation.	Affects depleted or shared resources within the locality or region, or resources protected by legislation.	Affects rare resources or resources protected by legislation.

3.6.2.1 ALTERNATIVE 1 - NO ACTION

Under the No Action Alternative, the project would not be undertaken; there would be no Mine Site development, Transportation Corridor, or Pipeline. Consequently, groundwater systems would remain in their natural state (where not already being utilized by other parties), and there would be no direct or indirect impacts on groundwater from implementation of the No Action Alternative.

3.6.2.2 ALTERNATIVE 2 – DONLIN GOLD'S PROPOSED ACTION

Based on comments on the Draft EIS from agencies and the public, one route option has been included in Alternative 2 to address concerns due to pipeline crossings of the Iditarod National Historic Trail (INHT):

- North Option: The MP 84.8 to 112 North Option would realign this segment of the natural gas pipeline crossing to the north of the INHT before the Happy River crossing and remain on the north side of the Happy River Valley before rejoining the alignment near MP-112 where it enters the Three Mile Valley. The North Alignment would be 26.5 miles long, with one crossing of the INHT and only 0.1 mile physically located in the INHT right-of-way (ROW). The average separation distance from the INHT would be 1 mile.

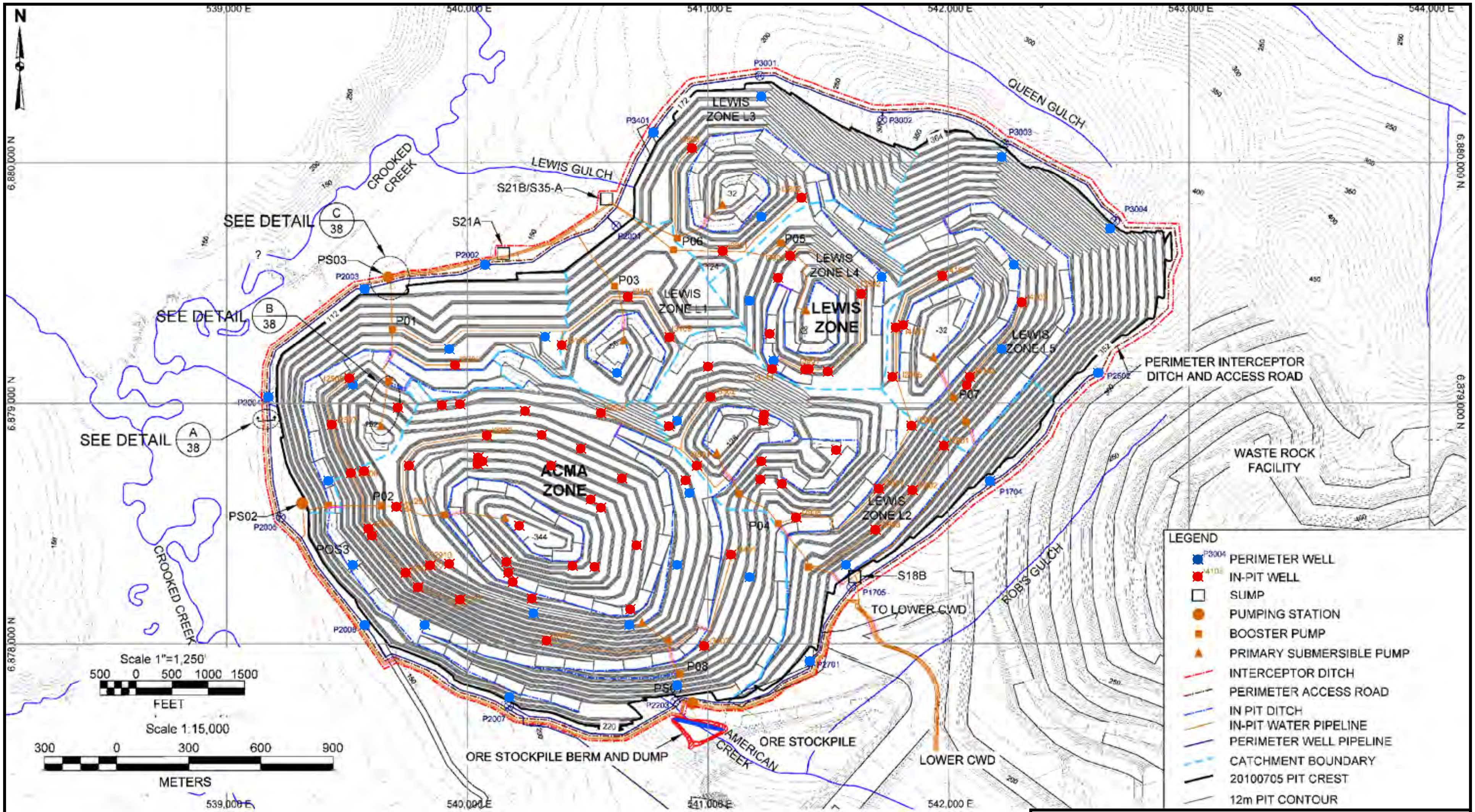
3.6.2.2.1 MINE SITE

Construction

Pit Dewatering

Construction of the open pit requires lowering the water table in and surrounding the area of the pit in order to establish stable pit walls and dry working conditions in the pit bottom. The water table is lowered by means of dewatering wells around the pit perimeter, wells in the pit bottom, and horizontal drains in the pit walls (see Figures 3.6-6 and 3.6-7). The resulting depression of the water table is known as a cone of depression. Pit dewatering would be initiated during the construction phase. Initially, approximately 17 wells would be drilled around the perimeter of the initial excavations and pumped at an average total rate of about 1,300 gpm, and up to a maximum rate of 1700 gpm when the dewatering system is turned on approximately two years prior to operations. Based on average precipitation conditions, it is estimated that approximately 4,300 acre-feet of groundwater would be pumped out during the two-year construction phase (SRK 2017b). This would result in a cone of depression that deepens and widens as excavation progresses and would last as long as the dewatering system is operated during construction and operation of the mine (see text and figures in the Operations and Maintenance section below) (BGC 2011d, 2014c).

The creation of a cone of depression around the pit changes the groundwater flow system by causing groundwater to flow towards the open pit from Crooked Creek. Groundwater would no longer discharge to the east bank of Crooked Creek in the vicinity of the pit and some of the water flowing in Crooked Creek would leak into the groundwater system and ultimately flow into the pit dewatering system. This is further described in the Operations and Maintenance section below.



Data Source: BGC 2014c

NOTES:

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DONLIN GOLD PROJECT NUMERICAL HYDROGEOLOGIC MODEL," AND DATED JULY 2014.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR DEM PROVIDED BY BARRICK GOLD CORP. DATED SEPTEMBER 1, 2004. CONTOUR INTERVAL IS 10 m.
4. FSU II PIT DESIGN (DC_MY10_DESIGN(JUL 5TH 10).dxf) PROVIDED BY BARRICK GOLD CORP. JULY 5, 2010.
5. PROJECTION IS NAD83 UTM ZONE 4N.
6. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

DONLIN GOLD
PROJECT EIS

OPEN PIT
DEWATERING SYSTEM

DECEMBER 2017

FIGURE 3.6-7

Water Use

The existing exploration camp wells would be decommissioned in early construction in accordance with ADEC (2017e) guidance, and replaced with eight water wells that would be drilled between Omega Creek and an unnamed creek to the south (Figure 2.3-7). These new wells would supply fresh water for the construction camp and ancillary water uses such as dust control, truck washing, and fire protection. The wells would be drilled approximately 3,000 to 4,000 feet from Crooked Creek. Total flow from the wells would be an average of approximately 156 gallons per minute (BGC 2014c). The wells would draw from the bedrock aquifer in an area south of Omega Gulch that forms a groundwater high or interfluve[1] between Omega Gulch and Anaconda Creek (Figure 3.6-2). An infrequent, discrete cone of depression caused by this pumping would develop around the well field, lasting primarily as long as the construction camp is operational (about three years). This cone of depression, which would be very small compared to that caused by early pit dewatering during the Construction period, would be considered within historic seasonal or minimal variation. Water rights for this proposed use of water have been applied for in the amount of 201 acre-feet / yr (125 gpm on a continuous basis).

Contact Water

Contact water would be likely to enter the groundwater system as seepage from the WRF beneath the construction-stage footprint of the WRF, the lower contact water pond, or as seepage through the lower contact water dam (CWD). This water, which could contain leachate from naturally occurring rock elements, or other mine-related materials potentially including undetonated ammonium nitrate / fuel oil explosive elements, would be captured by the ACMA pit dewatering system or by an ore stockpile berm designed to minimize runoff into the ACMA pit. In terms of intensity, groundwater flow systems would be maintained, since the water will be captured and used in the mining process. Impacts would be limited to discrete portions of the Project Area at the Mine Site. Some of the water pumped by the dewatering system would also be treated and discharged. After closure, the pit lake management system will ensure that the groundwater flow system continues to deliver this contact water to the pit lake for eventual treatment and discharge (see additional discussion of the pit dewatering system in Chapter 2).

Snow Gulch Reservoir

Construction of the Snow Gulch Reservoir would result in impoundment of surface waters and infiltration of surface water into the adjacent groundwater aquifer. The dam height of 151 feet indicates that ground water levels immediately adjacent to the reservoir would likely rise by a similar amount. Groundwater would also be expected to flow through the aquifer under and around the dam as a result of the steepened groundwater gradients, however the amount of flow is expected to be much less than the normal surface water flow in Snow Gulch as a result of the relatively low hydraulic conductivity of aquifer materials. The extent of the higher water table adjacent to the reservoir is not expected to extend any further than the Snow Gulch watershed boundaries as a result of the relatively low hydraulic conductivity of the aquifer and the relatively steep sides of the gulch above the reservoir.

---

[1] An interfluve in this context is a groundwater divide or ridge in the potentiometric surface between two adjacent drainages that flow in the same direction.

Operations

Pit Dewatering

As development of the pit proceeds, additional in-pit wells and horizontal drains would be installed to yield a peak total flow of 2,400 gpm in Year 12. Over the mine life, pit dewatering would require the use of a total of 35 vertical wells around the perimeter of the pit, approximately 80 wells in the interior of the pit, and approximately 1,790 horizontal drains progressively drilled into the pit walls, to dewater and reduce pore pressures in the bedrock aquifer. Initial wells and drains would be progressively mined out and replaced with new wells and drains, so only a fraction of the total wells and drains would operate concurrently. (The potential for the wells and drains to act as conduits for contamination to enter the aquifer is discussed in Section 3.7.3.2.3, Groundwater Quality.)

Based on average precipitation conditions, it is estimated that approximately 34,100 acre-feet of groundwater would be pumped out during the operations period, for a total of 38,400 acre-feet over the life of the mine (BGC 2015f; SRK 2017b). The effects of pit dewatering would extend to the location of the construction camp wells, which are also expected to be pumped at 30 gpm during the operational period for potable water for the plant. Pit dewatering would occur until the pit reaches its maximum depth of approximately 1,850 feet (below the high wall of the pit on the northeast side). As described in Section 3.6.1.4, a three-dimensional groundwater flow model was developed to plan and evaluate the pit dewatering, changes to the groundwater flow system, induced stream leakage into the groundwater system, and effects of the tailings and waste rock storage facilities. The results of the model analysis (BGC 2014g, c) are incorporated into the discussion below.

Groundwater obtained from the pit dewatering system would be used for mill process water, for returning water to Crooked Creek via a water treatment plant (WTP), and for dust control, fire training, and suppression. Water rights have been applied for in the amount of 5,645 acre-feet / year (3,500 gpm on a continuous basis).

The pit dewatering system is designed with numerous redundancies, including multiple wells and in-pit pumps. A complete failure of this system is considered extremely unlikely, in that it would threaten the safety of mine personnel, the stability of pit walls, and continued operation of the mine. A failure of a portion of the system, however, could result in the slow recovery of groundwater levels in the area of the failure until repairs were implemented. The effects of such a failure on the spatial extent of any contaminated groundwater in the vicinity of the pit would be minimal because it would take months to years for there to be any substantial changes in the groundwater flow systems from such a failure.

The cone of depression represents the level of the water table in the vicinity of the pit; it expands with time as groundwater is pumped and the pit expands and deepens. The maximum drawdown from the pre-mining water table at the ACMA zone (on the southwest side of the pit) is expected to be approximately 1,600 feet, occurring before the end of mining in the ACMA pit. A cone of depression would form around the open pit (see Figure 3.6-8 and Figure 3.6-9). The lowered water table would also extend southeastward to the areas of the WRF and TSF as a result of reduced groundwater recharge under those areas.

The effects of dewatering on groundwater flow directions is shown by the difference in the potentiometric surface between pre-mining conditions (Figures 3.6-2 and 3.6-4) and that predicted for the end of mine life (Figure 3.6-10). Dewatering would cause groundwater flow in the pit area to shift from the current pre-mining direction (roughly perpendicular towards Crooked Creek) toward the pit from all sides during Operations.

Effects on Crooked Creek Flow

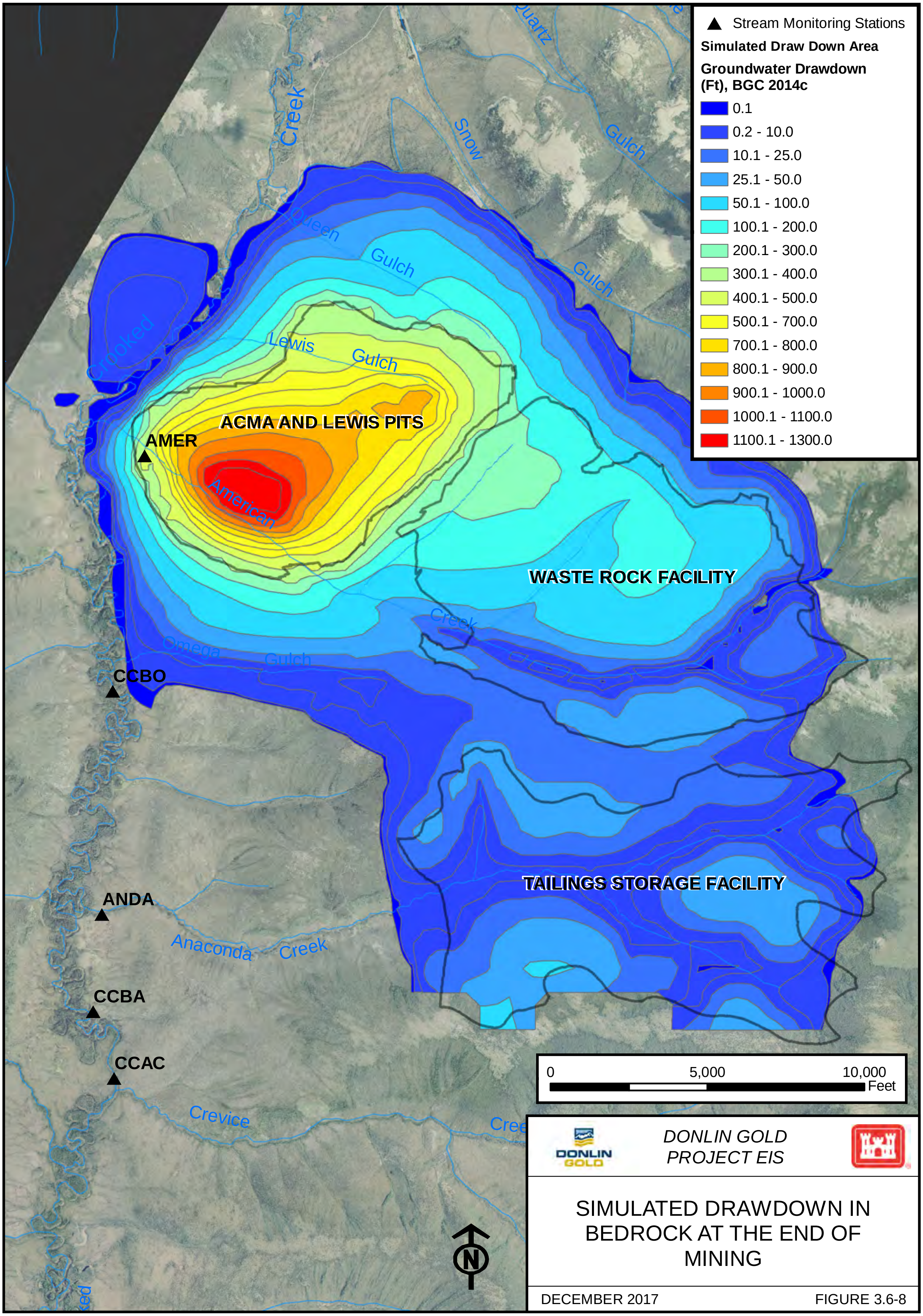
One of the effects of the cone of depression would be to direct groundwater flow radially towards the pit from all directions, rather than towards the lower reaches of local creeks and Crooked Creek, as occurs under natural conditions. The cone of depression would also induce flow of water from creeks into the groundwater system. The tight concentration of groundwater contours between the mine pit and Crooked Creek and the presence of drawdown in bedrock on the west side of Crooked Creek (Figure 3.6-8) is the result of continuous leakage of water from Crooked Creek into the groundwater flow system towards the pit and the resistance to groundwater flow caused by the relatively low hydraulic conductivity of the bedrock aquifer between the creek and the pit.

Flows in the lower reaches of local creeks and Crooked Creek adjacent to the pit would be reduced during mine operations compared to pre-mining conditions because of a reduction of groundwater discharge to streams, induced leakage from streams to the pit dewatering system, and the capture of American and Anaconda creeks for use in mining operations. Additional discussion of these surface water effects are contained in Section 3.5, Surface Water Hydrology.

The effects of pit dewatering on Crooked Creek are largest in the winter when streamflow is most supported by groundwater as baseflow. The base case groundwater model that simulates the mine scenario (see Section 3.6.1.4) predicts that some flow of Crooked Creek would be diverted to the pit dewatering system through stream leakage and groundwater flow. Sensitivity analysis simulations (see discussion below in this section) suggest that prediction of the amount of streamflow depletion is difficult.

A streamflow reduction analysis was performed that uses a combination of the groundwater flow model and a surface water flow model (called the Water Balance Model or WBM) in an integrated modeling approach (BGC 2015c, h). The integrated approach is considered superior to analyses of stream depletion using the groundwater flow model alone, because it is capable of incorporating additional data, smaller time steps, and more realistic scenarios for analysis. The integrated model addresses seasonal streamflow reduction under normal flow (50 percent likelihood), low flow (10-percent likelihood), and both mid-range and high aquifer hydraulic conductivity scenarios for different stages of mine development. These results are explained more fully in Section 3.5, Surface Water Hydrology; however, key findings are summarized here that are pertinent to the groundwater system, which during base flow conditions is the dominant driver of streamflow changes.

Stream losses to groundwater are expected to occur mostly along a 2- to 3-mile long stretch of Crooked Creek and its tributaries located in closest proximity to the pit. The reduction in streamflow resulting from losses to groundwater is most pronounced during the winter months (December through March) because streamflow is naturally lower during those months and because most streamflow during those months under natural conditions is the result of groundwater discharge to the creeks. Also, the water treatment plant, which would return water to Crooked Creek during the summer months, would not normally be operating during the winter.

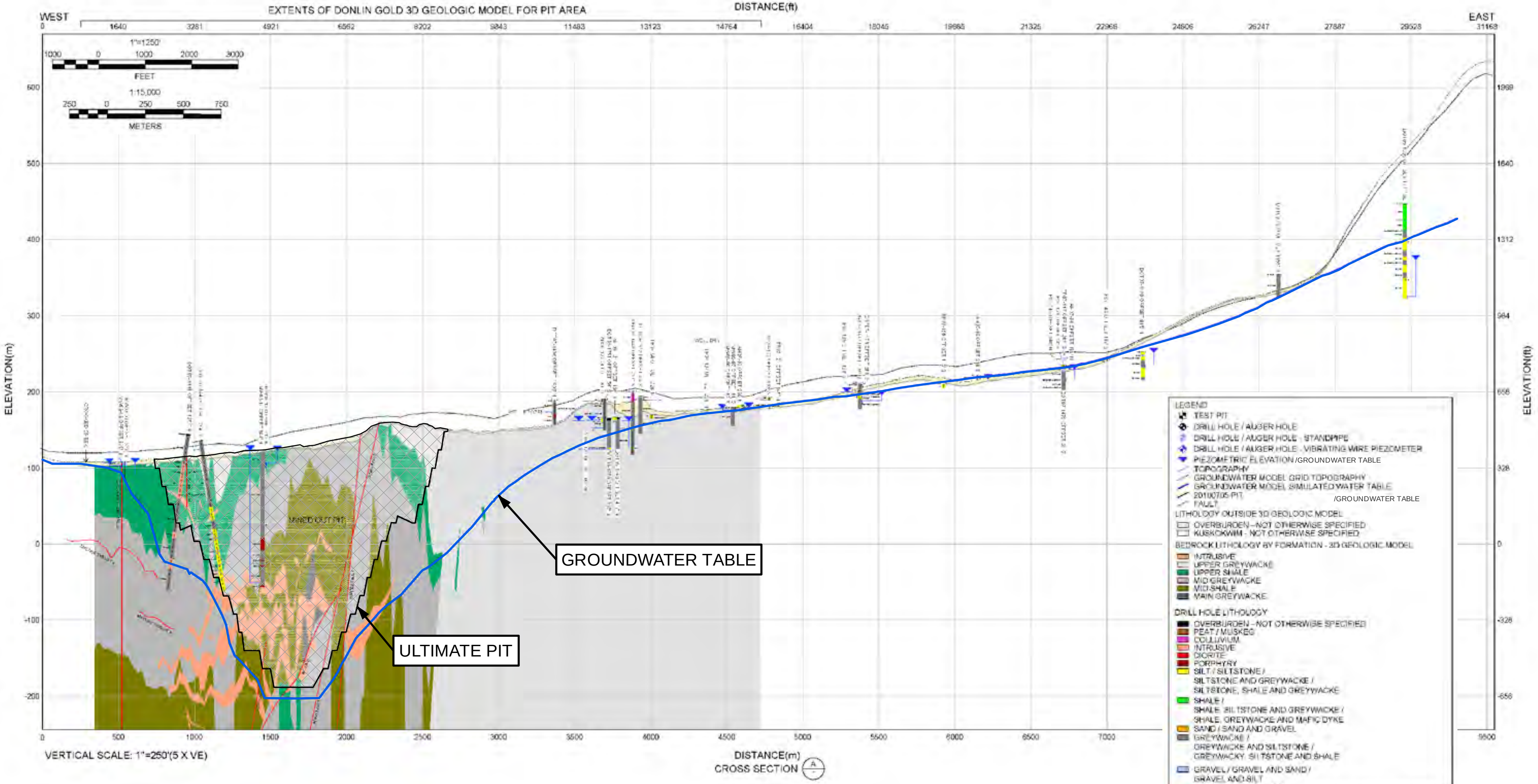


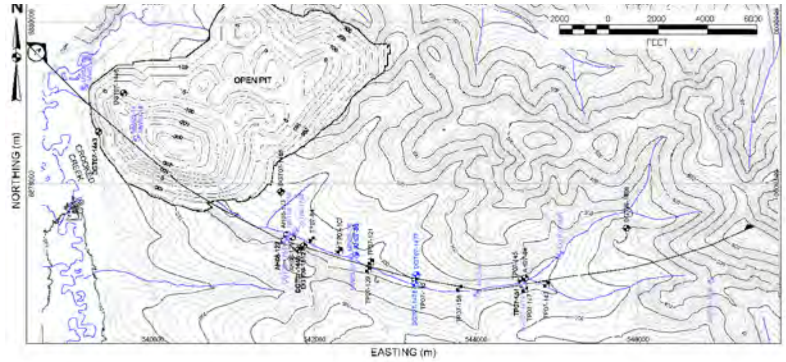
DONLIN GOLD
PROJECT EIS

SIMULATED DRAWDOWN IN BEDROCK AT THE END OF MINING

DECEMBER 2017

FIGURE 3.6-8





Data Sources: BGC 2014c

DONLIN GOLD PROJECT EIS

CROSS-SECTION SHOWING PROPOSED CONE OF DEPRESSION AROUND PIT

DECEMBER 2017

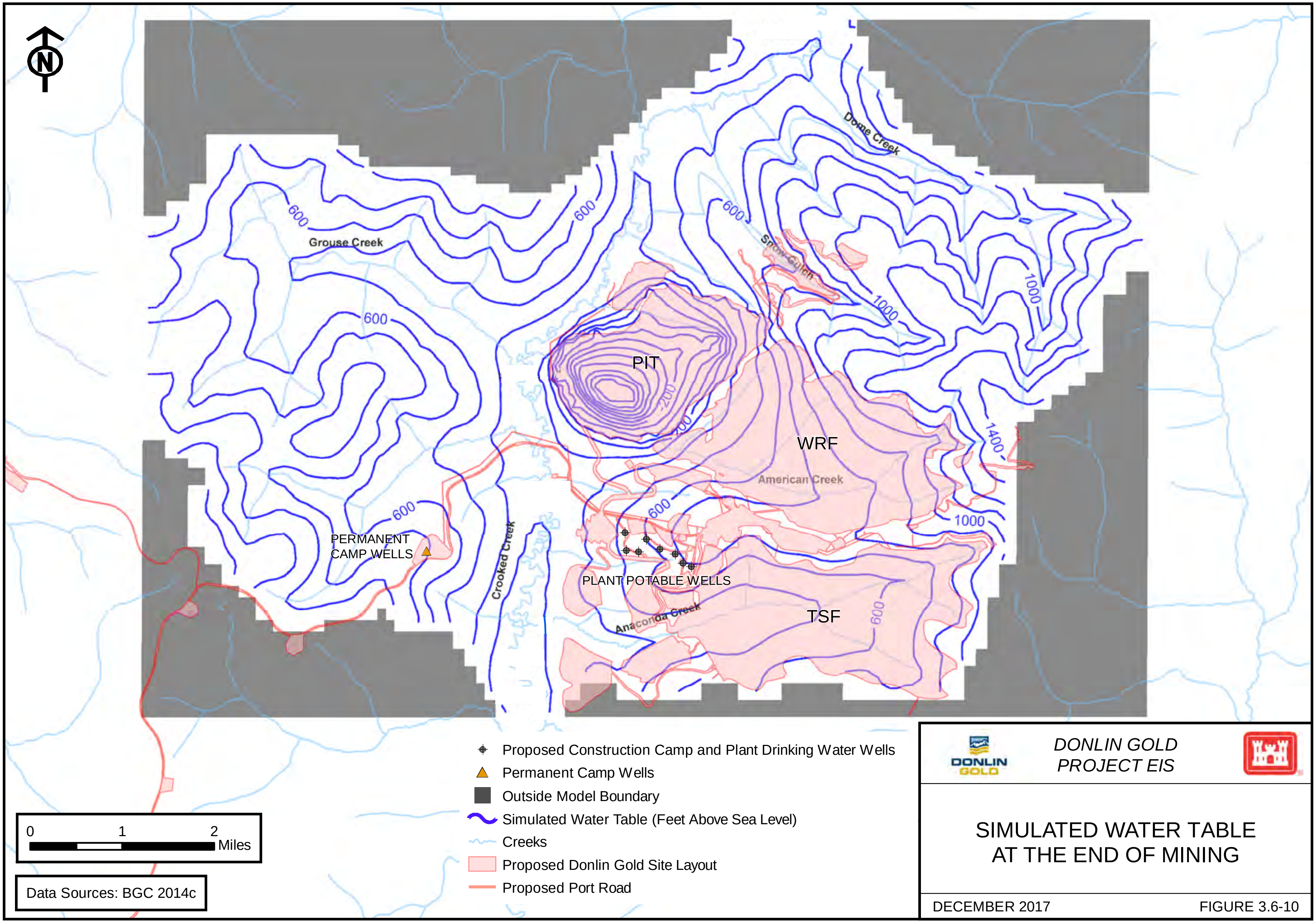
FIGURE 3.6-9

DONLIN GOLD PROJECT EIS

SIMULATED WATER TABLE AT THE END OF MINING

DECEMBER 2017

FIGURE 3.6-10



Data Sources: BGC 2014c

Under low flow conditions (10 percent probability), Crooked Creek streamflow at American Creek is expected to be reduced by almost one-third during the months of December through March (28 percent through 33 percent) at Year 20 of mine development, which is near the maximum development of groundwater impacts on streamflow (BGC 2015h). During average flow conditions, for comparison, flow reductions are expected to range from 19 to 23 percent during those months. Annual average streamflow reduction is expected to be 17 percent under average flow conditions and 22 percent under low flow conditions.

Streamflow reductions were also evaluated considering a scenario with high hydraulic conductivity (high K) values in the groundwater flow model as described in more detail below. Under this scenario at American Creek, 46 to 67 percent of wintertime flow in Crooked Creek is expected to be lost under normal (50 percentile) flow conditions, while 69 to 100 percent of the wintertime streamflow is expected to be lost under low-flow conditions at Year 20. Average annual streamflow reduction of Crooked Creek at American Creek under the high hydraulic conductivity scenarios is expected to be 31 percent under average conditions and 46 percent under low flow conditions.

During closure, impacts to streamflows are expected to gradually become reduced as the pit lake fills and the groundwater gradients driving seepage out of Crooked Creek weaken. After the pit lake reaches its full managed level, streamflow reductions in Crooked Creek caused by loss to groundwater, or by reduction in groundwater inflow to streams, are expected to be very low - generally a few percent or lower.

Effects on Crooked Creek Upwelling and Downwelling

Because of the potential effects of pit dewatering on surface water flow and upwelling in Crooked Creek (and consequently on salmon habitat and egg survival as discussed in Section 3.13.3.2.1, Fish and Aquatic Resources), a detailed analysis of upwelling and downwelling groundwater into and out of Crooked Creek was performed (BGC 2017a; Owl Ridge 2017d). The analysis, based on block-by-block examination of the groundwater model results, identified numerous discrete reaches of Crooked Creek that receive water from the alluvium (upwelling) or lose water to the alluvium (downwelling). The analysis found that pre-mining, there is a net wintertime upwelling and gain in Crooked Creek flow of 1.24 cfs in the affected reach near the mine. During mining in Year 20, downwelling flows are predicted to exceed upwelling flows to the streambed, and result in a net wintertime streamflow loss of 2.10 cfs, or about 3.8 percent of the winter (November through March) average flow of 54 cfs. This loss could reduce intergravel flow and egg survival in the segment of creek adjacent to the mine (Owl Ridge 2017d).

During post-Closure pit lake management, upwelling flows to the streambed would exceed downwelling flows, but upwelling flows would be lower than pre-mining by as much as 5 percent. The loss of upwelling flow in post-Closure represents a loss of 0.63 percent of the average winter flow of 54 cfs. It is likely that this level of change would not affect egg survival when compared to pre-mining (Owl Ridge 2017d).

Outside of the radius of influence of mine pit dewatering, affecting approximately a 4.4-mile stretch of alluvium adjacent to the mine, no changes in groundwater levels are predicted. Therefore, it is inferred that no changes to groundwater upwellings outside of this area of predicted influence (i.e., downstream from the Project) should be anticipated.

Crooked Creek Summary

Because of the effect that the flow reductions have on aquatic habitat or other streamflow-related resources (see further discussion in Section 3.13, Fish and Aquatic Resources), the intensity of impacts could result in alterations in flow quality and location, at least seasonally or under conditions of higher than expected aquifer hydraulic conductivity or unusually low natural streamflow.

The duration of maximum impacts would persist through the life of the mine and beyond, and would include chronic effects that would not be anticipated to return to pre-mining conditions. The extent or scope of potential flow reductions in Operations would occur mostly across about a 2- to 3-mile stretch around the Mine Site and would extend some distance downstream, however no further than the mouth of Crooked Creek located about 13 miles to the south. Downstream from the Mine Site, additional groundwater and surface water influx to Crooked Creek would tend to mitigate the loss of water near the Mine Site. For example, downstream of Crevice Creek, annual average flow reductions from pit dewatering would be in the range of 13 to 25 percent under average, low flow and high hydraulic conductivity scenarios, although peak monthly flow reduction would still be up to 85 percent under the low flow and high hydraulic conductivity scenario (Table 3.5-26 in Section 3.5, Surface Water Hydrology). The context of the water resource lost from Crooked Creek is considered a shared resource that is not currently depleted and is protected by legislation.

Tributaries on the east side of Crooked Creek (e.g., Queen’s Gulch) would also be depleted of water to varying degrees depending on their proximity to the open pit and use for other major mine facilities. However, tributaries on the west side of Crooked Creek are not expected to be affected because the cone of depression would not extend very far west of Crooked Creek.

Model Robustness and Accuracy

Evaluation of the results of the base case groundwater flow model includes an assessment of the model's robustness and accuracy because the reliability of the modeling results can influence management decision-making and the applicability of concepts such as adaptive management. Robustness of a groundwater model is a characteristic that describes the variability of the model’s outputs based on reasonable or plausible variations in model inputs.

As previously described, many of the input parameters to the groundwater model contain uncertainty. The resulting calibrated model, while meeting acceptable calibration criteria, is a non-unique solution to the groundwater flow equations. Other combinations of model parameters could provide comparable calibrations. Simulations of future conditions such as pit dewatering using different sets of input parameters could result in considerably different results. This effect is commonly addressed in groundwater modeling studies by performing a sensitivity analysis on the base case model (Anderson and Woessner 2002). The base case model is the calibrated transient groundwater flow model that simulates open pit dewatering as described in prior sections. During a sensitivity analysis, selected parameters are varied within plausible ranges and the effects on the models predictive results are compared. Generally, a robust model is one in which the results of such simulations do not vary significantly from the base case. If model results are found to vary significantly from the base case, then limitations on the potential accuracy and reliability of simulation results should be reported, particularly with respect to their use in making management decisions (Anderson and Woessner 2002).

A total of 11 sensitivity analysis scenarios were performed (BGC 2014c) and most of them provided relatively minor variations in model output, indicating that the model, in general, is relatively robust. One scenario was concluded to not represent a plausible variation in input parameters. Two other sensitivity analysis scenarios, however, resulted in significant variation from base case modeling results. First, the hydraulic conductivity of the bedrock aquifer was increased by a factor of five while all other model parameters remained unchanged. This variation is considered a plausible amount that hydraulic conductivity could differ from the base case (and is sufficiently different that significant differences in model output might occur) and is well within the observed range of field measurements for this parameter (BGC 2014f) (see Section 3.6.1.3.3). While this is not a probable scenario because the model is not as well calibrated under this scenario, it shows that the maximum hypothetical percent reduction in flow of Crooked Creek at Station CCBO during wintertime increases from 30 percent to 86 percent. This should not be regarded as the most reliable predictor of streamflow loss because, as previously described, the integrated modeling approach should be used for that purpose. The model results are described here because they demonstrate that the hydraulic conductivity of the bedrock is an important model variable in assessing streamflow loss.

Using the integrated modeling approach, and examining the 10th percentile low flow and high hydraulic conductivity scenario, Crooked Creek is expected to go dry above American Creek during the low flow season (Table 3.5-26 in Section 3.5, Surface Water Hydrology). Under this scenario and compared to the low flow base-case hydraulic conductivity scenario, the maximum summertime predicted reduction in flow increases from 26 percent to 61 percent and the annual average predicted reduction in flow increases from 22 percent to 46 percent. This verifies that the hydraulic conductivity of the bedrock aquifer is an important parameter of the model. Use of the base case results, even though they remain probable, should include consideration that other potential outcomes of the model, some quite different, are plausible. This is because bedrock hydraulic conductivity tends to vary from place to place by about three orders of magnitude and model projections based on a single realization of these values at or near the mean values have significant uncertainty.

Similarly, a second sensitivity analysis was conducted that simulates hydraulic conductivity zones associated with known faults. Faults have the potential to either enhance or inhibit groundwater flow, and the groundwater model has the ability to simulate the potential effects such structures may have on groundwater flow, mine facilities, and local surface water flow. Observations in the areas of the faults have not indicated that these faults exhibit either persistently higher or persistently lower hydraulic conductivity, and the base case model did not assign values to faults any different than the surrounding rock. Simulation of a low-hydraulic conductivity fault scenario (SR9) did not result in any major differences from the base case scenario (BGG 2014c). There were differences, however, in the simulations of high hydraulic conductivity faults. Conceptually, this scenario evaluates the situation where faults subcrop beneath Crooked Creek and extend for some distance away from the creek. Similar to the high-hydraulic conductivity analysis described above, the calibration worsens under this scenario. The maximum percent reduction in flow of Crooked Creek at Station CCBO during wintertime increases from 30 percent to 83 percent of flow under this scenario. The maximum summertime reduction in flow increases from 9 percent to 16 percent, and the maximum average reduction in flow increases from 20 percent to 49 percent.

Together, these scenarios demonstrate that the model results showing impacts to Crooked Creek should be regarded as uncertain, and that the analysis of project effects should include scenarios other than the base case (e.g., the sensitivity analyses described above). Should most or all of the water (at least during winter) in Crooked Creek be diverted by groundwater conditions similar to these sensitivity analysis scenarios, the loss of streamflow and creek habitat could result in substantial flow diversions and changes in flow systems affecting nearby uses or environments. The extent or scope of these impacts would affect hydraulically connected waters beyond the local area, but not beyond the mouth of Crooked Creek. The effect would last as long as the dewatering system is active during mine operations, and with gradually declining impacts through the closure period as the groundwater system recharges. In terms of intensity, chronic residual impacts caused by the permanent lowering of lake levels below the level of Crooked Creek would result in minimal historic seasonal variation or minimal variation.

Permanent Camp Water Use and Domestic Wastewater Disposal

Potable water for the permanent camp at the Mine Site would be obtained from four water wells that would be drilled at the permanent camp site about 1.3 miles west of Crooked Creek (Figure 3.6-10). These wells would be designed to supply a volume up to approximately 50 gpm during operations. The permanent camp would be sited on a ridgetop underlain by highly fractured granodiorite (same as material site MS01; see Figure 2.3-12 and Section 3.1.2.2.3). The permanent camp wells would likely draw groundwater from an aquifer in this fractured bedrock. Water rights for the permanent camp have been applied for in the amount of 50 acre-feet/year (equivalent to 31 gpm on a continuous basis).

Approximately 30 gpm would continue to be supplied from the wells near the construction camp for potable plant use. This is about one-fifth of the volume of water needed from these wells during construction. The infrequent, discrete cone of depression caused by pumping these wells in Construction (Section 3.6.2.2.1) would remain in Operations, but reduced in size. It would be very small compared to the cone caused by dewatering of the pit, which would result from pumping about 30 times as much water (average of 844 gpm, Figure 3.5-22). As a consequence of pit dewatering, groundwater flow directions near the pit would change during Operations and be directed toward the pit (Figure 3.6-10); however, flow directions in the area of the plant supply wells would remain largely unchanged from pre-mining conditions. The plant potable wells would lie outside of the pit/TSF cone of depression (Figures 3.6-8), and would be upgradient or cross-gradient from any shallow groundwater contamination that may develop in drainages beneath the WRF and TSF (see Section 3.7.3.2.3, Environmental Consequences, Groundwater Quality).

Impacts on groundwater from domestic well use would last through the life of the mine, with reduced impacts extending into the closure period. In terms of intensity, water usage would not create changes in water quantity outside of minimal variation levels.

Domestic wastewater may be treated and discharged to Crooked Creek or piped to the TSF during operations, with no impact on groundwater different from effects described separately in the TSF section below.

Snow Gulch Reservoir

Snow Gulch reservoir is planned to be operated near a reservoir-full condition during most operational periods when water from the reservoir is not needed. The water table near the reservoir would remain in an elevated position during this period and the conditions described during the construction period would remain.

Tailings Storage Facility

The TSF would be lined for the purpose of preventing leakage out of the TSF, and for controlling any leakage that does occur by conveying it to a Seepage Recovery System (SRS). However, for design purposes, it is the state-of-practice to assume that some leakage would occur. Studies have shown that a design liner defect ratio of 0.16 in^2 of flaw per acre is conservative for evaluating potential liner leakage rates on projects with full-time QA/QC monitoring by certified liner technicians during liner installation, material selection, foundation preparation, and use of appropriate equipment and construction personnel and practices (Giroud and Bonaparte 1989; Giroud et al. 1994; Schroeder et al. 1994b). These conditions are expected to be the case at the TSF based on proposed liner bedding selection and preparation (BGC 2011a), and experience at similar mines conducted under the oversight of the Alaska Dam Safety Program. Modeling studies have estimated that up to 18 gpm of water distributed across the spatial extent of the TSF would leak from the facility using this defect ratio. The TSF would be designed with a rock underdrain that would serve two purposes: 1) capture and direct any TSF leakage to the SRS located immediately downgradient of the TSF dam; and 2) collect groundwater from areas upgradient of the TSF and direct it to the SRS as TSF underflow. While predicted underflow would vary somewhat during operations as a result of varying pit dewatering and other factors, at mine closure, the quantity of groundwater captured by this system is estimated to be about 450 gpm, of which 18 gpm is estimated to be from the TSF (BGC 2014b, c; SRK 2017b). After closure, similar quantities of flow would persist. Thus, seepage of water from the TSF through defects in the liner is estimated to represent up to 4 percent of the water reporting to the SRS. The results of various sensitivity analysis scenarios suggest that groundwater flows to the underdrains could range from 200 gpm to 680 gpm (BGC 2014c).

The SRS would consist of an unlined pond, pumps, pipeline, ditches and monitoring/seepage recovery wells, the locations of which are shown in Figure 2.3-7 (Chapter 2, Alternatives). The SRS pond would function as a collection point to receive flow from groundwater entering the underdrain and any TSF leakage, and send it to either the process plant or water treatment plant (Figure 3.5-22, Sections 3.5.3.2.1 and 3.7.3.2.2). A sump would be completed into bedrock at the downstream end of this pond and would contain a gallery of submersible pumps. The water level would be maintained below the level of the base of both the underdrain and the overburden on the downslope side of the pond (Weglinski 2015d, SRK 2016c, BGC 2016c). Pre-development, the static water level in the pond area is predicted to be above the overburden/bedrock contact. Pumping from the pond would be sufficient to create hydraulic containment and prevent leakage to groundwater. Using hydraulic containment within the unlined SRS pond would allow the collection of underflow from a broader area than just the underdrain to ensure hydraulic containment.

Four monitoring/interceptor wells (MIWs) and four compliance wells would also be installed in two rows downgradient of the tailings pond, with two on each side of Anaconda Creek in each row (Figure 3.5-21). The MIWs installed on each side of Anaconda Creek would include one deep (328 feet) and one shallow (164 feet deep) well. The MIWs would be capable of pumping 45 to 90 gpm each and would discharge to the SRS pond (SRK 2017b). The purpose of the MIWs and compliance wells is to 1) monitor groundwater quality to verify that groundwater does not deteriorate; and 2) to create a completely closed flow system to capture any potential leakage from the TSF or SRS pond into the groundwater system if water quality deteriorates. The MIWs would essentially constitute a backup hydraulic containment capability that, in the absence of TSF leakage, would not be used. Pumps in the compliance wells would only be used for sampling, not hydraulic containment. The quality of water from the pond and wells would be monitored to determine the operational requirements of the system. Excess water in the pond would be pumped either to the process plant or directly into the TSF. Water rights for the diversion of groundwater via the TSF underdrains and seepage recovery wells have been applied for in the amount of 2,841 acre-feet / year (1,761 gpm on a continuous basis).

The effects of the TSF on groundwater resources in the immediate vicinity of the TSF would be:

- Local capture and diversion of approximately 760 gpm two years before operations begin, to a maximum of about 900 gpm in Year 4 of operations, and down to 480 gpm at Year 27, of groundwater flow from its natural flow system to a rock underdrain under the TSF and discharge to a newly constructed SRS pond (BGC 2016c). The water would then be incorporated into the water use / recycling system of the processing plant, the WTP system, and the TSF. Pumping capacity from the SRS will be sized during the design phase to accommodate the largest anticipated inflows to the SRS.
- Pumping of up to 360 gpm of groundwater from four monitoring / seepage recovery wells, if needed as determined by water quality sampling. The liner under the TSF, assuming it functions as intended, would prevent seepage from the TSF, and the SRS pond would collect water from the underdrain such that the wells would not need to be pumped. Should it occur, the pumping would create a local cone of depression around the wells that is designed to capture all leakage from the SRS; however, it would also capture other groundwater. This water would also be incorporated into the water use / recycling system of the processing plant, WTP, and TSF pond.

Downstream of the TSF, the flows of Anaconda Creek and Crooked Creek would be diminished by the diversions described above, as well as by the diversions of surface water flows into the TSF. The combined diversions of groundwater and surface water are expected to reduce average flow in Anaconda Creek at its confluence with Crooked Creek by approximately 30 percent at Year 20 of mining (Table 3.6-2, SRK 2012b). This is because additional water enters Anaconda Creek below the TSF and SRS. In terms of intensity, the effects of these diversions are expected to result in alterations in flow quantity and location, although flow systems would be partially maintained. The extent or scope would be limited to discrete portions of the Project Area at the Mine Site. These effects would be chronic and the resource would not be anticipated to return to previous conditions or would take longer than 100 years to do so.

The hydraulic containment system of the SRS would require monitoring, analysis, operation, periodic repair, and management to assure its continuing function and effectiveness. During operations, on-site observations and flow measurements would lead to rapid identification of pump failure problems and use of backup pumping capacity in the event of system failure, and the avoidance of the release of water to the environment. Thus, the likelihood of failure during this period of time is considered very low. Considering the long duration of pumping during Closure and post-Closure conditions; however, (especially during winter when staffing levels are reduced) the harsh climate, the remote location, and the number of task-critical components, the possibility of a pumping failure is plausible and the consequences of a failure merit examination. Long-term monitoring and maintenance is planned which would minimize such risk. The location of the facility in a different drainage than the pit and other facilities means that reliance on a gravity-driven backup diversion or storage system is likely not feasible.

Calculations suggest that if the SRS pumping system were to go completely off-line, the SRS would likely fill to overflowing in about a week under average precipitation conditions (Section 3.5, Surface Water Hydrology) and/or lose hydraulic containment with respect to groundwater in approximately two weeks, although there are many variables such as time of year and amount of drawdown at the start of the failure that could affect this calculation. Still, considering these variables, this is a very short timeframe in which to identify a problem, diagnose the cause, acquire any necessary components, and effect repairs, especially if it occurs during winter conditions during closure or post-Closure when staffing levels are lower than during operations. Analysis of the potential quality of water in SRS shows that the water would exceed relevant standards for several parameters (see Section 3.7.3.2.2, Surface Water Quality, Closure).

If the SRS pump system were to fail, in addition to the possibility of SRS overflow to surface water, it is likely that contaminated groundwater would enter the flow system towards Crooked Creek if hydraulic containment of the SRS system is lost. In this event, the affected groundwater would be impractical to retrieve because it would relatively quickly flow outside of the radius of influence of the SRS wells. Natural groundwater flow patterns in this area indicate that groundwater would eventually discharge to the lower reaches of Anaconda Creek and to Crooked Creek; however, natural attenuation processes in groundwater could slow and eventually halt the flow of contaminated groundwater between the SRS and Crooked Creek, a distance of about 1.6 miles. There are many factors that influence plume migration and natural attenuation (e.g., volume of release, season, precipitation, liner leakage rate, SRS water quality, hydraulic conductivity of alluvium, aquifer biogeochemistry), and the timeframe for groundwater to be restored to pre-development conditions is expected to be lengthy but unknown. Also, should contaminated groundwater eventually reach surface water, the rate of groundwater discharge would be relatively low and may be completely masked by dilution from surface water flow.

The release of SRS water to the environment during the approximately 52-year period when the covered tailings drain and consolidate, would only occur in the event of a pump failure greater than two weeks in duration, and such an event is considered unlikely but plausible under Alternative 2. The impacts of this (as described in Section 3.7, Water Quality), while considered a low probability, would result in substantial flow diversions and changes in flow systems affecting nearby uses or environments. Impacts could last for a number of years following such an incident. The extent or scope of impacts would be limited to discrete portions of the Project Area at the Mine Site. The context of impacts would affect shared resources that are not currently depleted and are protected by legislation.

Waste Rock Facility

The WRF would be located in the American Creek valley upstream of the pit. The WRF would be unlined, and long-term modeling shows that a portion of rainfall and snowmelt would infiltrate through the surface of the facility and flow out of the bottom of the waste rock pile (O'Kane Consultants, Inc. 2009). Beneath the facility, a rock underdrain would be constructed to direct some of this water into the lower contact water pond near the toe of the facility. The WRF and the rock underdrain system have the potential to pass water into the underlying groundwater because they are not underlain by liners. The flow of this contact water is further described in Section 3.7, Water Quality. However, the location of the WRF in the surface water and groundwater flow systems that drain into the pit lake create a closed system whereby the effects on groundwater are limited to the immediate vicinity of the WRF and the small area between the WRF and the open pit. Modeling analysis has shown that groundwater beneath and downgradient of the WRF would be captured by the pit dewatering system and, after the system is deactivated at the end of mining operations, by the groundwater flow system discharging into the pit lake (BGC 2014c). The regular active pumping of water from the pit lake would effectively prevent contaminated groundwater from flowing away from the pit.

South Overburden Stockpile

The South Overburden Stockpile (SOB) (Figure 2.3-6, Chapter 2, Alternatives) would contain terrace gravel and colluvium materials excavated from the open pits which are considered potentially metal leaching. Seepage and surface runoff that comes into contact with materials stored in the SOB may require collection and treatment. Surface and seepage runoff from the stockpile will be captured by a sediment pond and pumped to the Lower CWD.

During operations, the inactive faces of the stockpile will be progressively reclaimed to minimize the potential for surface entrainment and infiltration. All materials placed in the SOB will ultimately be returned to the WRF over the course of mine operations and placed either as the base cover layer for final reclamation of the WRF or used as internal capping materials for the PAG cells.

Water from the sediment pond has the potential to leak into groundwater. The sediment pond is located near the edge of the cone of depression created by pit dewatering, so that the direction of groundwater flow during at least part of the operations period is assumed to be towards Crooked Creek. The quantity of groundwater that may flow away from the sediment pond would be relatively low as a result of the small size of the facility, the limited collection of water in the sediment pond, the relatively low hydraulic conductivity of the colluvial deposits at the site, the accumulation of silty sediments in the pond, and the temporary presence of the SOB soils.

Water percolating through the SOB also has the potential to enter groundwater and flow towards Crooked Creek. The quantity of water entering groundwater through this process may also be low as a result of the small size of the facility, the relatively low hydraulic conductivity of the SOB soils and the underlying soils, and the temporary presence of the soils. The fate and transport of this groundwater is uncertain; however, the impacts on Crooked Creek may be minimal or nonexistent as a result of natural attenuation processes on dissolved constituents, such as sorption onto aquifer materials, chemical precipitation of dissolved constituents, dilution, and dispersion.

Several potential mitigating measures are described in Chapter 5, Impact Avoidance, Minimization, and Mitigation, including conducting further studies such as fate and transport groundwater modeling during final design to quantify the expected rate of seepage loss and impacts to Crooked Creek; creating a system of hydraulic containment for the sediment pond; installing a liner under the pond, the SOB soils or both; and installing groundwater monitoring wells. Also, during the operational period, maintenance, monitoring, and contingency plans should be used to ensure that the pond does not overflow as a result of pump failure. Following removal of the SOB soils, sediment accumulations in the sediment pond should be removed to eliminate a potential future source of groundwater contamination.

Closure

Pit Lake

Pit-Filling Period

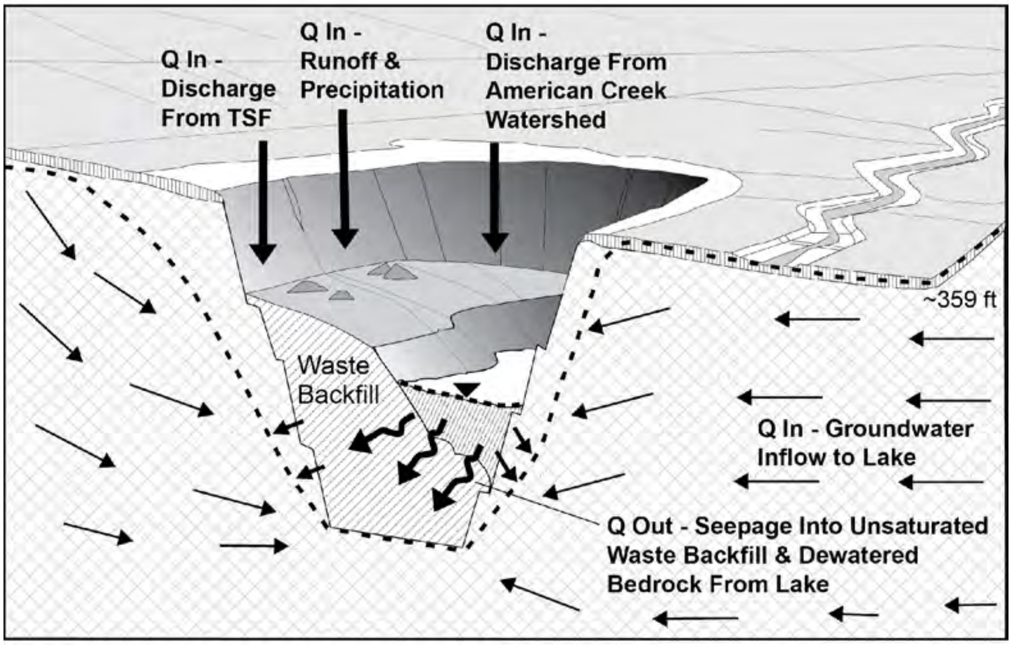
After completion of mining operations, the pit dewatering system would be turned off. The pit lake would fill to its maximum design water level in approximately 52 years with water from the following sources: groundwater inflow, runoff from the American Creek watershed, gravity-flow runoff and seepage from the WRF, and TSF discharge (BGC 2015g). Figure 3.6-11 shows the conceptual model of water flows during the period of pit lake filling.

During the entire 52-year filling period, water would also flow from the pit lake into the dewatered bedrock and waste rock backfill in the pit. The rate of this water flow would be greatest during the first eight years of pit lake filling, declining from about 2,300 gpm to about 1,000 gpm (Figure 3.6-12). After eight years and up to when the lake pit fills, the rate of water flowing out of the pit into groundwater would gradually decline from about 1,000 gpm to 0 gpm.

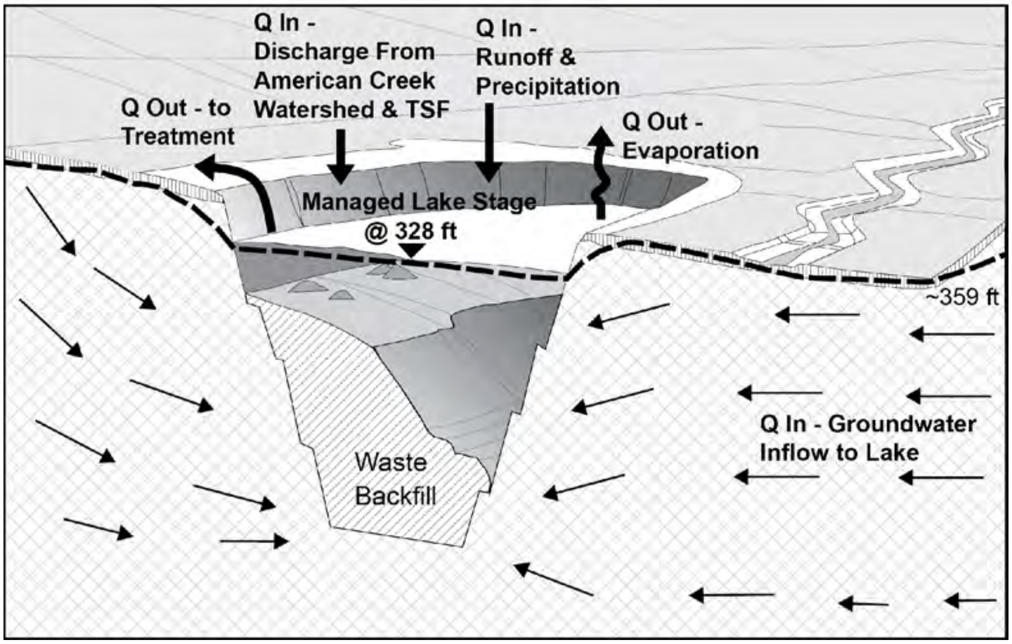
Water flowing out of the lake during this period would go into storage by filling pore spaces in the backfill and nearby bedrock. This is a long and slow process. From the end of mining, when the water levels in bedrock are expected to be more than 1,110 feet below sea level (BGC, 2014c), the potentiometric surface would rise to levels that are still below sea level in the pit bottom 10 years after closure (BGC, 2017f). Eight years after closure, the pit lake water level would be approximately 40 feet below sea level (BGC, 2014c, Drawing 48) compared to heads in the bedrock aquifer between approximately 300 and 350 feet above sea level beneath Crooked Creek (BGC 2017f), maintaining a strong hydraulic gradient towards the pit bottom during this time period.

Particle-tracking simulations and layer-by-layer displays illustrate how this flow changes with time and depth (BGC 2014c, Drawings 51 to 53; BGC 2016b, Slides 13-17; BGC 2017f). The analysis shows that overall hydraulic containment is maintained within the areal footprint defined by the perimeter of the pit rim. Water which has previously left the pit lake throughout the pit-filling period has no pathway for contaminated groundwater to leave the pit lake hydraulic sink system or temporary storage areas at various depths and not return. During the pit-filling period (Years 0-52 after cessation of dewatering), a strong hydraulic gradient, driven by topographic highs well beyond the temporary bedrock storage area, as well as the steepness and depth of the pit, would direct overall groundwater flow towards the pit lake.

The lateral extent of the temporary groundwater flow reversal during pit filling is expected to be localized, and would be hydraulically contained by groundwater flowing towards the pit lake, which would function as a hydraulic sink as shown in Figure 3.6-11. Thus, overall hydraulic containment of contact groundwater would still be maintained during the pit-filling period, and pathways for escape of contaminated water would not occur, as a result of the greater head from groundwater outside this zone and flow towards the pit lake. Water levels would be monitored in wells near the pit to confirm that these processes are occurring.



Early Pit Lake Filling Period



After Pit Lake is Full

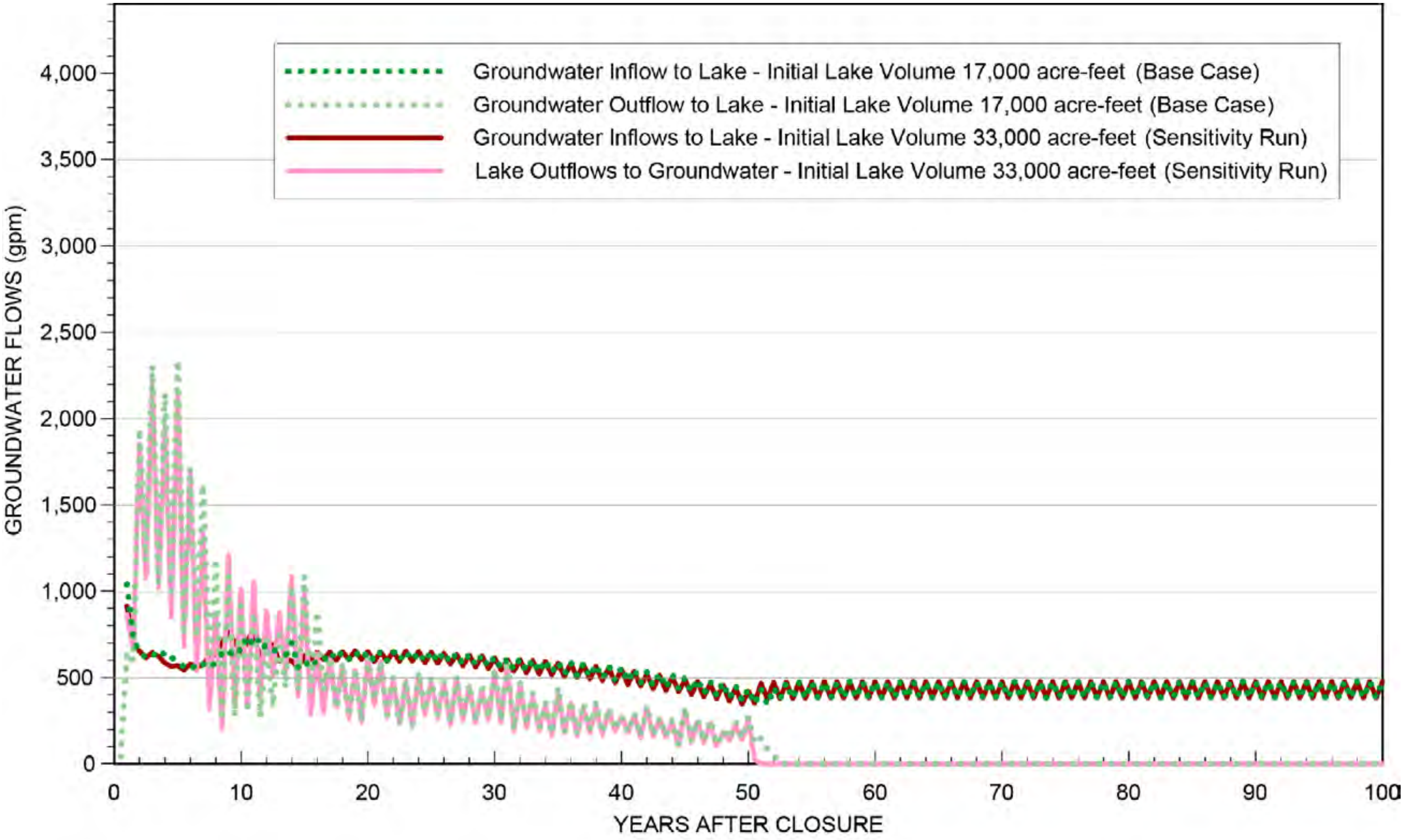
Q = Flow
Data Source: BGC 2014c

DONLIN GOLD
PROJECT EIS

GROUNDWATER SYSTEM AT PIT LAKE IN CLOSURE PERIOD

DECEMBER 2017

FIGURE 3.6-11



Data Source: BGC 2015g

DONLIN GOLD
PROJECT EIS

PREDICTED GROUNDWATER
FLOWS TO AND FROM
PIT LAKE

DECEMBER 2017

FIGURE 3.6-12

During the entire pit-filling period, groundwater would also flow into the pit at rates ranging from 200 to 600 gpm from seasonal recharge to the groundwater system (Figures 3.5-26 to 3.5-28) (SRK 2017b). Natural recharge to groundwater from the land surface and recharge to groundwater from pit lake water would cause the cone of depression to slowly recover.

Two sensitivity analyses scenario simulations of the groundwater model resulted in model variations of 13 or more years for the predicted fill time for the pit lake. By increasing groundwater recharge and streamflows by a factor of two throughout the model in order to explore a wet climate scenario, the pit lake was calculated to fill in 26 years following the cessation of mining (BGC 2015i). By increasing the hydraulic conductivity of bedrock by a factor of five (and using the base case recharge and streamflow values), the model predicted a fill time of 39 years, 13 years quicker than the base case scenario of 52 years (BGC 2015i). These scenarios serve to illustrate the range of uncertainty in the base case model findings on the length of time needed to fill the pit lake.

Post-Closure Pit Lake

The groundwater model also shows that groundwater is expected to flow into the pit lake from all directions during all seasons after the pit lake has achieved its maximum design water level. Analysis and simulations show that, around the west, southwest, and part of the northwest sides of the pit, there would be a groundwater divide between the pit lake and the creek at all layer depths in the model, preventing flow of pit lake water to Crooked Creek or beyond. This ridge is located about halfway between the pit rim and Crooked Creek. Along the remainder of the northwest side of the pit, there would be a continuous hydraulic gradient from the creek to the pit lake, also preventing flow of water from the pit lake to the creek. The areas with the water-table ridge and the areas with the continuous gradient towards the pit lake encompass all of the area between the pit lake and the Crooked Creek (BGC 2017f, Figures 6-9) and are outside of the pit rim perimeter, demonstrating complete hydraulic containment of the pit lake water and water that had previously entered dewatered pore spaces in the bedrock and backfill material.

The WRF would be located within the groundwater catchment basin of the pit lake, and any leakage beneath the facility would discharge to the pit lake and not enter other surface water bodies in the area. Water from the pit lake would be pumped and treated prior to discharge.

An analysis by Lorax (2012a) showed that, even under various scenarios, the predicted water quality of the lake will not meet applicable water quality criteria without treatment. Thus, a water treatment and lake level management plan has been developed. Under this plan, the maximum design water level of the pit lake would be approximately 10 to 30 feet below the level of Crooked Creek (adjacent to the open pit). The pit lake level would be managed by seasonal pumping, treating, and discharging of water to Crooked Creek to prevent unmanaged flow from the pit lake to Crooked Creek. As a result of pumping, and also because of seasonally-variable hydrologic inputs to the lake, the water level in the pit lake is expected to fluctuate at levels below the maximum design water level.

There would also be an ongoing change in the discharge/recharge relationship between Crooked Creek and groundwater near the pit. After stabilized water levels are achieved (i.e., after the filling of the pit lake to the design level), Crooked Creek would lose water to the groundwater system, opposite of the pre-mining flow system of groundwater providing recharge to the creek.

Separately, Crooked Creek would also experience changes in flow from the diversion of American Creek into the pit lake. Water would be diverted into the pit lake during both winter and summer, and then the pit lake water treatment plant would treat and discharge this water back to Crooked Creek during the summer. These changes are described more completely in Section 3.5.3.2.1, Surface Water Hydrology.

Thus, while changes to the groundwater flow system would be chronic and the resource would not be anticipated to return to previous conditions (or would take longer than 100 years to do so), the intensity of impacts is expected to result in flow systems levels that are maintained mostly within the limit of natural variation. The extent or scope of effects would be limited around the immediate vicinity of the pit lake and some distance down Crooked Creek.

Tailings Storage Facility

Water stored in the TSF at the end of mining operations would be pumped to the edge of the pit rim where gravity flow through a pipe would deliver the water to the bottom of the pit lake. After closure and reclamation, the liner beneath the tailings and on the upstream face of the dam would remain intact; therefore, the expected spatial extent and rate of seepage would be expected to be 18 gpm and would not change substantially from the operational conditions. Groundwater discharge to the TSF underdrain would vary seasonally, from an average of 370 gpm during winter to 440 gpm during summer (BGC 2014c). Monitoring would continue into the post-Closure period, and if the water quality is shown to meet water quality standards, then the SRS would be decommissioned. SRS water would be pumped to the pit lake until such time as it meets water quality standards (see Section 3.7, Water Quality). The local diversion of groundwater beneath the TSF through the rock underdrain would continue permanently.

After reclamation of the surface of the TSF is complete, surface water flows in the Anaconda Creek valley upstream of the tailings dam would be diverted into the Crevice Creek watershed. This would reduce groundwater recharge in the Anaconda Creek Valley compared to pre-development conditions, and result in a net increase in flow in Crevice Creek and a decrease in flow in Anaconda Creek downstream of the tailings dam. Because Crevice Creek and Anaconda Creek both discharge into Crooked Creek, the effects of these changes in flow would be limited to discrete portions of the Project Area and would not be expected to extend any further down Crooked Creek than the confluence with Crevice Creek. In terms of intensity, all of these impacts are expected to result in changes in water quantities that are within historic seasonal or minimal variations since small creeks commonly exhibit large natural variations in flow.

Waste Rock Facility

The effects of the WRF on groundwater during and after closure and reclamation would be similar to what they would be during operations. Capping and vegetation placed during closure would likely reduce seepage rates through the facility, but the overall effect on groundwater resources would be minor. Modeling analysis has shown that groundwater beneath and downgradient of the WRF is captured by the pit lake after the lake has achieved its highest design water level during both summer and winter conditions (BGC 2014c).

Snow Gulch Reservoir

During the closure process, the Snow Gulch Reservoir would be breached and groundwater conditions in the vicinity would gradually return to pre-development conditions.

Potable Water Wells

The potable water wells remaining in use at the plant site during Operations would be decommissioned at Closure in accordance with ADEC (2017e guidance), and the small cone of depression around these wells would gradually disappear. The permanent camp and associated potable water wells would remain during Closure to support continuing reclamation and water treatment activities, although flow rates would be reduced in proportion to staffing reductions.

Summary of Mine Site Impacts

In terms of intensity, mine pit dewatering during Construction and Operations at a maximum planned groundwater pumping rate of 2,400 gpm would range from changes in water quantities within historic seasonal or minimal variation, to substantial flow diversions and changes in flow systems affecting nearby uses or environments. During Closure, the intensity would range from changes in water quantities within historic seasonal or minimal variation, to changes that exceed historic variations, but nearby uses and environments are maintained. Most of the pumped water would be used for process water, and excess water would be treated and returned to Crooked Creek. Water would seep from Crooked Creek and tributaries near the pit into the pit dewatering system, although most of the time the amount would be a small proportion of the surface flow. During winter conditions and under low flow (i.e., dry year) and high hydraulic conductivity scenarios, a majority or all of the flow in Crooked Creek in some segments could leak into groundwater and be diverted into the pit groundwater dewatering system.

Infiltration of water through the SOB and pumping of the sediment pond could result in changes in potential migration of contact groundwater towards Crooked Creek. Potential impacts to groundwater quality at the SOB are discussed in Section 3.7, Water Quality.

At closure, contact water would temporarily migrate out of the pit lake into local surrounding bedrock during the period of lake filling, but would flow back towards the pit after the pit lake reaches its maximum managed stage. Overall hydraulic containment of contact water would be maintained at all depths of the pit lake due to strong topographic gradients well beyond the pit rim.

The highest intensity groundwater impacts would be during the period of active mining and early closure period. However, some effects to the groundwater flow system would result in chronic effects and the resource would not be anticipated to return to previous conditions or would take longer than 100 years to do so. The pit lake level will be managed in post-Closure to remain below the level of water in Crooked Creek, thereby inducing groundwater flow from the creek to the lake at all times. This constitutes a permanent reversal of groundwater flow directions towards the pit lake rather than towards local streams as occurs under pre-mining conditions. After the pit lake achieves its maximum managed level, the amount of leakage from Crooked Creek would be a small percentage of the overall flow in the creek, because the groundwater gradients would be very low compared to those present during mining, and because the intensity of the effects would result in changes in water quantities that are within historic seasonal or minimal variation.

Groundwater resources would be affected in a local area of approximately 20 square miles encompassing the pit, WRF, and TSF; however, impacts would mostly remain on the east side of Crooked Creek.

There are not expected to be any impacts to planned drinking water sources; however, local impairment of groundwater quality in the vicinity of the WRF, pit, SOB, and SRS could hamper future development of drinking water supplies in those areas, although none are currently planned. Groundwater is an abundant but shared resource in the area, and its use, diversion, and discharge is regulated by state laws and regulations.

3.6.2.2.2 TRANSPORTATION CORRIDOR

Port facilities planned for the Angyaruaq (Jungjuk) Port are anticipated to require development of water supply systems for offices and warehouses.

Construction

Construction of a potable water well would be required at the Angyaruaq (Jungjuk) Port. The well would be constructed in compliance with State public well construction standards. Water rights have been applied for from a well in the amount of 0.55 acre-feet/year (0.34 gpm on a continuous basis) and all conditions would be complied with.

Indirect impacts are expected at the Bethel and Dutch Harbor ports, where facilities would be operated by third parties. At the Bethel Port, facilities would most likely be hooked up to the Bethel public water and wastewater systems, and the increased demand would be within the capacity of the systems. Should on-site well water be needed, deep subpermafrost aquifers are assumed to be available, similar to water resources currently tapped by other users in the area (Section 3.6.1.2.2). Any wells drilled would be constructed in compliance with state public well construction standards. Authorization to use water would be obtained from the State of Alaska, and all permit conditions would be complied with. Any actions that would occur at Dutch Harbor or the Port of Bethel at the Bethel Yard Dock are not part of the proposed action, and are considered connected actions (see Section 1.2.1, Connected Actions, in Chapter 1, Project Introduction and Purpose and Need).

Operations

The potable supply well would be operated at the Angyaruaq (Jungjuk) Port for the duration of project operations. The quantity of water used would make up a small portion of the capacity of local or regional aquifers. These impacts would be limited to discrete portions of the Project Area and persist throughout the life of the mine for up to 100 years after the end of the Construction Phase.

Closure

At project closure, the potable water well at the Angyaruaq (Jungjuk) Port would be abandoned according to ADEC regulations. Any impacts on local and regional aquifers would be restored to pre-development conditions.

Summary of Transportation Corridor Impacts

Anticipated effects from the Construction, Operations, and Closure of the Transportation Corridor associated with Alternative 2 would be limited to small stresses on the aquifers tapped by water supply wells for new port facilities. In terms of intensity, these stresses are anticipated to be within the capacity of aquifers to support without impacting other water users or nearby surface water resources. Impacts would last the life of the project. The extent or scope of impacts would be limited to the vicinity of the wells constructed or pumped. The context may affect depleted or shared resources within the locality. It is anticipated that there will be no indirect effects on groundwater as a result of the Transportation Corridor.

3.6.2.2.3 PIPELINE

Construction

Groundwater and surface water resources are closely connected along portions of the pipeline route - primarily near stream crossings or at water take points. In many other locations, groundwater occurs within the planned pipeline burial depth (CH2MHill 2011b; SRK 2013b). Based on terrain features, the occurrence of shallow groundwater intersected by the pipeline trench along the Alternative 2-North Option is expected to be roughly 3 miles less than that of Alternative 2. Groundwater would also be used for camp water supply sources. Although not currently proposed, other potential uses of water for construction purposes if needed include hydrostatic pipeline testing, ice road construction, HDD and installation, dust suppression, and other uses.

Potential direct impacts to groundwater during the construction phase of the Pipeline could result from the installation of the pipeline at river and stream crossings, and temporary disturbance of groundwater during trenching activities. Rivers and streams on the pipeline route would be crossed primarily by open cutting in the winter months when flows are lowest, and disturbance of the river, stream banks, and local groundwater would be minimized, or by using HDD technology. BMPs and other mitigation measures would be used to minimize possible impacts during this phase (see Section 3.2, Soils).

Spring-fed areas tend to be important for spawning and overwintering fish because groundwater discharge usually occurs at a relatively steady rate and temperature in river bottomland environments. River bottoms commonly represent the natural discharge area for large groundwater flow systems of both local and regional scale. Groundwater tends to flow most vigorously through permeable sands and gravels into rivers. Along the project alignment, large alluvial fans and river alluvial deposits are present through which groundwater flows. The driving force to these groundwater discharges are head gradients.

The scale of disturbance caused by the pipeline is likely to be very small in comparison to the scale of the groundwater aquifers and head gradients that drive groundwater discharge, and would not affect those large-scale aquifers and head gradients.

At specific localities, the pipeline plan of development addresses the possibility of intercepting groundwater flows. Dewatering of the trench may be necessary to emplace the pipe; however this by itself would present very transient and minimal changes to the groundwater flow field.

If the trench breaches into a water-producing aquifer and creates a new flow path for groundwater to follow, the plan of development calls for emplacing temporary trench plugs consisting of excavated natural material in the empty trench, and / or permanent trench breakers consisting of sprayed and solidified foam, that would be used to slow such flow and minimize disruption to the natural flow of groundwater. There is a reason to do this because turbulent flow of groundwater along or underneath a pipeline can erode sediment particles and result in pipeline settlement. The trench breakers would be keyed about 6 inches into the sides and bottom of the trench (SRK 2013b), which would minimize the development of void space between the foam and trench walls in the event of settlement caused by permafrost thaw or deep frost movement. The trench breakers would have the effect of causing water to divert a few feet around the trench and pipeline, and groundwater would continue on its flow path in the aquifer towards its natural discharge locations with minimal disruption.

In areas where substantial groundwater is not encountered, the potential for affecting flows of spring water in nearby areas is extremely low because concentrated areas of groundwater flow that contribute to the springs would be localized and would have been missed by the pipeline.

In all cases, the potential for disruption of springs in rivers and streams is very low; either because the pipeline does not encounter groundwater (and misses disrupting the flowpath), or because trench breakers are installed to minimize the potential for the pipeline trench to create a preferred pathway and alter the natural flow of groundwater.

Water used by the project would be pumped or diverted and discharged in conformance with permit conditions. All potential water extraction sites, other than camp use, are from surface water sources. As a result, the intensity of effects on groundwater would result in changes in water quantities within historic seasonal or minimal variation. Impacts would not last longer than the span of the Construction Phase. The extent or scope would be limited to discrete portions of the Project Area.

Potential effects on groundwater would also occur from use of water supply wells for camp use. Peak numbers of construction personnel is estimated to be 650 people. At 55 gallons per day (gpd) / person, this is 35,750 gpd or 25 gpm, spread across several camp locations. These camps are in remote locations, however, and the quantity of water use would likely be small compared to the quantity of groundwater resource readily available. Resultant impacts would be the same intensity, duration, and extent as above for water extraction sites.

Operations

Operation and maintenance activities associated with the Pipeline under Alternative 2 would have no direct or indirect impacts on groundwater hydrology.

Closure

Closure, reclamation, and monitoring activities associated with the Pipeline would have no direct or indirect impacts on groundwater hydrology.

Summary of Pipeline Impacts

Anticipated effects from the Construction, Operations, and Closure of the Pipeline under Alternative 2 would be limited to temporary small stresses on the aquifers tapped by water supply wells for camp facilities, and temporary disturbances associated with pipeline construction. Disturbances to groundwater are anticipated to be relatively small compared to the amount of groundwater in the aquifers. In terms of intensity, impacts would result in changes in water quantities within historic seasonal or minimal variation. Impacts would last only as long as the period of construction. The extent or scope of groundwater effects would be limited to the close vicinity of the wells constructed or pumped. There would not be any indirect effects on groundwater expected as a result of the Pipeline.

3.6.2.2.4 CLIMATE CHANGE

Predicted overall increases in precipitation and changes in patterns of surface water distribution have the potential to influence the projected effects of the Donlin Gold Project on groundwater. These effects are tied to changes in water resources as discussed in Section 3.26.4.2.2.

3.6.2.2.5 SUMMARY OF IMPACTS FOR ALTERNATIVE 2

Table 3.6-4 outlines direct impacts to groundwater at the Mine Site, Transportation Corridor, and Pipeline components under Alternative 2. The intensity of impacts would vary depending on the type of activity and stressor. Groundwater flow changes at the SOB, or small stresses to aquifers tapped for water supply along the Pipeline or Transportation Corridor, would result in changes in water quantities within historic or minimal variation. Mine pit dewatering would result in substantial flow diversions and changes in flow systems that affect nearby uses or environments. Mine pit dewatering (at a maximum planned groundwater pumping rate of 2,900 gpm) would create up to 1,600 feet of drawdown in the local groundwater flow system. A cone of depression would be created around the open pit, generating impacts to the groundwater flow system near the pit by causing groundwater to flow toward the open pit from all sides. Groundwater would no longer discharge to Crooked Creek in the vicinity of the pit; as a result, flows in Crooked Creek and the lower reaches of creeks adjacent to the pit would be reduced during mine operations. The integrated groundwater-surface water modeling results indicate that wintertime streamflow may be reduced by 19 to 100 percent above American Creek near the end of mining, depending on conditions. Low flow (i.e., dry year) conditions and high hydraulic conductivity aquifer conditions result in the most streamflow loss. The most intense groundwater hydrology impacts on Crooked Creek would last for the life of the project at the Mine Site. At the end of mining operations when the pit dewatering system is deactivated, the water table will begin to recover and intensity of impacts on creeks will be reduced. At Closure, contact water would temporarily migrate out of the pit lake into local surrounding bedrock, but would flow back towards the pit after about eight years; overall hydraulic containment of contact water would be maintained due to strong topographic gradients well beyond the pit rim. Impacts associated with the construction of the Transportation Corridor and Pipeline would not last longer than the span of the Construction Phase. In terms of context, the groundwater that is impacted is considered a usual or ordinary resource, but one that is a shared resource governed by legislation.

Table 3.6-4: Summary of Impacts[1] to Groundwater Hydrology for Alternative 2

Impacts	Impact Level			
	Magnitude or Intensity	**Duration**	**Extent or Scope**	**Context**
Mine Site				
Change in water use	Groundwater flow systems are maintained. Changes in water quantity within historic seasonal or minimal variation.	Resource quantities would be changed throughout the life of the mine for up to 100 years after the end of construction; however, they would return to pre-activity levels sometime during that period.	Impacts limited geographically; discrete portions of the Project Area affected. Hydraulically connected waters beyond the Project Area are not affected.	Would affect usual or ordinary resources not currently depleted, but are shared and protected by legislation.
Change in water table and potentiometric surface	Construction/Operations: Impacts would range from changes in water quantity within historic seasonal or minimal variation to substantial flow diversions and changes in flow systems affecting nearby uses or environments. Closure: Impacts would range from changes in water quantity within historic seasonal or minimal variation to changes exceeding historic seasonal variations, but nearby uses and environments are maintained.	Construction/Operations: Same as above. Closure: Chronic effects; resource would not be anticipated to return to previous conditions or would take longer than 100 years to do so.	Same as above.	Same as above.
Transportation Corridor				
Change in water use	Groundwater flow systems are maintained. Changes in water quantity within historic seasonal or minimal variation.	Resource quantities would be changed throughout the life of the mine for up to 100 years after the end of construction; however, they would return to pre-activity levels sometime during that period.	Same as above.	Same as above.

Table 3.6-4: Summary of Impacts[1] to Groundwater Hydrology for Alternative 2

Impacts	Impact Level			
	Magnitude or Intensity	Duration	Extent or Scope	Context
Pipeline				
Change in water use	Same as above.	Resource would be reduced infrequently but not longer than the span of the Construction Phase and would be expected to return to pre-activity levels at the completion of the activity.	Same as above.	Same as above.

Notes:

[1] The expected impacts account for impact-reducing design features proposed by Donlin Gold and Standard Permit Conditions and BMPs that would be required. It does not account for additional mitigation or monitoring and adaptive management measures being considered.

3.6.2.2.6 MITIGATION AND MONITORING FOR ALTERNATIVE 2

Effects determinations take into account impact reducing design features (Table 5.2-1 in Chapter 5, Impact Avoidance, Minimization, and Mitigation) proposed by Donlin Gold and also the Standard Permit Conditions and BMPs (Section 5.3) that would be implemented.

Design features important for reducing impacts to groundwater hydrology include the following:

- Water management planning at the Mine Site would assist in controlling the flow of groundwater at the pit and other major facilities (WRF, TSF), as well as controlling the potential effects of groundwater flow on water quality downgradient of the mine. This would be accomplished through design elements such as dewatering wells, collection of groundwater infiltration through and around the TSF at the SRS pond, and lake level maintenance following closure;
- A variety of groundwater monitoring activities would also be planned, as indicated by generalized text in Table 5.2-1. Other than the monitoring wells downgradient of the TSF, however, these are not yet specified in current permitting plans. As such, additional recommendations specific to groundwater monitoring are presented in Section 3.6.2.2;
- Dewatering during Operations, as well as monitoring and maintenance of pit lake and groundwater levels during Closure and post-Closure, is designed to maintain overall groundwater flow gradients towards the pit, so that impacted mine contact water would not flow away from the Mine Site. Overall hydraulic containment is expected during all mine phases, including pit-filling in early Closure, due to head differences between groundwater away from the pit and lake level. Hydraulic containment would also continue in winter when no pumping occurs, due to summer stage management that accounts for expected rise in winter;
- A Crooked Creek aquatic resources monitoring plan would be developed in conjunction with ADF&G and ADNR through the habitat and water rights permitting processes. The objectives of the plan are to: 1) monitor for major changes to aquatic communities, 2) monitor for smaller scale and incremental changes to aquatic communities, and 3) guide results-based refinement to the monitoring program. The plan would build on the existing baseline dataset and include both biological and flow components, including: fish presence/abundance, invertebrate and periphyton sampling, and fish metals analysis; flow monitoring and winter surface water sampling to characterize fish habitat/passage and freezedown patterns; sediment sampling; and collection of additional geology and hydrology data to refine understanding of dewatering and groundwater/surface water flow dynamics (Donlin Gold 2018a,b; Owl Ridge 2017c). The ongoing data collection would be used in an adaptive management approach to refine the understanding of the dynamics surrounding Crooked Creek flow in winter as well as the open water seasons and to identify the most effective measures that can be used to ensure that minimum flows in Crooked Creek are maintained. If the project results in minimal losses to Crooked Creek flows, adaptive management measures may be unnecessary. If flow losses warrant a response, a range of measures could be considered that include but would not limited to: lining or relocating portions of the

stream channel; augmenting flows from the Snow Gulch Reservoir; pumping water from the Kuskokwim River, or grouting areas of bedrock demonstrating high flow rates. (Donlin Gold 2018a);

- Regular inspections and maintenance of the SRS would be performed, and specific contingency / back-up plans would be in place, so that if failure of the SRS were to occur, the situation would be identified and response actions begun immediately; and
- The project design includes installation of pipeline components (temporary roads and pipelines) at most water bodies and wetlands primarily in the winter months when frozen ground and snow are present, flows are lowest, and disturbance of the river, stream banks, and local groundwater would be minimized, or by using horizontal directional drilling (HDD) technology to avoid flow impacts at major pipeline river crossings.

Standard Permit Conditions and BMPs related to groundwater hydrology include:

- Controls on contact groundwater flow, treatment, and discharge in APDES water quality permits required under the CWA;
- Reporting of water use data under ADNR Water Management authorizations;
- Oversight of dam seepage flow under ADNR dam safety permitting;
- Potable well siting, construction, treatment, monitoring, and decommissioning in accordance with ADEC source water assessment and drinking water protection programs; and use of waste management BMPs under RCRA and ADNR solid waste programs (SRK 2016b) to minimize potential wellhead sources of contamination to drinking water wells; and
- Financial assurance under ADNR and ADEC permitting that would fund groundwater containment at the pit lake and SRS in post-Closure.

Additional measures are being considered by the Corps and cooperating agencies to further minimize project impacts, as reasonable and practicable, and are further assessed in Chapter 5, Impact Avoidance, Minimization, and Mitigation (Section 5.5 and Section 5.7). Examples of additional measures being considered that are applicable to this resource include:

- Complete a model run for the pit lake during post-Closure to confirm that containment will occur in the winter when there will be no pumping;
- Conduct an electrical leak detection survey of the TSF liner, using methods appropriate for the geomembrane type (TRI Environmental 2014), perform repairs prior to tailings placement, and update liner defect assumption in future WBM updates based on survey results and actual SRS flow and water quality data;
- Establish minimum flows in Crooked Creek;
- Install well field on west side of Crooked Creek to supplement flow loss from dewatering;
- Apply one of the following to the South Overburden Stockpile (SOB); in either case, install downgradient monitoring wells, equip the sediment pond with redundant and

freeze-protected pumping systems, and excavate and properly dispose of sediment at Closure:

  - Hydraulic containment (deep sump as part of sediment pond). Feasibility of digging a deep sump should be evaluated during design work; or
  - Additional studies during design work (fate and transport groundwater modeling) to demonstrate a lack of substantial groundwater volume that would result in no serious impact on the creek, as a result of natural attenuation of a small temporary slug of contaminated groundwater;

- Add an upstream monitoring site on Donlin Creek as a control point for monitoring water quality and discharge to enhance understanding of dewatering impacts on Crooked Creek habitat (monitoring site DCBO was specifically suggested as a location for background monitoring);
- Based on performance of the Seepage Recovery System (SRS) in Operations, add an additional well field and/or pond that acts as a secondary containment system and/or supplemental storage to the SRS downgradient of the SRS. This measure may minimize the likelihood of an extended pumping failure in Alternatives 2 and 5A, if determined to be an issue through adaptive management;
- Perform testing of the SRS monitoring/pumping wells periodically throughout Operations and Closure to demonstrate that adequate hydraulic containment of TSF seepage is occurring;
- Construct one monitoring well to a depth equal to or deeper than the lowest elevation of the pit bottom, on the southwest side of the pit rim between Crooked Creek and the pit, prior to any pumping to dewater the pit. The primary purpose is to measure hydraulic head at the bottom of the hole and to confirm model predictions that water from the pit lake would not leak into a regional groundwater flow system. The well should be completed as water quality sampling well and incorporated into the groundwater monitoring program for the project in order to verify continuing protection of deep groundwater resources by the process of hydraulic containment through mining and post-mining periods. The well should be drilled at an elevation above Crooked Creek floodplain, if possible, to avoid having the well exhibit flowing artesian conditions;
- Reexamine the groundwater flow model sooner than required by typical permit reevaluations, e.g., three years after the commencement of pit dewatering, to evaluate unexpected conditions (including impacts from faults and effects on WTP capacity), minimize uncertainty in the model, update and recalibrate the model as more groundwater level data are available, revise projections, and adjust management plans as needed;
- Conduct a reevaluation of the groundwater model and sensitivity analysis of potential contaminant migration from the pit lake after Year 15 of mining, when the ACMA pit is within a few 100 feet of its maximum depth;
- Collect relevant geotechnical and groundwater data (such as dewatering well testing, production rates, fault information, and water table levels around the pit) as mining progresses to refine interpretations and facilitate model revisions;

- Expand monitoring plans and data evaluation details to describe the proposed approach to facilitate comparisons with baseline data, and how it will be determined that water quality standards have been met and management activities can/should change. Baseline data should be evaluated using non-statistical means, such as spatial and temporal distribution, to allow a range of interpretive assessments;
- Include additional alluvial and/or bedrock groundwater monitoring wells at locations downgradient of mine facilities not already covered by the planned monitoring network (Figure 2.3-38, SRK 2016h) (e.g., overburden stockpiles), where sufficient alluvial aquifer material is present that could represent a pathway for contaminant migration to Crooked Creek, and bedrock groundwater is not captured by the pit cone of depression;
- The pit lake model should be rerun at regular intervals using the latest groundwater modeling results to predict the estimated duration of the pycnocline, the estimated source water quality going to the Closure WTP, and evaluate whether groundwater and reclaimed WRF runoff and seepage water delivered below the pycnocline would affect these changes;
- If substantially more dewatering water needs to be treated in Operations than the current WTP design basis allows, apply adaptive management measures such as extending the treatment season beyond April-November; storing more water in the TSF which would have excess capacity, reducing inflow from faults/fractures through grouting or sealing, and/or expanding the WTP which would take about 2 years; and
- Groundwater monitoring during Operations, Closure, and post-Closure should be sufficient to show that the hydraulic gradient towards the pit from Crooked Creek is maintained, and that dewatering drawdown has not extended beyond the monitoring system. If significant drawdown occurs at distant wells (e.g., due to the presence of faults), additional monitoring wells should be installed. Construction of dewatering wells should be suitable, to the extent practicable, for use or eventual conversion to monitoring wells for both water level and water quality purposes. Specifically, dewatering wells between the pit Rim Road and Crooked Creek should be converted for monitoring purposes in Closure;
- Develop a Pit Lake Groundwater Sampling and Monitoring Plan to focus on long-term water quality monitoring, sampling, and testing of the groundwater around the pit for the presence, abundance, and migration of contaminants such as mercury and arsenic;
- Develop a Mine Pit Dewatering Monitoring Plan to ensure that flow reductions to Crooked Creek are being monitored in real time as the pit is being developed, and design features, mitigation measures, and advanced water treatment are appropriate and adequately implemented to minimize impacts;
- Conduct Crooked Creek monitoring that may incorporate adaptive management elements, including:
    - Conduct further analysis of alternative WTP discharge points higher in the drainage (e.g., Queen, Lewis or American) or use of Snow Gulch Reservoir to supplement flow to reduce impacts to aquatic species; and

  - Implement low flow requirements in Crooked Creek in the event that, based on streamflow monitoring, flow losses from pit dewatering are outside the magnitude of historical seasonal variations; and
  - Monitor for adequate winter discharge measurements at the Crooked Creek gauging stations; and
- Extend pit lake pumping and treatment into winter months if necessary to maintain managed lake level, based on monitoring of lake and groundwater levels;
- If warranted, install a slurry wall or grout curtain between Crooked Creek and the pit (recommended placement at the margin of the alluvium) to minimize stream flow loss due to pit dewatering. This measure would require monitoring during dewatering and further evaluation to assess effectiveness in reducing vertical flow; and
- If warranted, divert water in Crooked Creek that is subject to streambed loss from dewatering through a culvert or lined open-flow channel (flume), which could be seasonally controlled by a floodgate or similar structure.

3.6.2.3 ALTERNATIVE 3A – REDUCED DIESEL BARGING: LNG-POWERED HAUL TRUCKS

The expected effects of this alternative are similar to those discussed under Alternative 2. The reduced barging of diesel fuel associated with Alternative 3A would create lower intensity impacts to groundwater resources than Alternative 2 by reducing the exposure of groundwater to potential spills or leaks from diesel fuel transport and storage systems along the Kuskokwim River corridor and at the Mine Site (see Sections 3.24.6, Spill Risk and Section 3.7, Water Quality).

3.6.2.3.1 SUMMARY OF IMPACTS FOR ALTERNATIVE 3A

Direct and indirect effects for Alternative 3A would be the same as discussed under Alternative 2. Impacts associated with climate change would also be the same as those discussed for Alternative 2.

Design features, Standard Permit Conditions and BMPs related to groundwater hydrology are described in Alternative 2. Examples of additional measures being considered that are applicable to this resource are listed under Alternative 2.

3.6.2.4 ALTERNATIVE 3B – REDUCED DIESEL BARGING: DIESEL PIPELINE

The expected effects of Alternative 3B are similar to those discussed under Alternative 2. The reduced barging of diesel fuel associated with Alternative 3B would reduce the exposure of groundwater to potential spills or leaks from diesel transport and storage systems along the Kuskokwim River corridor and the mine access road from the Angyaruaq (Jungjuk) Port. Construction and operation of a diesel pipeline is expected to increase the risk of groundwater contamination from a pipeline spill or leak along the pipeline corridor (see Sections 3.24.6, Spill Scenarios and 3.7, Water Quality).

Two options to Alternative 3B have been added based on Draft EIS comments from agencies and the public:

- Port MacKenzie Option: The Port MacKenzie Option would utilize the existing Port MacKenzie facility to receive and unload diesel tankers instead of the Tyonek facility considered under Alternative 3B. A pumping station and tank farm of similar size to the Tyonek conceptual design would be provided at Port MacKenzie. A pipeline would extend northwest from Port MacKenzie, route around the Susitna Flats State Game Refuge, cross the Little Susitna and Susitna rivers, and connect with the Alternative 3B alignment at approximately MP 28. In this option, there would be no improvements to the existing Tyonek dock; a pumping station and tank farm would not be constructed near Tyonek; and the pipeline from the Tyonek tank farm considered under Alternative 3B to MP 28 would not be constructed.
- Collocated Natural Gas and Diesel Pipeline Option: The Collocated Natural Gas and Diesel Pipeline Option (Collocated Pipeline Option) would add the 14-inch-diameter natural gas pipeline proposed under Alternative 2 to Alternative 3B. Under this option, the power plant would operate primarily on natural gas instead of diesel as proposed under Alternative 3B. The diesel pipeline would deliver the diesel that would be supplied using river barges under Alternative 2 and because it would not be supplying the power plant, could be reduced to an 8-inch-diameter pipeline. The two pipelines would be constructed in a single trench that would be slightly wider than proposed under either Alternative 2 or Alternative 3B and the work space would be five feet wider. The permanent pipeline ROW would be approximately two feet wider. This option could be configured with either the Tyonek or Port MacKenzie dock options.

Groundwater along both the Port MacKenzie Option and Tyonek / Collocated Natural Gas and Diesel Pipeline Option routes is used by public and private parties for water supply, and could be impacted in the event of a pipeline release.

Based on terrain features along the right-of-way (ROW) under Alternative 3B, the occurrence of shallow groundwater along the Alternative 3B-Tyonek and Collocated Natural Gas and Diesel Pipeline Options is expected to be roughly 10 miles longer than Alternative 2, and along the Alternative 3B-Port MacKenzie Option roughly 9 miles longer than Alternative 2 (Figures 2.3-40 and 3.6-1). An additional water well would be required at the operation center at either Tyonek or Port MacKenzie; however, the quantity of water used is expected to be only a small portion of the capacity of local or regional aquifers.

3.6.2.4.1 SUMMARY OF IMPACTS FOR ALTERNATIVE 3B

Direct and indirect effects for Alternative 3B would be mostly the same as discussed under Alternative 2. There would be roughly 9 to 10 miles shallower groundwater that would be intersected by the pipeline trench under this alternative compared to Alternative 2, and more groundwater use near the Alternative 3B terminals that could be affected in the event of a diesel release. Impacts associated with climate change would also be the same as those discussed for Alternative 2.

Design features, Standard Permit Conditions and BMPs related to groundwater hydrology are described in Alternative 2. Examples of additional measures being considered that are applicable to this resource are listed under Alternative 2.

3.6.2.5 ALTERNATIVE 4 – BIRCH TREE CROSSING PORT

The expected effects of this alternative are similar to those discussed under Alternative 2. The Mine Site and Pipeline components are identical to Alternative 2; therefore, impacts would not change under Alternative 4.

Compared to Alternative 2, construction of a potable water well would be required at the BTC Port, and a water well would not be constructed at the Angyaruaq (Jungjuk) Port. The well would be constructed in compliance with State public well construction standards. A water rights or temporary water use authorization would be obtained complying with all permit conditions. The potable water well would be operated at the BTC Port for the duration of project operations. In terms of intensity, the quantity of water used would create impacts on groundwater resources that result in use levels making up a small portion of the capacity of local or regional aquifers. The extent or scope of impacts would be limited to discrete portions of the Project Area and last the duration of project operations. The context of impacts would primarily affect usual or ordinary resources, but are protected by legislation and may be a shared resource within the locality.

3.6.2.5.1 SUMMARY OF IMPACTS FOR ALTERNATIVE 4

Direct and indirect effects for Alternative 4 would be the same as discussed under Alternative 2. Impacts associated with climate change would also be the same as those discussed for Alternative 2.

Design features, Standard Permit Conditions and BMPs related to groundwater hydrology are described in Alternative 2. Examples of additional measures being considered that are applicable to this resource are listed under Alternative 2.

3.6.2.6 ALTERNATIVE 5A – DRY STACK TAILINGS

This alternative includes two options:

- Unlined Option: The tailings storage facility (TSF) would not be lined with a linear low-density polyethylene (LLDPE) liner. The area would be cleared and grubbed and an underdrain system placed in the major tributaries under the TSF and operating pond to intercept groundwater base flows and infiltration through the dry stack tailings (DST) and convey it to a Seepage Recovery System (SRS). Water collecting in the SRS pond would be pumped to the operating pond, lower contact water dam (CWD), or directly to the processing plant for use in process.
- Lined Option: The DST would be underlain by a pumped overdrain layer throughout the footprint, with an impermeable LLDPE liner below. The rock underdrain and foundation preparation would be completed in the same manner as the Unlined Option.

3.6.2.6.1 MINE SITE

<u>Unlined Dry Stack Option</u>

Alternative 5A-Unlined Option consists of placing tailings directly on a prepared overburden surface with coarse rock underdrains in the valley bottoms. An impermeable cap would be placed on the dry stack at closure. A seepage analysis of the dry stack was conducted by BGC (2015d) using an integrated groundwater/surface water model, HydroGeoSphere (HGS) (Aquanty 2013, as cited in BGC 2015d), for the purpose of understanding differences between various configurations of the lined and unlined dry stack options. This model has been shown to be effective in simulating both saturated and unsaturated flow under similar conditions and settings as the dry stack (e.g., Brunner and Simmons 2012, Aquanty 2017). Major assumptions and boundary conditions in the model include material properties of the tailings and liner/cover (e.g. hydraulic conductivity, saturation), flux at the top and base of the dry stack, climatic data, groundwater level, runoff, and slope angle. The dry stack was simulated as an 11-square foot, 164-ft high column, with internal grid discretization ranging from 0.3 to 3.3 feet (BGC 2015d). Together with the scale and input assumptions, the model provides a reasonable characterization of seepage through the dry stack for the intended purpose.

Under the Unlined Option (BGC 2015d, Scenario 1), the model was run under two different pressure heads (16 and 33 feet) applied to the base of the dry stack to simulate groundwater wicking into the tailings from the sides of the valley under artesian pressure. The pressure heads (i.e., groundwater flow from the valley sides) were applied throughout the 200-year simulation. Groundwater from the valley slopes outside of the dry stack is predicted to flow into the tailings pile in the early Operations phase. A water table would develop within the dry stack from both groundwater inflow and infiltration through the dry stack. After 1-1/2 to 2 years, when seepage flow through the tailings begins to exit through the dry stack, the groundwater flow direction would change and groundwater would flow away from the dry stack. At this point, tailings seepage could potentially reach groundwater beneath the dry stack, although the underdrains would be expected to continue to capture some if not all of the tailings seepage.

At Closure, placement of the impermeable LLDPE cover is predicted to decrease seepage rates through the tailings from about 78 gpm at the beginning of the closure period to about 18 gpm after 200 years, as porewater drains from the dry stack and very little new water infiltrates through the cover (BGC 2015d, Scenario 1). The water table would decrease in elevation over time as the cover limits infiltration. The spatial extent of seepage from the dry stack would be smaller than for Alternative 2 because the dry stack has a smaller footprint. For the first 200 years after closure the rate of seepage from the dry stack under the Unlined Option would be higher - approximately 78 gpm at closure - and gradually decreasing to match the Alternative 2 seepage rate of 18 gpm after 200 years.

Following removal of the operating pond and dam in post-Closure, if contaminated groundwater is present in native materials beneath the dry stack or operating pond footprint, it would continue to migrate towards and be captured by the SRS and/or pumping wells, and report to the pit lake. Meanwhile, the supply of tailings porewater that could potentially feed the contaminant plume would be reduced by the impermeable cover, and seepage flow through the dry stack would gradually reduce to the same as that predicted under Alternative 2 (and Alternative 5A-Lined Option) after 200 years. In other words, a contaminant plume, if present under the Unlined Option, would eventually improve in quality to that of Alternative 5A–Unlined Option and Alternative 2. Beyond 200 years, the amount of seepage flow under the Unlined Option is expected to continue its gradual decline as a result of the impermeable cover blocking infiltration of water to the flow system.

The SRS would include wells constructed similarly to those described under Alternative 2. The hydraulic containment system would consist of pumps in the seepage recovery pond, as well as pumping from four groundwater wells as needed. Whether or not the SRS could eventually be decommissioned after 200 years would be the same as under Alternative 2 (i.e., continued SRS operation in perpetuity cannot be ruled out and there are provisions for these activities in Donlin Gold plans). As with Alternative 2, the capture and treatment of groundwater and seepage flow under both Alternative 5A options could lead to decreased concentrations of certain constituents in Crooked Creek compared to existing baseline conditions.

As a result of the larger amount of water in the Operating Pond compared to the TSF of Alternative 2 at the end of mine operations that would be pumped to the pit lake, the pit lake would fill to a level requiring treatment of pit lake water in about 42 years compared to about 52 years under Alternative 2 (BGC, 2015k).

Lined Dry Stack Option

Under Alternative 5A-Lined Option, tailings would be placed on top of an overdrain layer that is constructed over an impermeable LLDPE liner beneath the dry stack. The overdrain would be pumped to reduce mounding of the water table in the dry stack (BGC 2015d, Scenario 4). The overdrain water would not be pumped to the SRS; rather it would be pumped through a dedicated line back to the central mine area for plant operations, water treatment, or, after closure, to the pit lake. An impermeable cap would be placed on the dry stack at closure to limit infiltration into the dry stack. During operations and closure, the rate of seepage through the liner below the dry stack would be similar to Alternative 2 (estimated to be 18 gpm) as a result of estimated leakage through the liner, although it could be less as a result of the smaller footprint of the dry stack compared to Alternative 2.

The potential SRS overflow and loss of hydraulic containment of the groundwater due to failure of pumping systems under both Alternative 5A options is similar to that described for Alternative 2, except that during the first 200 years or so following the end of mining under the Unlined Option, larger volumes of water (up to about 80 gpm versus about 18 gpm under Alternative 2), would initially be expected to drain out of the tailings. The rate of water draining out of the dry stack would gradually decline during the period to the approximate amounts projected to leak through the liner under Alternative 2. Also, if SRS overflow and loss of hydraulic containment occurred during the early years of closure of the Unlined Option, the quality of water released could be much poorer than under Alternative 2 because of the higher leakage rates from the dry stack and less dilution from the underdrain flows. Except for these differences related to the larger amount of water initially draining out of the dry stack, the impacts to groundwater under the Lined Dry Stack Option, including the time until the seepage pump system can be decommissioned, would be no different than under Alternative 2.

As a result of the larger amount of water in the Operating Pond compared to the TSF of Alternative 2 at the end of mine operations that would be pumped to the pit lake, the pit lake would fill to a level requiring treatment of pit lake water in about 47 years compared to about 52 years under Alternative 2. This option results in slower filling of the pit lake than the Unlined Option because the liner allows more surface runoff during the closure period to be discharged to Anaconda Creek (BGC, 2015k).

Climate Change

Impacts associated with climate change that are related to groundwater at the Mine Site under Alternative 5A are discussed in Section 3.26.4.6.2.

3.6.2.6.2 TRANSPORTATION CORRIDOR

Impacts to groundwater resources associated with the construction, operations, and closure of the Transportation Corridor under Alternative 5A would be the same as discussed under Alternative 2.

3.6.2.6.3 NATURAL GAS PIPELINE

Impacts to groundwater resources associated with the Construction, Operations, and Closure of the Pipeline under Alternative 5A would be the same as discussed under Alternative 2.

3.6.2.6.4 SUMMARY OF IMPACTS FOR ALTERNATIVE 5A

The effects of the dry stack Alternative 5A-Unlined and Lined Options on groundwater are expected to be similar to those of Alternative 2. Modestly more water (up to about 20 percent more) will require pumping and treating during the first 200 years of closure under the Unlined Option than under both Alternative 5A-Lined Option and Alternative 2. The amount of extra water would gradually decline to approximately the amount of water under Alternative 2. The extra water during the first 200 years of closure for Unlined Option creates a slightly higher likelihood of groundwater contamination from pump failures and unplanned releases than Lined Option; however, the difference is small and would not affect the summary impacts. Overall effects associated with climate change would be the same as those discussed for Alternative 2.

Design features, Standard Permit Conditions and BMPs related to groundwater hydrology are described in Alternative 2. Examples of additional measures being considered that are applicable to this resource are listed under Alternative 2.

3.6.2.7 ALTERNATIVE 6A – MODIFIED NATURAL GAS PIPELINE ALIGNMENT: DALZELL GORGE ROUTE

For Alternative 6A, the Pipeline would follow an alignment through the Dalzell Gorge. Shallow groundwater conditions (Section 3.6.1.2.3) and impacts to shallow groundwater from pipeline construction and operations are expected to be substantially similar to those of the Alaska Range portion of Alternative 2. Based on geotechnical borehole and terrain mapping data (SRK 2012i), the Dalzell Gorge route would encounter about 1 mile less shallow groundwater than Alternative 2 (Figure 3.6-1). Thus, this modification would have the same direct and indirect effects to groundwater resources as Alternative 2 for the Mine Site, Transportation Corridor, and Pipeline components of the project. Impacts associated with climate change would also be the same as those discussed for Alternative 2.

Design features, Standard Permit Conditions and BMPs related to groundwater hydrology are described in Alternative 2. Additional mitigation and monitoring measures are also described in Alternative 2. If these mitigation measures were adopted and required, the summary impact rating would be the similar to Alternative 2 depending on actual bedrock and groundwater conditions encountered during mining.

3.6.2.8 ALTERNATIVES IMPACT COMPARISON

A summary of impacts from Alternative 2 is presented in Table 3.6-4, and a comparison between alternatives is presented below in Table 3.6-5.

Table 3.6-5: Comparison of Impacts by Alternative* for Groundwater

Impact-causing Project Component	Alternative 2 – Proposed Action	Alternative 3A – LNG-Powered Haul Trucks	Alternative 3B – Diesel Pipeline	Alternative 4 – BTC Port	Alternative 5A – Dry Stack Tailings	Alternative 6A – Dalzell Gorge Route
Mine Site						
Mine pit dewatering	Groundwater elevation change below original conditions: • 1,600 feet in operations; • 30 feet in post-Closure. Groundwater flow direction changes: • Flow towards pit in construction and operations. • Temporary (8 years), localized (within pit rim) flow away from pit, though overall hydraulic containment maintained due to strong topographic gradients beyond pit. • Flow towards pit in post-Closure (in perpetuity). Areal extent of cone of depression: • 9,000 acres in operations; • 2,000 acres in post-Closure.	Mostly the same as Alternative 2, except reduced potential for diesel spill impacts.	Mostly the same as Alternative 2, except increased potential for diesel spill impacting groundwater.	Same as Alternative 2.	Similar to Alternative 2, except capture of up to about 20% more water during early closure period of Unlined Option, declining to equal amount of capture as Lined Option or Alternative 2 200 years after closure.	Same as Alternative 2.
Reduced or loss of wintertime flow in Crooked Creek	Range from average K-average flow to high K-low flow conditions:[1] • 20%-100% flow reduction near pit; • 10%-40% flow reduction 8 miles downstream.					
Capture and diversion of groundwater in Anaconda watershed	Under TSF and SRS: 450 gpm of groundwater is used for processing water in operations, and piped to pit lake after closure.					

Table 3.6-5: Comparison of Impacts by Alternative* for Groundwater

Impact-causing Project Component	Alternative 2 – Proposed Action	Alternative 3A – LNG-Powered Haul Trucks	Alternative 3B – Diesel Pipeline	Alternative 4 – BTC Port	Alternative 5A – Dry Stack Tailings	Alternative 6A – Dalzell Gorge Route
Transportation Corridor						
Groundwater usage at port sites.	Groundwater flow systems are maintained. Changes in water quantity within historic seasonal or minimal variation.	Mostly the same as Alternative 2. Slight reduced potential for diesel spill impacts from a reduction in fuel barge trips from 58 to 19 per season along the Kuskokwim River.	Mostly the same as Alternative 2, except decreased potential for diesel spill impacting groundwater.	Mostly the same as Alternative 2 except translocation of port water well; slight increased potential for trucking-related spill as a result of longer road.	Same as Alternative 2.	Same as Alternative 2.
Pipeline						
Groundwater usage at camps.	Groundwater flow systems are maintained. Changes in water quantity within historic seasonal or minimal variation.	Same as Alternative 2	Mostly the same as Alternative 2, except increased potential for diesel spill impacting groundwater and shallow groundwater: 10 miles > Alternative 2 for Tyonek/Collocated Natural Gas and Diesel Pipeline Options, and 9 miles > Alternative 2 for Port MacKenzie Option.	Same as Alternative 2.	Same as Alternative 2.	Mostly the same as Alternative 2 (shallow groundwater 3 miles < Alternative 2).
Potential diversion of groundwater during construction or operations.	Effect on shallow groundwater beneath 112 miles (1/3rd) of ROW (about 3 miles less under Alternative 2-North Option). Groundwater flow systems are maintained. Changes in water quantity within historic seasonal or minimal variation.					

Notes:

1 Data are from Table 3.5-26, Surface Water Hydrology.
2 Based on range of results from groundwater model sensitivity runs.
* Alternative 1 (No Action Alternative) would have no impacts to groundwater hydrology.
K = hydraulic conductivity