4.17 GROUNDWATER HYDROLOGY

This section describes the effects of the project on the distribution and movement of groundwater in the subsurface. Potential direct and indirect effects from the project may include:

- Drawdown of groundwater, primarily around the open pit from dewatering activities, but also around quarries, bulk and pyritic tailings storage facilities (TSFs), and water management ponds (WMPs) from drainage/underdrain systems and consequent reduction of groundwater available to surrounding surface water and wetlands
- Reduction in natural recharge to groundwater from filling drainage areas beneath large project facilities such as WMPs and TSFs
- Changes in groundwater flow patterns from shallow groundwater interception or surface water withdrawals during road and pipeline construction
- Drawdown of groundwater around potable wells from water-supply use
- Changes to groundwater flow from horizontal directional drilling (HDD) activities

The Environmental Impact Statement (EIS) analysis area includes the mine site, transportation corridor, pipeline corridor, and port for all alternatives and variants, and includes the watersheds most likely to be affected by the project (see Figure 3.17-1). The geographic area considered in the analysis of groundwater hydrology is the near vicinity of all project components (i.e., 0.5 mile to several miles away) where project effects could be expected to occur on groundwater flow patterns.

Scoping comments and comments on the Draft EIS (DEIS) were received on potential impacts to groundwater systems, aquifers, and the flow of groundwater. Commenters requested that existing groundwater in the area of both the project and alternatives, including groundwater levels and flow, be characterized; and that a thorough understanding of the groundwater and surface water hydrology and how they relate to each other should be demonstrated. Impacts to groundwater and surface water quality are addressed in Section 4.18, Water and Sediment Quality.

4.17.1 Summary of Key Issues

Table 4.17-1 provides a summary of key issues related to groundwater hydrology. A concept common to the analysis of potential groundwater hydrology impacts associated with the mine pit, pit lake, TSFs, and water management ponds associated with this project is hydraulic containment and capture, treatment, and discharge of contact water. An extensive review of these types of features at mines in general, and especially at the five operating large hard rock mines in Alaska (Red Dog, Pogo, Fort Knox, Kensington, and Greens Creek) provides examples of successful seepage control and prevention strategies based on hydraulic containment at TSFs and WMPs. Numerous other examples of similarly successful TSFs and WMPs in the US and Canada, as well as worldwide, are described on mine websites (AECOM 2019o). Regulatory oversight is an important component of the environmentally safe practices and technologies that have been implemented at these mines.

Table 4.17-1: Summary of Key Issues for Groundwater Hydrology Resources

Impact Causing Project Component	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
Mine Site				
Groundwater capture and diversion and reduction of recharge during construction and operations at pyritic TSF, WMPs, and other mine facilities Water-table mounding in the bulk TSF	Diverted groundwater at TSFs and WMPs would be captured, treated, and discharged to the affected drainages during construction and operations to approximately restore natural flow conditions, as described in more detail in Section 4.16, Surface Water Hydrology. Reduction of several feet to several tens of feet of groundwater elevation expected beneath lined facilities during operations due to blocked recharge and underdrain and water catchment system. Groundwater in non-lined bulk TSF would discharge to underdrains, through the north embankment, and into the upper portion of the groundwater system and flow to the catchment system and be pumped for treatment, or to the pit lake for the long-term. Groundwater at the pyritic TSF and WMPs would recover after reclamation during closure.	Same as Alternative 1a. **Summer-Only Ferry Operations Variant:** Additional facilities at the mine site and Amakdedori port for storage of materials would cause additional changes in groundwater recharge through operations phase.	The downstream dam would have a 25-foot-higher maximum crest, and the water table elevation is slightly more likely to create potential seepage through topographic saddles on the eastern and northwestern sides. Otherwise, same as Alternative 1a.	Same as Alternative 1a. **Concentrate Pipeline Variant:** No impacts to groundwater resources.
Groundwater use for potable water supply	Groundwater use would be highest during construction and operations, with drawdown of several feet extending to about 0.1 mile; and drawdown from groundwater use is expected to decrease to negligible amounts during closure.	Same as Alternative 1a.	Same as Alternative 1a.	Same as Alternative 1a.
Open pit and pit lake dewatering	Groundwater-level change up to 2,000 feet below baseline conditions during operations, recovering to 90 to 350 feet below original level during post-closure. The large range is because of the high pre-mining water-table slope across the open pit footprint (see Section 3.17, Groundwater Hydrology, Figure 3.17-9). Groundwater flow direction change caused by flow towards the open pit, which acts as a hydraulic sink and would remain so for the long-term (centuries).	Same as Alternative 1a.	Same as Alternative 1a.	Same as Alternative 1a.

Table 4.17-1: Summary of Key Issues for Groundwater Hydrology Resources

Impact Causing Project Component	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
	During operations, the areal extent of the zone of influence surrounding the open pit would increase as mining proceeds and as the pit deepens. The estimated maximum area of the zone of influence at end of mining would be about 2,600 acres. The areal extent of the zone of influence would decrease as the pit fills with water to form a pit lake; however, a zone of influence would exist around the pit for the long-term. The estimated area of the zone of influence during post-closure would be about 1,200 acres.			
Transportation Corridor				
Groundwater diversion during construction	Groundwater flow systems are maintained; temporary flow interruptions during construction.	Similar to Alternative 1a. **Summer-Only Ferry Operations Variant:** No impacts to groundwater from seasonal lake crossings. **Kokhanok East Ferry Terminal Variant:** Similar to Alternative 1; slightly less impact during road construction due to 15 percent shorter route, and slightly more during material extraction due to larger footprint.	Similar to Alternative 1a, although slightly more impacts due to greater route length through areas of shallow groundwater-bearing deposits and steep cut slopes. **Summer-Only Ferry Operations Variant:** Slightly more groundwater diversion at Williamsport container storage along cut slope.	Similar to Alternative 1a, although impacts slightly more than other Alternatives due to greater route length through areas of shallow groundwater-bearing deposits and steep cut slopes. **Concentrate Pipeline Variant:** Similar to Alternative 3. Buried in the same trench as the natural gas pipeline; trench is slightly larger than the gas pipeline-only installation and may slightly increase temporary groundwater impacts; groundwater flow systems are maintained; temporary flow interruptions during construction.
Water extraction and groundwater use during construction and operations	Impacts to groundwater from surface water extraction and groundwater use at the construction camps would be short-term, and the aquifer would return to historical levels once operations end.	Same as Alternative 1a.	Same as Alternative 1a.	Same as Alternative 1a.

Table 4.17-1: Summary of Key Issues for Groundwater Hydrology Resources

Impact Causing Project Component	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
Port Sites				
Groundwater diversion during construction	Groundwater flow systems are maintained; temporary flow interruptions during construction.	Same as Alternative 1a. **Summer-Only Ferry Operations Variant:** Similar to Alternative 1; increased likelihood of intersecting shallow groundwater along Amakdedori Creek floodplain due to larger footprint. **Pile-Supported Dock Variant:** Slightly less impact to groundwater at borrow sites due to fewer fill needs.	Types of impacts similar to Alternative 1a, although construction excavations at Diamond Point terminal are more likely to intersect shallow groundwater-bearing deposits than at Amakdedori. **Pile-Supported Dock Variant:** Same as Alternative 1a.	Magnitude and extent of shallow groundwater flow interruption slightly greater at material stockpiles, and slightly less at port facilities, than Alternative 2. Likelihood and duration of effects similar to Alternative 2. **Concentrate Pipeline Variant:** Same as Alternative 3.
Groundwater use at port during operations	Changes in groundwater quantity from water supply well would be within historical seasonal variability.	Same as Alternative 1a.	Same as Alternative 1a, except at Diamond Point port.	Same as Alternative 2.
Natural Gas Pipeline				
Groundwater diversion during construction	Groundwater flow systems are maintained; temporary flow interruptions during construction.	Similar to Alternative 1a. **Kokhanok East Ferry Terminal Variant:** Similar to Alternative 1a; slightly less impact due to shorter pipeline route.	Similar to Alternative 1a; temporary groundwater impacts would be slightly more due to greater route length through areas of shallow groundwater-bearing deposits and steep cut slopes.	Same as Alternative 2.
Groundwater use during construction	Groundwater use at the construction camps would be short-term, and aquifer would return to historical levels once construction ends.	Similar to Alternative 1a.	Similar to Alternative 1a, although camp locations may be different.	Similar to Alternative 1a, although camp locations may be different.

Notes:
TSF = Tailings Storage Facility
WMP = Water Management Pond

4.17.2 Methodology for the Analysis of Groundwater Impacts

Impacts to groundwater hydrology were evaluated based on baseline data, water management plans, and groundwater modeling. The methodology applied to analyze and predict direct or indirect impacts is based on the range of effects for each of the following factors:

- **Magnitude**—Effects on groundwater flow systems are estimated by predicting changes in water-table elevation, flow direction, or distance of impact from project activity. Effects could be maintained within historic seasonal variation; could exceed baseline variations, but nearby uses and conditions would be maintained; or there could be groundwater flow changes that affect nearby uses or the environment.
- **Duration**—The duration of effects depends on project phase, length of construction activities, and aquifer characteristics. The duration of impacts to groundwater would either be short-term, lasting only though construction; medium-term, lasting though the life of the mine and resolved during post-closure; or long-term, lasting centuries.
- **Geographic Extent**—Groundwater flow effects are described in terms of area. Effects might be limited to portions of the project footprint or component area and not hydraulically connected to waters outside the component area; effect could occur beyond local project component areas, potentially throughout the analysis area; or flow effects could be hydraulically connected to areas beyond the analysis area.
- **Potential**—Most effects on groundwater flow at the mine site are considered likely to occur. The likelihood of occurrence for other project components is correlated to the distribution of shallow groundwater-bearing deposits, which varies across the project area, and the likelihood that the water table would be intercepted during specific construction activities.

4.17.2.1 No Action Alternative

Under the No Action Alternative, federal agencies with decision-making authorities on the project would not issue permits under their respective authorities. The Applicant's Preferred Alternative would not be undertaken, and no construction, operations, or closure activities specific to the Applicant’s Preferred Alternative would occur. Although no resource development would occur under the Applicant's Preferred Alternative, Pebble Limited Partnership (PLP) would retain the ability to apply for continued mineral exploration activities under the State's authorization process (ADNR 2018-RFI 073) or for any activity not requiring federal authorization. In addition, there are many valid mining claims in the area, and these lands would remain open to mineral entry and exploration by other individuals or companies.

It would be expected that current State-authorized activities associated with mineral exploration and reclamation, as well as scientific studies, would continue at levels similar to recent post-exploration activity. The State requires that sites be reclaimed at the conclusion of their State-authorized exploration program. If reclamation approval is not granted immediately after the cessation of activities, the State may require continued authorization for ongoing monitoring and reclamation work as it deems necessary.

It is possible for permitted exploration and environmental baseline data collection to continue under this alternative (ADNR 2018-RFI 073), which could include groundwater extraction from pumping tests. These tests temporarily lower groundwater elevations in the immediate area surrounding a well, which typically recovers to natural conditions in a matter of hours to days.

Groundwater along the transportation corridor, pipeline corridor, and at the port sites would remain in its current state. There would be no effects on existing private wells. In summary, there would be little to no direct or indirect impacts on baseline groundwater conditions from implementation of the No Action Alternative.

4.17.3 Alternative 1a

4.17.3.1 Mine Site

Groundwater conditions resulting from mine site activities were modeled by Piteau Associates (2018a) using an updated version of the groundwater flow model originally developed by Schlumberger (2011a). A new groundwater flow model was subsequently developed by BGC (2019a), and is used for all analysis for this EIS. Where comparable, the results of the two models are similar; however, BGC (2019a) developed a complete model-calibration and sensitivity-analysis report. The modeling work includes updated numerical solution algorithms, additional sensitivity analyses (to address model uncertainty), particle-tracking analyses, and responses to numerous requests for information (RFIs). Model development and calibration to baseline groundwater and streamflow conditions are described in Section 3.17 and Appendix K3.17, Groundwater Hydrology. The results of using the model to predict project effects on groundwater are described in this section, with additional details provided in Appendix K4.17. Model uncertainty and reliability are also summarized in this section, and additional details are provided in Appendix K4.17. The analysis of project impacts using the model addresses five general areas: 1) the open pit and (post-closure) pit lake; 2) the main and open pit WMPs; 3) the bulk TSF; 4) the pyritic TSF; and 5) potable water supply wells, quarries, and miscellaneous other mine facilities. In BGC 2019a, the geographic extent of impacts caused by the project are illustrated by a series of figures that depict groundwater level drawdown in response to pumping water from the pit or underdrain systems, or by reduction of recharge by lined impoundments or removal of upper portions of the bedrock aquifer at quarries B and C. These figures are shown for end-of-mining and post-closure conditions. The project effects on groundwater flow systems are illustrated by a series of zone-of-influence maps, particle trace maps, and capture zone maps showing the locations of groundwater divides that separate different groundwater flow systems. For the operations phase, the BGC 2019a model estimated the effect of open pit dewatering on groundwater flow conditions at end of mining, the groundwater inflow rate to the pit, the related reduction of groundwater discharge to Upper Talarik Creek (UTC), South Fork Koktuli (SFK), and North Fork Koktuli (NFK) drainages, impacts to wetlands, and groundwater and seepage flow from the TSFs and the WMPs. The model was also used to assess groundwater flows after mining ceases, including the time to form a pit lake and the lake-level elevation needed for it to function as a long-term hydraulic sink. Post-closure in this section refers to the time after the pit lake reaches its maximum managed level at approximately Closure Year 20.

Pit Dewatering

Construction and Operations. Dewatering of the open pit would be required to facilitate mining. Construction of the open pit would require lowering groundwater levels in the pit area through dewatering to establish stable pit walls, provide dry working conditions, and establish a groundwater capture zone[1]. Although a specific dewatering design has not been made at this stage of project development, the ultimate pit dewatering design would be based on a series of interim pit phases that successively expand and deepen the pit. This phased approach would allow the pit dewatering program to be adjusted, based on the operational performance of each preceding phase (Knight Piésold 2018e). Dewatering is typically accomplished by placement of dewatering wells around the pit perimeter and in the pit bottom as mining progresses, and ditches and horizontal drains along the pit walls (Figure 4.17-1). Dewatering results in a groundwater

[1] **Capture zone** is the area in which all groundwater flow is towards a groundwater "sink" and all groundwater recharge is captured by the sink. The outer boundary of the capture zone is a groundwater divide. Groundwater outside of the groundwater divide would flow away from the groundwater "sink."

"zone of influence[2]" because the water table is lowered in the pit, and the effect extends laterally beyond the pit area into the adjacent bedrock and overburden aquifers (see Appendix K3.17, Table K3.17-1 for aquifer descriptions). The zone of influence would deepen and widen as pit excavation progresses and dewatering expands, and would last as long as the dewatering system is operated during construction, operation, closure, and post-closure phases. The magnitude and extent of impacts would be that groundwater levels would ultimately need to be lowered below the bottom of the final mine pit, which is estimated to be up to 1,950 feet below grade. To evaluate model uncertainty, sensitivity analysis simulations of the groundwater model were used to estimate the effects of mine dewatering assuming a range of potential dewatering configurations and aquifer properties. Potential effects of groundwater drawdown resulting from this uncertainty analysis on other resources such as wetlands, streamflow, water treatment/water quality, aquatic habitat, and vegetation are described in Section 4.22, Wetlands and Other Waters/Special Aquatic Sites; Section 4.16, Surface Water Hydrology; Section 4.18, Water and Sediment Quality; Section 4.24, Fish Values; and Section 4.26, Vegetation, respectively.

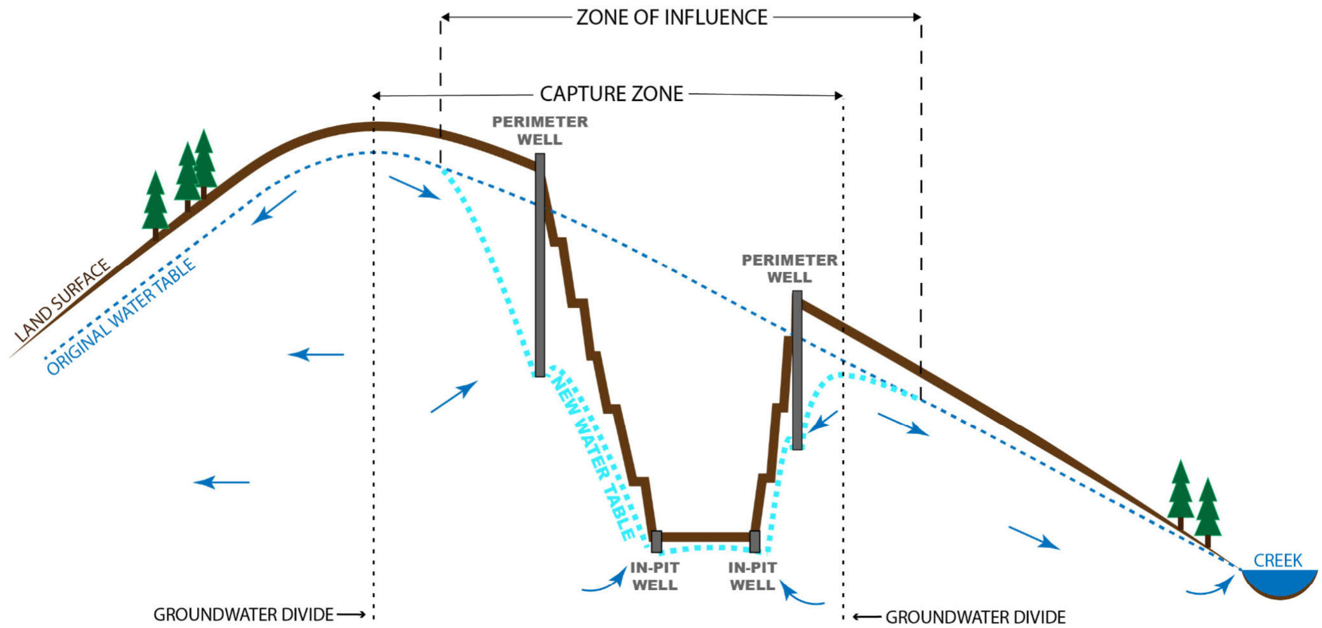
The initial dewatering well field during construction is conceptualized to consist of approximately 30 operating wells installed to depths of 150 feet and spaced about 200 feet apart around the starter pit perimeter (Knight Piésold 2018e). The wells would initially be pumped at rates of 50 gallons per minute (gpm) each, with a total rate of approximately 1,500 gpm. The estimated groundwater inflow to the pit at the end of operations is estimated to be 1,500 gpm (with in-pit and perimeter wells); however, inflow could be in the range of 670 to 4,300 gpm, depending on dewatering configurations and hydraulic properties of the aquifers (BGC 2019a, b).

The zone of influence for the open pit at the end of mining is shown in Figure 4.17-2, which assumes a 3-foot drawdown cut-off criterion for the outer edge of the zone of influence. This 3-foot criterion is near the predictive limitations of the groundwater model, and is a useful criterion for comparison of different sensitivity analysis scenarios. Figure 4.17-2 also shows the lowered water table at the quarries, pyritic TSF, and main WMP. Projected mounding of the water table in the bulk TSF tailings caused by the discharge of tailings slurries and ponding of water in the bulk TSF is also shown.

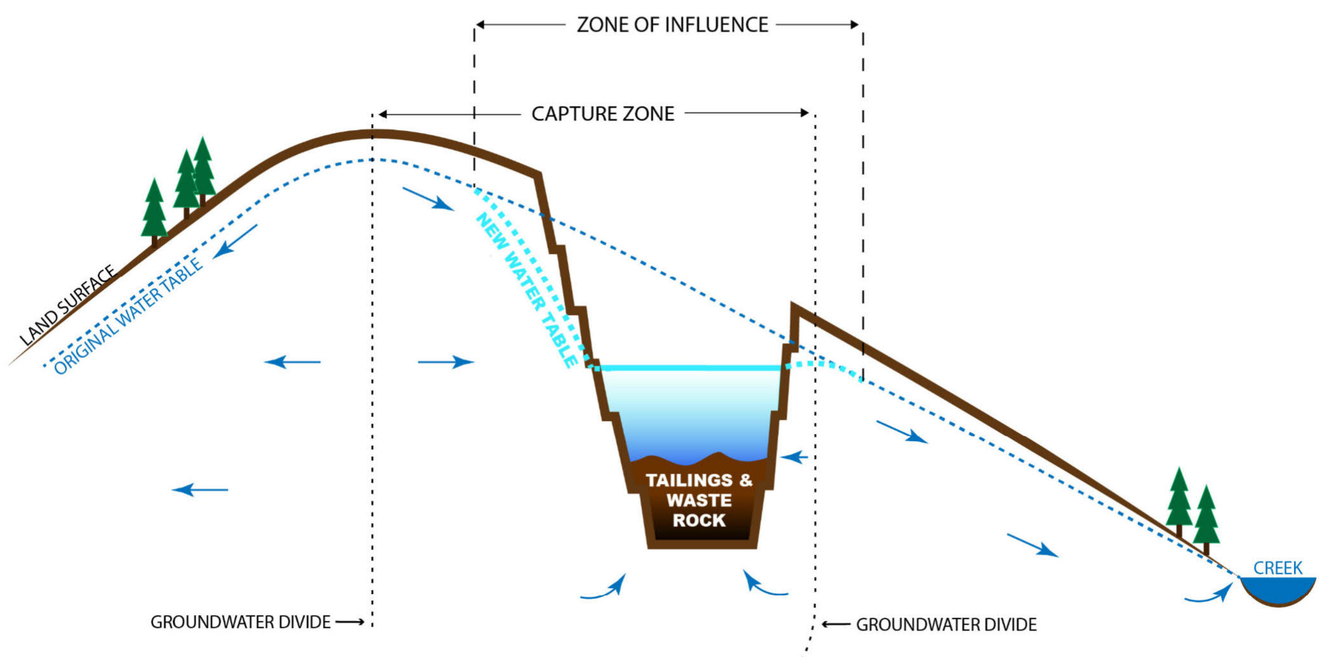
The capture zone for the pit at the end of mining for both the water table and bedrock aquifers is shown in Figure 4.17-3.

The rates of estimated groundwater inflow to the pit described above are based on a calibrated model in which recharge was adjusted (calibrated) from initial inputs from the historical 76-year record of precipitation data (see Section 3.16, Surface Water Hydrology). Potential changes in future precipitation due to climate change that result in more rain and less snow would tend to even out swings in seasonal recharge quantities to the groundwater system, and would be in the sensitivity analysis scenarios for recharge estimated by BGC (2019a). To estimate the effects of potential higher meteoric recharge on the groundwater model results, the model was run using 1.5 times the amount of recharge than was used for the base-case simulations. This would result in roughly 12 percent more inflow to the pit that would need to be pumped and treated compared to the comparable base-case scenario (BGC 2019a). Recharge was found to be a less important parameter than hydraulic conductivity of bedrock or faults on groundwater flow to the pit, and as a driver for designing water treatment capacity.

[2] **Zone of influence** is the area in which a man-made hydraulic stress (such as dewatering) lowers groundwater elevations. The zone of influence may be larger than the capture zone, because groundwater elevations can be affected outside the groundwater divide that defines the capture zone. The zone of influence may also be smaller than a capture zone in cases where the "sink" captures water flowing from a nearby groundwater divide that is beyond the limit of the zone of influence. These relationships are illustrated in Figure 4.17-1.



PIT DEWATERING SCHEMATIC: OPERATIONS
(NOT TO SCALE)



PIT LAKE SCHEMATIC: POST CLOSURE
(NOT TO SCALE)

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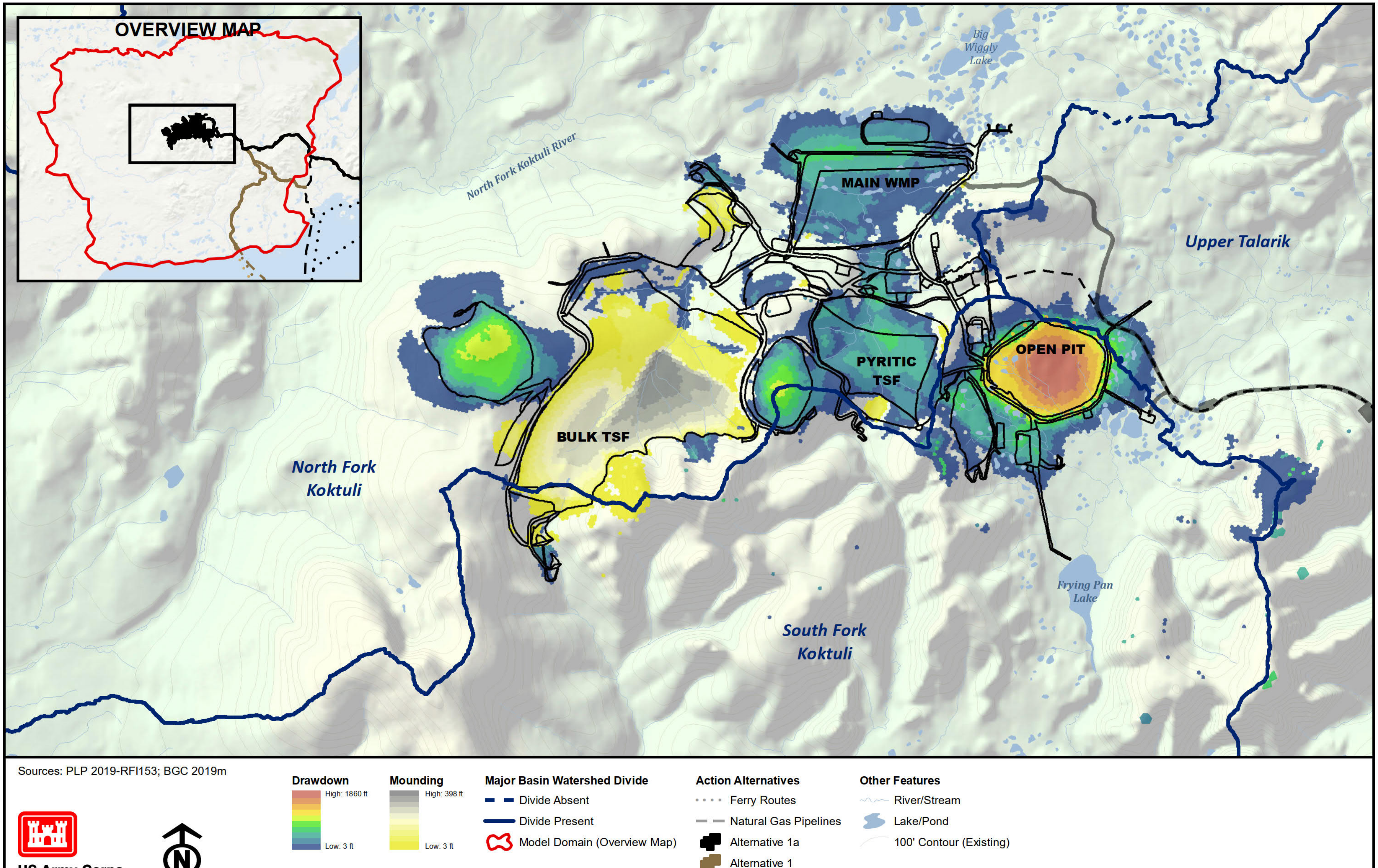
CONCEPTUAL GROUNDWATER SYSTEM AROUND PIT DURING LATE OPERATIONS AND POST-CLOSURE

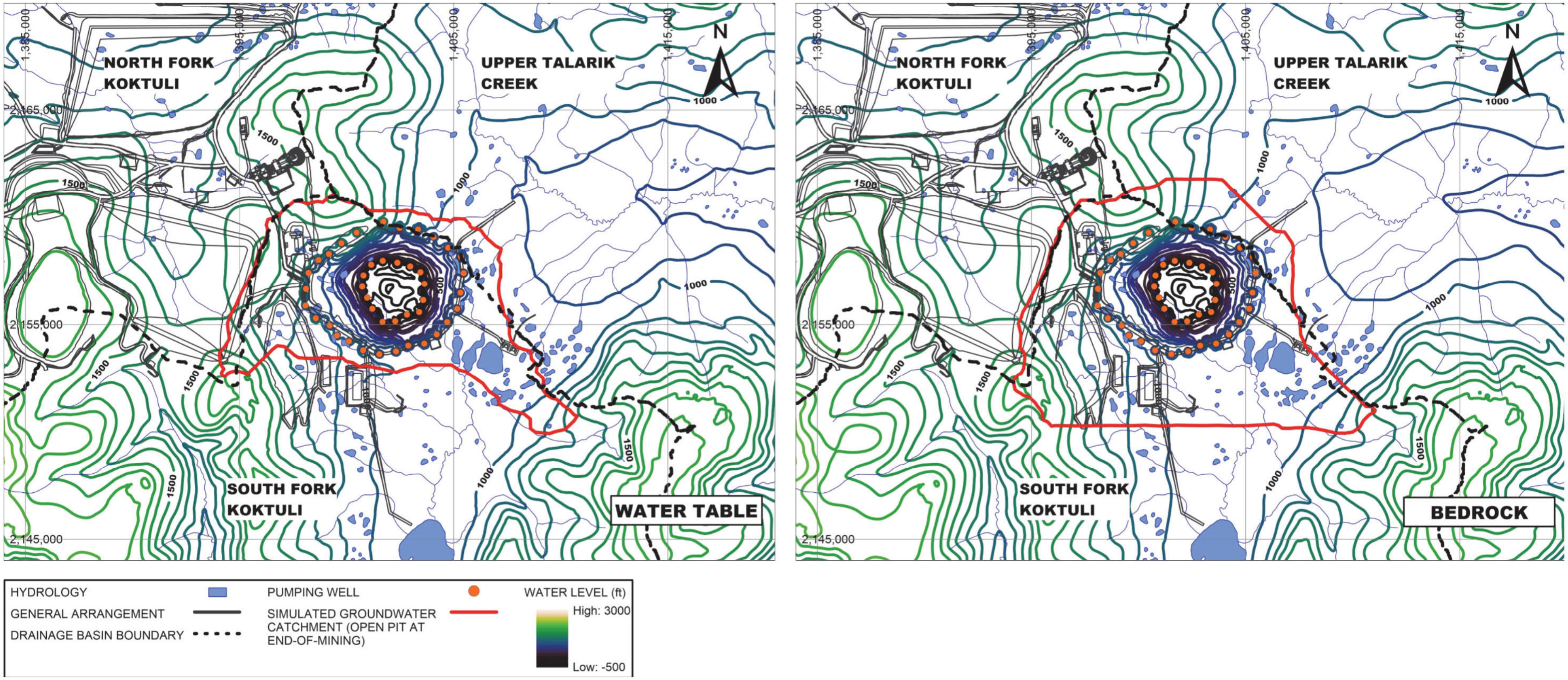
FIGURE 4.17-1



SIMULATED END OF MINING DRAWDOWN AND MOUNDING: WATER TABLE

PEBBLE PROJECT EIS

FIGURE 4.17-2



Source: BGC 2019p

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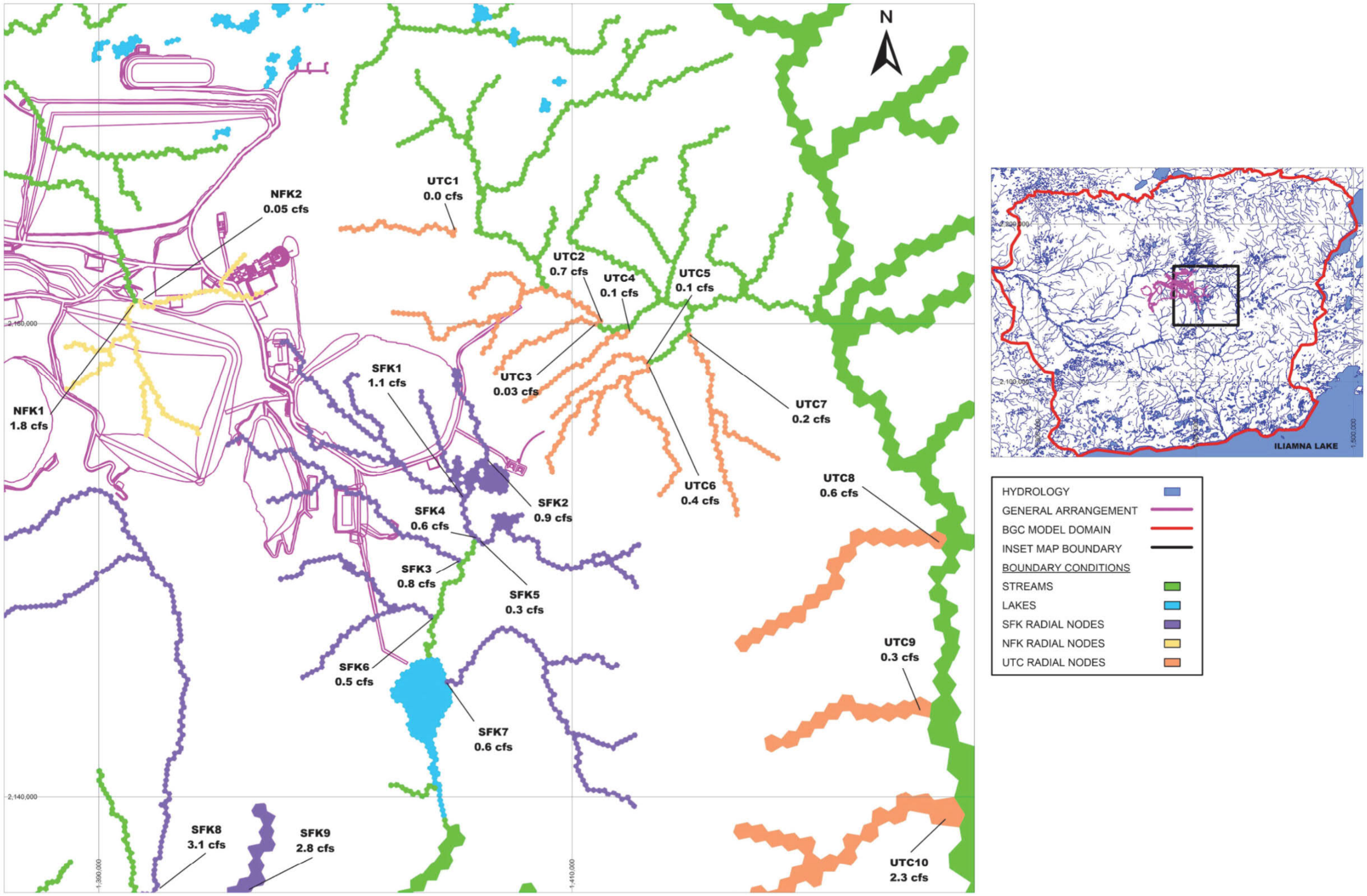
SIMULATED OPEN PIT CAPTURE ZONES: END OF MINING

During operations, water in and near the open pit would be managed using a water storage pond (open pit WMP) and runoff controls. Groundwater inflow to the open pit would be pumped to the open pit WMP for storage, then treated prior to discharge from the water treatment plant (WTP) (see Section 4.18, Water and Sediment Quality). Runoff from areas upslope of active mining would be intercepted and diverted around the open pit to the extent possible (see Section 4.16, Surface Water Hydrology). Direct rainfall, snowmelt, and runoff from the open pit walls would be collected and pumped using in-pit pumps to the open pit WMP for storage prior to treatment and discharge. WTP discharge would be outside of the pit zone of influence. The expected average rate of water treatment at the end of mining under base-case conditions is 36 cubic feet per second (cfs) (16,000 gpm) (Knight Piésold 2019s). This illustrates that groundwater inflow into the pit is expected to be a small percentage of total water treatment, even under sensitivity analysis scenarios with approximately triple the projected amount of groundwater inflow to the pit (4,300 gpm, or 9.6 cfs) compared to the base case simulation (1,500 gpm or 3.3 cfs).

Pumping water from the pit and from wells in and surrounding the pit would locally change groundwater flow patterns so that groundwater would flow radially inwards and vertically upwards towards the pit. Groundwater/surface water interactions and surface water flows would also be impacted by pit dewatering. Natural groundwater discharge to seeps, wetlands, streams, ponds, or lakes immediately adjacent to the pit may cease or be reduced, resulting in lower surface water base flows, lower pond or lake levels, or lower groundwater levels beneath wetlands. Analysis of these lower water levels or flows is complex, because substantial water would still be provided to these waterbodies from precipitation and snowmelt, and because of uncertainty in the groundwater modeling. The groundwater model simulates base flow to streams and stream losses to groundwater in different segments based on local hydrogeologic conditions, as illustrated in Figure 3.17-14. These close interconnections between groundwater and surface water in headwaters catchments are integrated into the watershed modeling described in Section 4.18, Water and Sediment Quality, and interpreted with respect to aquatic resources in Section 4.24, Fish Values. The uncertainty in the groundwater model related to these interconnections was evaluated by conducting numerous sensitivity analyses. The results of the sensitivity analyses are propagated through other predictive components of this EIS.

The groundwater model was used to estimate changes in baseflow in headwaters streams as a result of mine development. The streamflow segments analyzed are shown in Figure 4.17-4, along with estimated average baseflow under baseline conditions (pre-mine). Figure 4.17-5 shows the expected reduction in baseflow at end of mining. Analysis was also conducted for conditions during post-closure, and baseflow impacts were found to be less than shown in Figure 4.17-5 because of the partial recovery of the groundwater with filling of the pit lake (BGC 2019o). Additional analysis about potential streamflow loss under different sensitivity analysis scenarios is provided in Appendix K4.17.

In terms of magnitude and extent, some wetlands, stream segments, ponds, and lakes in the immediate pit area may be eliminated as the water table is lowered, and water leaks out of these waterbodies during construction and mining operation and into the pit dewatering system. The duration of these impacts would be medium- to long-term, lasting for the life of the project, and some would continue through post-closure (when the zone of influence would be smaller); they are certain to occur if the project is permitted and built. Indirect impacts to wetlands from the lowered water table around the pit were evaluated by PLP (PLP 2018-RFI 082) by comparing the hydrogeomorphic classification of impacted wetlands to the permeability and recharge potential of surficial geologic units in the groundwater model to determine their susceptibility to dewatering impacts. Areas with highly permeable layers such as glacial outwash would be most affected by drawdown, whereas areas underlain by glacial lake deposits are relatively isolated from groundwater and less impacted by drawdown. Areas of drawdown that coincide with susceptible wetlands and acreages are provided in Section 4.22, Wetlands and Other Waters/Special Aquatic Sites.



Source: BGC 2019o

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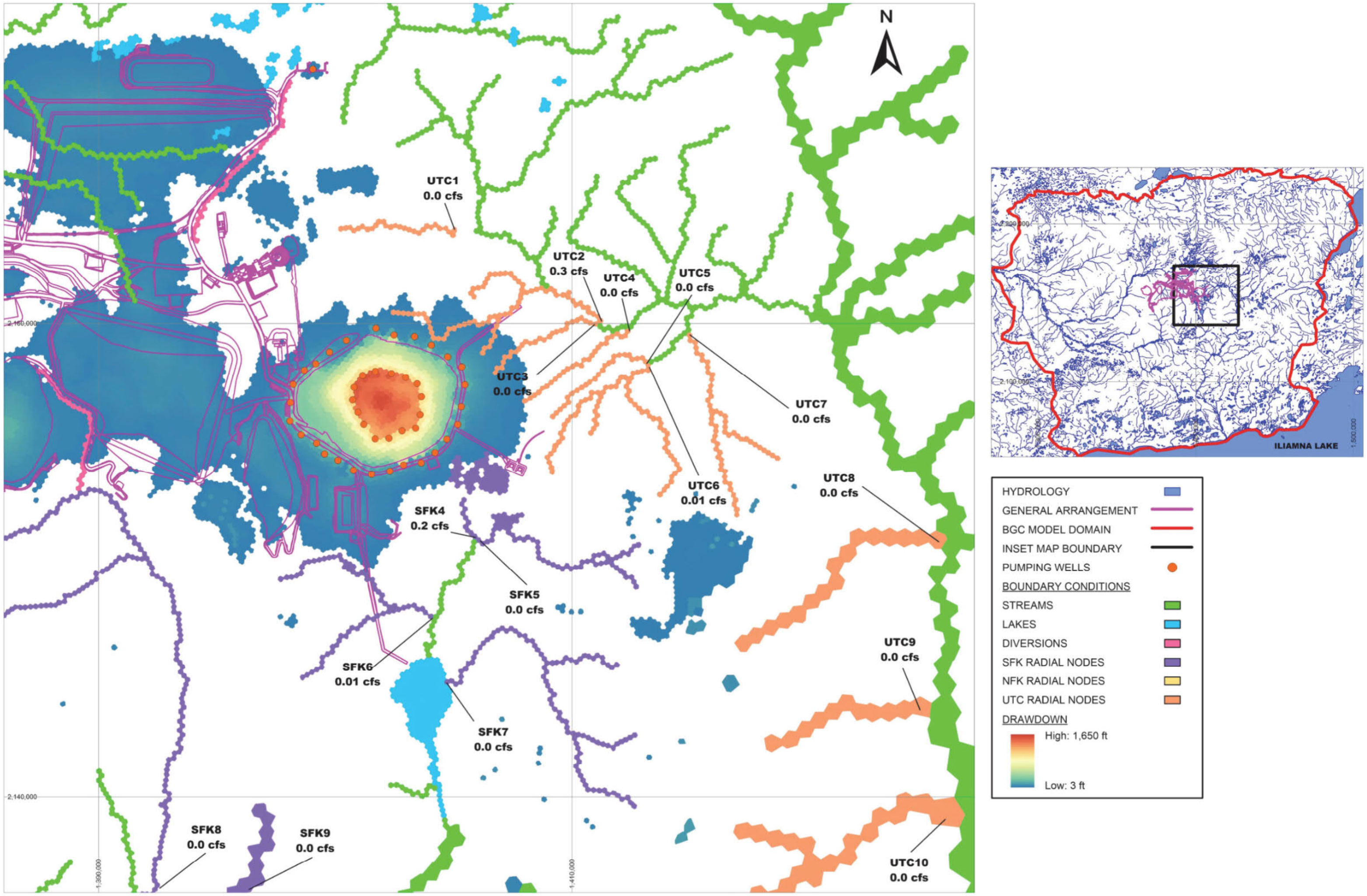
CUMULATIVE BASEFLOW TO STREAM SEGMENTS THAT MAY BE IMPACTED BY THE OPEN PIT: PRE-MINE CONDITIONS



Source: BGC 2019o

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CUMULATIVE BASEFLOW REDUCTIONS TO STREAM SEGMENTS THAT MAY BE IMPACTED BY DEVELOPMENT OF THE OPEN PIT: END OF MINING

Streamflow reduction during operations and closure is further addressed in Section 4.16, Surface Water Hydrology, and related effects on wetlands and fish are addressed in Section 4.22, Wetlands and Other Waters/Special Aquatic Sites; and Section 4.24, Fish Values, respectively.

The contiguous zone of influence for the open pit at the end of mining would be approximately 2.4 miles in diameter, although somewhat less in northerly and southeasterly directions. The zone of influence at the end of mining for the top of competent bedrock would be somewhat larger, extending up to approximately 3 miles in diameter (BGC 2019b). Additional figures depicting the extent of the zone of influence under sensitivity analysis scenarios are provided in Appendix K4.17.

The extent of primary impacts to groundwater flow associated with the open pit would be in the overburden and bedrock aquifers in the open pit footprint and zone of influence. Local, intermediate, and regional groundwater flow in these aquifers would flow radially towards the pit and be captured by the dewatering system. Groundwater beneath the pit would also flow upwards towards the pit and be captured. The magnitude of impacts to groundwater flow patterns would increase as mining proceeds to the full depth of the pit, and the zone of influence surrounding the pit becomes wider. The contiguous zone of influence at its widest extent at the end of operations would range from approximately 500 feet from the pit rim along its northern side, to approximately 4,000 feet from the pit rim along the southern and western boundaries of the zone. On the west, the zone of influence merges with a drawdown zone caused by the pyritic TSF and its underdrain system, and to the south it merges with a drawdown zone caused by the lined open pit WMP(Figure 4.17-2). A non-contiguous portion of the zone of influence occurs on a ridgetop area approximately 2 to 2.5 miles southeast of the pit rim. This is caused by propagation of drawdown through bedrock. Groundwater outside of the capture zone is predicted to discharge to local streams or seeps. The maximum area of the zone of influence for the pit at the end of operations would be about 2,600 acres.

Considering the high variability of model inputs such as hydraulic conductivity, recharge, and faulting, evaluation of model uncertainty on model predictions such as groundwater inflow to the pit, effects on wetlands and streamflow, and maintenance of hydraulic containment is important to establishing the reliability and usability of model results for this EIS. As further described in Appendix K4.17, different predicted zones of influence have been identified that are based on simulating a broad range of variability in hydrogeologic properties and boundary conditions assigned to the model to evaluate the effects of variability of these parameters. Although the base case model is considered to be a suitable tool for evaluating the effects of pit dewatering, other viable simulations of the model using different input parameters are possible, and are discussed in this section and Appendix K4.17.

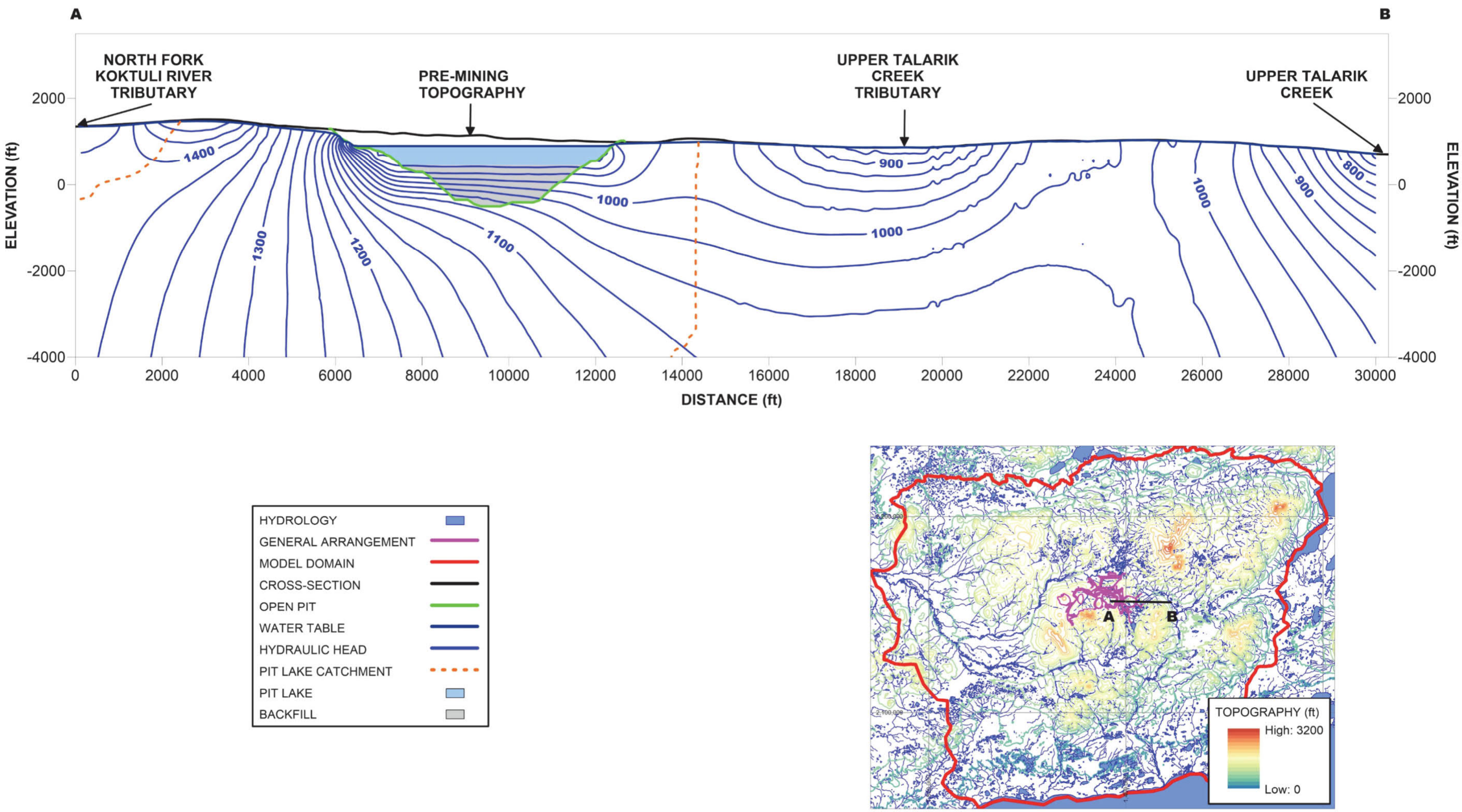
Closure and Post-Closure—Once mining ceases, dewatering activities would be reduced while potentially acid-generating (PAG) waste rock and pyritic tailings are placed in the open pit, and groundwater in the open pit would be allowed to rise. It is estimated it would take 21 to 23 years for the groundwater in the pit to reach the maximum management (MM) level at the beginning of closure phase 3 (890 feet above mean sea level [amsl]) (Knight Piésold 2019s). The not-to-exceed (NTE) level, which provides additional freeboard to contain short-term hydrologic events, would be 900 feet amsl (Knight Piésold 2019s). Water would be pumped from the pit lake to maintain the level below the MM level under the remainder of closure phase 3 (through approximately year 50 of closure and throughout post-closure. Under these conditions, the pit lake would be classified as a groundwater discharge lake (Webster et al. 2012) in which groundwater enters the lake from all sides and from beneath the lake, and no water leaves the lake through groundwater flow. Maintenance of the lake level at a sufficiently low level that the lake remains as a groundwater-discharge type of lake is termed “hydraulic containment” (i.e., contact water in the pit lake is contained except for that which evaporates or is pumped out, treated, and released). Figure 4.17-6 is a cross section through the simulated pit lake that depicts the configuration of the groundwater flow system beneath the pit lake.

The groundwater model was used to evaluate and confirm various elevations of the pit lake water surface that could result in loss of hydraulic containment of the pit lake (BGC 2019i). Results of the evaluation indicate that even under different sensitivity analysis scenarios, the pit lake would not lose hydraulic containment until the pit lake reached a level of 950 feet amsl or more, depending on the scenario. Therefore, the model predicts that all groundwater flow directions are towards the pit lake under the MM level of 890 feet with 50+ vertical feet of water storage available. This amount of water storage would provide for approximately 1 year of water-level recovery in the event of complete failure of all water pumping for any reason. This is estimated from the rate of water level recovery of the pit lake during late closure conditions, when no pumping of water from the pit lake is planned (Figure 4.18-6). Further simulations (BGC 2019n) indicate the conclusions regarding hydraulic containment of the pit lake also applied to hydraulic containment of the tailings and waste rock placed in the bottom of the pit lake during closure under all sensitivity analyses considered. Appendix K4.17 provides additional details and analysis about possible upset conditions that could interfere with planned pumping. Considering a wide range of circumstances, it is possible that release of contact water could occur under some conditions. Groundwater levels surrounding the pit would be monitored throughout post-closure to measure groundwater elevation, estimate hydraulic gradient, and monitor for indications of seepage from the pit lake (PLP 2019p).

The water level in the pit lake would be maintained to create a long-term groundwater sink to prevent pit lake water from discharging to the environment. For the purpose of this section, “long-term” is defined as lasting centuries. Knight Piésold (2018d) estimates an average annual pit water surplus of 3 cfs, of which approximately 1.8 cfs (800 gpm) would be from groundwater inflow to the pit lake. The expected average rate of water treatment during post-closure under average hydrologic and base-case conditions would be 13 cfs (5,800 gpm) (Knight Piésold 2019s). This illustrates that groundwater inflow into the pit is expected to be a small percentage of total water treatment during post-closure.

Sensitivity analysis results suggest that the range of groundwater inflow to the lake during post-closure could be between 1.4 and 4.0 cfs (BGC 2019a). Pit lake levels would be managed by pumping and treating water from the lake to maintain the MM level in the pit lake and prevent lake water from discharging into the environment. This would result in a pit lake that would be pumped to maintain the MM level long-term. The current closure water balance and water quality models are based on monthly flows with water being pumped year-round (Knight Piésold 2018g). As a result of seasonally variable hydrologic inputs and the relatively constant rate of water treatment, lake levels would fluctuate below the MM level. During post-closure conditions, additional groundwater inflows to the pit lake that could result from increased recharge as a result of climate change would be treated and discharged. Potential seasonal redistribution of recharge as a result of climate change (more wintertime recharge and less spring freshet snowmelt recharge) would not affect the annual quantity of water requiring treatment.

The presence of a long-term groundwater sink at the pit lake would continue to influence groundwater flow in the immediate vicinity of the pit lake throughout post-closure. However, the influence on groundwater flow would be smaller than in the pit’s fully-dewatered state during active mining operations. Figure 4.17-7 shows the projected post-closure zone of influence around the pit lake, and water-table changes near the quarries and the bulk TSF. It is assumed for this simulation that the main WMP, the pyritic TSF, and their associated underdrain systems have been removed. The estimated size of the pit lake zone of influence is approximately 2 miles wide (east to west) by 1 mile wide (north to south). Appendix K4.17 presents the results of sensitivity analysis that show a larger zone of influence using a higher hydraulic conductivity for the simulation. The predicted capture zone during post-closure conditions is shown in Figure 4.17-8.



Source: BGC 2019n

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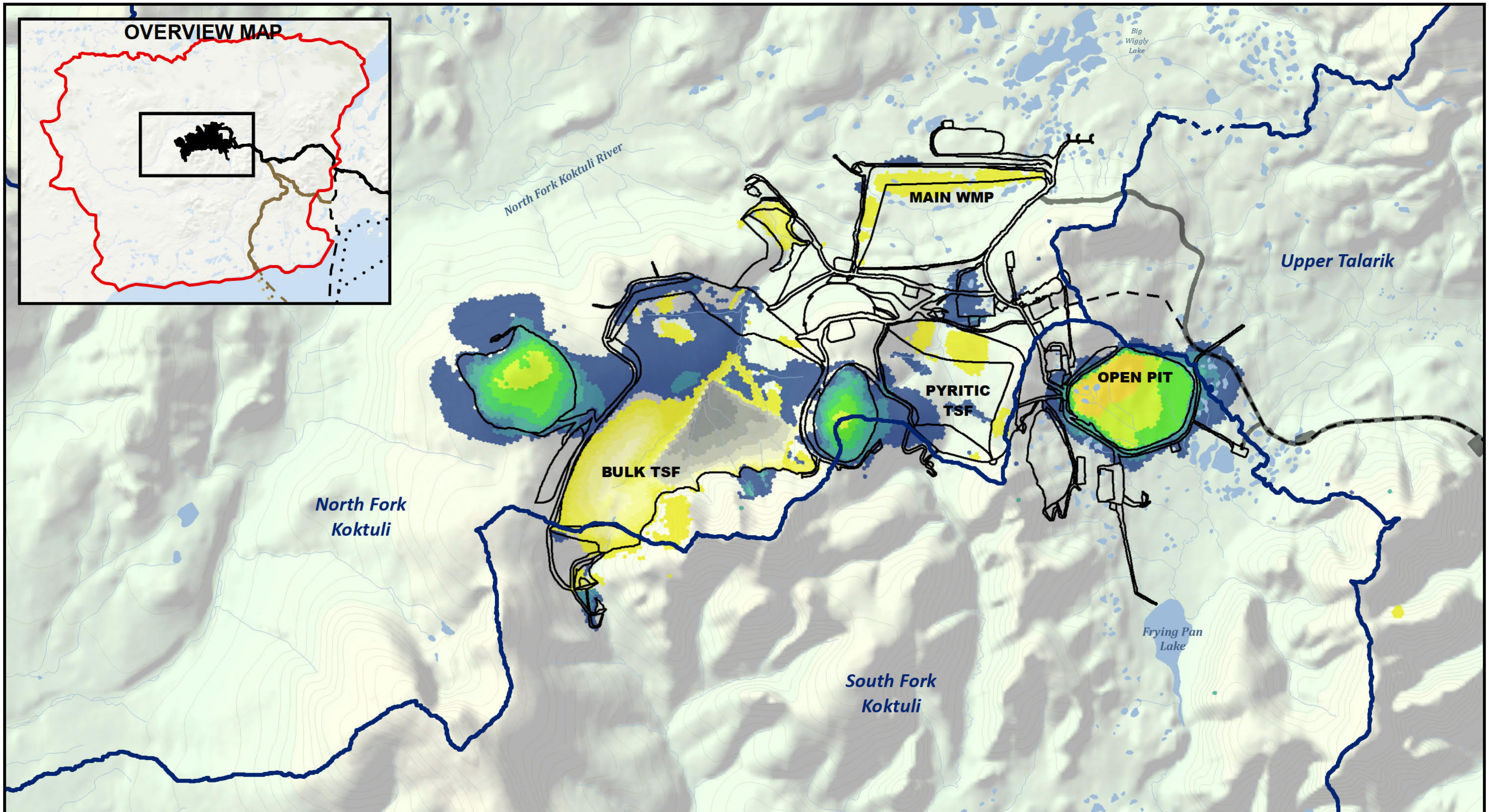
CROSS-SECTION OF SIMULATED PIT LAKE



Sources: PLP 2019-RFI153; BGC 2019m

Drawing
High: 1860 ft
Low: 3 ft

Mounding
High: 398 ft
Low: 3 ft

Major Basin Watershed Divide
- Divide Absent
- Divide Present
- Model Domain (Overview Map)

Action Alternatives
- Ferry Routes
- Natural Gas Pipelines
- Alternative 1a
- Alternative 1

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

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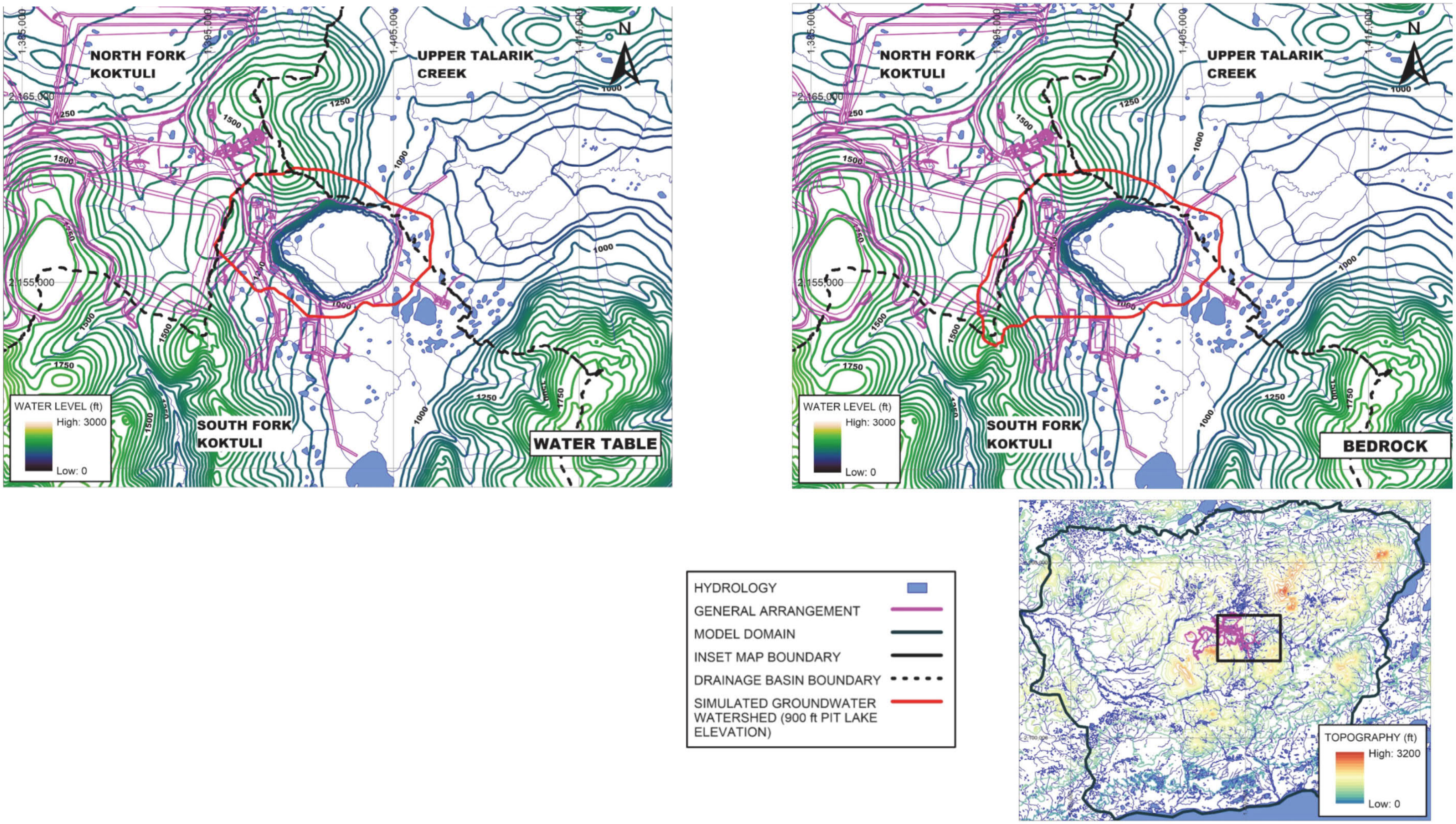
0.5 0 0.5 1
Miles

SIMULATED POST-CLOSURE DRAWDOWN AND MOUNDING: WATER TABLE



Source: BGC 2019i

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SIMULATED PIT LAKE CAPTURE ZONES: POST-CLOSURE

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FIGURE 4.17-8

In terms of magnitude and extent, areas of wetlands affected by drawdown during post-closure would also be smaller than those affected during operations, as shown on Figure 4.22-2 (acreages are provided in Section 4.22, Wetlands and Other Waters/Special Aquatic Sites). Duration of these impacts would be long-term. Impacted wetlands in the operations zone of influence outside of the post-closure zone of influence would be expected to recover after the MM pit lake level is reached (PLP 2018-RFI 082).

Impacts to groundwater from pit-lake pumping would occur if the project is permitted and constructed, and could include groundwater flow changes that affect the nearby environment. The duration of impacts would be for centuries, and the geographic extent could occur beyond local project component areas in the analysis area.

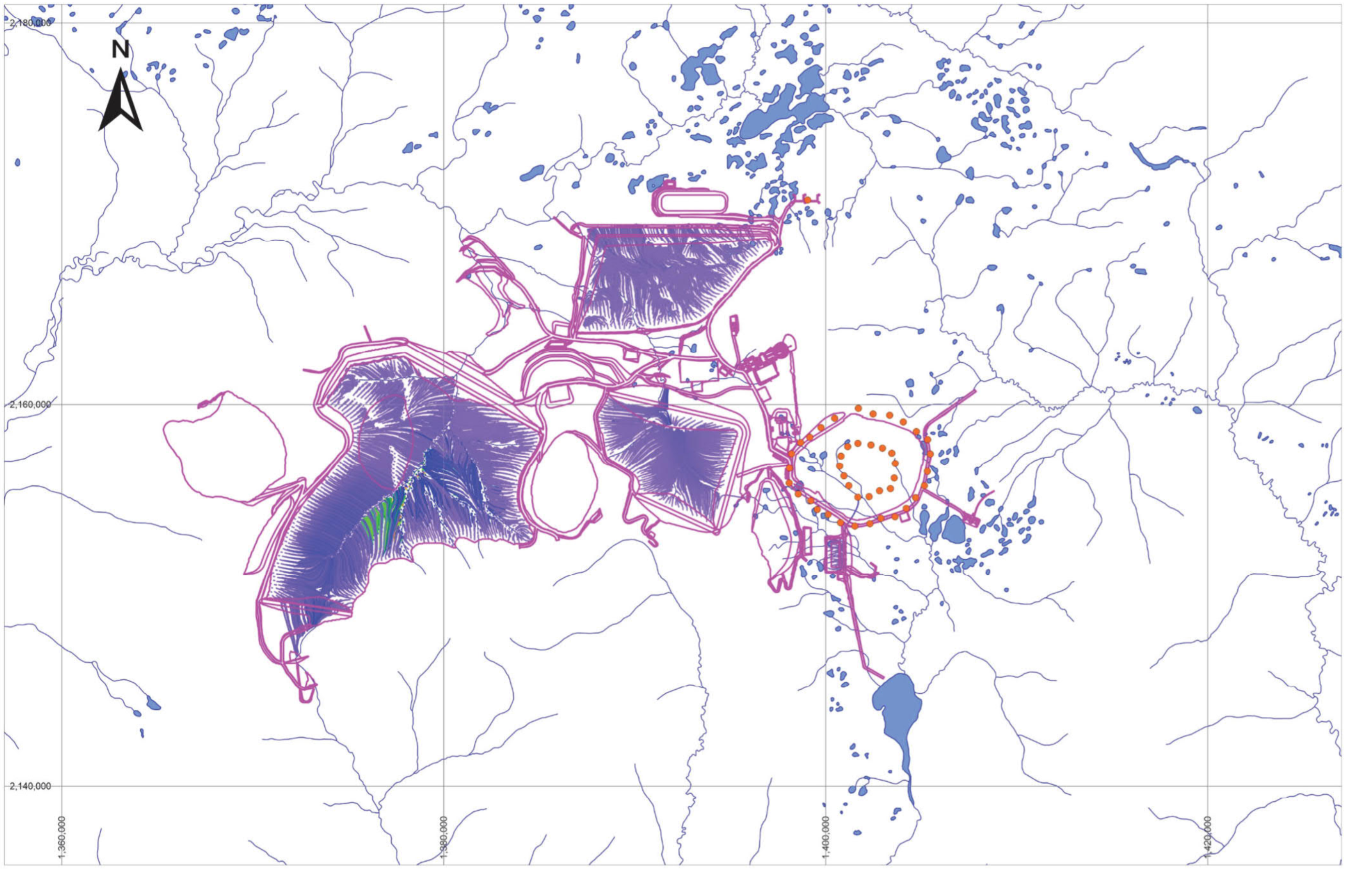
Water Management Ponds

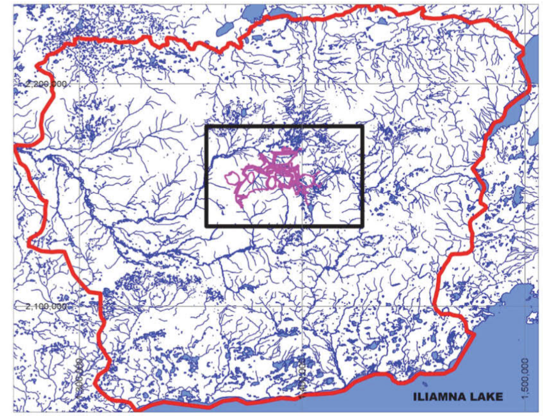
The main and open pit WMPs would be constructed at the mine site to manage water removed during pit dewatering; manage water from the milling and concentrating operations; and manage groundwater collected at the seepage collection ponds (SCPs) and surface water runoff collected at the mine site. These ponds would be lined with high-density polyethylene (HDPE). The main WMP would be equipped with underdrains in a herringbone pattern to minimize or avoid leakage of water with potentially elevated particulate and constituent concentrations to the underlying groundwater (PLP 2018-RFI 006; Knight Piésold 2019c). Construction of embankment foundations would require dewatering. Total groundwater inflow from the main WMP excavation dewatering is estimated to be 4.3 cfs (BGC 2019c), although staged construction would likely result in lower flow. Sensitivity analysis suggests that the flow could range from 2.7 cfs to 12 cfs. This water would be treated and discharged prior to construction of the WMPs.

During operations, water in the WMPs would be treated as needed and used in the milling operations. The water may also be used in tailings disposal operations to create a tailings slurry. Surplus water would be treated to discharge standards and released downstream of the mine site at specified discharge areas (see Section 4.16, Surface Water Hydrology, Figure 4.16-1) to mitigate projected surface water flow reductions downstream of the mine site (Section 4.16, Surface Water Hydrology). Surplus water that is treated and discharged downstream of the mine site would help restore downgradient groundwater flow as it infiltrates into the subsurface to help maintain pre-development flow conditions.

Groundwater flow would be impacted by the WMPs, including local reduction in recharge caused by the presence of the liners and collection of water by the underdrain system. The groundwater model results indicate that groundwater levels would be lowered in the area of the main WMP (Figure 4.17-2), extending approximately 0.7 mile north of the main embankment. Groundwater model particle tracking results [3] indicate that the underdrain system, including drains beneath the embankment, would effectively capture leakage of contact water that could flow through imperfections in the liner (Figure 4.17-9). The proper functioning of the ditches and underdrain system is critical to the proper functioning of hydraulic containment of the main WMP. Chapter 5, Mitigation, includes provision for design and construction to account for higher than expected seepage flows or potential cementation of the materials in the drains.

[3] Predictions of potential migration of contaminants in groundwater were simulated using a "particle-tracking" methodology whereby simulated particles (theoretical "particles" that are small enough and inert enough to travel unimpeded "with" the groundwater) are inserted into the upper layer of the model and tracked forward in time until they exit the flow system at surface water features such as SCPs, or to the ground surface; or until 100 years of elapsed simulation time have elapsed.





HYDROLOGY
GENERAL ARRANGEMENT
BGC MODEL DOMAIN
INSET MAP BOUNDARY
PUMPING WELLS
PARTICLE TRAVEL TIME (yr)
High: 100
Low: 0

Source: BGC 2019j

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END OF MINING PARTICLE TRACKING RESULTS: TSFS AND WMPS

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FIGURE 4.17-9

Removing the main WMP after closure would allow natural recharge to be re-established, groundwater elevations to recover, and predevelopment local groundwater flow systems to be restored in the vicinity of the former main WMP.

Sensitivity analysis results indicate that the simulated perimeter ditches and underdrains capture all particles released within the footprints of the WMPs for the base case and all sensitivity scenarios evaluated (BGC 2019c).

After decommissioning of the main WMP, water that may have leaked through the main WMP liner to shallow groundwater would be monitored and collected by pumpback wells if needed and sent to the pit lake (Knight Piésold 2018b) as long as required to intercept potential leakage until affected groundwater meets permitted discharge criteria, as allowable under applicable State of Alaska permits. Monitoring/pumpback wells would primarily be operated as monitoring wells unless leakage is detected; therefore, their impact on groundwater levels is expected to be intermittent, and limited to the immediate vicinity of the mine site. Based on data collected during construction and operations, the monitoring well network would be expanded as required (Knight Piésold 2018n).

The open pit WMP would be outside of the pit capture zone during operations and post-closure (Figure 4.17-3 and Figure 4.17-8). Leakage through the liner beneath this pond is expected to be collected by a system of drains, a collection point, and monitoring/pumpback wells (BGC 2019p). The open pit WMP would be removed and reclaimed in Phase 1 of closure (SRK 2019d); reclamation generally includes monitoring for water that may have leaked through the open-pit WMP liner to shallow groundwater, collecting it in pumpback wells if needed, and sending it to the pit lake (Knight Piésold 2018b) as long as required to intercept potential leakage that exceeds permitted discharge criteria as allowable under applicable State of Alaska permits.

Impacts to groundwater from the main WMP and open pit WMP would occur if the project is permitted and constructed. The duration of impacts would be medium-term (decades), lasting until the facilities are removed and reclaimed during closure. Effects could slightly exceed historic seasonal variation, but would not extend beyond project component areas.

Bulk TSF

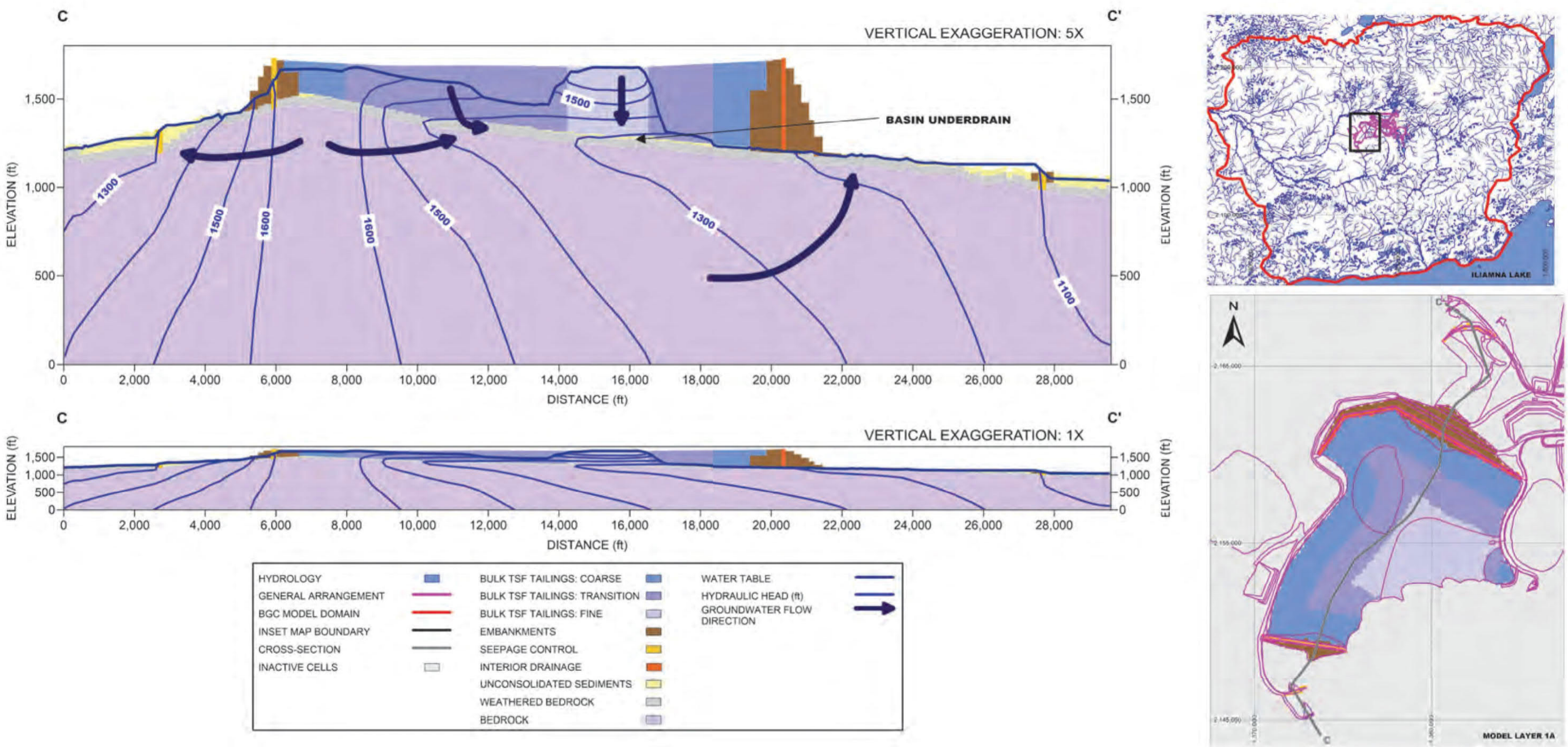
Construction and Operations—Bulk flotation tailings primarily composed of non-acid-generating finely ground rock material generated during milling would be stored in the bulk TSF. With the exception of the upstream face of the bulk TSF south embankment, which would be lined with HDPE, the bulk TSF would be unlined, and the bulk TSF main embankment would operate as a flow-through structure draining primarily towards the north (see Section 4.15, Geohazards and Seismic Conditions, for more detail about the embankments). The bulk TSF would be constructed almost entirely in the NFK watershed, with a series of embankments to impound the tailings and entrained and ponded water. A small area in the southern portion of the bulk TSF lies in the SFK drainage basin. An underdrain system beneath the tailings and the main embankment would manage seepage water draining through and beneath the main embankment from the tailings. The underdrains would primarily follow existing small drainage courses in the facility footprint. A grout curtain and liner at the south embankment would limit seepage draining through and beneath the south embankment. The thickened bulk flotation tailings discharged to the TSF would settle, and water would collect in a pond on top of the tailings.

During construction of the north and south embankments and the embankment at the north SCP, foundation areas would require dewatering (BGC 2019d). Total estimated flow of groundwater into these three foundation excavations (assuming a starter excavation for the north embankment, which would have staged construction) is 2.3 cfs, although the timing of construction would likely cause water to be pumped at less than this rate. Sensitivity analysis suggests that the total flow could range from 1.3 cfs to 4.9 cfs. It is anticipated that groundwater pumped during construction for dewatering purposes would be treated if required and discharged (PLP 2020d). Figure 4.17-10 illustrates groundwater flow systems in, beneath, and downgradient from the bulk TSF as simulated by the new groundwater flow model for conditions after mining ceases and tailings slurries are no longer being discharged into the facility (BGC 2019d). The figure shows that seepage water draining through the main embankment from the tailings would be collected by an underdrain system and routed to an SCP north of the bulk TSF. Modeling results indicate that the water table in the fine tailings in the center area of the bulk TSF would be perched or near-perched, and that the water table would be lower around the perimeter of the bulk TSF where coarser tailings would have been deposited and the main embankment would provide drainage as shown in Figure 4.17-10. During mining, discharge of tailings slurries into the bulk TSF would add water to the groundwater system in the tailings near the embankments, and a higher water table would be expected locally near the discharge points, depending on the dynamics of the placement and relocation of discharge sites and the permeability of the coarse and transition tailings (see Figure K4.15-3 and associated text in Appendix K4.15 for additional detail).

The bulk TSF would discharge approximately 1.7 cfs to the underdrains beneath the TSF under steady-state conditions without discharge of tailings at the end of operations. A smaller component of flow (about 0.3 cfs) would go through the main TSF embankment. The underdrains would also capture groundwater from the surrounding groundwater flow system. Seepage through and beneath the main embankment would be collected in the bulk TSF main SCP (see Section 4.16, Surface Water Hydrology, Figure 4.16-1). As described in Appendix K4.15, Geohazards and Seismic Conditions, the bulk TSF main SCP would be founded on bedrock and situated between two hillslopes to take advantage of a geomorphic constriction in this area. Any leakage through or around the bulk TSF south embankment would report to the bulk TSF south SCP (Figure 4.17-9). The SCP embankments would be constructed with low-permeability cores and grout curtains to block groundwater flow. A conceptual monitoring program, with number and placement of wells to be further considered during State of Alaska permitting should the project proceed, is provided in PLP 2019-RFI 135, and indicates that a monitoring/pumpback well would be downgradient of each SCP and associated sediment pond to ensure that all seepage would be captured. Water collected in the SCPs would be used for tailings dust control, or transferred to the main WMP for subsequent use in ore processing (or to the pit lake during post-closure). Surplus water in the main WMP would be treated to discharge standards and released downstream of the mine site outside of the pit zone of influence.

Sensitivity analyses were performed on various assumptions used in the modeling of seepage from the bulk TSF (BGC 2019d). These simulations resulted in a range of predicted seepage from the facility (not including flow through the embankments) from 1.1 to 81 cfs, although the high estimate of 81 cfs is unlikely to be a sustainable average flow rate. Base case seepage was estimated to be 1.7 cfs. Separate two-dimensional cross-sectional modeling yielded similar results, with estimated seepage from the facility at the end of mining ranging between 3.5 and 5.5 cfs, depending on parameter and boundary condition assumptions. Sensitivity analysis suggested the flow could be as high as 18 cfs.

Because tailings along the northwestern ridge of the bulk TSF would be built up higher than the two saddles along this ridge, it is possible that there would be a potential for groundwater flow paths through these saddles during late operations. However, the potential for this is low because the tailings emplacement plan (Knight Piésold 2019o) calls for deposition of relatively coarse (and more permeable) tailings adjacent to this ridge, and maintenance of a water table in this area that is below the water table beneath the saddles. Particle tracking model results indicate that contact water in this area would not flow through either saddle to escape containment (BGC 2019d). Groundwater levels would be monitored during operations in piezometers along the ridge and downstream of the embankment, and operational rules established to maintain hydraulic containment. If seepage through the ridge is detected, contingencies such as relief wells and/or seepage recovery wells would be implemented (Knight Piésold 2018n) (see Chapter 5, Mitigation).



Source: BGC 2019d

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GENERALIZED GROUNDWATER FLOW CONDITIONS FOR BULK TSF CROSS-SECTION C

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FIGURE 4.17-10

Under baseline conditions and facilitated by flow through the underdrains, seepage from the bulk TSF tailings that enters shallow groundwater beneath the tailings would be expected to flow laterally and report to the north SCP, where the model shows that pumping of water from the pond and a lined, low-permeability embankment would maintain containment and prevent seepage of water in a down-valley direction (BGC 2019d). As shown in Figure 4.17-10, the underdrains would also capture groundwater from the surrounding area that would flow upwards towards the upper fractured layer of bedrock and the underdrains.

Groundwater model sensitivity analyses and particle tracking were performed under a variety of conditions and are described in more detail in Appendix K4.17. The particle-tracking technology provides a useful visual summary of where contact water would be expected to flow under conditions of the simulations. Appendix K4.17 presents two cases where models of sensitivity analysis scenarios suggested potential escapement of contact water; however, these conditions were further analyzed and concluded to be unlikely to be realized. The sensitivity and particle tracking analyses are useful, even if improbable, for formulating potential design, mitigation, and monitoring provisions for the project.

Specifically, particle tracking results indicate that under all scenarios except two (Scenario S7 and a fault zone through the western wall of the bulk TSF [BGC 2019l]), essentially all particles released report to either the north or south SCP. Scenario S7 exhibited flow bypassing the SCPs. Scenario S7 was performed using a high K scenario, and the resulting simulation showed that baseline groundwater levels were poorly represented; the quality of the calibration had deteriorated; and that flow of particles past both SCPs is considered improbable. (BGC 2019d).

BGC (2019l) also conducted a sensitivity analysis to evaluate the potential effects of a fault through the western wall of the bulk TSF, and concluded that seepage pathways from the facility could be influenced if the hydraulic conductivity of the faulted bedrock is sufficiently high. Although field hydraulic conductivity data, monitoring well (water level) data, and model calibration degradation suggest that such a scenario is unlikely, further hydrogeologic data could be collected at future stages of project design to characterize the hydraulic properties of the bedrock in the vicinity of this interpreted fault to allow for design of appropriate mitigation (e.g., grouting, partial liner placed over the fault trace, seepage collection wells), should this be necessary.

Closure and Post-Closure—The bulk TSF would be covered and allowed to consolidate during closure and early post-closure, but would continue to produce water for the long-term via the drains and underdrains to the north and south SCPs. Long-term pumping of water from the SCPs to the pit lake to prevent escapement of contaminated water is expected to occur. In the future, if monitoring showed that seepage water was no longer exceeding water quality standards, the pumping system would be discontinued and water would be released to the NFK and SFK basins downstream from the north SCP and south SCP, respectively.

The proper functioning of the ditches and underdrain system is critical to the proper functioning of hydraulic containment of the bulk TSF. Chapter 5, Mitigation, includes provision for design and construction to account for higher than expected seepage flows or potential cementation of the materials in the drains.

The bulk TSF would locally impact groundwater and surface water at the site; this impact is expected to affect groundwater at approximately 2,700 acres at and near the bulk TSF, and would be permanent. The extent and magnitude of the higher water table (a groundwater mound[4]) resulting from the TSF is shown on Figure 4.17-2. The underdrain system and the zone of weathered bedrock would collect water from the bulk TSF and convey it to the north SCP. Flow

[4] Groundwater mounding refers to areas of locally higher water table elevation caused by infiltration or downward vertical percolation of surface water to groundwater.

from the deeper bedrock system would also flow towards the weathered bedrock zone and discharge at the north SCP. The underdrain and the weathered zone of bedrock would prevent the groundwater mound in the tailings from extending into the groundwater aquifers beneath the underdrain/weathered bedrock system and affecting regional groundwater flow. Grout curtains installed at the southern TSF embankment and SCPs would locally impact groundwater flow in the overburden and shallow bedrock, but would not affect regional flow patterns. The seepage collection system associated with the bulk TSF is further described in Section 4.18, Water and Sediment Quality, along with potential impacts to groundwater quality as a result of seepage.

Pyritic TSF

The pyritic tailings and PAG waste rock would be stored in the pyritic TSF, which would be fully lined with HDPE and include an underdrain system. Construction of the pyritic TSF embankment foundation would require dewatering. Total groundwater inflow from excavation dewatering of the starter embankment is estimated to be 1.7 cfs (BGC 2019c). Sensitivity analysis suggests that the flow could range from 1.0 cfs to 2.3 cfs. Prior to the construction of the WMPs, this water would be treated if necessary and discharged.

Tailings would be placed on top of the liner and covered with water to minimize oxidation and the potential release of acidic contact waters to the environment. Groundwater levels would be reduced by this impoundment due to local reduction in recharge caused by presence of the liner and diversion of groundwater into the underdrain system. Groundwater flow exiting sub-basin NK119A would be reduced from 0.8 cfs to 0 cfs without return of water from the WTP (Knight Piésold 2019r) (see Appendix K4.17). Like the main WMP, removing the pyritic TSF after closure would allow natural recharge to be re-established and groundwater elevations and flow systems to recover.

The fate of liner leakage that reaches shallow groundwater beneath the pyritic TSF was modeled assuming a leakage rate of 1 liter/second (L/s), or about 30 gallons/acre/day (BGC 2019a; Giroud and Bonaparte 1989). Liner leakage that reaches subdrains or shallow groundwater is predicted to migrate northward. Liner leakage would be mitigated by placing foundation drains beneath the liner to direct leakage flow towards the SCP. This flow would be captured by the downgradient SCP (Figure 4.17-9), which would contain a grout curtain, low-permeability core zone, and monitoring wells (PLP 2020d).

Results of particle tracking analysis indicate that liner leakage that may reach groundwater beneath the pyritic TSF is expected to be captured by the underdrain and seepage collection system (Figure 4.17-9). Monitoring/pumpback wells would continue to operate as long as necessary following decommissioning to intercept potential leakage (Knight Piésold 2018n, b).

The proper functioning of the ditches and underdrain system is critical to the proper functioning of hydraulic containment of the pyritic TSF. Chapter 5, Mitigation, includes provision for design and construction to account for higher than expected seepage flows or potential cementation of the materials in the drains.

The pyritic tailings would be moved to the bottom of the open pit at the end of mining and submerged in the pit lake to prevent oxidation. The pyritic TSF liner and embankments would be removed at closure, and the site reclaimed by removing impacted materials, regrading, and capping with growth media (Section 4.16, Surface Water Hydrology, describes closure in more detail) (Knight Piésold 2018d). Therefore, groundwater flow in this tributary drainage (the one containing the pyritic TSF) to the NFK River is expected to essentially return to pre-mining conditions during post-closure (Section 4.16, Surface Water Hydrology).

Impacts to groundwater from the pyritic TSF facility would occur if the project is permitted and constructed, and would be medium-term, lasting until the facilities are removed and reclaimed during closure. The magnitude and extent of effects could slightly exceed historic seasonal variation, but would not extend beyond project component areas.

Potable Well Supply and Other Impacts

There would be no effects on any community groundwater or surface water supplies from the changes in groundwater flows at the mine site. The closest such water systems are about 15 to 20 miles east and southeast of—and on the opposite side of the UTC-Newhalen River watershed divide from—the pit groundwater capture zone (see Section 3.16, Surface Water Hydrology, Figure 3.16-25; and Section 3.17, Groundwater Hydrology, Figure 3.17-15).

Potable water at the mine site would be supplied by a series of groundwater wells approximately 3,000 feet northeast of the main WMP, outside of the estimated zone of influence around the open pit. The wells would be upgradient or side-gradient of the main WMP (see Section 3.17, Groundwater Hydrology, Figure 3.17-9 and Figure 3.17-10; and Section 4.16, Surface Water Hydrology, Figure 4.16-1), which is the closest potential source of groundwater contamination. The wells would be pumped at rates described below to provide sufficient potable water for mine site personnel living and working at the site. The potable water supply wells would also be used for fire-fighting, if needed.

As indicated in the project description (PLP 2020d) and Knight Piésold (2018e), a 250-person camp would initially be built to support early site construction activities. This camp would then be supplemented by the main camp, which would accommodate about 1,700 workers during construction. The main camp would be converted at the end of construction into a permanent facility expected to house 850 workers. Assuming an average water requirement of 50 gallons per day (gpd) per person to support the camps (ADNR 2018f), and an additional 10 gpd per person for the other facilities, the magnitude of impacts from camp water requirements would be a maximum daily volume of 102,000 gallons. In terms of magnitude, the total average water flow requirement rate during construction for the camps is estimated to be about 70 gpm, which is near the upper end of the range of pumping rates achieved during the pumping tests. This average demand is expected to be met by the installation of a single pumping well with two backup wells to allow for regular downtime and maintenance; however, up to six water supply wells may be installed Knight Piésold (2019s). During operations, the potable water requirement would be reduced to about 35 gpm. The potable water would be distributed through a pump-and-piping network to supply fresh water to holding tanks at the camps and other facilities. The holding tank capacity would be sufficient for a 24-hour supply.

Pumping for potable water supply during operations was simulated in the mine site groundwater model using the well (WEL) package in MODFLOW, assuming one well would be about 0.5 mile northeast of the main WMP; completed in weathered bedrock; and pumped at a rate of approximately 35 gpm (BGC 2019j). The results for the modeled base case (scenario S0) indicate that minor drawdown of roughly 3 feet would occur up to a distance of about 0.1 mile around the well, with drawdown increasing slightly in the immediate vicinity of the well (Figure 4.17-2). Under the high K sensitivity analysis scenario (S7), drawdown would be of a similar magnitude (3 feet), but the extent of drawdown around the well would merge with the drawdown zone surrounding the main WMP (BGC 2019m). The water-level fluctuations caused by potable water pumping are expected to be approximately of the same magnitude as natural seasonal fluctuations of water levels (Section 3.17, Groundwater Hydrology).

The water supply well or wellfield would remain into Closure Phase 3 to support reclamation and closure activities, and would be removed by Closure Phase 4 (SRK 2019d). A limited camp would remain in post-closure, and mine site infrastructure would be reconfigured to support long-term water treatment activities (RFI 2018-RFI 024; PLP 2020d). Because there would be a much smaller workforce than during operations, if a new potable water well were installed for the post-closure camp, pumping needs would be much smaller than during operations. Drawdown is expected to be less than that expected during operations, and would have negligible impact on local groundwater flow.

During construction and operations, the mine site area would undergo development to become an industrial site, and would be subject to typical development impacts such as increases in impervious area, increased surface runoff, decreased groundwater recharge, and the potential for small-scale spills and leaks of contaminants such as oil and grease and fugitive dust. Small-scale spills and leaks are further addressed in Section 4.18, Water and Sediment Quality. Changes in groundwater levels or groundwater flow directions or amounts from this type of development are expected to be very small and generally within the range of natural variation, in comparison to the effects described in this section attributable to the major mine facilities.

Estimated effects of the project on streamflow are described in Section 4.16 and Appendix K4.16, Surface Water Hydrology. Downstream of the treated water discharge locations, these changes in streamflow could result in changes in stream stages that could affect groundwater levels adjacent to the stream. These changes would occur in the context of varying natural changes in streamflow resulting from storms, snowmelt, dry spells, and winter conditions. These natural changes in streamflow are expected to result in changes in water levels in streams that are of greater magnitude than changes of water level caused by the projected average changes in flow. Therefore, groundwater levels that respond to changes in streamflow would be expected to be subject to a range of highs and lows that typically exceed the changes imposed by Alternative 1a. The potential changes in streamflow and groundwater levels are expected to exert only a very small impact on amount and directions of groundwater flow in wetland and habitat areas downstream of the treated water discharge locations.

The water table at two quarries in the mine site area would be lowered as a result of removal of the uppermost portion of the bedrock aquifer. Under undeveloped conditions, the water table is in the mass of rock material that would be removed. Drawdown associated with these features is depicted in Figure 4.17-2.

4.17.3.2 Transportation Corridor

Shallow Groundwater Interception—The transportation corridor is designed to avoid wetlands and stream crossings where feasible, and its alignment would be optimized for the most amenable soil and geotechnical conditions. Road beds are typically constructed well above the water surface elevation in adjacent ditches, and are typically of suitable materials to avoid groundwater retention in the road prism. Therefore, road construction would not have an areal effect on groundwater/surface water interactions, other than the possible need to temporarily dewater some stream or lowland crossings as construction proceeds. Local groundwater flow impacts may occur along the corridor, where the roadway is constructed across wetlands that may be supported by groundwater inflow. Where technically feasible, coarse granular road base and additional culverts would be installed to facilitate the flow of shallow groundwater through segmented wetlands (PLP 2019-RFI 071b; Recon 2019b).

Some road segments would require road cuts to maintain proper road grade. These are represented by wide areas of the road footprint on hillslopes, which are prevalent throughout much of the mine and port access and Kokhanok spur road corridor under Alternative 1a (PLP 2017: Attachment 5).

Because shallow groundwater is expected to be present across the mine access road and port access road corridor, it is possible that road cuts could intersect groundwater in some areas, and cause a local diversion of groundwater flow, as drainage controls (construction BMPs as described in Chapter 5, Mitigation) direct potential seepage away from the road. In addition, benched cuts at material sites would likely intercept groundwater. These diversions would generally not move water to a different drainage, or cause dewatering of wetlands or waterbodies extending more than a few feet from the road corridor or material sites.

Therefore, the magnitude and extent of groundwater interception along the transportation corridor are expected to be localized in the immediate vicinity of the roadways. The duration of impacts would range from temporary for construction dewatering at streams, to long-term in areas of road cut diversions and segmented groundwater-supported wetlands, because the access roads would remain throughout post-closure to support ongoing mine site water treatment activities.

Ferry Terminals—At the ferry terminals, there would be a slight deviation of shallow groundwater flow on a facility footprint scale as a result of foundation materials that differ in hydraulic properties from native soil. The extent of these effects is expected to be limited to the footprint of the terminal facilities. The duration would be long-term, because the ferry terminals would be partially removed and reclaimed at closure, leaving behind some foundation materials and smaller facilities in post-closure to support ongoing mine site water treatment activities (SRK 2019d). The lake portion of ferry terminal construction is not expected to impact groundwater.

Water Extractions—Surface water/groundwater interaction is expected to occur at locations used for surface water extraction where shallow groundwater is present. Groundwater occurrence in glacial and alluvial deposits along the mine access road to Eagle Bay is similar to that of the mine site.

Shallow groundwater occurrence is limited along the Amakdedori port access road due to the presence of shallow bedrock. In terms of magnitude and extent, approximately 63 million gallons of surface water would be extracted from 21 potential water extraction sites to support project construction and operations of Alternative 1a (PLP 2018-RFI 022) (see Chapter 2, Alternatives) (see Figure 4.16-7). This water would be extracted at specific permitted locations along the mine and port access road corridors over months to years of construction (see Section 4.16, Surface Water Hydrology). The extraction would draw connected shallow groundwater toward extraction sites. Temporary construction camps at Amakdedori port, Kokhanok, Iliamna, Newhalen, the mine site, and the north and south ferry terminals may be supplied by local groundwater sources, and would be authorized by Temporary Water Use Authorizations from ADNR. The extent of impacts would be limited to the immediate area of the camps, and duration would be medium-term, lasting throughout the mine life, but would be temporary; because once water drawdown ceases, groundwater would no longer be drawn towards the extraction facilities.

4.17.3.3 Amakdedori Port

Shallow Groundwater Interception—The port site is designed to avoid wetlands where feasible, and its footprint would be optimized for the most amenable soil and geotechnical conditions. Excavations across the port footprint may be required during port and dock construction. The elevation of the terminal area is about 15 to 20 feet above that of the Amakdedori Creek floodplain, which has a high water table in alluvial deposits that are hydraulically connected to Amakdedori Creek. The closest distance of the terminal to the floodplain would be about 700 feet (see Figure 2-28). Because of the elevation difference and distance to the floodplain, excavations are not expected to intercept shallow groundwater in this area. Mounding of groundwater is not expected to occur due to infiltration of fill placed for terminal construction, because the terminal would be paved and runoff controlled.

The marine portion of the port construction would have no effect on groundwater. Impacts to groundwater would be limited to within the footprint of material sites used for dock construction, and would occur only during construction.

Groundwater Use—Based on limited hydrogeologic information at the port site, shallow glacial and fluvial sediments in the area are likely to host groundwater (Glass 2001; Detterman and Reed 1973; Zonge 2017). A groundwater well is planned to supply potable water for port personnel and/or fresh water for operations. The precise location for the well would be identified during detailed design. The well would be sited on uplands far enough from the shore to avoid any potential for saltwater intrusion, and water would be piped to the site from the wellhead (PLP 2018-RFI 022a). It is anticipated that such a well would have a local (i.e., a few feet to a few tens of feet radius) impact on groundwater flow and quantity, depending on rate and frequency of drawdown caused by pumping. The duration of impacts would be long-term, lasting through the life of the project and into post-closure as long as the facility is used. Water rights authorization for water production from the well would be acquired, and the design of the well production activities would be reviewed and approved by ADEC.

4.17.3.4 Natural Gas Pipeline Corridor

Shallow Groundwater Interception—Along the pipeline corridor from Amakdedori to the south ferry terminal, the water table is the same as described above for this portion of the transportation corridor, and is expected to be close to the surface along much of the corridor, as evidenced by abundant wetlands, kettle ponds, and exposed bedrock.

Groundwater along the pipeline corridor coincident with the mine access road from the mine to Eagle Bay is expected to be held in shallow aquifers of glacial sediment, as demonstrated in similar geologic terrain at the mine site (see Section 3.13, Geology). The pipeline-only segment from Iliamna Lake to the mine access road would follow a generally low-elevation route commonly underlain by permeable soils that would be expected to have abundant shallow groundwater. Much of the buried pipeline in this area could intersect shallow groundwater, as shown by the distribution of wetlands on Figure K4.22-1. Shallow groundwater occurrence along the pipeline adjacent to the southern part of the port access road is expected to be more limited, because much of this route appears to be sited on a well-drained terrace of surficial deposits several tens of feet above First Creek floodplain. Shallow groundwater along the route south of Iliamna Lake is expected to be sparse and intermittent due to lengthy segments through exposed bedrock.

Potential impacts to groundwater would involve interception of shallow groundwater during trenching and trench dewatering activities. Groundwater could also be captured and locally re-routed along the trench backfill. Modifications to groundwater flow would occur mostly in the immediate vicinity of the trench. Impacts could extend beyond the life of the project, because the pipeline may be abandoned in place. Low-permeability trench plugs, considered a typical best management practice (BMP) for pipeline installation (USACE 2018c), could be installed to minimize movement of groundwater along the trench; reduce erosion along the trench backfill; and minimize alteration of the natural groundwater flow path.

Horizontal Directional Drilling—On the Kenai Peninsula, the pipeline would be trenched for a short distance west of the compressor station, and then installed by HDD between the bluff and Cook Inlet from an elevation of about 200 feet to -12 feet mean lower low water (Figure 2-40) (PLP 2018-RFI 011). The HDD-installed pipeline segment would be expected to intersect aquifers used by private wells in the area. As discussed in Section 3.17, Groundwater Hydrology, 12 private wells are within 0.5 mile of the HDD route. The closest of these, designated well 53874 in the state WELTS database, is thought to lie approximately 100 feet to the north of the pipeline route (Figure 3.17-16), although it could be closer due to imprecision in the database, which uses a centroid (parcel-center) location system. (For comparison, a common separation distance used in siting a domestic well and septic system is 100 feet to avoid cross-contamination effects.) Construction activities and compressor station operations would be directly upgradient of well 53874, and possibly upgradient of other private wells to the north.

Well 53874 pumps from a sand aquifer at a depth of 60 to 61 feet (ADNR 2016). Other wells in the area draw from shallow glacial deposits at depths between 8 and 30 feet, and from deeper aquifers in both glacial deposits and bedrock between 50 and 120 feet deep (USGS 1967; Nelson and Johnson 1981; ADNR 2018). Based on a "typical" cross-section in Figure 2-40, the depth of the HDD near well 53874 would be on the order of 50 to 100 feet, similar to that of the aquifer from which the well pumps.

Impacts to the closest well during HDD installation or compressor station construction and operations could include surface disruption, well pressurization effects, fuel spills infiltrating into the subsurface, or natural gas diffusion into the aquifer in the event of a pipeline leak, as described below (e.g., TRCA 2010). Dewatering would not be required for HDD drilling (PLP 2018-RFI 051); therefore, groundwater drawdown in the private well would not be expected.

Surface disruption near the wellhead during construction could include changes to surface runoff, wellhead damage from truck traffic, and small leaks or spills. Assuming no wellhead damage occurs, the aquifer would be protected from surface infiltration at the wellhead by its grouted steel casing and several clay layers above the aquifer (ADNR 2016). Construction at the HDD drill-site and compressor station, and compressor station operations, are industrial activities that pose the usual risk of fuel spills. As described in Section 4.18, Water and Sediment Quality, well 53874 would be directly downgradient in the event such spills were large enough to infiltrate the subsurface and reach groundwater. Other private wells to the north may also be in the path of potential contaminated groundwater migration as a result of advection/dispersion through heterogeneous deposits, as contaminant sources in such environments can create fan-shaped plumes.

Pressurization of the HDD borehole may force drilling fluids into the same aquifer used by the nearby well, which could affect local flow patterns and quality depending on the exact well location; final HDD location and depth; and drilling methods used. In terms of extent, it is possible for drill fluid to travel short distances (on the order of inches to feet) from the borehole due to this pressure. Drill fluid injection at very high pressures could create fracture openings at increased distances, although such effects are less likely in unconsolidated deposits than in bedrock. Drilling fluid returns would be monitored during drilling, and drilling specifications and a mud plan would be developed during detailed engineering to avoid the potential for injection of drill fluid into the aquifer. Typical mitigation procedures (see Chapter 5, Mitigation) may include lowering drill fluid pressure, temporary rig shutdown, adjusting fluid viscosity, and adding solids to the fluid to reduce loss into the formation (PLP 2018-RFI 051). Drill fluid effects on groundwater flow patterns in the immediate vicinity of the drill site are expected to be temporary, recovering days or weeks after construction. Potential effects on groundwater quality from drill fluid loss are discussed in Section 4.18, Water and Sediment Quality.

A leak during pipeline operations could travel laterally through the aquifer and affect well 53874 because of the effect of confining clay layers. Repair of the leak would stop the source, but ongoing leaks could require replacement of the well and associated water line to the residence because of combustion hazards or water quality impairment and the need for homes to have reliable water supply.

Recommendations for additional mitigation to further protect the nearby private well are provided in Appendix M1.0, Mitigation Assessment. These include a surveyed location of the private well compared to the HDD final design route; contact with the owner to confirm the status, use, and pumping rate at the well; designation of a surface buffer around the wellhead during construction; geotechnical drilling along the HDD route to further assess subsurface units and HDD route planning; consideration of moving the HDD route further to the south and/or adjusting the depth to provide additional distance or stratigraphic separation from the private well aquifer; monitoring of well flow and quality during construction activities in the area; and contingency plans for response in the event groundwater flow or quality at the private well are altered, including well replacement and associated activities and costs.

4.17.4 Alternative 1

4.17.4.1 Mine Site

The magnitude, duration, extent, and likelihood of expected effects of Alternative 1 on shallow groundwater at the mine site would be the same as described for Alternative 1a.

4.17.4.2 Transportation Corridor

Impacts to groundwater along the port access road would be the same as those described for Alternative 1a because the road corridor is the same. Some road segments would require road cuts to maintain proper road grade. These are represented by wide areas of the road footprint on hillslopes (see drawings in PLP 2017: Attachment A5), which are prevalent throughout much of the mine access road, port access road, and spur road corridors (including both the Kokhanok and Iliamna spur roads for Alternative 1).

North and South Ferry Terminals—Impacts to groundwater would be the same as those described for ferry terminals under Alternative 1a.

4.17.4.3 Amakdedori Port

The magnitude, duration, extent, and likelihood of expected effects of Alternative 3 on shallow groundwater at the Amakdedori port would be the same as described for Alternative 1a.

4.17.4.4 Natural Gas Pipeline Corridor

Groundwater impacts at the eastern terminus (Kenai) and from Amakdedori to the south ferry terminal would be the same as those described for Alternative 1a. Groundwater impacts along the mine access road from north ferry terminal to the mine site would be similar to the impacts described for the mine access road between the mine site and the Newhalen River under Alternative 1a.

4.17.4.5 Alternative 1—Summer-Only Ferry Operations Variant

The expected magnitude, duration, extent, and likelihood of effects of this alternative variant are similar to those described under Alternative 1. The main difference between Alternative 1 and this variant relates to the need to construct concentrate and fuel storage facilities at the mine site or at the Amakdedori port site (Ausenco 2018). There would be no effects on groundwater from the seasonal-only use of Iliamna Lake. The extent of the expanded container yard at the port site would reach the edge of the Amakdedori floodplain. Therefore, excavations during construction in this area are more likely to intercept shallow groundwater than under Alternative 1 without this variant.

The expanded facilities at both the mine and port sites could have a short-term impact on shallow groundwater during construction from drainage controls or fill; and longer-term impacts on surface water/groundwater interactions and groundwater recharge from the installation of liners to control leaks or spills, which would be disturbed during construction, and continue throughout the life of the project. The extent of these effects would be limited to the immediate vicinity of the mine or port. Although long-term, lasting though the life of the project, they would be reasonably restored once mining ends and the port site is reclaimed (PLP 2018-RFI 024).

4.17.4.6 Alternative 1—Kokhanok East Ferry Terminal Variant

The expected magnitude, duration, extent, and likelihood of effects of this alternative are similar to those described under Alternative 1. The main difference between Alternative 1 and this variant is that the extent of the Kokhanok east route is approximately 15 percent shorter, which would reduce potential shallow groundwater and water extraction impacts (if any) associated with access road and pipeline construction. It is also anticipated that fewer streams and wetlands would be impacted (see Section 4.16, Surface Water Hydrology; and Section 4.22, Wetlands and Other Waters/Special Aquatic Sites), because the Kokhanok east route is shorter, and the Kokhanok east spur and port access roads are along ridge tops once they separate from the route in Alternative 1. However, the footprint of material sites associated with this variant are larger than Alternative 1 (Table 2-2), and would therefore have a slightly greater impact on shallow groundwater in the immediate vicinity of the materials sites during construction. Shallow groundwater impacts from construction of the Kokhanok east ferry terminal would be short-term, and similar to those of the south ferry terminal, and would only occur during construction.

4.17.4.7 Alternative 1—Pile-Supported Dock Variant

The expected magnitude, duration, extent, and likelihood of effects of this alternative are similar to those described under Alternative 1a for the onshore parts of the Amakdedori port site. Because there would be no need for fill by the dock structure, the effects of borrow material extraction on shallow groundwater interaction would be slightly less for Alternative 1 under this variant. Therefore, a pile-supported dock would have less impact than the earthfill dock under Alternative 1.

4.17.5 Alternative 2—North Road and Ferry with Downstream Dams

4.17.5.1 Mine Site

The expected magnitude, duration, extent, and likelihood of effects of this alternative are similar to those described under Alternative 1a for the mine site. The downstream dam (and bulk TSF south embankment) would be about 25 feet higher in elevation at its maximum height (see Table K4.15-1), and therefore would be slightly more likely to experience seepage through the topographic saddles on the eastern and northwestern sides of the impoundment. This is expected to be mitigated by piezometer monitoring and relief wells and/or seepage recovery wells as necessary (PLP 2018-RFI 019c). The predicted seepage rates through the embankment and vertically through the tailings to shallow groundwater would be essentially the same as those predicted by the groundwater model under Alternative 1a.

4.17.5.2 Transportation Corridor

The expected magnitude, duration, extent, and likelihood of effects of Alternative 2 on shallow groundwater along the mine access road are the same as for Alternative 1a, because this corridor is the same.

The effects of Alternative 2 on shallow groundwater along the port access road would likely be less than the effects of Alternative 1a, because the port access road to Williamsport would be shorter than the port access road to Amakdedori, even though the Alternative 2 port access road

(Williamsport) has steep terrain and more side-hill cut requirements than the port access road (Amakdedori) under Alternative 1a, which has sparse surficial deposits and fewer cut-slope requirements.

4.17.5.3 Diamond Point Port

In terms of magnitude and extent, the onshore footprint of the Diamond Point port is larger than the Amakdedori port site because of the need for a dredge materials storage area. The port is in an area of alluvial fan deposits at the mouth of the small drainage, which is expected to have a shallow water table. In terms of potential, construction excavations are likely to intercept groundwater and temporarily alter natural flow patterns in this immediate area of the Diamond Point port. The duration of impacts would be short-term, lasting only through construction. Placement of fill in this area could also result in groundwater mounding in the fill, which would likely be mitigated through drainage controls (see Chapter 5, Mitigation). The expected impacts on groundwater at Diamond Point port from Alternative 2 would be similar to those described under Alternative 1a for Amakdedori port.

4.17.5.4 Natural Gas Pipeline Corridor

The magnitude, duration, extent, and likelihood of effects of Alternative 2 on shallow groundwater along the natural gas pipeline corridor would be similar to those described under Alternative 1a. The onshore natural gas pipeline lengths would be similar (87 miles for Alternative 2 versus 66 miles for Alternative 1a), and both pipelines would be installed in a diverse variety of geologic conditions (Detterman and Reed 1973). The extent and duration of impacts would be an effect on shallow groundwater flow in the vicinity of the pipeline right-of-way during construction; however, the use of trench plugs, as is typical of pipeline construction BMPs in wet areas, would reduce the alteration of the natural groundwater flow patterns and minimize erosion along the trench backfill. There would also be localized dewatering of trenches where needed, with temporary and localized impacts.

4.17.5.5 Alternative 2—Summer-Only Ferry Operations Variant

The expected magnitude, duration, extent, and likelihood of effects of Alternative 2 on shallow groundwater for the Summer-Only Ferry Operations Variant would be similar to those described for the Summer-Only Ferry Operations Variant under Alternative 1. Impacts to groundwater from the additional container storage at Williamsport would be similar to those described for the transportation corridor for this variant. The footprint at this location is slightly wider than the mine and port access road corridors under Alternative 2. Therefore, there would likely be additional groundwater intersection and diversion on the 2,500-foot-long cut-slope side of the storage area, which would last throughout operations.

4.17.5.6 Alternative 2—Pile-Supported Dock Variant

The magnitude, duration, extent, and likelihood of expected effects of this variant on shallow groundwater for the onshore part of the Diamond Point port site are similar to those described for Alternative 2. There would be no effects on groundwater for the onshore part of this dock variant.

4.17.6 Alternative 3—North Road Only

4.17.6.1 Mine Site

The magnitude, duration, extent, and likelihood of expected effects of Alternative 3 on shallow groundwater at the mine site would be the same as those described for Alternative 1a.

4.17.6.2 Transportation Corridor

The duration of the effects of Alternative 3 on shallow groundwater in the transportation corridor are similar to those described under Alternative 1a. The magnitude and extent of affected groundwater resources would be slightly greater than the other alternatives because the combined distance of the north access road and port access road under Alternative 3 would be about 9 miles longer than the combined distance for Alternative 1a, 6 miles longer than Alternative 1, and 29 miles longer than Alternative 2. The Alternative 3 transportation corridor would require a greater distance of side-hill cuts in steep terrain that could intersect groundwater.

4.17.6.3 Diamond Point Port

The Alternative 3 port facilities would be located at the base of a steep bedrock slope with possible fracture flow. The dredge material stockpiles and material site would be located adjacent to similar bedrock slopes, groundwater-bearing talus deposits, and alluvium with shallow groundwater in the Williams Creek drainage. Like the Alternative 2 port site, the Alternative 3 port facility and material site are likely to intercept groundwater in construction excavations and temporarily alter natural flow patterns in the immediate area. Placement of fill at the port facilities and dredge stockpiles could also result in groundwater mounding, which would likely be mitigated through drainage controls.

The expected duration and likelihood of effects of Alternative 3 on shallow groundwater at the Diamond Point port would be similar to those described under Alternative 2 at Diamond Point port. The magnitude and extent of effects under Alternative 3 would be slightly greater than those under Alternative 2 at the dredged material stockpiles due to the greater volume of dredge material, and would be slightly less at the port facilities due to the smaller footprint and lower groundwater flow volume expected in bedrock. There would be no impacts on groundwater from the caisson dock under Alternative 3.

4.17.6.4 Natural Gas Pipeline Corridor

The magnitude and duration of the effects of Alternative 3 on shallow groundwater along the natural gas pipeline corridor are similar to those described under Alternative 2. The extent of affected groundwater resources under both Alternative 2 and Alternative 3 would be greater than Alternative 1a due to the greater pipeline length (87 miles) through areas of groundwater-bearing deposits north of Iliamna Lake.

4.17.6.5 Alternative 3—Concentrate Pipeline Variant

The magnitude, duration, extent, and likelihood of expected effects of this variant on shallow groundwater are similar to those described under Alternative 3 for the transportation corridor and gas pipeline, given that the concentrate pipeline would be placed in the same excavation as the natural gas pipeline along the north access road. The primary difference in water use between this variant of Alternative 3 and other alternatives is the loss of 1 to 2 percent of the water used to slurry the concentrate that would otherwise be available for discharge at the mine site to drainages affected by embankment blockage and pit dewatering. Reduced flow to surface water at the NFK, SFK, and UTC discharge sites by a similar percentage would result in slightly decreased recharge to groundwater in the upper portions of these drainages.

The magnitude, duration, extent, and likelihood of impacts to groundwater at the Diamond Point port site under this variant would be the same as under Alternative 2 and Alternative 3 because there would be no change in total footprint and no impacts to groundwater from treatment and offshore discharge of slurry water.

4.17.7 Cumulative Effects

Potential cumulative effects to groundwater include drawdown of groundwater; reduction in natural recharge to groundwater; changes in groundwater flow patterns from shallow groundwater interception or surface water withdrawals during road and pipeline construction; drawdown of groundwater around potable wells from water supply use; and changes to groundwater flow from HDD activities. See also Section 4.16, Surface Water and Hydrology, for information on potential effects to surface water. The cumulative effects analysis area encompasses the footprint of the project, including alternatives and variants; the Pebble Project expansion footprint (including road, pipeline and port facilities); and any other reasonably foreseeable future actions (RFFAs) in the vicinity of the project that would result in potential synergistic and interactive effects. The geographic area considered in the cumulative effects analysis for groundwater hydrology is the near vicinity (i.e., within 0.5 mile to several miles) of all project components where project-related effects on groundwater flow patterns and use could overlap with other past, present, and RFFA surface and groundwater uses.

Past, present, and RFFAs in the cumulative impact study area have the potential to contribute cumulatively to impacts on groundwater. Section 4.1, Introduction to Environmental Consequences, details the past, present, and RFFAs considered for evaluation. Several of these are considered to have no potential for cumulative impacts on groundwater flow and quantity in the analysis area. These include non-industrialized point-source activities that are unlikely to result in any appreciable impact beyond a temporary basis (e.g., subsistence, tourism, recreation, hunting, and fishing). Other RFFAs removed from further consideration include those sufficiently distant from the study area to eliminate groundwater co-use by others, or those RFFAs that occur in the marine environment of Cook Inlet.

4.17.7.1 Past and Present Actions

Past and present activities that have affected groundwater hydrology in the analysis area include development of water supply wells in communities around Iliamna Lake, small-scale wells or seeps associated with cabins and camps along the pipeline route, mining exploration near the project area (e.g., pumping tests, camp water use), and community roads and airports. Impacts associated with these activities include localized changes in groundwater flow patterns, reductions in groundwater in aquifers, and use of streams that are hydraulically connected with groundwater. These past and present actions are expected to continue throughout the project area, primarily in and around Iliamna Lake villages. Other parts of the project would be in more remote areas; characterized as having very little development; and past and present activities are seasonal in nature and do not substantially draw from groundwater resources during mining exploration (see Section 3.17, Groundwater Hydrology). Mining exploration activities on State lands are subject to exploration permits, with requirements for inspections, authorizations for the temporary use of water, and appropriate reclamation.

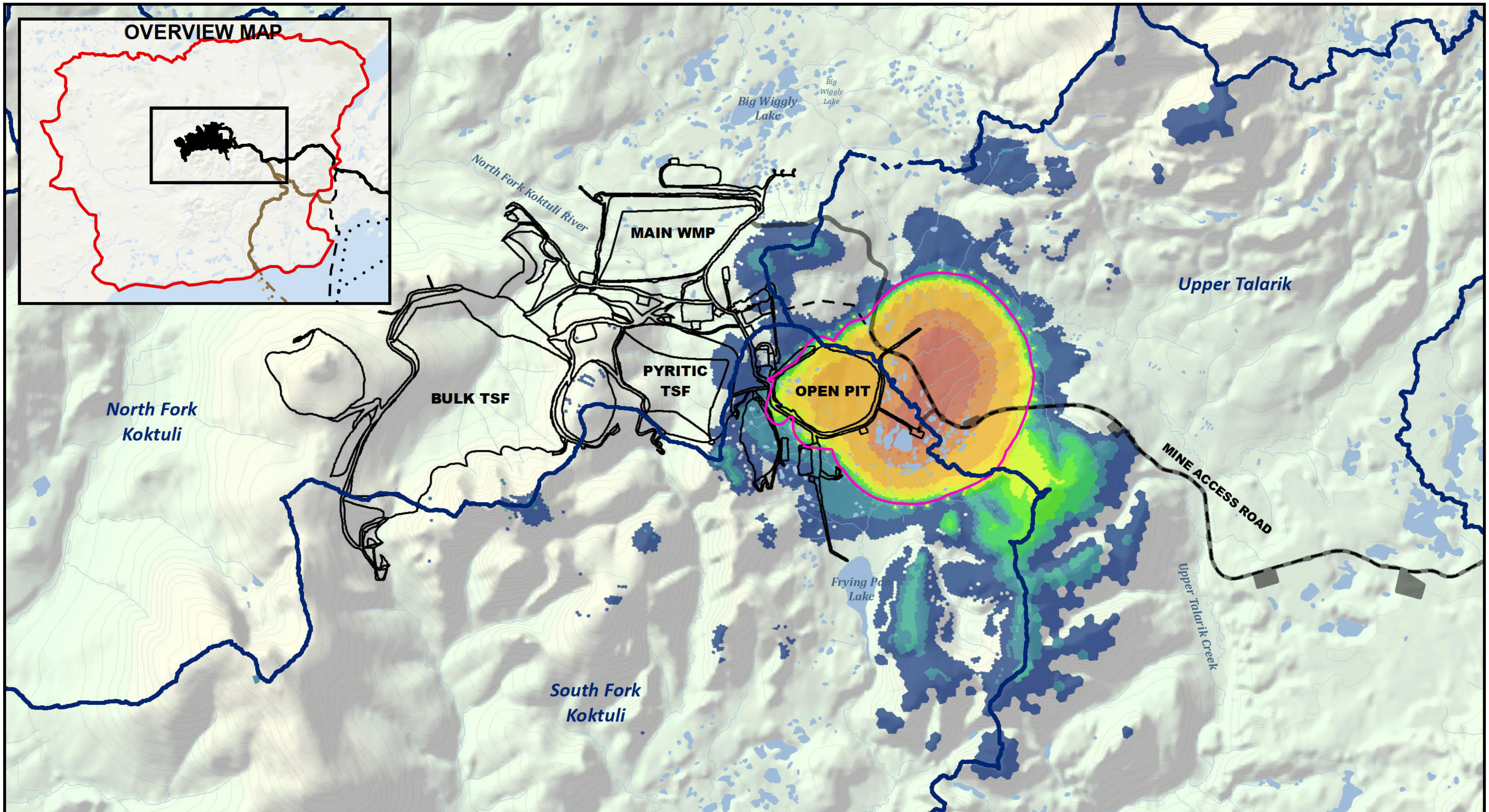
4.17.7.2 Reasonably Foreseeable Future Actions

The most important potential future actions in this analysis are those that are likely to contribute to impacts on groundwater flow and quantity in close vicinity to aquifers affected by the project. RFFAs that could contribute cumulatively to groundwater quantity and flow impacts, and that are therefore considered in this analysis, are limited to those activities that would occur in the mine site vicinity, or immediately in or adjacent to the transportation corridor. These include: Pebble Project expansion scenario; mining exploration activities for Big Chunk South and Groundhog mineral prospects; onshore oil and gas development; Lake and Peninsula Borough (LPB) transportation projects along Williamsport-Pile Bay Road, or Nondalton-Iliamna, and the continued development of the Diamond Point Rock Quarry.

The new groundwater model was used to estimate the size of the zone of influence of the expanded pit, which is expected to be the component of Pebble Project expansion scenario with the largest impacts to groundwater flow systems. The zone of influence for the expanded pit is shown in Figure 4.17-11. Dewatering this pit at the end of mining would require pumping approximately 8,700 gpm (19 cfs) of groundwater from perimeter and in-pit wells, and in-pit water collection systems (BGC 2019k). Most of the zone of influence would be in the SFK and UTC watersheds, split approximately equally between the two. There would also be a portion of the zone of influence extending into the NFK watershed.

Under the No Action Alternative, exploration activities would continue to occur at the mine site and other exploration prospects in the vicinity. During these activities, there could be limited groundwater extraction from pumping tests that result in a temporary localized lowering of the water table, which would be expected to recover to natural conditions within hours or days after the tests.

RFFA contribution to cumulative effects on groundwater are summarized by alternative in Table 4.17-2.



Sources: PLP 2019-RFI153; BGC 2019k

US Army Corps of Engineers

0.5 0 0.5 1
Miles

Drawdown
High: 4498 ft
Low: 3 ft

Major Basin Watershed Divide
Divide Absent
Divide Present
Model Domain (Overview Map)

Expanded Development
Open Pit

Action Alternatives
Ferry Routes
Natural Gas Pipelines
Alternative 1a
Alternative 1

Other Features
River/Stream
Lake/Pond
100' Contour (Existing)

SIMULATED END OF MINING DRAWDOWN FOR THE EXPANDED OPEN PIT: WATER TABLE

Table 4.17-2: Contribution to Cumulative Effects on Groundwater

Reasonably Foreseeable Future Actions	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
Pebble Project Expansion Scenario	**Mine Site**: The Pebble Project expansion scenario pit would correspond to a 6.66-fold increase in the footprint of the pit, a likely increase in pit depth to about 3,500 feet (PLP 2018-RFI 062; PLP 2018-RFI 094), and a duration increase of up to 78 years for the operations zone of influence. The magnitude and extent of the expanded pit capture zone would be larger to account for the deeper and wider pit. The estimated zone of influence for the expanded dewatered pit during operations would be approximately 21 square miles (compared to about 4 square miles for the 20-year pit) straddling the SFK and UTC drainages and extending into the NFK drainage (BGC 2019k). The expanded zone of influence would cause indirect impacts to wetlands and loss of water from streams and lakes in the zone of influence. Based on the position of the expanded pit relative to watershed divides, the expanded capture zone would likely draw roughly equal amounts of inflow from the SFK and UTC watersheds. Pit dewatering would generate excess water that would be returned to streams after treatment, partially or substantially restoring streamflow and groundwater resources impacted by dewatering downstream of the treated water discharge locations. Seepage from the waste rock facilities would be captured by seepage collection systems, or would flow directly into the pit or pit lake along with groundwater that is in the pit or pit lake capture zones. The North WRF would be in the UTC drainage. At least some groundwater recharge that currently occurs there would infiltrate through the WRF, and be captured by the North WRF collection pond, or flow directly into the pit or pit lake, where it would be pumped for treatment	**Mine Site**: Same as Alternative 1a. **Other Facilities**: Similar to Alternative 1a, except that the portion of the access road from the north ferry terminal to the existing Iliamna area road system would already have been constructed, and the segment of road between the Eagle Bay ferry terminal north to the north access road corridor would not be constructed. **Magnitude:** The magnitude of cumulative impacts to groundwater would be similar to the magnitude of Alternative 1a, although affecting a larger amount of acreage by about 526 acres. **Duration/Extent**: The duration and extent of cumulative impacts to groundwater would be similar to the duration and extent of Alternative 1a, although affecting a larger amount of acreage. **Contribution:** The contribution to cumulative effects would be slightly more than Alternative 1a, and also slightly more than Alternative 2 and Alternative 3.	**Mine Site**: Same as Alternative 1a. **Other Facilities**: Under the Pebble Project expansion scenario, the north access road would be extended east from the Eagle Bay ferry terminal to Iniskin Bay. Concentrate and diesel pipelines would be constructed along the Alternative 3 road alignment and extended to a new deepwater port site at Iniskin Bay. The potential for shallow groundwater interception impacts along the Alternative 2 transportation and pipeline corridors would increase under the Pebble Project expansion scenario, because the north access road corridor would be wider and longer to accommodate the concentrate/ diesel pipelines, associated access road, and port at Iniskin Bay. These could include localized flow changes in wetland areas supported by groundwater flow or rerouting of groundwater flow around road cuts. However, overall cumulative effects under Alternative 2 with Pebble Project expansion would be less than that of Alternative 1a with Pebble Project expansion scenario, because the Pebble	**Mine Site:** Same as Alternative 1a. **Other Facilities:** Expansion would use the existing north access road; Concentrate and diesel pipelines would be constructed along the existing road alignment and extended to a new deepwater port site at Iniskin Bay. The potential for localized shallow groundwater interception impacts for the Alternative 3 non-mine components would increase slightly under the Pebble Project expansion scenario, because the north access road corridor would be slightly wider and longer to accommodate diesel and concentrate pipelines and the Iniskin Bay port. However, overall cumulative effects under Alternative 3 with Pebble Project expansion would be less than those of Alternative 1a and Alternative 1 with Pebble Project expansion, because the Alternative 3 Pebble Project expansion scenario would not use the south access corridor or Amakdedori port site.

Table 4.17-2: Contribution to Cumulative Effects on Groundwater

Reasonably Foreseeable Future Actions	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
	and released. Similarly, the South WRF would be in the SFK drainage. At least some groundwater recharge that currently occurs there would infiltrate through the WRF and be captured by the South WRF collection pond, or flow into the pit or pit lake, where it would be pumped for treatment and released. Presumably, additional design work would be needed to design a system of underdrains that achieve hydraulic containment and prevent groundwater recharge through the WRFs into groundwater flow systems beneath the WRFs. Effects on streamflow reduction from the Pebble Project expansion scenario are further discussed in Section 4.16, Surface Water Hydrology. The extent of the pit capture zone would not affect existing drinking water supply wells in Newhalen or Iliamna, or the community surface water system in Nondalton (Section 3.16, Surface Water Hydrology), which are about 10 to 12 miles east and southeast of the expanded pit capture zone, respectively; and in a different drainage on the other side of the UTC-Newhalen River watershed divide. The estimated footprint of the lined pyritic TSF would be about 2.5 times greater than under Alternative 1a. This would reduce the amount of natural recharge to groundwater and lower the water table elevation beneath the expanded facility in a fashion similar to that described under Alternative 1a, but in an area about 2.5 times larger. The area of lowered water table beneath the main WMP would remain the same under the Pebble Project expansion scenario. Diverted runoff and collected seepage from unlined project facilities, such as the expanded bulk TSF and WRFs, would alter local groundwater flow patterns and natural discharge to streams over a wider area		Project expansion scenario under Alternative 2 would not use the south access corridor or Amakdedori port site. **Magnitude:** The Pebble Project expansion scenario footprint would impact approximately 31,528 acres, compared to 9,829 acres under Alternative 2. Impacts to groundwater along the transportation and pipeline corridor would be mostly within natural variations, but changes to groundwater flow conditions at the mine site under the Pebble Project expansion would affect the environment with greater magnitude than the impacts associated with Alternative 2. **Duration/Extent**: The duration and extent of cumulative impacts to groundwater would be similar to the duration and extent of Alternative 1a, although affecting a slightly smaller amount of acreage because the Amakdedori port and access road would not have been built. **Contribution:** Similar to Alternative 1a.	**Magnitude:** The Pebble Project expanded development scenario project footprint would impact approximately 31,541 acres, compared to 10,166 acres under Alternative 3. Given that the north road and gas pipeline would already have been constructed, impacts to groundwater from the Pebble Project expansion would be slightly less than Alternative 1a and Alternative 1. **Duration/Extent**: The duration and extent of cumulative impacts to groundwater would be similar to duration and extent of Alternative 1a and Alternative 1, although affecting a smaller amount of acreage. **Contribution:** The contribution to cumulative impacts would be similar to Alternative 1a and Alternative 1, although affecting a smaller amount of acreage.

Table 4.17-2: Contribution to Cumulative Effects on Groundwater

Reasonably Foreseeable Future Actions	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
	than under Alternative 1a, because the flow is captured in downstream SCPs and treated and discharged to streams. **Other Facilities:** A north access road and concentrate and diesel pipelines would be constructed along the Alternative 3 road alignment and extended to a new port facility at Iniskin Bay. The potential for impacts on shallow groundwater interception along the transportation and pipeline corridors would increase under the Pebble Project expansion scenario, because both the north and south access corridors would be used, and the north corridor would eventually be wider and longer to accommodate a diesel pipeline. In addition, the development of a port at Iniskin Bay would increase the potential for localized shallow groundwater interaction effects during construction. The cumulative effects of the non-mine site components under the Pebble Project expansion scenario would be similar to the combined impacts of both Alternative 1a or Alternative 1 and Alternative 3. A diesel pipeline would also present a risk for diesel fuel spills and impact to groundwater from diesel pipeline breaks or ruptures that is not present in any of the alternatives. **Magnitude:** The Pebble Project expansion scenario footprint would impact approximately 31,892 acres, compared to 9,612 acres under Alternative 1a. Impacts to groundwater along the transportation and pipeline corridor would be mostly in natural variations, but changes to groundwater flow conditions at the mine site would affect the environment with greater magnitude than the impacts associated with Alternative 1a.			

Table 4.17-2: Contribution to Cumulative Effects on Groundwater

Reasonably Foreseeable Future Actions	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
	Duration/Extent: The effects of the project on groundwater would be mostly limited to the near vicinity of the mine site, and would be reduced in post-closure as the site is reclaimed and groundwater returns to pre-mining conditions in all areas except the bulk TSF, WRFs, collection ponds, quarries, and open pit, where groundwater impacts would remain. The post-closure pit zone of influence would likely be reduced compared to the operations zone of influence by an amount similar to that of Alternative 1a; that is, the capture would be about one-half of the extent than during operations, and would remain for the long-term (centuries) to maintain hydraulic containment and a hydraulic sink at the pit lake. Similar to Alternative 1a, it is anticipated that water from the pit lake would be pumped, treated, and discharged to partially or substantially restore streamflow and groundwater levels downstream of the water discharge locations in the SFK, NFK, and UTC watersheds. Conceptually, during post-closure, the project would neither create nor destroy water, just rearrange where and when it goes in and near the footprint of the mine. Therefore, the quantities of water should be available to substantially restore average streamflow conditions impacted by the mine (downstream of the treated water discharge locations). As a result of seasonal variations in precipitation, evaporation, and snowmelt, and the relatively constant capacity to treat and discharge water, there would likely be intra-annual changes in storage of water in the pit lake, and fluctuations of the pit lake level below the MM level. Also, although the annual average streamflow may be relatively unchanged downstream of the treated water discharge locations, short-term fluctuations in streamflow			

Table 4.17-2: Contribution to Cumulative Effects on Groundwater

Reasonably Foreseeable Future Actions	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
	and groundwater during post-closure conditions may be less than under pre-development and Alternative 1a conditions. **Contribution:** The expanded pit development scenario contributes to cumulative effects on groundwater through drawdown and altered groundwater flow patterns, primarily in the area of the mine footprint. Similar to Alternative 1a, treated water discharge locations would likely be located a short distance downstream of the mine footprint. The effects of groundwater contributing to surface water would not likely exceed natural variations downstream of those locations in the UTC, NFK, or SFK watersheds. The project footprint in the Kvichak and Nushagak river watersheds is a relatively small area in the watersheds.			
Other Mineral Exploration Projects	**Magnitude:** Nearby RFFAs associated with mineral exploration activities (e.g., Big Chunk South and Groundhog) could have some limited impacts on groundwater in common watersheds to the Pebble Project—for example, from pumping tests or camp groundwater use; however, they would be seasonally sporadic, temporary, and localized, based on their remoteness and types of activities anticipated. **Duration/Extent:** Exploration activities typically occur at a discrete location for one season, although a multi-year program could expand the geographic area affected in a specific mineral prospect. Table 4.1-1 in Section 4.1, Introduction to Environmental Consequences, identifies seven mineral prospects in the analysis area where exploratory drilling is anticipated (four of which are in relatively close proximity of the Pebble Project).	Similar to Alternative 1a.	Similar to Alternative 1a.	Similar to Alternative 1a.

Table 4.17-2: Contribution to Cumulative Effects on Groundwater

Reasonably Foreseeable Future Actions	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
	Contribution: This contributes to cumulative effects on groundwater, although the areal extent of disturbance is a relatively small portion of the Kvichak/Nushagak watersheds. Assuming compliance with permit requirements, contributions to groundwater effects would be minimal.			
Oil and Gas Exploration and Development	**Magnitude**. Onshore oil and gas exploration activities could involve seismic and other forms of geophysical exploration, and in limited cases, exploratory drilling. Should it occur, exploratory drilling would involve the construction of temporary pads and support facilities, with permit conditions to minimize impacts to groundwater and restore drill sites after exploration activities have ceased. The magnitude of effects to groundwater resources would likely be within natural variations. **Duration/Extent:** Exploratory drillings are typically single-season temporary activities. The 2013 Bristol Bay Plan Amendment shows 13 oil and gas wells drilled on the western Alaska Peninsula, and a cluster of three wells near Iniskin Bay. It is possible that additional exploratory drilling could occur in the analysis area, but based on historic activity, is not expected to be intensive. **Contribution:** Onshore oil and gas exploration activities would be required to minimize potential impacts to groundwater, and would occur in the analysis area, but distant from the project. The project would have minimal contribution to cumulative effects.	Similar to Alternative 1a.	Similar to Alternative 1a.	Similar to Alternative 1a.

Table 4.17-2: Contribution to Cumulative Effects on Groundwater

Reasonably Foreseeable Future Actions	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
Road Improvement and Community Development Projects	**Magnitude:** The potential exists for greater impacts on groundwater hydrology during construction and maintenance of LPB transportation infrastructure that is co-located or close to the Pebble Project. For example, a Nondalton-Iliamna road project could intercept shallow groundwater during construction that is co-located with shallow aquifers intercepted during the Alternative 1a or Pebble Project expansion scenario road or pipeline construction. Increased local groundwater flow impacts could occur where roadways are constructed across wetlands supported by groundwater inflow, or in steep areas where road cuts cause a local effect on groundwater flow as drainage controls direct it away from the road. Communities in the immediate vicinity of project facilities such as Iliamna, Newhalen, and Kokhanok would have the greatest contribution to cumulative effects. Some limited road upgrades could also occur in the vicinity of the natural gas pipeline starting point near Stariski Creek, or in support of mineral exploration previously discussed. The Diamond Point Rock Quarry has potential to effect groundwater in the analysis area. The estimated area that would be affected is approximately 140 acres (ADNR 2014a). **Duration/Extent:** Disturbance from road construction would typically occur over a single construction season. Geographic extent would be limited to the vicinity of communities and Diamond Point. **Contribution:** Road construction would be required to minimize effects on groundwater, and would occur in the analysis area, but removed	Similar to Alternative 1a.	The footprint of the Diamond Point Rock Quarry coincides with the Diamond Point port footprint in Alternative 2 and Alternative 3. Cumulative impacts resulting from expanded quarry development would be limited to a potential increase in temporary localized impacts on groundwater flow during construction, material extraction, and groundwater supply from commonly shared project footprints and infrastructure with the quarry site under Alternative 2. The contribution of LPB transportation infrastructure projects to cumulative effects under Alternative 2 would be slightly greater than under Alternative 1a, due to a greater potential for co-location with these RFFAs. In addition to the Nondalton-Iliamna project—portions of which could be co-located with shallow aquifers along the mine access roads under Alternative 1a, and Alternative 1 and Alternative 2—the Williamsport-Pile Bay Road upgrade could increase local groundwater flow impacts across wetlands or steep road cuts along the eastern portion of the north access road under Alternative 2. Cumulative	Similar to Alternative 2.

Table 4.17-2: Contribution to Cumulative Effects on Groundwater

Reasonably Foreseeable Future Actions	Alternative 1a	Alternative 1 and Variants	Alternative 2 and Variants	Alternative 3 and Variant
	from the project. The project would have minimal contribution to cumulative effects.		Impacts would be less than under Alternative 1a because the segment of gas pipeline between Iliamna Lake and the mine access road would not have been built under Alternative 2.	
Summary of Project Contribution to Cumulative Effects	Overall, the contribution of the Pebble Project expansion scenario to cumulative effects on groundwater would alter the groundwater flow systems for the long term in the mine site area, comprising 46 square miles (29,631 acres). Taking other past, present, and RFFAs into account and considering the acreage of area affected in the context of area watershed sizes and likely permit conditions, groundwater impacts are expected to be largely within the range of natural variations downstream of the mine site area in terms of magnitude, duration, and extent. The mine site footprint would be in 0.3 percent of the combined drainage areas of the Kvichak River upstream of Igiugig and the Nushagak River upstream of Ekwok (USGS site numbers 15300500 and 15302500).	Similar to Alternative 1a.	Similar to Alternative 1a, although slightly less acreage would be affected by the Pebble Project expansion, given that the Amakdedori port and south access road would not have been constructed under Alternative 2.	Similar to Alternative 1a, although less acreage would be affected by the Pebble Project expansion than either Alternative 1a or Alternative 1, given that the north access road would already have been constructed and the Amakdedori port and south access road would not have been constructed.

Notes:
LPB = Lake and Peninsula Borough
MM = maximum management
NFK = North Fork Koktuli
SCPs = seepage collection ponds
SFK = South Fork Koktuli
TSF = tailings storage facility
UTC = Upper Talarik Creek
WRF = waste rock facility