3.17 GROUNDWATER HYDROLOGY

This section describes the distribution and movement of groundwater in soil, sediment, and rock beneath the ground surface that could be impacted by the project. Groundwater is water that is held in the openings (i.e., pore spaces) of soil and sediment and in openings (e.g., faults, joints, fissures) in bedrock. Groundwater recharge (i.e., input) may occur through precipitation migrating to the groundwater (e.g., snowmelt, rainfall). In addition, surface water features (e.g., streams, ponds, and wetlands) may "leak" water into the ground and then to the groundwater. Groundwater discharge (i.e., output) is generally to surface water features (e.g., streams, ponds, seeps, wetlands). Whether surface water features contribute to groundwater (losing stream) or receive groundwater flow (gaining stream) depends on factors such as precipitation, groundwater and surface water levels, and the ability of the subsurface material to transmit water (i.e., permeability), and may vary seasonally and annually as water levels fluctuate with seasonal precipitation, or because of other influences such as pumping groundwater from nearby wells.

It is important to characterize the existing groundwater hydrology and define how the local groundwater flow system interacts with the regional (deeper) groundwater flow system, as well as characterize the nature and degree of interactions between groundwater and surface water to inform the understanding and characterization of aquatic resources, fish resources, and wetlands habitat.

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

Aquifers[1] and confining units[2], groundwater flow systems, groundwater/surface water interactions, and aquifer properties are discussed in this section for the areas that could be most affected by the project. Groundwater use is described in this section, and surface water use is described in Section 3.16, Surface Water Hydrology. Appendix K3.17 provides additional technical information to support or explain in greater detail the hydrogeological characterization programs conducted to date (i.e., baseline studies), the methods of technical review, and conclusions presented in the body of the EIS. Appendix K3.17 is frequently referenced where applicable. In addition, other sections of the EIS that support the development of the hydrogeology discussion or are influenced by the results of the groundwater studies are cross-referenced.

3.17.1 Mine Site

This section describes existing groundwater conditions in the mine site area that are anticipated to be affected by project activities, such as dewatering associated with pit operations and changes to existing flow pathways in the vicinity of major mine facilities. The analysis area for the mine site under all alternatives and variants is the same (Figure 3.17-1). Over the course of several field programs between 2004 and 2012, Schlumberger (2011a, 2015a) collected hydrogeologic data (as well as geologic and groundwater quality data) in the vicinity of the mine site using various methods, including geologic mapping and characterization (see Section 3.13, Geology), drilling and borehole logging, well and piezometer installation, pumping tests, permeability tests, streamflow measurements at gaging stations (see Section 3.16, Surface Water Hydrology),

[1] An **aquifer** is a groundwater-bearing rock or unconsolidated deposit (e.g., gravel, sand).
[2] **Confining units** are composed primarily of silt and clay with varying amounts of sand and gravel.

monitoring of meteoric inputs (e.g., rainfall, snowfall), aerial surveys of wintertime open water leads, and routine measurement of groundwater levels.

These studies provide baseline data regarding groundwater conditions at the mine site that form the basis of the analysis in this EIS. Appendix K3.17 summarizes the data collection programs and methods. Details of these programs and data summaries are provided in Schlumberger (2011a, 2015a).

Figure 3.17-2 depicts locations of observation (e.g., monitoring) wells, piezometers, and seeps. Identification numbers for data points are shown on more detailed maps in Appendix K3.17 (Figure K3.17-1a through Figure K3.17-1g). Well depths and completion lithologies (i.e., physical characteristics of the geologic material) are provided in Table K3.17-1. Seeps (i.e., springs) occur as groundwater discharge to the surface where natural topography intersects the water table (groundwater surface). A seep can also occur if an excavated slope were to intersect the water table (e.g., at a road cut).

The objective of the groundwater studies was to determine key aspects of the local and regional groundwater flow systems, including:

- Aquifer properties of the overburden[3] and bedrock
- Groundwater levels and gradients
- Groundwater flow directions
- Relationships between local, intermediate, and regional groundwater flow systems
- Interaction and seasonality of groundwater and surface water systems

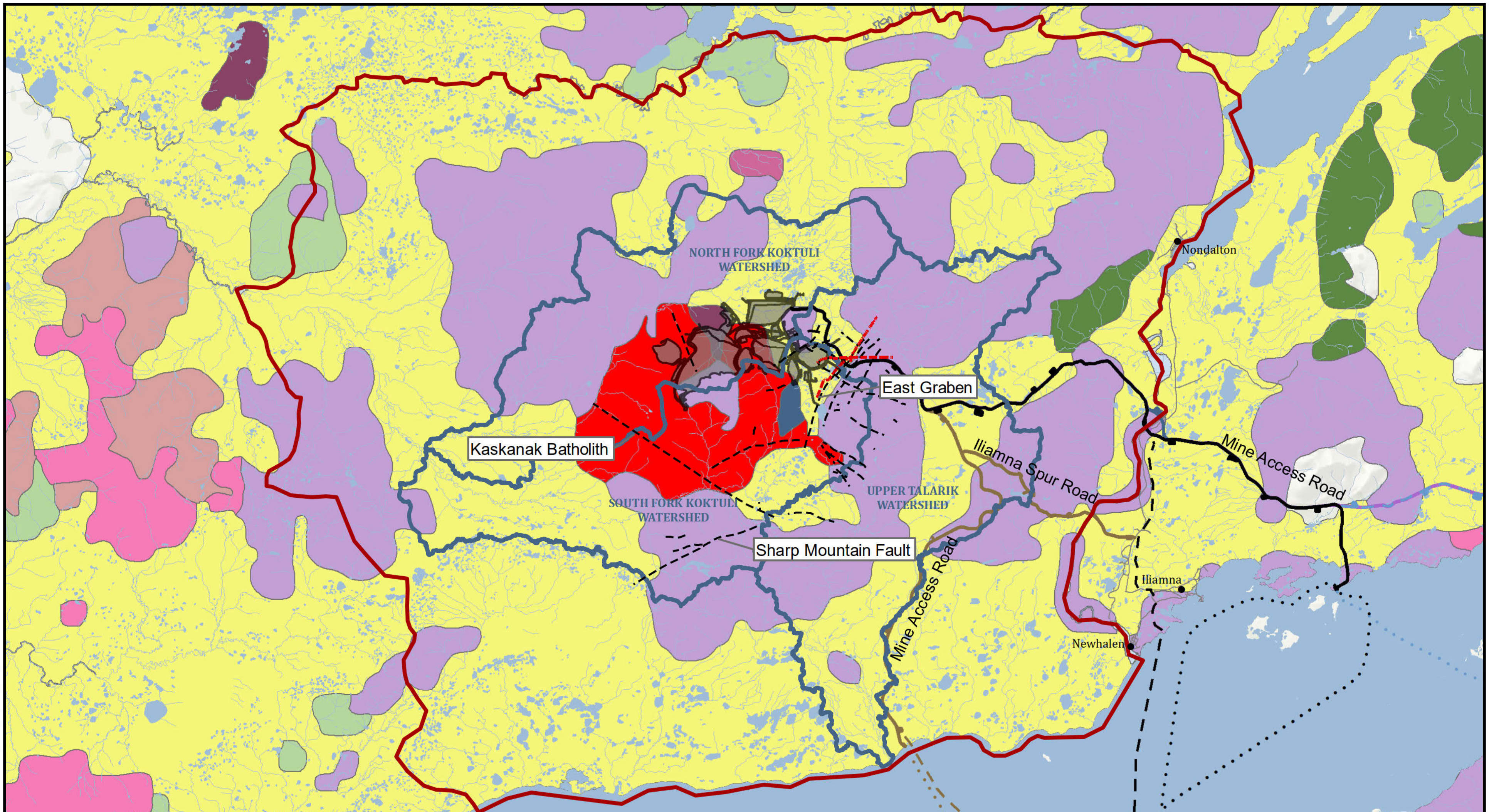
The results of these characterization programs form the basis for a baseline watershed model (Schlumberger 2011a), and a baseline, end-of-mining, and post-closure numerical groundwater flow model (BGC 2019a), and site-wide water-balance and water quality models for operations, closure, and post-closure (Knight Piésold 2018a, d). The hydrogeologic characterization data and model results are used to inform water management planning, processes, and facility design for all phases of the project and provide the basis for this EIS. The groundwater flow model (BGC 2019a) replaces models considered in the Draft EIS (DEIS) (Schlumberger 2011a, Appendix 8.1J; Piteau Associates 2018a).

3.17.1.1 Aquifers and Confining Units

Topography of the analysis area is characterized by hills separated by wide valleys with elevations ranging from 2,500 feet above mean sea level (amsl) at the mine site to 46 feet amsl at Iliamna Lake. Weathered (i.e., highly fractured) bedrock is exposed at higher elevations. Below about 1,400 feet amsl, the valleys are covered with overburden, generally composed of glacial deposits, with some areas overlain by alluvial (river) and lacustrine (lake-bed) deposits. Composition of the overburden material varies both laterally and with depth, typical of areas where material has been transported and deposited by both ice and water, with interbedding and gradations between types of material (see Section 3.13, Geology). The complex overburden geology can be more easily understood in a hydrogeologic context through a conceptual model based on the classification of overburden into aquifers, confining units, and semi-confining units.

Aquifers are composed primarily of sand and gravel with minor amounts of silt. Multiple sand and gravel aquifers may be present at some surface locations (and may be known locally as surficial, intermediate, and deep aquifers) separated by silty confining units. Confining units are composed primarily of silt and clay with varying amounts of sand and gravel.

[3] **Overburden** refers to surface soil and unconsolidated surficial deposits overlying bedrock.



Sources: PLP 2020-RFI168;
PLP 2019-RFI153; BGC 2019a

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3 0 3 6

Miles

- Fault
- Vulcan Model Fault
- Model Domain (BGC 2019a)
- Major Drainage Divide

USGS Bedrock Geology (Generalized)

- Jlmgr Plutonic rocks
- Jtk Volcanic flows, breccia, tuff, and agglomerate
- KJgn Marine graywacke and mudstone
- KTrvs Volcanic and sedimentary rock
- Klgr Granitic rocks of Central and Southeast Alaska
- Kmgr Granitic rocks of Central and Southeast Alaska
- QTs Unconsolidated and poorly consolidated surficial deposits
- TKgi Granitic rocks of Southern and Interior Alaska
- Trmb Massive basalt and greenstone
- Tvme Older volcanic rocks, undivided

Action Alternatives

- Ferry Routes
- Natural Gas Pipelines
- Alternative 1a
- Alternative 1
- Alternative 2
- Alternative 2 Newhalen River North Crossing Variant
- Alternative 3

MINE SITE GROUNDWATER ANALYSIS AREA

PEBBLE PROJECT EIS

FIGURE 3.17-1

Semi-confining units are composed of sand and silty sand, with varying amounts of clay and gravel. Small-scale aquifers may be present in this unit, and semi-confining units are generally capable of leaking water to or from aquifers from recharge or streams, ponds, or wetlands. The distribution of aquifers, confining units, and semi-confining units in the vicinity of the open pit is very complex. Detailed geological information has been incorporated into a groundwater flow model, and Appendix K3.17 contains maps showing the locations of aquifers, semi-confining units, and confining units in the mine vicinity (see Figure K3.17-7, Figure K3.17-8, and Figure K3.17-9).

For bedrock in the analysis area, aquifer characteristics are controlled by rock fracturing and weathering (i.e., a high degree of fracturing from repeated freeze/thaw cycles in the upper bedrock and chemical breakdown of minerals), and in deeper bedrock by fracturing and fault zones[4]. The weathered upper bedrock is more permeable than the deeper bedrock and forms a laterally persistent aquifer up to approximately 50 feet thick throughout the mine site vicinity. Deeper bedrock is fractured and faulted, with generally low permeability. Figure 3.17-3 shows a schematic representation of the site-wide groundwater flow systems and geologic units. Additional details of the distribution and characteristics of the overburden and bedrock aquifers in the areas that would be most affected by the project are summarized in Table K3.17-1.

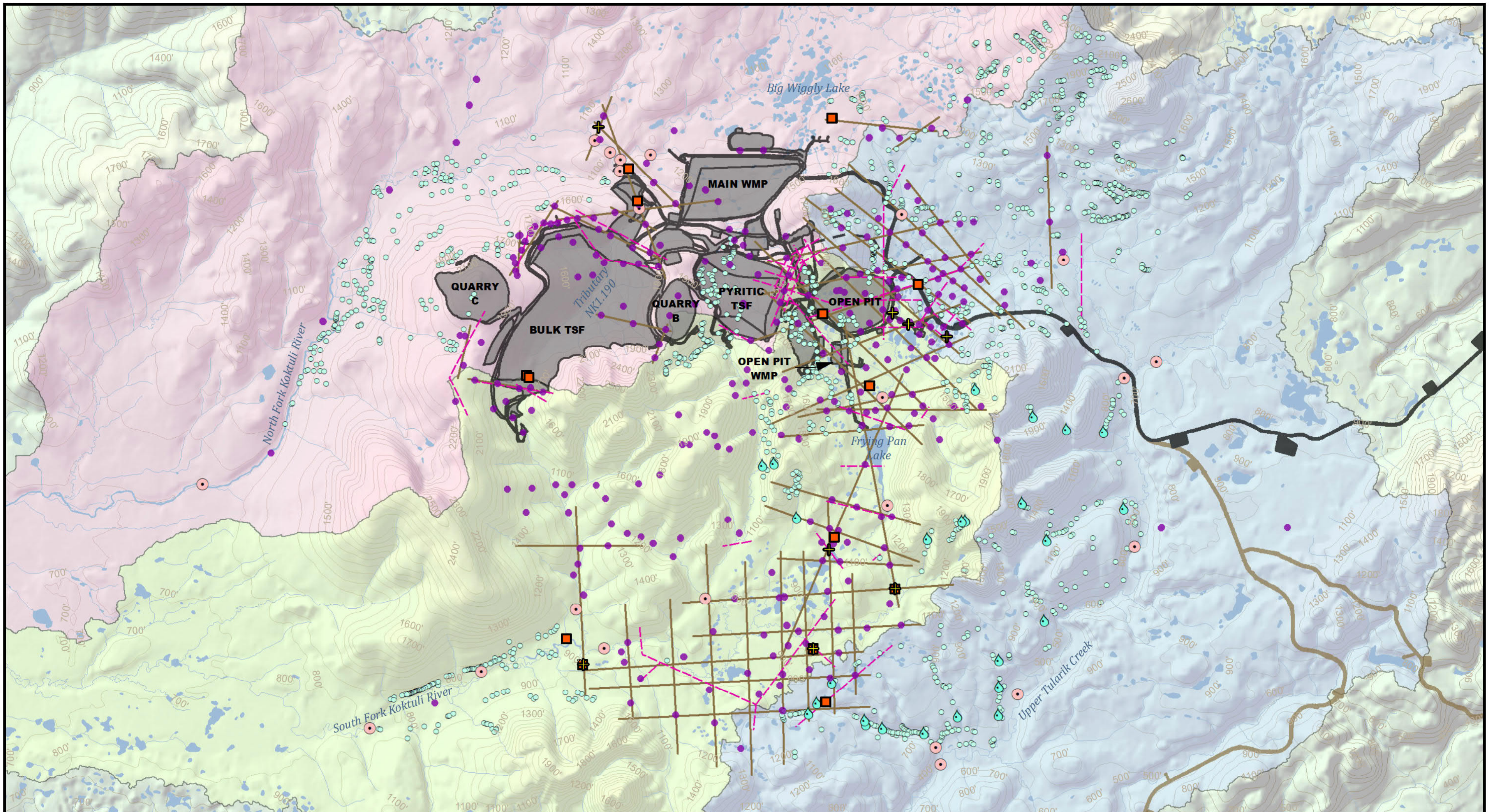
Cross-sections were developed from borehole data to illustrate the subsurface distribution of aquifers, semi-confining units, and confining units in overburden and bedrock in the mine vicinity (BGC 2019a; Schlumberger 2015a, Appendix 8.1B). Five hydrogeologic cross-sections are shown in Figure 3.17-4 through Figure 3.17-9, as listed below (Figure 3.17-7 is a cross-section location map):

- Figure 3.17-4: Cross-section E-8—southwest-northeast section through the open pit.
- Figure 3.17-5: Cross-section L-3—an approximately 5-mile north-south section along the eastern side of the open pit.
- Figure 3.17-6: Cross-section L-4—an approximately 8.5-mile-long north-south section along the Koktuli River valley below Frying Pan Lake.
- Figure 3.17-8: Cross-section S-1—north-south cross-section across the South Fork Koktuli (SFK) River at the western end of the analysis area.
- Figure 3.17-9: Cross-section M1—northwest-southeast cross-section across the North Fork Koktuli (NFK) River, across the north seepage collection pond (SCP), to the eastern end of the bulk TSF main embankment.

The cross-sections illustrate that the surficial geology (i.e., overburden) varies both laterally and with depth, which is consistent with regional geologic mapping and borehole data. Additional description of aquifer units beneath individual structures and embankment foundations is provided in Section 4.17, Groundwater Hydrology, and in Appendix K4.15, Geohazards and Seismic Conditions.

Shallow groundwater flow patterns in the unconsolidated aquifer are shown in Figure 3.17-10. This figure illustrates the location and direction of interbasin groundwater flow from the SFK to the Upper Talarik Creek (UTC) drainage basin that is expressed in the UT1.190 tributary. Flow patterns during high- and low-water seasons are similar (Schlumberger 2015a). Flow patterns in bedrock are shown in Figure 3.17-11.

[4] These fault zones may be geologically ancient and are not necessarily capable of generating modern earthquakes. See Section 3.15, Geohazards and Seismic Conditions, for a discussion of active faults in the area.



Sources: PLP 2019-RFI153;
Schlumberger 2011a, Figures 8.1-4 and 9.1-5

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1 0 1 2
Miles

Location Type
- Pumping Well
- Monitoring Well
- Piezometer
- Stream Gaging Station
- Seep Sampling Location
- Seep Location

- 2004-2010 Seismic Line
- Cross Section Line

Watershed
- North Fork Koktuli River
- South Fork Koktuli River
- Upper Talarik Creek

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

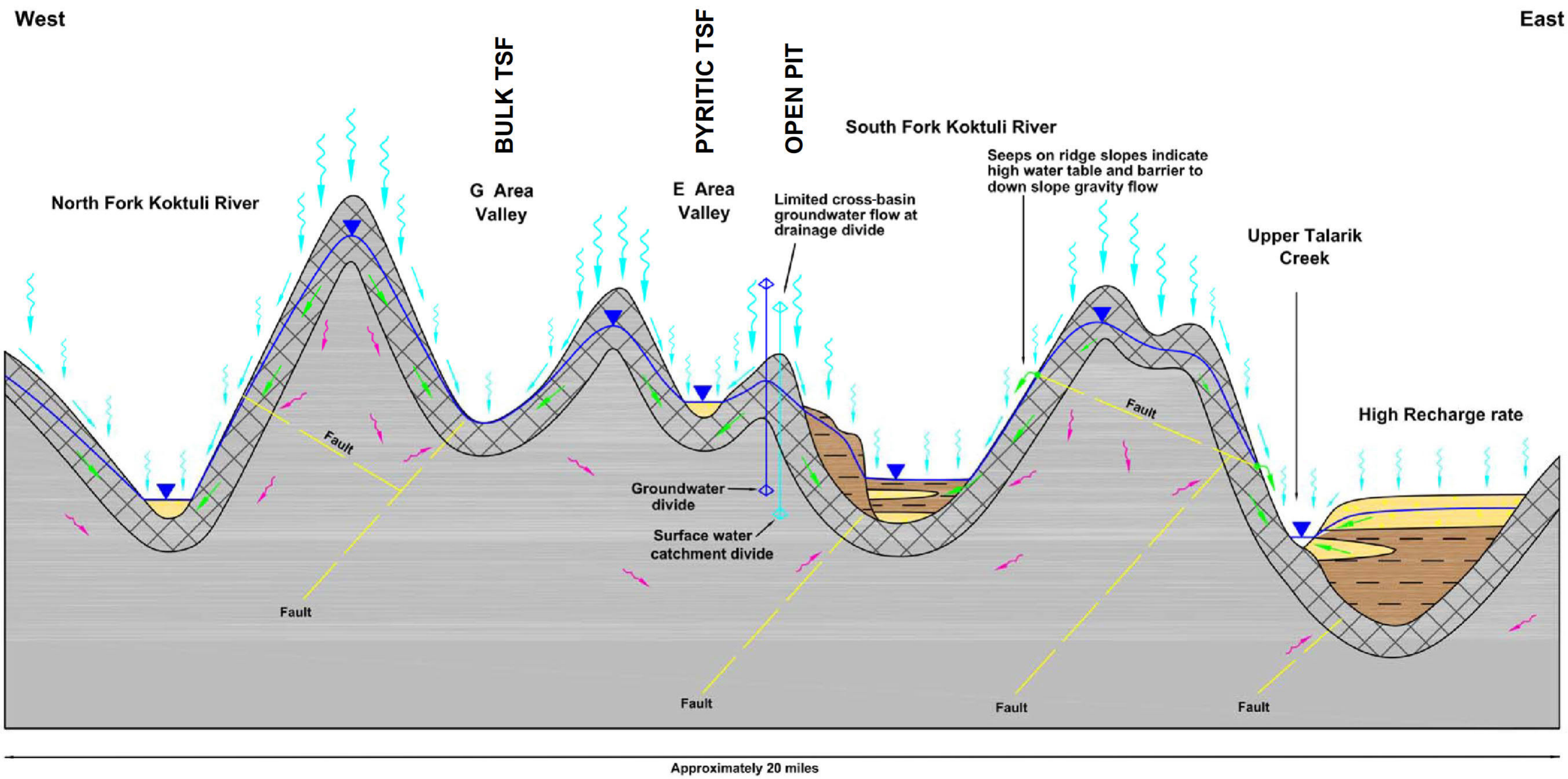
Other Features
- River/Stream
- Lake/Pond
- 100' Contour (Existing)

Note: Figures K3.17-1a through K3.17-1g show identification numbers for wells, cross-sections, and stream gaging stations.

WELL, PIEZOMETER, AND SEEP LOCATIONS

PEBBLE PROJECT EIS

FIGURE 3.17-2



Sources: PLP 2011d

LEGEND

- Sand and gravel
- Silt and clay
- Fractured bedrock
- Bedrock
- Recharge
- Seasonal surface runoff
- Spring
- Shallow bedrock groundwater flow
- Minor deep bedrock groundwater circulation
- Potentiometric surface - alluvium
- Water Table
- Groundwater divide
- Surface water catchment divide

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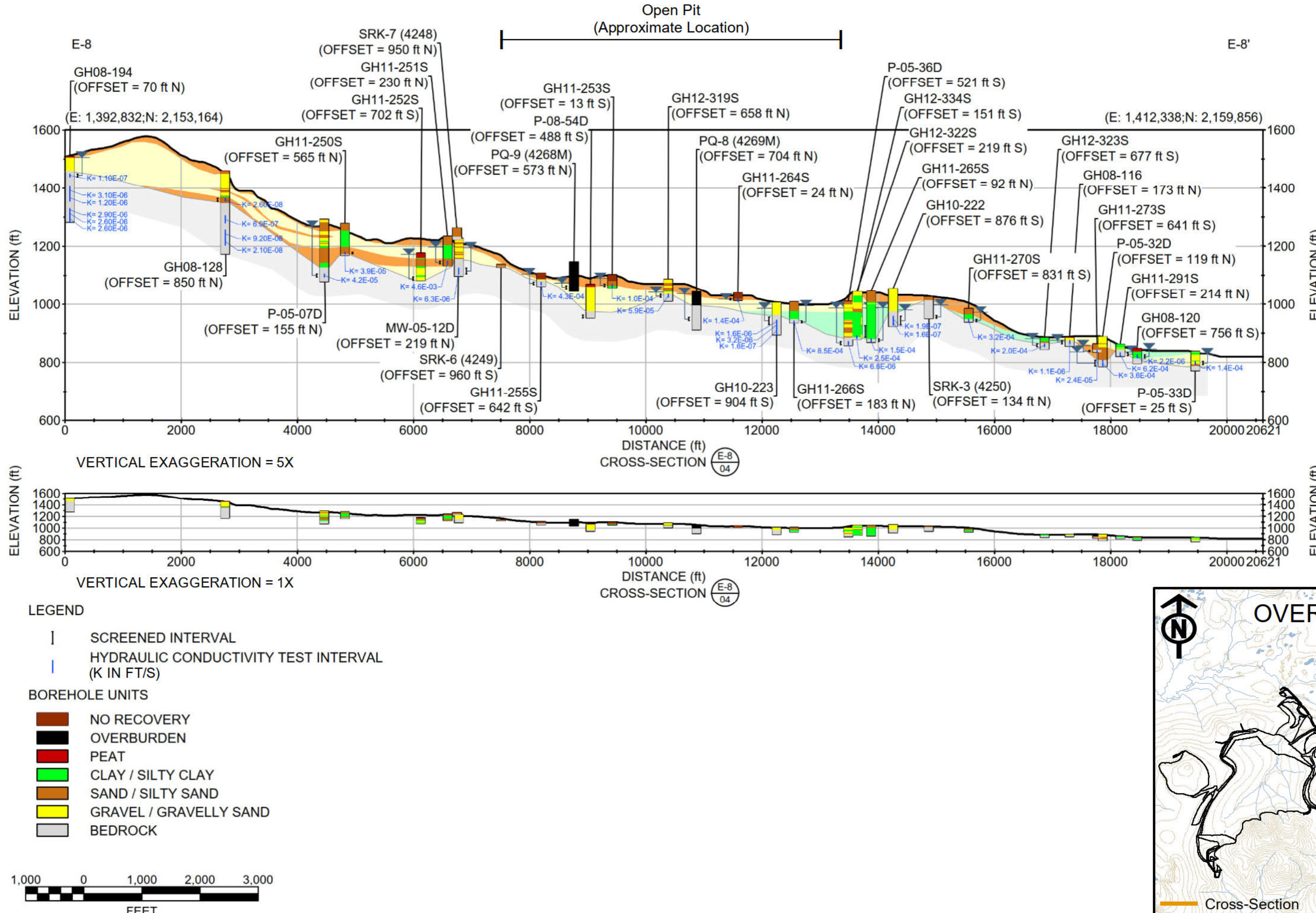
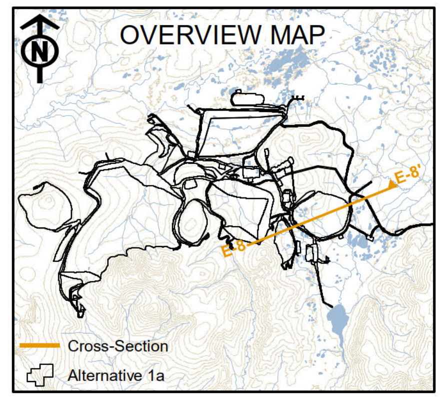
SCHEMATIC REPRESENTATION OF SITE-WIDE GROUNDWATER SYSTEM

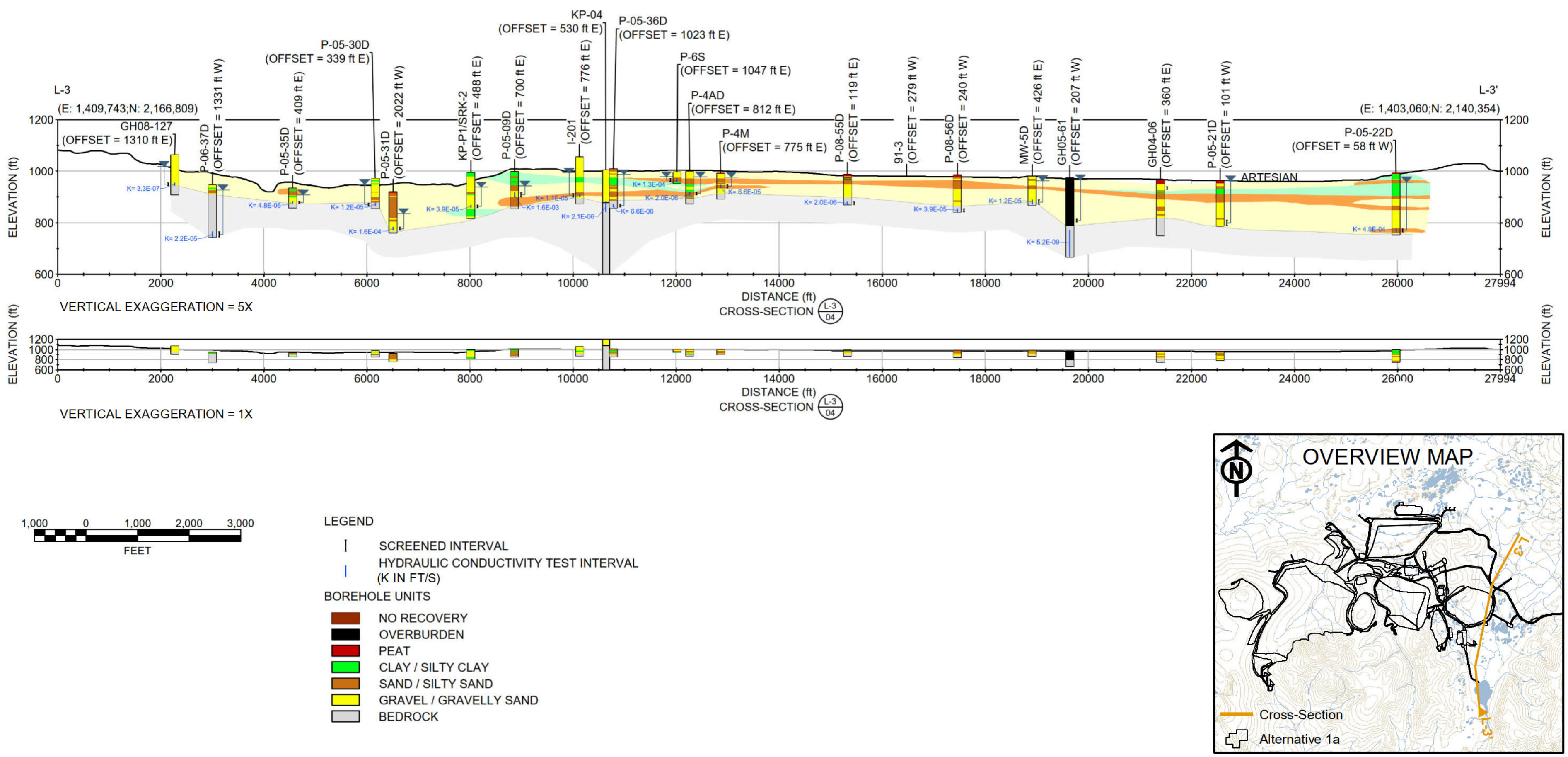




Sources: BGC 2019a

US Army Corps of Engineers

SURFICIAL GEOLOGY CROSS-SECTION E-8



Sources: BGC 2019a

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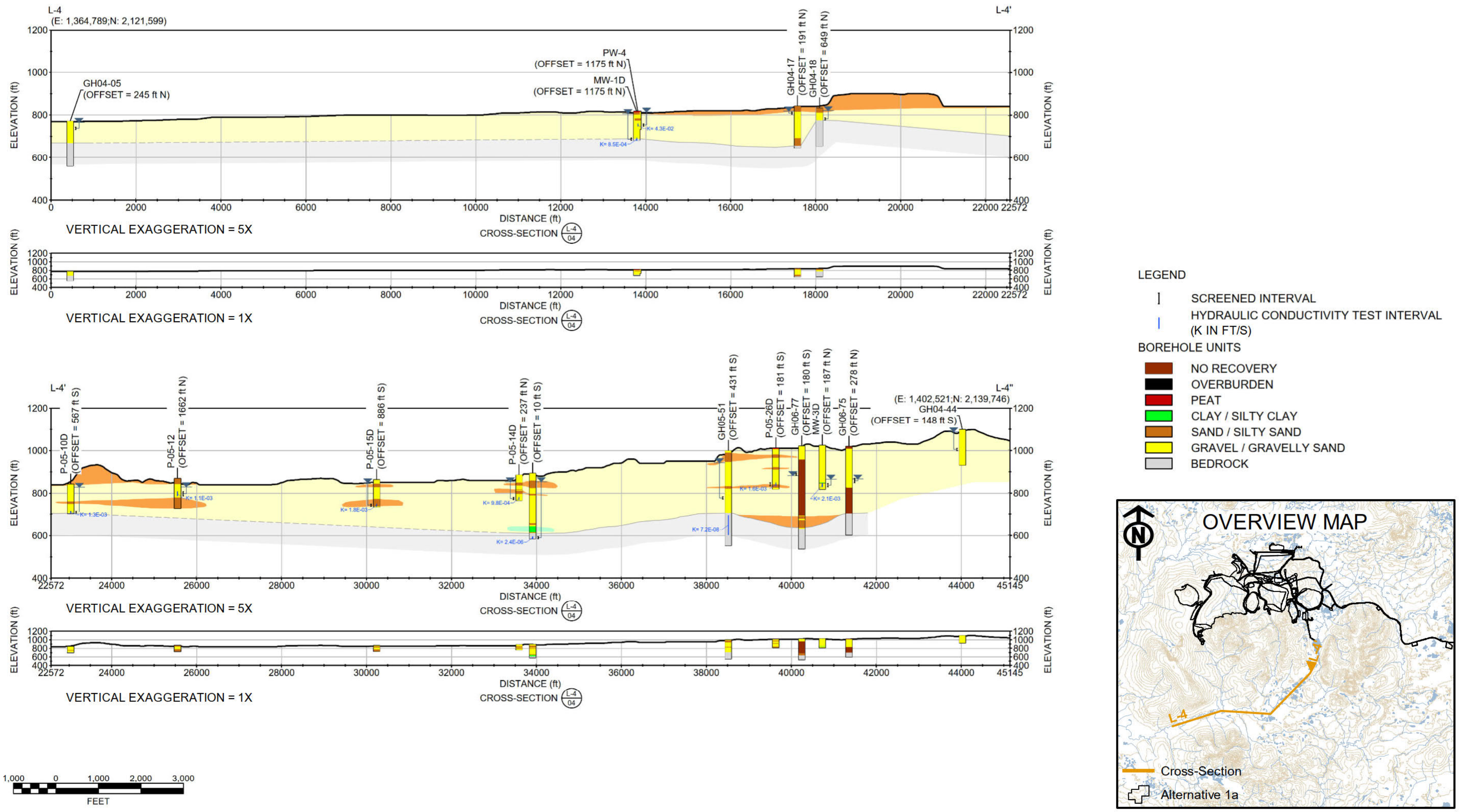
SURFICIAL GEOLOGY CROSS-SECTION L-3

PEBBLE PROJECT EIS

FIGURE 3.17-5



Sources: BGC 2019a

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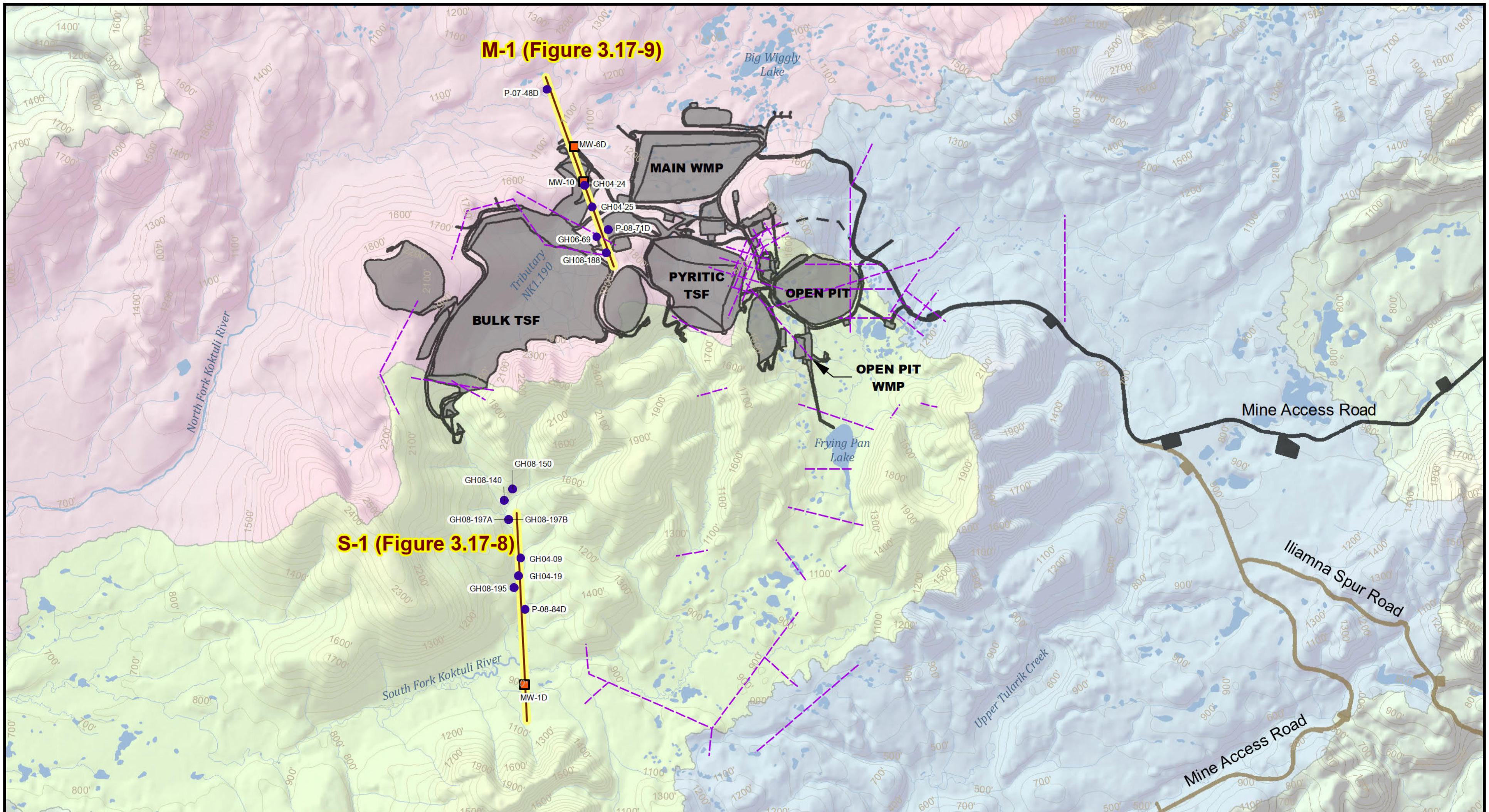
SURFICIAL GEOLOGY CROSS-SECTION L-4

PEBBLE PROJECT EIS

FIGURE 3.17-6



Sources: PLP 2019-RFI153;
Schlumberger 2011a, Figure 8.1-4

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1 0 1 2
Miles

Location Type
- Monitoring Well
- Piezometer
- Cross Section Line
- 2004-2010 Seismic Line

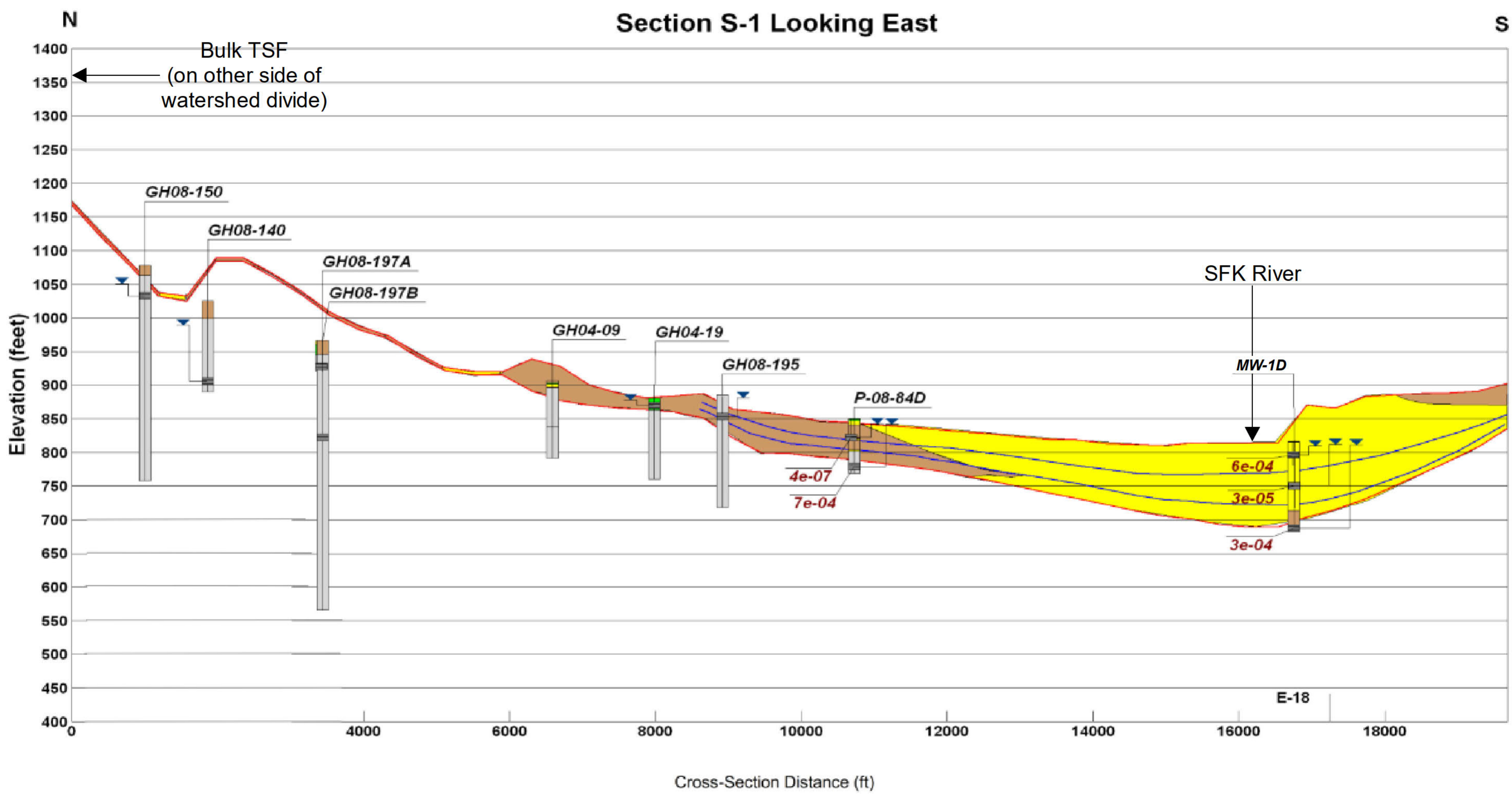
Watershed
- North Fork Koktuli River
- South Fork Koktuli River
- Upper Talarik Creek

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

CROSS-SECTION LOCATION MAP

PEBBLE PROJECT EIS

FIGURE 3.17-7



Note: Location of cross-section is depicted on Figure 3.17-7. Vertical Exaggeration = 13x

Source: Schlumberger 2015a, Appendix 8.1B

Lithology
sand, silty sand
clay, silty clay
gravel, gravelly sand
no recovery
bedrock
weathered bedrock

Water level elevation (data from October, 2008)

Model Layer Surfaces (Piteau Associates 2018a)

4e-06 Hydraulic Conductivity (m/s)

Screened Interval

GH05-62 Well Name

E-13 Intersecting Cross-Section

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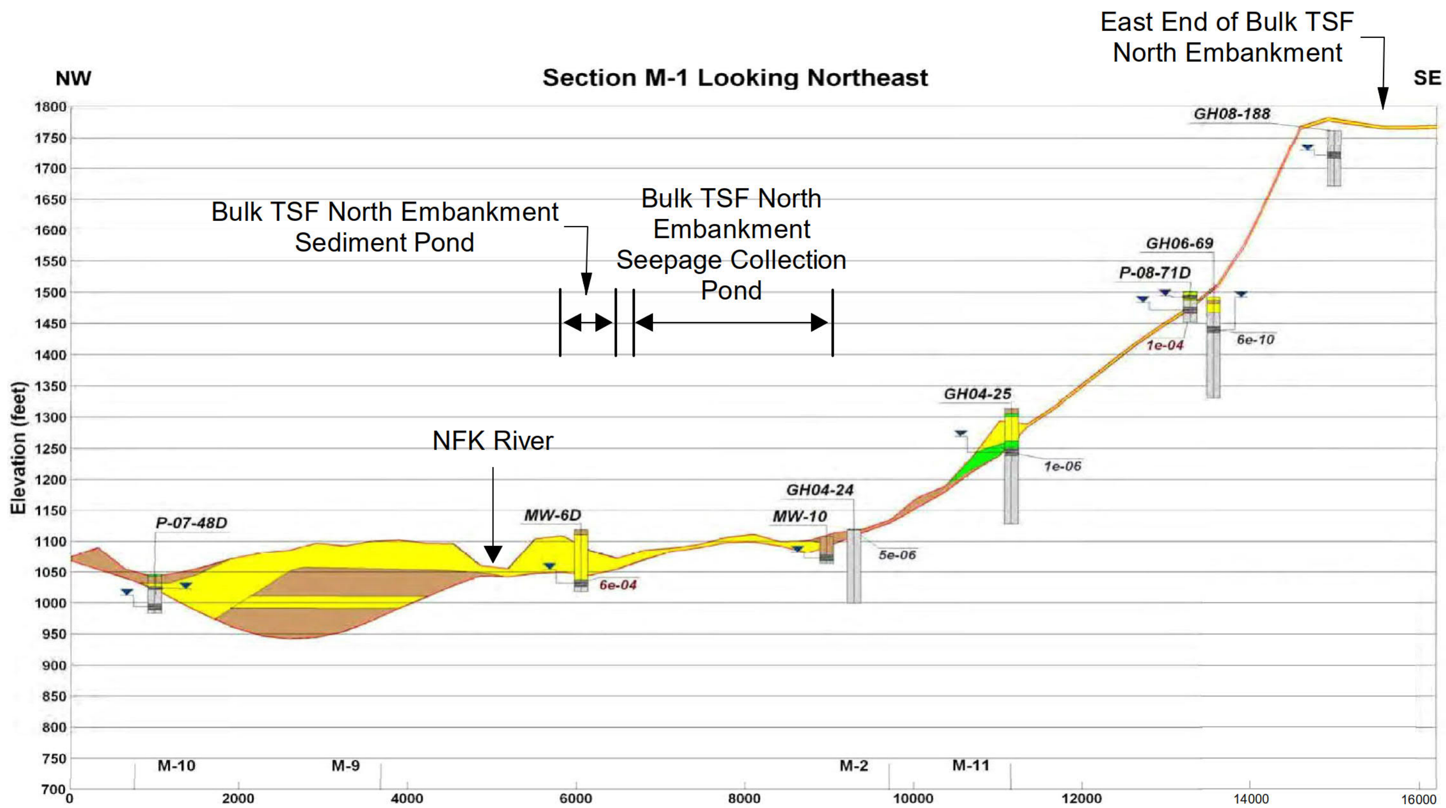
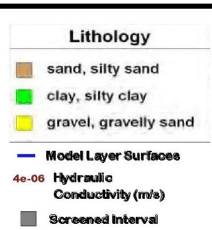
CROSS-SECTION S-1
SOUTH FORK KOKTULI GROUNDWATER DISCHARGE AREA



Note: Location of cross-section is depicted on Figure 3.17-7. Vertical Exaggeration = 8x

Source: Schlumberger 2015a, Appendix 8.1B



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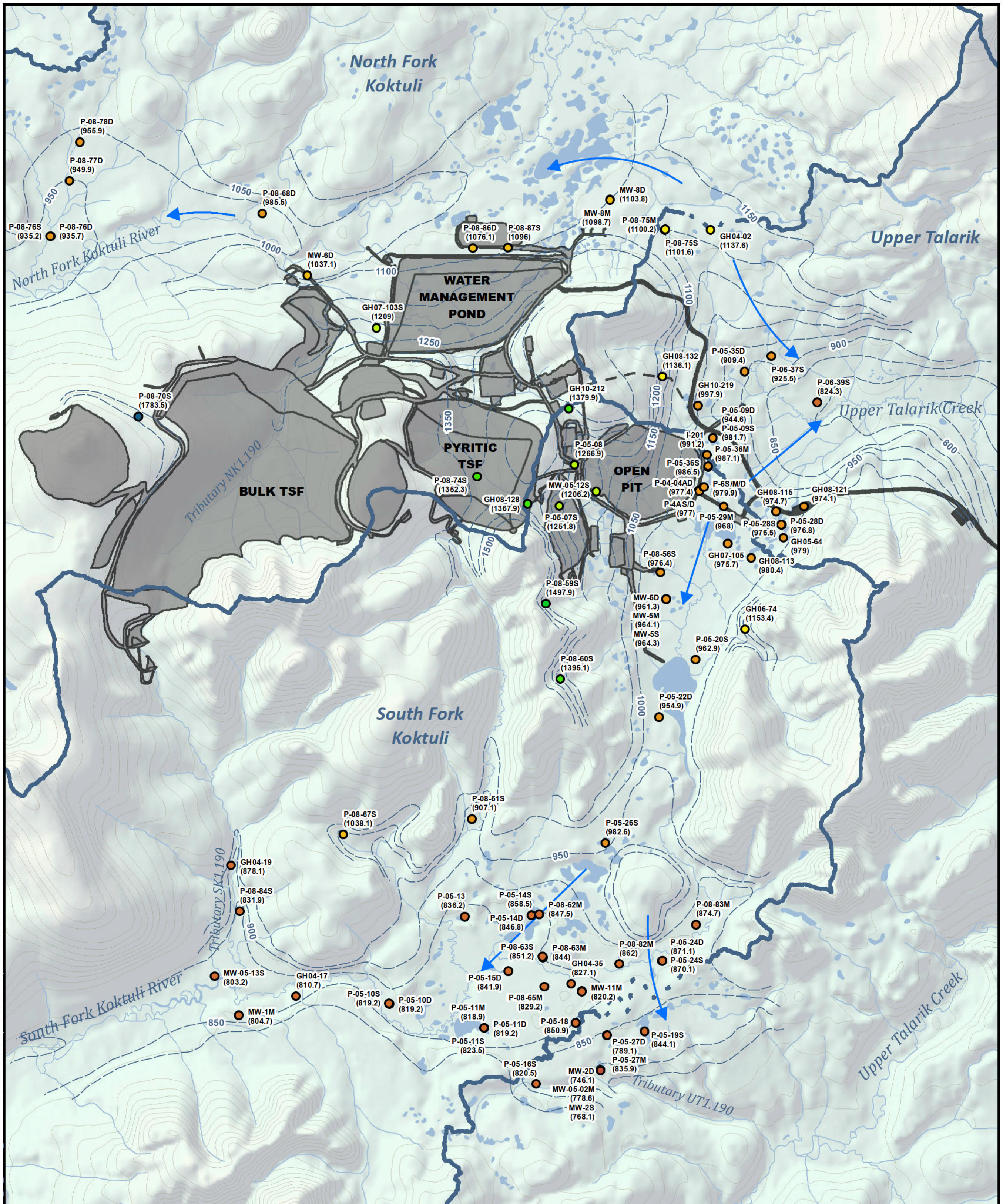
CROSS-SECTION M-1
NORTH FORK KOKTULI DRAINAGE

PEBBLE PROJECT EIS

FIGURE 3.17-9



Sources: PLP 2019-RFI153; BGC 2019a

Observed Elevation (ft)

- 746.1 - 800.0
- 800.1 - 900.0
- 900.1 - 1000.0
- 1000.1 - 1100.0
- 1100.1 - 1200.0
- 1200.1 - 1300.0
- 1300.1 - 1400.0
- 1400.1 - 1500.0
- 1500.1 - 1600.0
- 1600.1 - 1700.0
- 1700.1 - 1800.0
- 1800.1 - 1900.0
- Interpreted GW Contours
- Generalized Groundwater Flow Direction
- 100' Contour (Existing)

Major Basin Watershed Divide

- Divide Absent
- Divide Present

Action Alternatives

- Natural Gas Pipelines
- Alternative 1a

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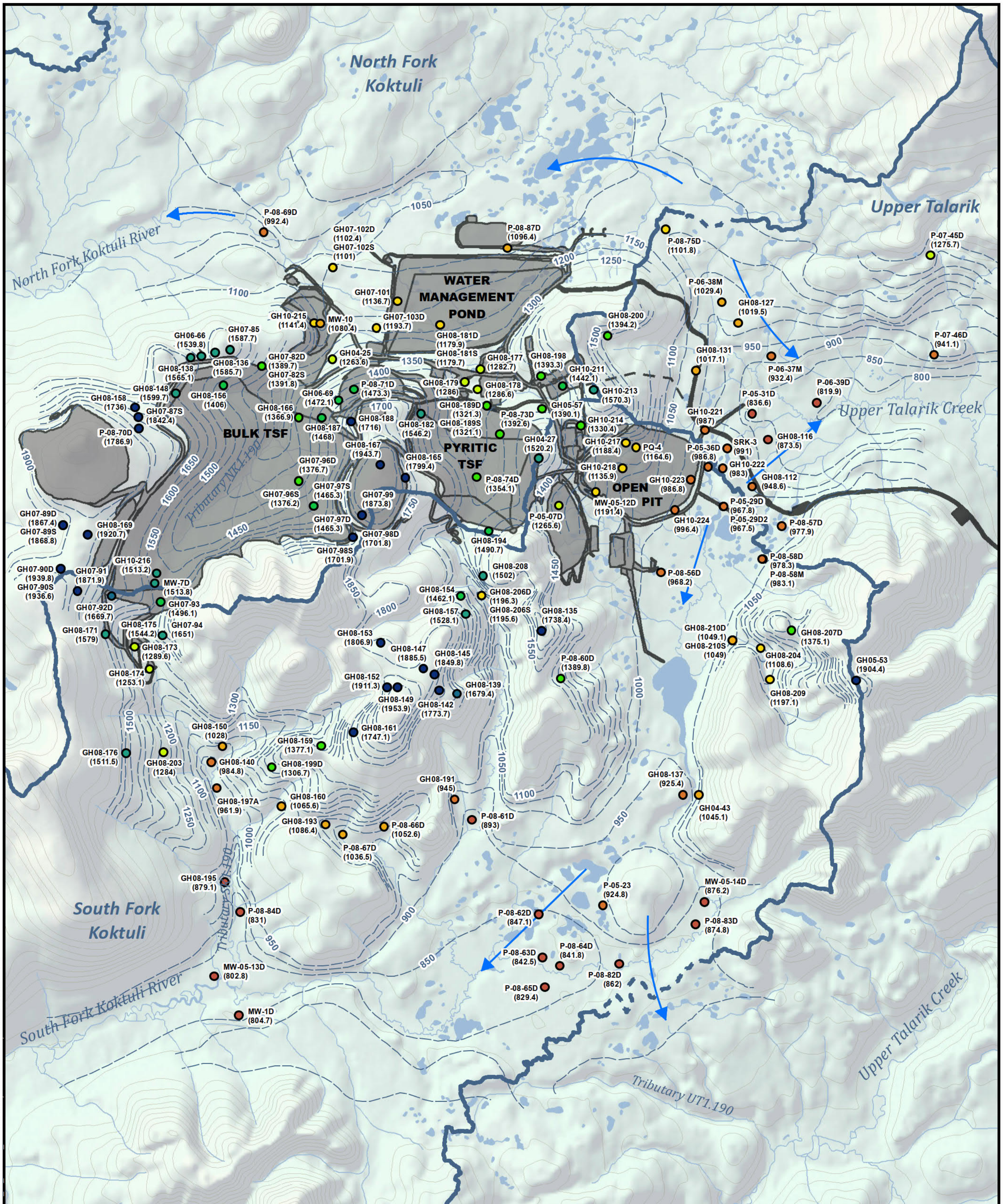
0.5 0 0.5 1

Miles

INTERPRETED GROUNDWATER ELEVATION CONTOURS (UNCONSOLIDATED SEDIMENTS)



Sources: PLP 2019-RFI153; BGC 2019a

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0.5 0 0.5 1
Miles

Observed Elevations (ft)

- 802.8 - 900
- 900.1 - 1000
- 1000.1 - 1100
- 1100.1 - 1200
- 1200.1 - 1300
- 1300.1 - 1400
- 1400.1 - 1500
- 1500.1 - 1600
- 1600.1 - 1700
- 1700.1 - 2000
- Interpreted GW Contours
- Generalized Groundwater Flow Direction

- 100' Contour (Existing)

Major Basin Watershed Divide

- Divide Absent
- Divide Present

Action Alternatives

- Natural Gas Pipelines
- Alternative 1a

INTERPRETED GROUNDWATER ELEVATION CONTOURS (BEDROCK)

PEBBLE PROJECT EIS

FIGURE 3.17-11

3.17.1.2 Overview of Groundwater Flow Systems

The hydrogeology of the mine site area is largely composed of tributary valleys containing overburden ("Aquifers and Confining Units" above) and adjacent ridges and knobs underlain by permeable weathered and fractured bedrock, talus[5], rubble, and solifluction[6] deposits. The weathered and fractured bedrock, which is up to approximately 50 feet thick, provides a pathway for groundwater recharge beneath these bedrock ridges. Below the weathered bedrock, bedrock permeability generally decreases with depth. This decrease is likely responsible for the numerous seeps observed on hillsides, where downward-percolating groundwater recharge is blocked by relatively low-permeability rocks at depth, and is forced to emerge at the land surface and flow as surface water. Deeper bedrock is both fractured and faulted, with mapped faults shown in Figure 3.17-1. Some fractured and faulted rocks produce areas of enhanced permeability through open fractures. In some faults, reduced permeability may occur where clay-rich fault gouge[7] plugs the fractures. Therefore, where faults are mapped, it is not immediately known whether the faults contribute to enhanced permeability, reduced permeability, or have practically no effect at all. Some faults are laterally extensive, and have the potential to function as barriers to groundwater flow that would result in the compartmentalization of groundwater flow. Deep aquifer testing (up to 4,000 feet deep) has shown that faults can be interpreted to be at least a localized barrier to groundwater flow. However, regionally there are no anomalously elevated or lowered water-level data from the bedrock aquifer to suggest that either enhanced or reduced permeabilities associated with faults or localized compartmentalized flow affect regional flow.

Most groundwater storage occurs in the overburden, which sustains winter base flow[8] along most of the streams and rivers (Schlumberger 2015a). Streams in the deposit area exhibit complex interactions with groundwater, with both gaining and losing reaches, depending on local soil types, land surface gradients, and water-table gradients. In some places, hyporheic flow[9] occurs on a very local scale in response to channel features, substrate types, and fluctuating stream water levels. Considering these variations, there is generally a net positive contribution to base flow from groundwater in most stream segments.

The interaction between groundwater and wetlands depends on the nature of the wetlands and the underlying permeability and recharge potential of the surficial geologic units. Wetland areas underlain by highly permeable layers, such as glacial outwash, would have a greater degree of hydrologic connectivity to shallow groundwater than units such as fine-grained glacial lake deposits (PLP 2018-RFI 082). Surficial units such as glacial drift and colluvium would have a moderate degree of connectivity. For example, some wetlands are on hillslopes where groundwater discharges as seeps or springs; whereas wetlands underlain by glacial lake deposits in flat areas may be perched, more dependent on precipitation and surface flows, and may be isolated from the groundwater below the fine-grained confining units. The distribution of surficial deposits around the mine site are shown in Section 3.13, Geology, Figure 3.13-2; Figure 3.17-4 through Figure 3.17-9; and Section 4.22, Wetlands and Other Waters/Special Aquatic Sites, Figure 4.22-2. The effects of project-related groundwater drawdown on wetlands are described in Section 4.17, Groundwater Hydrology, and Section 4.22, Wetlands and Other Waters/Special Aquatic Sites.

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[5] **Talus** is a steep slope deposit formed by the accumulation of broken rock debris.

[6] **Solifluction** refers to the slow creep of surficial soil layers downslope from freeze-thaw action.

[7] **Fault Gouge** is very fine crushed rock (e.g., clay-size) that results from friction caused by movement along a fault plane (i.e., between the two sides of a fault).

[8] **Base Flow** refers to groundwater that flows into surface streams as groundwater discharge, which occurs where the water table is higher than the adjacent stream surface.

[9] **Hyporheic Flow** refers to flow of surface water through sediments in flow paths that return to surface water.

The groundwater flow pattern in the mine site vicinity is dominated by recharge and flow in the weathered bedrock from the ridges and knobs toward the overburden sediments, wetlands, streams, and lakes in the valleys. Groundwater in the valley sediments and wetlands typically flows downstream along the axis of the valley, predominantly in permeable sands and gravels and the underlying weathered and fractured bedrock. Except for some inter-basin groundwater flow between the SFK River and UTC (and probably between the NFK River and UTC), most of the water remains in each surface water watershed and is eventually discharged to streams along the valley bottoms. The SFK River downstream of Frying Pan Lake loses water into the groundwater system to the extent that the river is known to go dry during low-flow conditions. Some of this groundwater flows through a large, permeable, glaciofluvial aquifer and crosses the surface water divide between the SFK and UTC basins. The water reemerges into the UTC tributary (UT1.190) as an unusually strong baseflow (Figure 3.17-12). Another probable instance of interbasin flow occurs along the surface water divide between the NFK and UTC basin upstream of gaging station UT100E. These areas of interbasin flow are shown in Figure 3.17-10 and Figure 3.17-11 as areas where the groundwater divide is absent (further discussion is provided under the “Local Groundwater Flow Systems” subsection).

3.17.1.3 Aquifer Properties—Hydraulic Conductivity and Storativity

Hydraulic conductivity (K) describes the ability of earth materials to allow water to move through saturated pore spaces or fractures in subsurface material. This parameter is a key input for mathematical models that quantify groundwater flow rates to streams and wetlands; predict pumping rates and zones of influence of the mine pit and pit lake; and flow beneath and surround major mine structures such as TSFs and WMPs.

Storativity (or specific yield in the case of an unconfined aquifer) is a measure of how much water the aquifer stores (i.e., how much water the aquifer will accept or release with changes in water level). Pumping tests provide information for estimating storativity and the specific yield of aquifers in the mine site area.

Results of technical review and analysis of previous hydrogeologic data are provided in Appendix K3.17. A summary of aquifer properties is provided below.

Overburden—Overburden hydraulic conductivity values range from 8×10^{-9} meters per second (m/s) to 1×10^{-3} m/s (see Table K3.17-2), which reflects the heterogeneous (diverse) nature of the interbedded glaciofluvial sediments. The hydraulic conductivity of overburden is similar throughout the mine site, with median values ranging from 1×10^{-5} m/s (UTC) to 4×10^{-4} m/s (SFK Flats area). Hydraulic conductivity values for overburden materials in the Pebble deposit (3×10^{-5} m/s) and UTC (1×10^{-5} m/s) areas were an order of magnitude lower than those measured in the SFK River, NFK River, and Frying Pan Lake areas, based on the median values, likely due to the presence of silty glacial deposits in these areas.

A summary of the hydraulic conductivity measurements in overburden and bedrock in the mine site vicinity determined by pumping and response tests is shown in Figure K3.17-10 through Figure K3.17-14. The results of pumping tests in overburden indicate that hydraulic conductivity was almost 10 times (one order of magnitude) higher than values derived from response tests (Schlumberger 2011a, 2015a). Pumping test results estimate the hydraulic conductivity over a larger area than response tests, and are generally assumed to be more reflective of the areal hydraulic conductivity. Results of the pumping tests indicate that the overburden aquifers are capable of conveying moderate to large quantities of groundwater. Most pumping test rates ranged from 45 to 85 gallons per minute (gpm), which is a good indicator of the range of expected well yields in the areas tested. Storativity and specific yield determinations indicate that some aquifers are confined and some are unconfined.

Bedrock—Similar to overburden, measured hydraulic conductivities of bedrock also vary widely throughout the mine site vicinity, ranging from 9.4x10^{-9} m/s to 3x10^{-3} m/s, which reflect widely varying degrees of weathering and fracturing (Appendix K3.17, Table K3.17-2, and Figure K3.17-10 through Figure K3.17-14). Bedrock hydraulic conductivity generally decreases with depth, although several measurements between depths of 1,900 feet and 2,800 feet exhibited higher values, similar to the highest values determined in the weathered zone of bedrock. Determinations deeper than about 1,500 feet are relatively sparse. The strongest trend of decreasing hydraulic conductivity with depth is noted with data collected at shallower depths of less than about 1,500 feet. However, the deeper data indicate there is considerable variability at depth, likely associated with faulting and fracturing in the area. Geometric mean hydraulic conductivity values measured with response tests in bedrock in the Pebble deposit (2x10^{-5} m/s) and SFK River (2x10^{-5} m/s) areas are about 4 to 21 times higher than those measured in the NFK (9.7x10^{-7} m/s), Frying Pan Lake (4.4x10^{-6} m/s), and UTC (1.9x10^{-6} m/s) areas, possibly due to the variability of weathered and fractured bedrock in these areas (Section 3.13, Geology). Results of pumping tests in bedrock (Schlumberger 2015a, Table 8.1-6) were similar to those for slug tests in bedrock wells (Table K3.17-2).

A summary of hydraulic conductivity measurements collected by pumping and response tests in bedrock in and outside the Pebble deposit is provided in Appendix K3.17, Figure K3.17-10. Results of packer tests are shown in Figure K3.17-11 through Figure K3.17-13.

Packer tests were used to measure hydraulic conductivity in the deeper bedrock to depths up to 4,500 feet. In the Pebble deposit, deeper bedrock hydraulic conductivities ranged from 1x10^{-10} to 4x10^{-6} m/s. The highest hydraulic conductivity measurements were in the upper 500 feet of bedrock, but are less than those in the shallow weathered bedrock, where the response test results ranged from 4x10^{-7} to 1x10^{-3} m/s. Outside the Pebble deposit, deep bedrock hydraulic conductivities were measured to depths up to 400 feet, but most were at depths less than 200 feet. Deep bedrock hydraulic conductivities in these areas ranged from 1x10^{-9} to 1x10^{-5} m/s. As a generality, the shallow weathered bedrock zone exhibits hydraulic conductivities that are approximately 2 orders of magnitude (a factor of 100) higher than the deep bedrock hydraulic conductivities, although each zone exhibits wide variability, at individual sites up to approximately 2 to 3 orders of magnitude around the mean levels.

3.17.1.4 Local Groundwater Flow Systems

Gravity-driven groundwater flow systems are commonly classified as local, intermediate, or regional following framework established by Tóth (1963). Local flow systems typically deliver locally recharged groundwater to adjacent streams. Intermediate flow systems may deliver groundwater to an adjacent or downstream stream, lake, or river. Regional flow systems typically deliver groundwater from major regional divides to large regional base-level waterbodies.

Two of the most important factors governing flow systems are local topographic relief, and the presence of local-, intermediate-, or regional-scale aquifers. In the mine site vicinity, the most permeable aquifers are of limited extent (sand and gravel aquifers mostly in valley bottoms), or of limited depth (weathered upper regions of bedrock), or both. In deeper bedrock, evidence suggesting the presence of significant permeable zones associated with different rock types or faults on an intermediate or regional scale is lacking.

The topographic relief in the vicinity of the mine site is high enough that modeling studies suggest that most or all groundwater flow systems would be local, being driven by high local differences in groundwater elevations on ridges versus valley bottoms. Therefore, where high topographic relief is present, the majority of water that recharges the groundwater system in local watersheds generally discharges in the same watersheds.

Maps showing groundwater elevations and contours in overburden (unconsolidated) aquifers (Figure 3.17-10) and in bedrock (Figure 3.17-11) illustrate several features of the local and intermediate groundwater flow systems. Generally, groundwater contours based on wells tapping overburden are characteristic of the water table. The water table generally mimics the ground surface topography, although it is deepest below ridge tops, and nearer ground surface in valley bottoms.

Groundwater generally flows from ridge areas, where surface water and groundwater divides occur in the weathered and fractured bedrock, to valley bottoms filled with glacial and alluvial sediments (mainly sands and gravels), eventually discharging to surface water (wetlands, streams, rivers, and lakes). Groundwater seeps emerge in some hillside areas where lower-permeability materials restrict downward groundwater flow.

Groundwater level monitoring and interpreted contours (Figure. 3.17-10 and Figure 3.17-11) suggest the presence of three mostly continuous groundwater divides in the analysis area as follows:

- Between the UTC drainage and the NFK River drainage (except for a segment where the divide is probably absent; Figure 3.17-10 and Figure 3.17-11)
- Near the Pebble deposit between the SFK River drainage and the UTC drainage (except for a segment where the divide is absent; Figure 3.17-10 and Figure 3.17-11)
- Between the SFK River drainage and the NFK River drainage

Groundwater divides are generally considered to be approximately coincident with surface water divides. An exception to this is in the area of the surface water drainage divide between the SFK and tributary UT1.190 basins, where the groundwater divide is interpreted to be absent, reflecting interbasin groundwater flow from the SFK to the UTC drainage (see below).

In bedrock (Figure 3.17-11), groundwater contours are more tightly packed together in hillslope areas compared to valley bottoms, likely reflecting the lower permeability of the weathered bedrock aquifer compared to the more permeable valley-bottom overburden aquifers. There are no apparent areas showing unusually elevated, truncated, or depressed deep groundwater contours that would indicate either compartmentalized (fault-bounded) or preferential conduit-like flow associated with bedrock faults.

The water table and bedrock groundwater contour maps (Figure 3.17-10 and Figure 3.17-11) also present evidence of intermediate-scale groundwater flow systems. Groundwater contours for the area near the boundary between the Tributary UT1.190 drainage and the SFK drainage depict a steady slope of the contoured surfaces to the southeast, reflecting groundwater flow from the SFK basin into the Tributary UT1.190 drainage. This can be regarded as an intermediate groundwater flow system delivering groundwater from one drainage basin into an adjacent drainage basin. Another example of interbasin groundwater flow is likely present along the surface water divide separating the NFK drainage from the UTC drainage upstream of stream gage UT100E (Figure 3.17-10 and Figure 3.17-11). A large glaciofluvial aquifer in this area appears to convey groundwater across the surface water divide and into the UTC basin.

As a result of the presence of low-permeability bedrock aquifers and the high topographic relief of the mine vicinity, regional groundwater flow systems may not be present. If they are present, the low permeability of deep bedrock and the long flow paths involved would transmit only a small amount of water to regional discharge areas, such as Iliamna Lake, and would constitute only a very small portion of the overall groundwater budget of the area.

Local groundwater flow systems are driven by local precipitation, snowmelt, and gravity. Precipitation in the vicinity is primarily the result of marine storm systems, with the most precipitation occurring from late summer to early winter. Precipitation is greater in upland areas than lowland areas due to topographic effects. Precipitation and additional climate data are addressed in Section 3.16, Surface Water Hydrology, and Section 3.20, Air Quality. This strong seasonal precipitation drives rising groundwater levels that commonly occur during fall or early winter (see additional discussion in Appendix K3.17). In some years, there is also a significant water-level rise associated with spring snowmelt. These observations support the concept that local flow systems with relatively short groundwater flow paths that are quickly responsive to precipitation and snowmelt events are important features in the mine vicinity.

Data from two monitoring wells were used to characterize general seasonal and vertical groundwater level fluctuations: monitoring well (MW) MW-11 in the SFK Flats area and MW-5 in the Pebble deposit area (see Figure K3.17-15 and Figure K3.17-16) (Schlumberger 2015a). Lowest groundwater levels were recorded during late winter; and highest water levels were typically recorded during spring freshet[10] or fall rain events. Groundwater levels seasonally fluctuated approximately 10 to 20 feet. Similar to groundwater levels, measured discharge from seeps seasonally varied by factors between 3 and 10. Vertical hydraulic gradients were variable in direction (upwards versus downwards) and strength over the seasons and with depth. Additional details of the locations, directions, and strengths of vertical hydraulic gradients observed in the area during both high- and low-water conditions are provided in Appendix K3.17.

3.17.1.5 Water Modeling Systems Overview

A comprehensive modeling system was developed that consists of three primary models: a watershed model, a groundwater model, and a mine site water balance model. The watershed model and the groundwater model were constructed using consistent information, including the same climate and streamflow data (including details about gaining and losing reaches), and surficial geological mapping. The watershed model simulates long-term natural streamflows and is useful for quantifying the estimated effects of the mine on flows downstream of the mine site. It also provides calibrated hydrologic parameters and flow estimates that are used in the development of the mine site water balance model. The groundwater model is used to assess the hydrogeologic effects of the mine and provides inputs to both the watershed model and the mine site water balance model. The mine site water balance model is used to calculate flows associated with the mining, milling, and water treatment and discharge processes, which supports mine planning. Details of the interactions of the three models are provided by Knight Piésold (2019f).

3.17.1.6 Site-Wide Watershed Model

A watershed model is essentially a means to calculate inflow, outflow, and water storage in and between a set of hydrologic sub-basins or watersheds. It can be used to predict and manage water supply and environmental stream conditions. The watershed model was developed to inform the characterization of mine site hydrology, understand the nature and extent of interactions between groundwater and surface water, and provide estimates of groundwater recharge to support calibration of the groundwater model.

The watershed model is also used to estimate water flows during project operations and during the closure and post-closure periods. The watershed model was calibrated (adjusted) to 4.5 years of continuous streamflow data at six SFK River, three NFK River, and three UTC gaging stations, as well as a long-term synthetic series of temperature and precipitation data for the period from 1942 to 2017, based on data from mine site and regional weather stations.

[10] **Spring freshet** refers to runoff and groundwater recharge that occurs during and shortly after seasonal snowmelt.

The watershed model results are described in Section 3.16, Surface Water Hydrology, and briefly summarized below. An important use of the watershed model is to determine the effects of uncertainty from the groundwater model on streamflow predictions.

The average annual estimated precipitation for the catchments (watersheds) in the water balance model ranged from 45 to 55 inches. Ten sub-catchments (sub-catchments 2, 3, 4, 5, 7, 8, 9, 10, 13, and 14: see Figure K3.16-2) had estimated annual unit flows that ranged from 1.4 to 6.9 cubic feet per second per square mile (cfs/mi^2), averaging about 2.9 cfs/mi^2 (Schlumberger 2011a). Average annual groundwater recharge varied from 11 to 24 inches per year as averaged over the large NFK River, UTC, and SFK River drainage areas. Estimated groundwater recharge in small individual catchments was more variable and ranged from 4.7 to 46.8 inches per year. The majority of groundwater tends to discharge to surface water in the same drainage basin, with the primary exception of groundwater transfer between the SFK Flats area to the UTC drainage along Tributary UT1.190, estimated to be 6 inches per year, or about one-third of the total underflow in the SFK Flats area. A lesser amount of groundwater also appears to flow between the NFK watershed and the UTC watershed.

3.17.1.7 Mine Site Groundwater Flow Model

For the DEIS, a three-dimensional numerical groundwater flow model was developed to simulate baseline groundwater conditions as described by Schlumberger (2011a: Appendix 8.1J; Piteau Associates 2018a). A new groundwater flow model was subsequently developed (BGC 2019a) and is used for the analysis in this EIS. Where comparable, the models are generally equivalent; however, the BGC 2019a model has a more comprehensive calibration and sensitivity analysis, used more capable numerical solution methods, and has produced more detailed results from a wider variety of mine conditions and sensitivity analysis scenarios. Importantly, as a result of the uncertainties inherent in the groundwater model, a robust uncertainty analysis was conducted, with the results propagated through other predictive components of this EIS, such as streamflow, water treatment, and wetlands analysis. The model setup and calibration are discussed in Appendix K3.17 and summarized below.

A numerical model is a computer simulation of local, intermediate, and regional groundwater flow. The model was constructed with 12 layers to represent flow in the overburden, the shallow weathered and fractured bedrock, and deeper bedrock. Transient (time varying) recharge estimates from the site-wide watershed model and field-based estimates of hydraulic conductivities were used as initial model input. Groundwater levels at wells (both average values and time-varying), simulation of a pumping test, and streamflow measurements at 26 locations were used as calibration targets.

Model parameters were calibrated (adjusted) until the model produced an adequate match to the calibration targets. The model reasonably matched most field-measured water levels from monitoring wells and successfully estimated most streamflows, indicating that the calibrated hydrogeologic model is a reasonable simulation of the groundwater system (BGC 2019a).

The baseline groundwater model is important because it is used to predict potential effects of the mine by incorporating project-specific information to address activities, such as pit dewatering and recovery. The groundwater model simulates the exchange of water between streams and groundwater, and model estimates were compared with streamflow measurements during periods of time when surface water flows were low, and primarily groundwater derived. The application of the model in predicting the effects of mining activities on groundwater and related impacts to surface water, wetlands, and water management activities are discussed in Section 4.17, Groundwater Hydrology.

3.17.1.8 Groundwater and Surface Water Interaction

Upwelling groundwater in stream bottoms is recognized as an important factor in creating habitat for incubation and rearing of salmonids in the drainages surrounding the mine site and there are observed groundwater-surface water interactions in this area. Groundwater and surface water interaction was characterized based on conceptualization of processes such as hyporheic flow, streamflow gain (upwelling), and streamflow loss (downwelling). These processes were used to interpret data and modeling results, including detailed low-flow and wintertime open water streamflow surveys, geological mapping, and results from groundwater modeling and the site-wide watershed model.

Surface water flow surveys were conducted during periods of low streamflow and are described in detail in Knight Piésold et al. 2011a, Knight Piésold 2015b, and Section 3.16, Surface Water Hydrology. These surveys included gages in the NFK River, the SFK River, and the UTC drainage basins. Figure 3.16-4 and Figure 3.16-5 show stream gage locations. Although groundwater and surface waters interact during all seasons, the interactions are most easily discerned during low-flow conditions when precipitation or snowmelt are low or absent and practically all water in the streams is supplied by groundwater. Groundwater flow to streams surrounding the mine site is complex and controlled by the hydraulic conductivity of sediments and bedrock, bedrock topography (Knight Piésold et al. 2011a), thickness of sediments, and topographic slope (BGC 2019a). Streams in the NFK and SFK basins have both gaining and losing reaches, while streams in the UTC basin are primarily gaining (Schlumberger 2011a).

Gaining streamflow reaches can be inferred by identifying stream reaches that exhibit open water during late-winter conditions because the relatively warmer upwelling groundwater contributes to ice-free conditions. Open water surveys conducted in 2006, 2007, and 2008, showed that many reaches exhibited consistent patterns during these years, although some differences in observed conditions may be attributable to flowing-water effects and variable air temperature and snowpack conditions. The open water survey results for 2006 are shown in Figure 3.17-12.

Streams also lose water to groundwater in several identified areas, which is inferred from actual losses of streamflow identified during near-synoptic low-flow streamflow surveys, as shown in Figure 3.17-13. In addition to these identified stream segments, there are likely other, shorter reaches where streamflow losses to groundwater are also likely to occur.

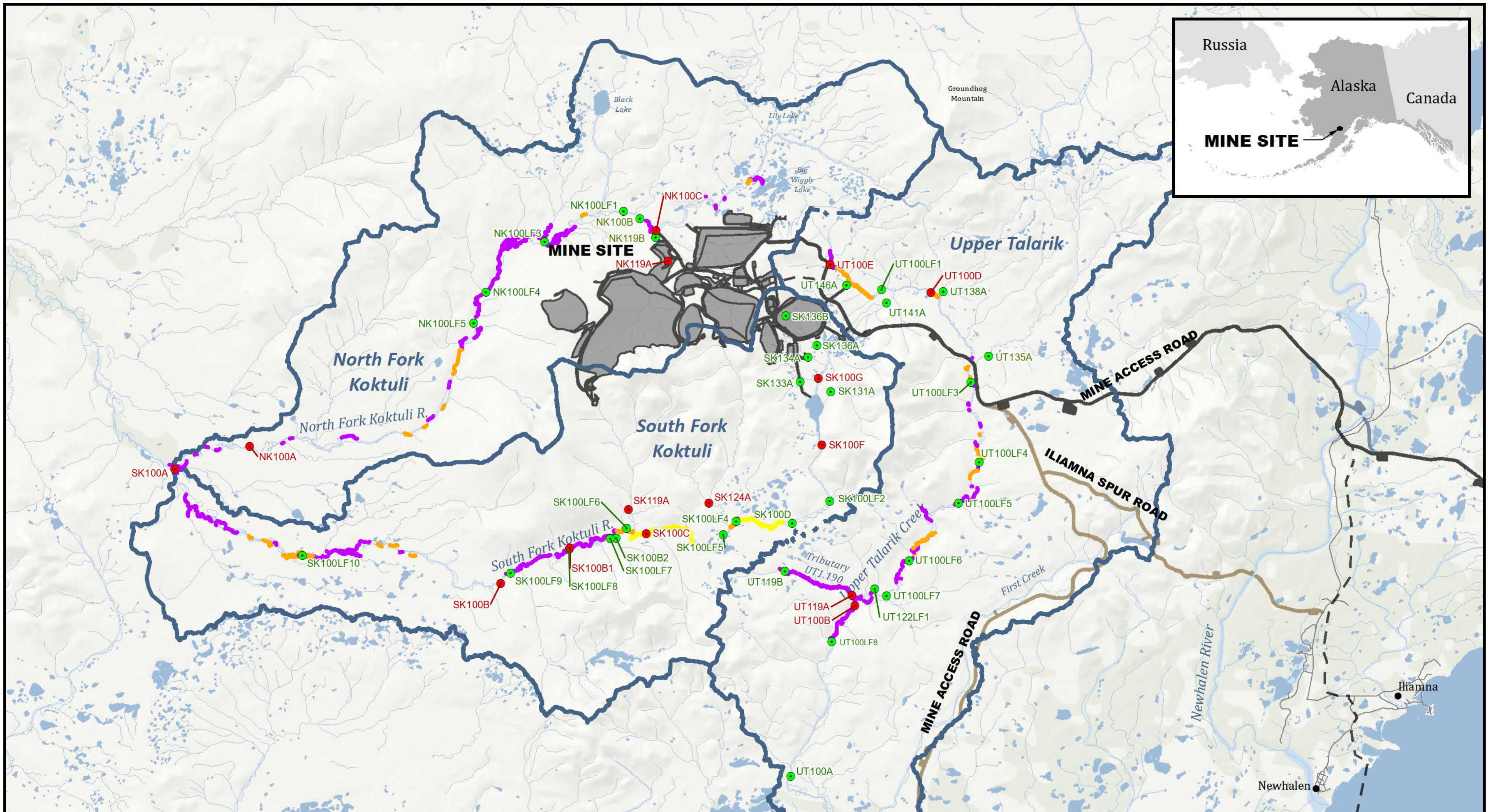
One section of SFK loses so much water to groundwater that the stream has been observed to go dry. Some of the infiltrated water then crosses the SFK-UTC surface water drainage divide and discharges into Tributary UT1.190, where anomalously high base flow quantities and winter-time open water (Figure 3.17-12) have been observed.

Field observations indicate that the majority of stream reaches were found to be receiving groundwater discharge from the underlying aquifer (i.e., gaining). However, the NFK River was found to be losing water to the underlying aquifer between gages NK100B and NK100LF1, and for some distance downstream from NK100LF1 towards NK100LF3, although the exact boundary is not well defined (see Section 3.16, Surface Water Hydrology).

The SFK River was found to be losing water to the underlying aquifer(s) between SK100F and SK100C, and between SK100B and SK100LF10. Figure 3.17-13 shows losing stream segments that have been identified.

In some areas, gaining and losing reaches have been compared to known salmon spawning locations (Figure 3.24-2A, Figure 3.24-3A, Figure 3.24-4A).

The groundwater model simulates both gaining and losing segments of streams (Figure 3.17-14). The model indicates considerable geographic complexity of gaining and losing segments of streams, likely based on the factors described above, that make detailed, accurate, (and likely time-variant) delineation of gaining and losing reaches of streams challenging. Nevertheless, the model appears to capture the major trends of areas where streams have been inferred to gain or lose water based on field observations. Even if the model only approximately captures the natural complexity of groundwater/stream interactions near the mine site, it presents a consistent base scenario against which potential future changes to the groundwater hydrology can be compared and quantified. These potential changes are addressed in Section 4.17 and Appendix K4.17, Groundwater Hydrology, and in other sections describing surface water, water quality, wetlands, and fish values resources.



Sources: PLP 2019-RFI153;
Knight Piesold et al. 2011a, 2015a

US Army Corps of Engineers

Continuous Monitoring Gage Stations

Early Spring Low-Flow Measurement Sites

February 2006 Survey Results

No Flow

Intermittent

Open Water

Major Basin Watershed Divide

Divide Absent

Divide Present

Action Alternatives

Natural Gas Pipelines

Alternative 1a

Alternative 1

Alternative 2 Newhalen River North Crossing Variant

Other Features

Local Roads

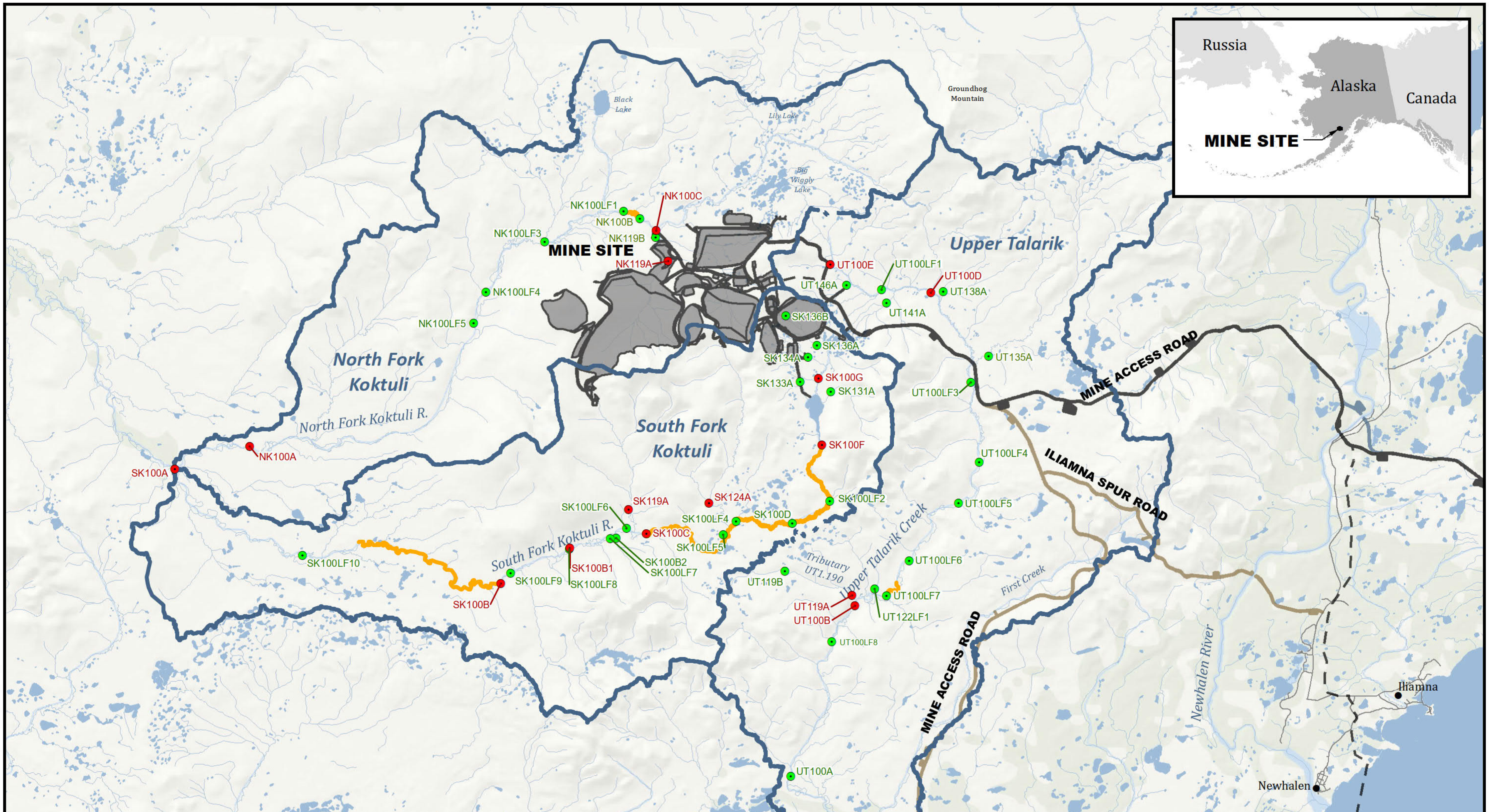
2 0 2 4

Miles

2006 OPEN WATER SURVEY RESULTS

PEBBLE PROJECT EIS

FIGURE 3.17-12



Sources: PLP 2019-RFI153;
Knight Piesold et al. 2011a, 2015a

US Army Corps of Engineers

2 0 2 4
Miles

- Continuous Monitoring Gage Stations
- Early Spring Low-Flow Measurement Sites
- Losing Stream Segment

Major Basin Watershed Divide
- Divide Absent
- Divide Present

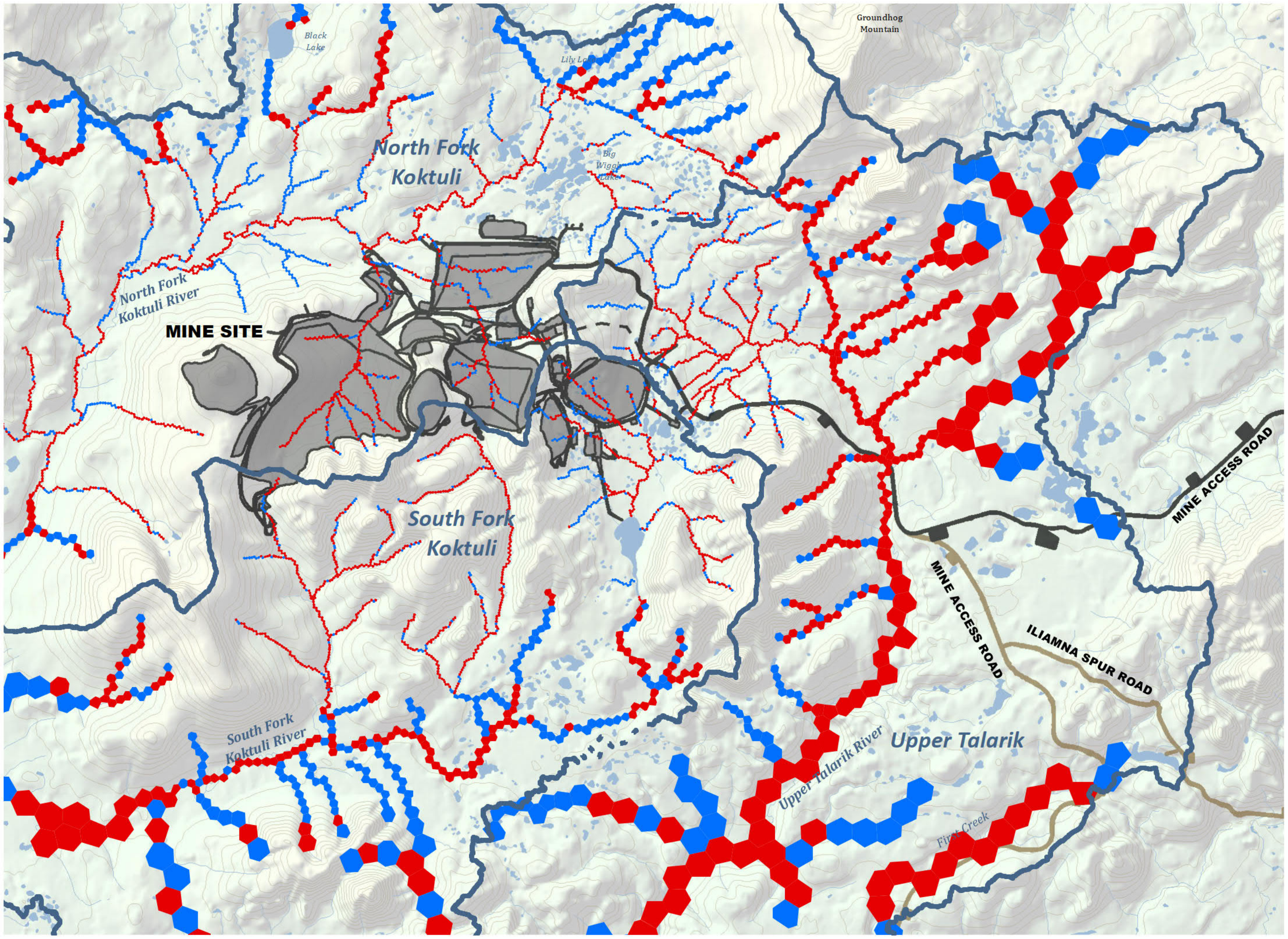
Action Alternatives
- Natural Gas Pipelines
- Alternative 1a
- Alternative 1
- Alternative 2 Newhalen River North Crossing Variant

Other Features
- Local Roads

IDENTIFIED LOSING STREAM SEGMENTS

PEBBLE PROJECT EIS

FIGURE 3.17-13



Sources: PLP 2019-RFI153; BGC 2019a

US Army Corps of Engineers

1 0 1 2
Miles

Simulated Flow Conditions at Surface Water Bodies and Drainages*
- Gaining
- Losing
- 100' Contour (Existing)

Major Basin Watershed Divide
- Divide Absent
- Divide Present

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

*Note: Size of stream segments reflects model cell sizes.

SIMULATED GAINING AND LOSING SURFACE WATERBODIES AND DRAINAGES

PEBBLE PROJECT EIS

FIGURE 3.17-14

3.17.2 Transportation Corridors and Ports

3.17.2.1 Hydrogeological Characterization

The sections below summarize the available baseline hydrogeological data for the transportation corridors and port sites in the analysis area under all alternatives and associated variants. The road corridors span multiple drainage basins; starting at the southeastern edge of the Nushagak River drainage in the mine site, across the greater Kvichak River drainage (including Iliamna Lake) to the Aleutian Range divide, and then into the greater Cook Inlet drainage east of the divide.

Western portions of the mine access road are in the well-studied UTC drainage. Limited data are available for the port access road under Alternative 1a and Alternative 1 or the port access road under Alternative 2—North Road and Ferry with Downstream Dams and Alternative 3—North Road Only. No known hydrogeological investigations have been conducted along the port access roads or port sites. A geophysical survey conducted at the Amakdedori port site (Zonge 2017) and regional mapping (Detterman and Reed 1973) provides information on the depth and lateral extent of likely unconsolidated deposits (overburden) in this area.

Climatic factors influencing groundwater across the corridor are the same or similar to those described above for the mine site. There are no glaciers or known permafrost in the transportation corridors or port sites (see Section 3.14, Soils).

3.17.2.2 Aquifers

The transportation corridor begins at the mine site, which straddles the drainage divide between the SFK and UTC drainage basins. Glacial sands and gravels generally host multiple surficial and intermediate aquifers that likely contain most of the groundwater, while the weathered and fractured shallow bedrock aquifer stores significantly less groundwater (Schlumberger 2015a, Appendix 8.1B). Western portions of the mine access road are mostly in the UTC drainage, where groundwater occurs in surficial aquifers of glacial sediment and in weathered and fractured shallow bedrock.

The port access road under Alternative 1a and Alternative 1 parallels First Creek (west of the road route), a tributary basin that drains southward into the main UTC drainage about 4 miles upgradient of Iliamna Lake. Hydrogeologic data for this area are limited. Bedrock and surficial geology along the port access road are similar to those of the mine access road to the north, with Tertiary (Paleogene and Neogene) volcanic bedrock and thick deposits of surficial glacial sediments (see Section 3.13, Geology). Based on the similar geologic setting and topography across the mine access road and port access road, aquifers and confining units in the transportation corridor are likely similar. Permeable sands and gravels, which make up the abundant glacial till and outwash across the mine access road and port access road, as well as lake terrace and beach deposits 1 to 2 miles from the north ferry terminal (under Alternative 1) (Detterman and Reed 1973) (Figure 3.13-4), likely host surficial and/or intermediate aquifers. It is possible that weathered and/or fractured bedrock stores additional groundwater at depth.

The mine access road from the mine to Eagle Bay under Alternative 1a and Alternative 2 and the western part of the north access road under Alternative 3 cross mostly glacial and alluvial deposits in the UTC, Newhalen River, Eagle Bay Creek, Chekok Creek, and Canyon Creek drainages (Figure 3.13-4). Aquifers in these areas are likely similar to those of the mine access road under Alternative 1, described above (mine site to north ferry terminal). East of Knutson Mountain, groundwater-bearing surficial deposits are more limited in extent to steep, narrow drainages with large areas of exposed bedrock in between. Alluvium, alluvial fan, and mass wasting deposits in Knutson Creek, Pile River, Iliamna River, and Chinkelyes and Williams creeks may host surficial aquifers. Small areas of ground moraine and lake terrace deposits in the Pile and Iliamna river valleys may also contain shallow groundwater. It is possible that groundwater may be present near the surface along steep slopes in weathered or fractured bedrock in this area. At the Diamond Point port sites under Alternative 2 and Alternative 3, shallow groundwater may be present in alluvial fan material in the small drainage on the northern side of Cottonwood Bay, in fractured bedrock slopes along Iliamna Bay, in alluvium mapped in the Williams Creek drainage, and in talus deposits mapped on the south side of Williams Creek (Detterman and Reed 1973).

No known groundwater resource investigations have been conducted south of Iliamna Lake, and aquifers and confining units have not been delineated for this area. Lake terrace and beach deposits that occur in the south ferry terminal area (Detterman and Reed 1973) likely host shallow groundwater. The geologic setting along the port access road and the Kokhanok spur road is somewhat distinct from that north of Iliamna Lake. Jurassic age intrusive bedrock is commonly exposed at the surface, and glacial sediments are less abundant. The water table approaches the surface in lowland areas, as evidenced by abundant kettle ponds and wetlands. Glacial deposits are significantly thinner along the south access road corridor compared to the mine access road, but likely host shallow aquifers where present (Glass 2001).

Shallow groundwater is likely present in surficial alluvium, alluvial fan, marine terrace, and beach deposits near Amakdedori port (Detterman and Reed 1973). Overburden is estimated to be about 50 to 100 feet thick in the terminal area (Zonge 2017). The degree of weathering and fracturing in bedrock is not well-known along the port access road, and it is unknown if bedrock fractures host significant groundwater. It is also unknown if local fault zones host groundwater, or if they contain fine-grained fault gouge that may impede groundwater flow.

3.17.2.3 Aquifer Properties—Hydraulic Conductivity and Storativity

In the UTC drainage, groundwater occurs in aquifers of surficial glacial sediments and in fractured shallow bedrock. The permeability of the glacial sediments allows groundwater to pass through relatively easily. Therefore, the hydraulic conductivities are moderately high, ranging from 2×10^{-6}m/s to 4×10^{-5} m/s in this area (Schlumberger 2015a). The modest variation of hydraulic conductivity by one order of magnitude is to be expected with the lateral diversity of the glacial deposits, which vary in permeability, largely depending on the amount of silt present.

Shallow, weathered, and fractured bedrock along the northern segment of the mine access road has hydraulic conductivities that range from 2×10^{-7} m/s to 2×10^{-5} m/s (Schlumberger 2015a). These hydraulic conductivities are similar to those for silty sands and sand aquifers. Because this bedrock is fractured, groundwater is able to flow through the cracks in the rock relatively easily, at rates similar to those of the overlying glacial sediments. However, deeper, unweathered, and less-fractured bedrock does not readily transmit or store groundwater.

To the south and east, the Alternative 1a and Alternative 1 transportation corridor (port access road) parallels the First Creek tributary basin, which drains southward into the main UTC drainage above Iliamna Lake; the mine access road in the Alternative 1a, Alternative 2, and Alternative 3 corridors crosses the UTC and several similar watersheds that drain to Iliamna Lake. No detailed studies have been conducted on aquifer properties here, but a similar geologic setting suggests that groundwater occurs in both surficial sedimentary aquifers and weathered and fractured shallow bedrock, as it does to the northwest.

No data on hydraulic conductivity or aquifer storage are available along the transportation corridors south or northeast of Iliamna Lake.

3.17.2.4 Groundwater Flow Systems

Groundwater flow systems in the northwestern portion of the transportation corridors have complex surface water/groundwater interactions (Schlumberger 2015a). The UTC drainage has both gaining and losing reaches because groundwater migrates generally southeast across the area. Farther south and east along the mine access road corridors, the water table remains near the ground surface in lowland areas, and groundwater/surface water interaction likely occurs, as has been demonstrated in and around the mine site. Existing data and regional groundwater trends suggest a generally southerly flow of groundwater along the southern half of the mine access road and along the north access road (Schlumberger 2015a, Appendix 8.1B).

There are no known groundwater studies of the transportation corridors south or northeast of Iliamna Lake. Groundwater flow along the port access road corridor likely parallels surficial flow, following general hydrologic trends (see Figure 3.16-11). In the Kvichak drainage, groundwater is expected to flow northwest toward Iliamna Lake. Across the Aleutian Range divide in the Tuxedni-Kamishak drainage, groundwater likely flows southeast towards Kamishak Bay. In the steep drainages along the eastern part of the north access road (see Figure 3.13-4 and Figure 3.16-23), groundwater likely flows perpendicularly through steep slope deposits into the narrow valleys, and then parallels the direction of the surface water flow in the valleys.

Near the Amakdedori port site, shallow groundwater in surficial deposits and bedrock (where present) likely flows from hill slopes toward Amakdedori Creek and wetlands near the southern end of the port access road, then parallels the creek flow south and southeast toward Kamishak Bay (see Figure 3.16-11). Groundwater at the Alternative 2 Diamond Point port site likely flows south toward Cottonwood Bay (see Figure 2-71). If present, groundwater in fractured bedrock along the west side of Iliamna Bay and at the Alternative 3 port facilities would flow towards the bay. Groundwater in talus deposits on the south side of Williams Creek would flow towards the creek, and groundwater in alluvium in the creek bottom would flow east toward Williamsport. Groundwater flow beneath beach and alluvial deposits at the port sites may have a diurnal directional component due to large tidal fluctuations.

3.17.2.5 Groundwater and Surface Water Interaction

Groundwater/surface water interactions have not been studied in the transportation corridor or at port sites. However, groundwater/surface water interaction is likely to be similar to the mine site based on the geology and hydrology of the area. Studies in the mine site suggest that groundwater discharge to streams or rivers prevails, and that where it is occurring, groundwater base flow is highest in the winter, and lowest (on a percent volume basis) during the spring and summer runoff events.

3.17.3 Natural Gas Pipeline Corridors

No specific hydrogeologic studies have been conducted in the natural gas pipeline corridors, and data are the same as those discussed above for the transportation corridors, with the exception of Kenai Peninsula at the eastern pipeline shore approach and tie-in, and the pipeline segment between Ursus Cove and Diamond Point. The latter likely contains shallow groundwater in surficial alluvium and marine terrace deposits (Detterman and Reed 1973). Groundwater beneath Kenai Peninsula is known to occur in multiple aquifers in thick glacial and alluvial deposits above sedimentary bedrock (Karlstrom 1964; Nelson and Johnson 1981). Groundwater flow is generally to the west toward Cook Inlet, and seeps commonly occur along Cook Inlet bluff, where fine-grained glacial lake deposits form aquitards and support perched groundwater zones. Private groundwater wells, drilled on top of the Cook Inlet bluff at elevations of approximately 200 feet, produce water at depths between 8 and 61 feet below ground surface (ADNR 2016, 2018a).

Deeper aquifers are also locally present in glacial deposits and sedimentary bedrock at depths up to 120 feet (Nelson and Johnson 1981).

3.17.4 Groundwater Use

This section addresses groundwater use in the analysis area for all components, alternatives, and associated variants described above. Existing use of surface water for domestic supply is described in Section 3.16, Surface Water Hydrology.

Mine Site—As described above, groundwater wells across the mine site area were used to collect data on aquifer properties, site water balance, and water quality (Schlumberger 2011a, 2015a). Groundwater use at the mine site is currently limited to sampling and hydrogeologic testing. There is currently no domestic water use at the mine site; exploration employees use community water supplies while staying in Iliamna. PLP received multiple Temporary Water Use Authorizations (TWUAs) for exploration activities between 2004 and the present. There are currently three active authorizations in place. The TWUAs allow a limited volume to be withdrawn per day, up to a specified annual limit, from specified sources, which are mostly groundwater wells.

Transportation Corridors—Some communities in the Iliamna Lake area rely on groundwater wells for their domestic water supply (Figure 3.17-15) (ADNR 2018a[11]). The villages of Newhalen and Iliamna have both public and private groundwater wells, while the community of Pedro Bay (along the Alternative 2 and Alternative 3 transportation corridors) relies on private groundwater wells.

Section 3.18, Water and Sediment Quality, describes the available water quality information for groundwater supply wells relevant to the analysis area. No water quality data are available for private groundwater wells. No public data are available on drinking water sources for Pile Bay and Williamsport near the Alternative 2 and Alternative 3 transportation corridors (ADEC 2018f; ADNR 2018a).

To meet the requirements of the Safe Drinking Water Act, elements of the US Environmental Protection Agency (EPA) 1986 Wellhead Protection and 1997 Source Water Assessment and Protection programs have been combined under the Alaska Department of Environmental Conservation (ADEC) Drinking Water Protection Areas (DWPAs) program. The DWPA program's intent is to delineate the boundaries of public drinking water sources, identify potential risks from contamination, and determine the vulnerability of water sources. The data may be used by local governments and state agencies when reviewing permits for activities that may affect public drinking water sources. There are currently no regulatory restrictions associated with DWPAs (ADEC 2018f). DWPAs surround the public groundwater supply wells in Newhalen and Iliamna (Figure 3.17-15). These overlap DWPAs identified for surface water supply systems around Iliamna Lake, shown in Figure 3.16-25. Various zones in the DWPAs for groundwater wells reflect buffers around wellheads, groundwater travel time, and flow directions. Private wells in Newhalen, Iliamna, and other villages along the transportation corridor do not have designated DWPAs.

Port Sites—There is no known or documented groundwater use at either the Amakdedori or Diamond Point port sites (ADEC 2018f, g).

[11] ADNR Well Log Tracking System (WELTS) website—Locations are based on data provided by ADNR in Global Positioning System (GPS) coordinates; based on property parcel boundaries; or as US Public Land Survey System (PLSS) using the centroid locations (i.e., the calculated center of a parcel defined by legal land description boundaries [i.e., the Section, Township, and Range convention]).

Pipeline—Residents of Anchor Point, near the eastern terminus of the natural gas pipeline corridor on the Kenai Peninsula, use private groundwater wells for their domestic water supply. There are 12 private groundwater wells within 0.5 mile of the pipeline infrastructure on the eastern side of Cook Inlet (ADNR 2018; ASDGC 2020) (Figure 3.17-16). As private wells, these do not have designated DWPAs. The closest of the private wells to the pipeline route is thought to be approximately 100 feet north of the proposed route; however, it may be closer as a result of locational imprecision in the WELTS database. Designated well 53874 in the database, it was drilled in 1993 to a total depth of 61 feet, draws water from a sand aquifer below a 60-foot grouted casing, and was pump-tested at 15 gpm when installed. The well encountered several interbedded clay and sand layers above this depth, including a 12-foot-thick clay layer between depths of 45 and 57 feet (ADNR 2016).

Sources: PLP 2019-RFI153; ADEC 2018g; ASGDC 2020

US Army Corps of Engineers®

0.5 0 0.5 1

Miles

Public Water Supply Wells

- Community Water System
- Non-Community Water System (School, Lodge)

Private Water Supply Wells

- Well Locations Identified by ADNR Well Log Tracking System (WELTs)

Drinking Water Protection Areas (DWPAs) for Groundwater

- Zone A - Several Months Travel Time
- Zone B - 2-year Travel Time

Alternative 1a

- Ferry Route
- Natural Gas Pipeline

Alternative 1

- Iliamna Spur Road

Other Features

- Local Roads

Well locations are approximate and are plotted based on ADNR and ADEC data.

WATER SUPPLY WELLS IN NEWHALEN AND ILIAMNA

PEBBLE PROJECT EIS

FIGURE 3.17-15

Sources: PLP 2019-RFI153;
ASGDC 2020

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500 0 500 1,000
Feet

Private Water Supply Wells

Well Locations Identified by ADNR Well Log Tracking System (WELTs)

Other Features

Local Roads

Alternative 1a

Natural Gas Pipeline

Compressor Station

Well locations are approximate and are plotted based on ADNR data.

WATER SUPPLY WELLS NEAR PIPELINE EASTERN TERMINUS

PEBBLE PROJECT EIS

FIGURE 3.17-16