3.15 GEOHAZARDS

This section provides information currently available regarding geological hazards (geohazards) in the vicinity of the proposed project. Geohazards include geophysical processes (e.g., earthquakes, volcanoes), surficial or geomorphological processes (e.g., landslides) and other hazards (e.g., ice effects, erosion, tsunamis). Regional-scale descriptions of the geohazards are presented in this section, followed by local descriptions enhanced with information gathered from geotechnical engineering studies where available. The project area is in a region of active tectonic (geophysical) processes, and the potential for multiple types of geohazards across the project area depends on location, topography, natural materials present, and proximity to hazard sources. The Environmental Impact Statement (EIS) analysis area for geohazards ranges from the immediate vicinity of the project footprint for each alternative (e.g., slope instability) to regional areas with geohazards that could affect project facilities from long distances (e.g., earthquakes, volcanoes).

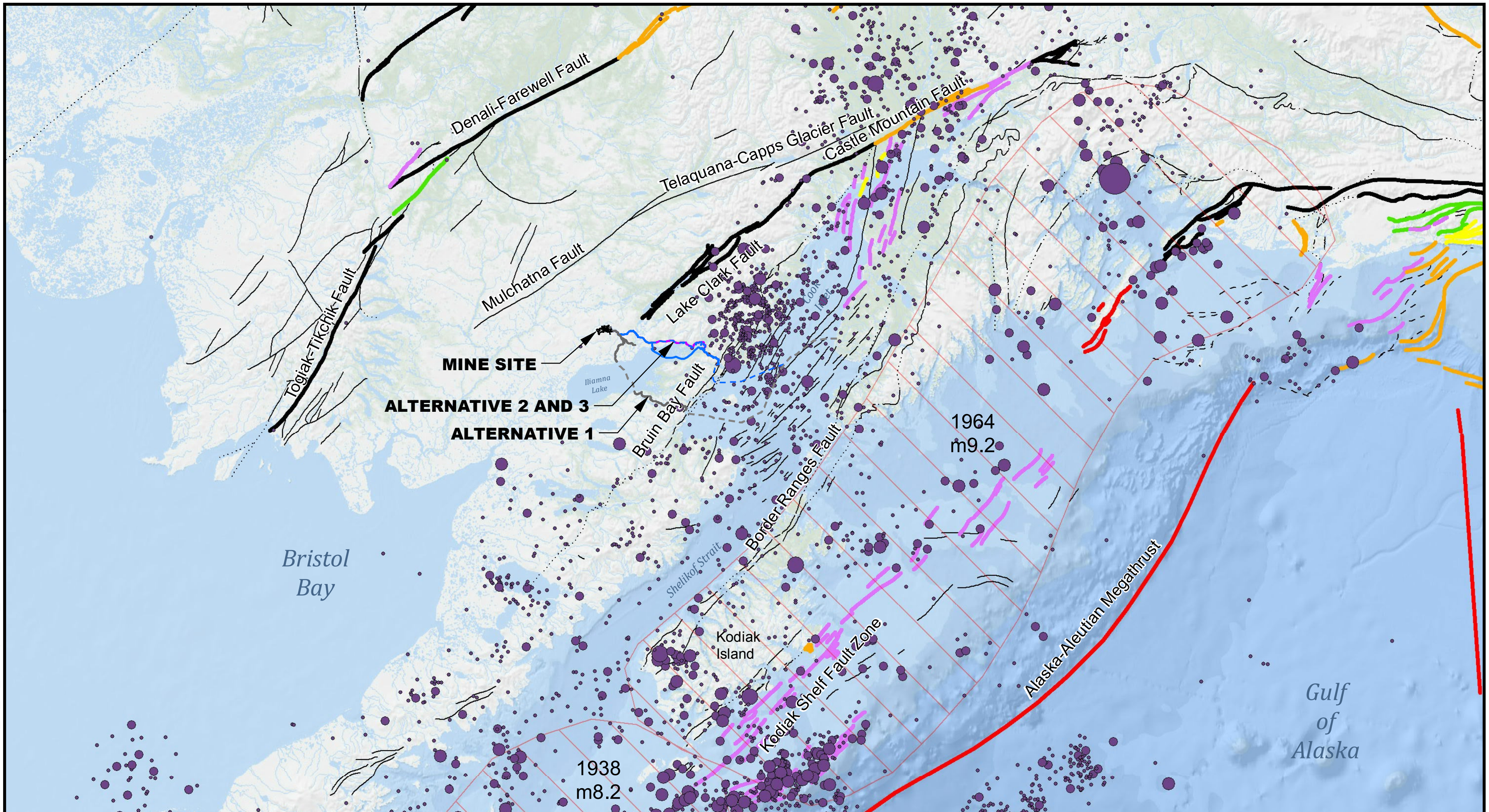
3.15.1 Earthquakes

3.15.1.1 Active Faults

The Pebble Project is in a tectonically active region of southern Alaska near the subduction zone between the Pacific and North American plates. Both shallow crustal earthquakes and deeper earthquakes associated with the subduction zone megathrust affect this region.

In general, faults that have demonstrated geologic displacement and earthquakes during the Holocene epoch (the last 11,000 years) are considered to be active, and have the potential for future movement. Earthquake hazards generally increase with the magnitude (M) of the event, proximity to the site, and fault length. The likelihood of fault movement is typically described in terms of recurrence interval or return period (i.e., how often the fault is expected to generate a large earthquake based on field evidence and past seismic record). This is described below under “Ground Shaking,” and in Section 4.15, Geohazards, as applied to project facilities. Active and potentially active faults in the project area are shown on Figure 3.15-1, and include the following:

- The closest active surface fault to the project area is the northeast-trending Lake Clark-Castle Mountain Fault, about 15 miles northeast of the mine site at the western end of Lake Clark (Haeussler and Saltus 2004). Studies of surficial geology and geomorphology in the mine area did not find evidence of Holocene fault activity between Lake Clark and the mine site (Hamilton and Klieforth 2010; Koehler 2010; Haeussler and Waythomas 2011; Knight Piésold 2015a). This fault exhibits evidence of Holocene activity in the Susitna Valley area, where it is considered capable of a maximum earthquake of M7.1 (Wesson et al. 2007), but shows no evidence of activity younger than Late Pleistocene along the Lake Clark segment southwest of Tyonek (Koehler and Reger 2011). This conclusion is further supported by a review of Light Detection and Ranging (LiDAR) data collected in 2004 in the vicinity of the mine site. No lineaments were observed that suggest possible fault-related movement in surficial deposits southwest of the previously mapped termination point of the Lake Clark fault (AECOM 2018m).



Sources: USGS 2018; Koehler 2013; Haeussler and Saltus 2004; Plafker et al. 1994

Earthquake Magnitude 1900 - 2018
- 4.0 - 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9
- 9.2

Fault Activity (Age of Most Recent Surface Deformation)
- Historical, <150 yrs
- Latest Pleistocene and Holocene, <15,000 yrs
- Latest Quaternary, <130,000 yrs
- Mid-Quaternary, <750,000 yrs
- Quaternary, <1,600,000 yrs
- Questionable, Class B

- Pre-Quaternary Fault
- Rupture Zone of Megathrust Earthquake

Alternative 1
- Mine Site
- Natural Gas Pipeline
- Transportation Corridor

Alternative 2
- Transportation Corridor

Alternative 2/3
- Natural Gas Pipeline

Alternative 3
- Transportation Corridor

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EARTHQUAKES AND ACTIVE FAULTS

PEBBLE PROJECT EIS

FIGURE 3.15-1

- The Alaska-Aleutian Megathrust, associated with the subduction zone of the Pacific Plate beneath the North American Plate, is responsible for some of the largest earthquakes globally, including the 1964 M9.2 Great Alaskan (Good Friday) Earthquake and 1938 M8.3 Alaska Peninsula earthquake. The megathrust lies at the seafloor more than 200 miles southeast of the project area, and dips to the northwest beneath the project area. Its 30-mile-thick zone of seismicity ranges from 20 to 50 miles deep beneath the eastern end of the natural gas pipeline corridor, to about 90 to 120 miles deep near the mine site (Plafker et al. 1994; Knight Piésold 2015a). The Kodiak and Prince William Sound areas of the megathrust are considered capable of a maximum M9.2 earthquake every 650 years. Intraslab faults associated with the deeper part of the subduction zone are considered capable of earthquakes in the range of M7+ (Wesson et al. 2007).
- The Denali-Farewell Fault, about 120 miles northwest of the project area, was the source of the 2002 M7.9 Denali earthquake that originated along the central part of the fault in Interior Alaska. The westernmost extension of this fault system, called the Togiak-Tikchik Fault, about 140 miles west of the mine site, exhibits evidence of mid-Quaternary activity. Although evidence of Holocene activity along the western part of the fault is limited compared to that of Interior Alaska, it is considered capable of generating large earthquakes in the range of M7.5 to M8.0 (BGC 2011; Knight Piésold 2015a).
- The Telaquana-Capps Glacier and Mulchatna faults are about 40 miles north and northwest of the mine site, respectively (Haeussler and Saltus 2004; Gillis et al. 2009). Evidence of Holocene activity along these faults has not been established. If active, they are considered capable of maximum earthquakes in the range of M6.0 to M7.0 (Knight Piésold 2015a).
- The Bruin Bay Fault extends along the western shore of Cook Inlet near the Amakdedori port site. Although there is no evidence for Holocene offset at the surface, this fault is associated with several small to moderate earthquakes up to M7.3 in 1943 (Stevens and Craw 2003).
- Several fault-cored folds in Upper Cook Inlet show evidence of Quaternary-age activity and possible bending of the seafloor. The closest of these lies about 130 miles east of the mine site and 10 miles north of the eastern end of the pipeline corridor. These structures are considered capable of generating earthquakes up to M6.8 (Haeussler et al. 2000). Recent activity has not been documented on similar folds and faults in Lower Cook Inlet near the Amakdedori port and natural gas pipeline corridor submarine crossing (Haeussler and Saltus 2011; Koehler et al. 2012).
- The Kodiak Shelf fault zone, comprised of a series of northeast-trending faults, lies in the upper plate of the subduction zone. These faults, about 120 miles southeast of the closest project components, show geomorphic evidence of Holocene activity, and are considered capable of earthquakes up to M7.5 (Wesson et al. 2007; Carver et al. 2008).
- The Border Ranges Fault, extending northeasterly through Kodiak Island and Kenai Peninsula, has been inactive since the early Tertiary (65 million years ago), but contains a 3- to 6-mile-wide shear zone that is considered by some to be capable of a future earthquake in the range of M7.0 (Suleimani et al 2005; Knight Piésold 2015a).

3.15.1.2 Ground Shaking

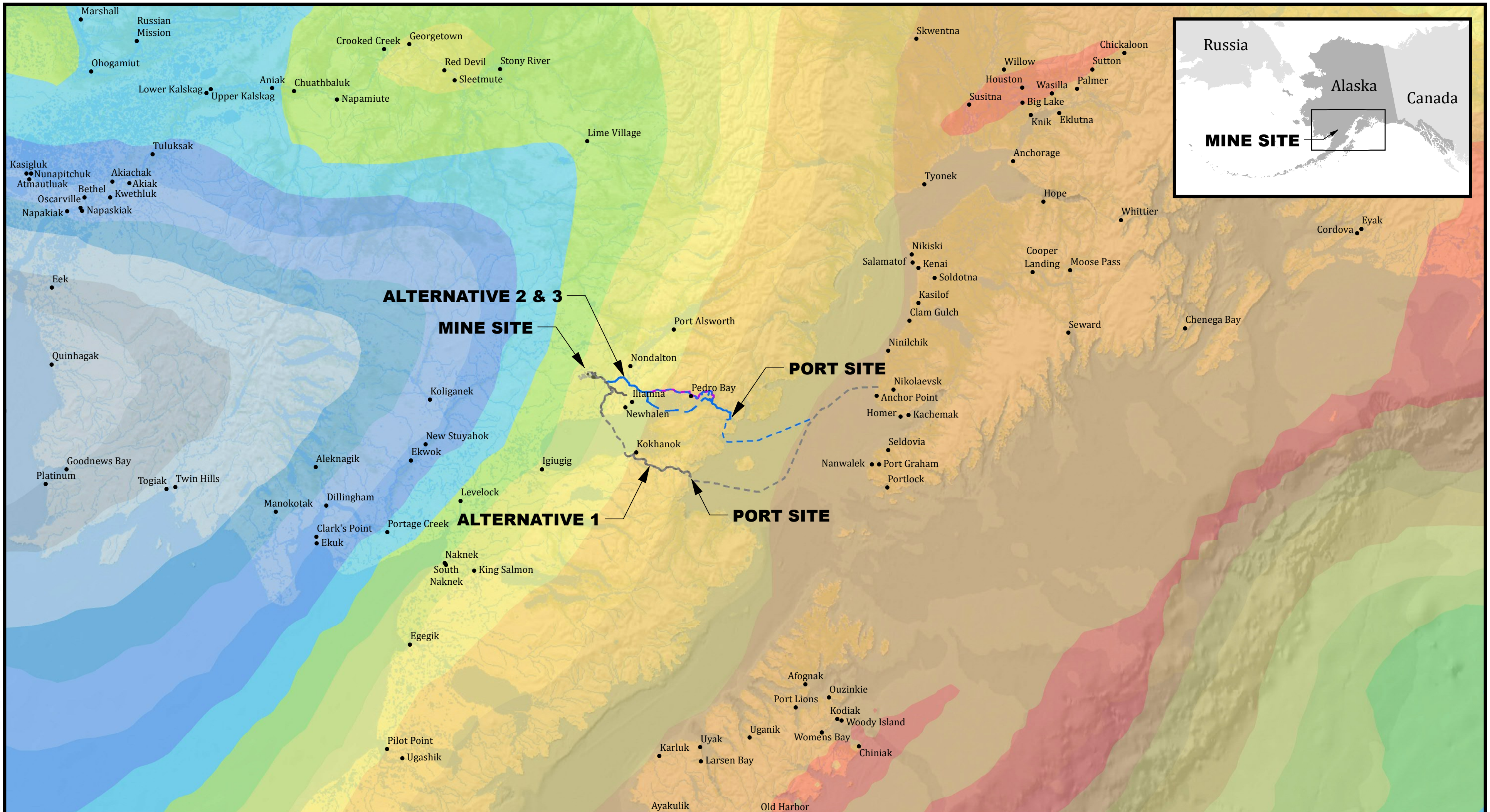
Earthquake-induced ground shaking is typically expressed in terms of peak ground acceleration (pga), measured as a fraction of gravity (g), with a probability of exceeding a certain level over a specific period of time in the future. For example, a pga of 0.1g in bedrock is considered the approximate threshold at which damage occurs in buildings that are not specially constructed to withstand earthquakes. An earthquake with a 10 percent probability of exceedance in 50 years (about a 500-year return period) is the most common event used in building codes for seismic design (e.g., Gould 2003). Larger, more infrequent seismic events, such as those with a 2,500-year return period (a 2 percent probability of exceedance in 50 years) are typically used for design of critical structures such as dams (ADNR 2017a).

Ground shaking prediction in Alaska has been studied both regionally by the US Geological Survey (USGS) (Wesson et al. 2007) and for the Pebble Project area by Knight Piésold (2011c, 2015a, 2018c). Based on published USGS data for the 2,500-year event, Figure 3.15-2 depicts a general trend from high ground shaking near the subduction zone offshore of Kodiak to less ground shaking further inland. Predicted ground shaking for the 2,500-year event ranges from a pga of about 0.3g near the mine site to 0.6g at the eastern end of the natural gas pipeline corridor. In comparison, predicted ground shaking for a smaller 500-year earthquake ranges from about 0.2g near the mine site to 0.4g at the eastern end of the natural gas pipeline corridor (Wesson et al. 2007). Site-specific seismic hazard analyses conducted for project facilities are discussed in Section 4.15, Geohazards.

3.15.1.3 Liquefaction

Liquefaction is an earthquake-caused phenomenon that reduces the strength and stiffness of a soil by ground shaking. Where the groundwater table is near surface, or the ground is otherwise saturated, the pore space between soil particles containing water can increase (i.e., increase pore pressure), changing the physical character of the landform and weakening the natural material; in essence, the ground temporarily behaves like a liquid. Liquefaction generally affects unconsolidated, fine-grained (sand and silt) deposits in lowland areas. The susceptibility of an area to liquefaction is a consideration in design and construction in earthquake-prone areas because the loss of strength of the foundational material can cause structural damage. The potential for liquefaction from ground shaking at the mine site is less for features built where bedrock is near the surface, than in lowland areas underlain by unconsolidated material. A more detailed explanation of liquefaction is provided in Appendix K3.15. Areas believed to be susceptible to liquefaction in the project area are described below.

Areas susceptible to liquefaction are typically found along rivers, streams, lake shorelines, and in areas with relatively shallow groundwater. Lateral spread of liquefied soil up to a few feet can occur on gentle slopes or in areas near a free face, such as an incised river channel. Section 3.18, Water and Sediment Quality, provides a description of sediment types in areas of the project that could be subject to liquefaction. These include portions of the mine site with shallow groundwater and fine-grained soils, such as the glacial lake deposits in the eastern part of the mine site (Section 3.13, Geology), and in project facilities that contain fine-grained saturated tailings (bulk and pyritic tailings storage facilities [TSFs]). Wide stream crossings along the road and pipeline corridors and marine sediment at port sites that contain predominantly sand and silt, such as along the northern portion of the mine access road, protected bays in Iliamna Lake, and Cottonwood and Iliamna bays in Cook Inlet, may be subject to liquefaction. Other sediment with high gravel content, such as at the north ferry terminal, high-energy stream crossings along the port access road and north road route (Alternative 2 and Alternative 3), and nearshore Kamishak Bay are less likely to liquefy (PLP 2018-RFI 036; PLP 2018-RFI 039).



Sources: Wesson et al. 2007

Project Components

Alternative 1	Alternative 2	Alternative 3
Natural Gas Pipeline	Natural Gas Pipeline	Natural Gas Pipeline
Transportation Corridor	Transportation Corridor	Transportation Corridor
Project Features	Ferry Route	

Peak Ground Acceleration (% g [1])

5 - 6	9 - 11	17 - 21	32 - 40	61 - 76
6 - 7	11 - 14	21 - 26	40 - 49	76 - 94
7 - 9	14 - 17	26 - 32	49 - 61	94 - 117

1. Ground shaking expressed as the probability of exceeding a certain amount of peak ground acceleration (PGA), measured in % of gravity (g), over a 2,500-year time period (return period), which is equivalent to a 2% probability of exceedance in 50 years.

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SEISMIC HAZARD MAP

PEBBLE MINE EIS

FIGURE 3.15-2

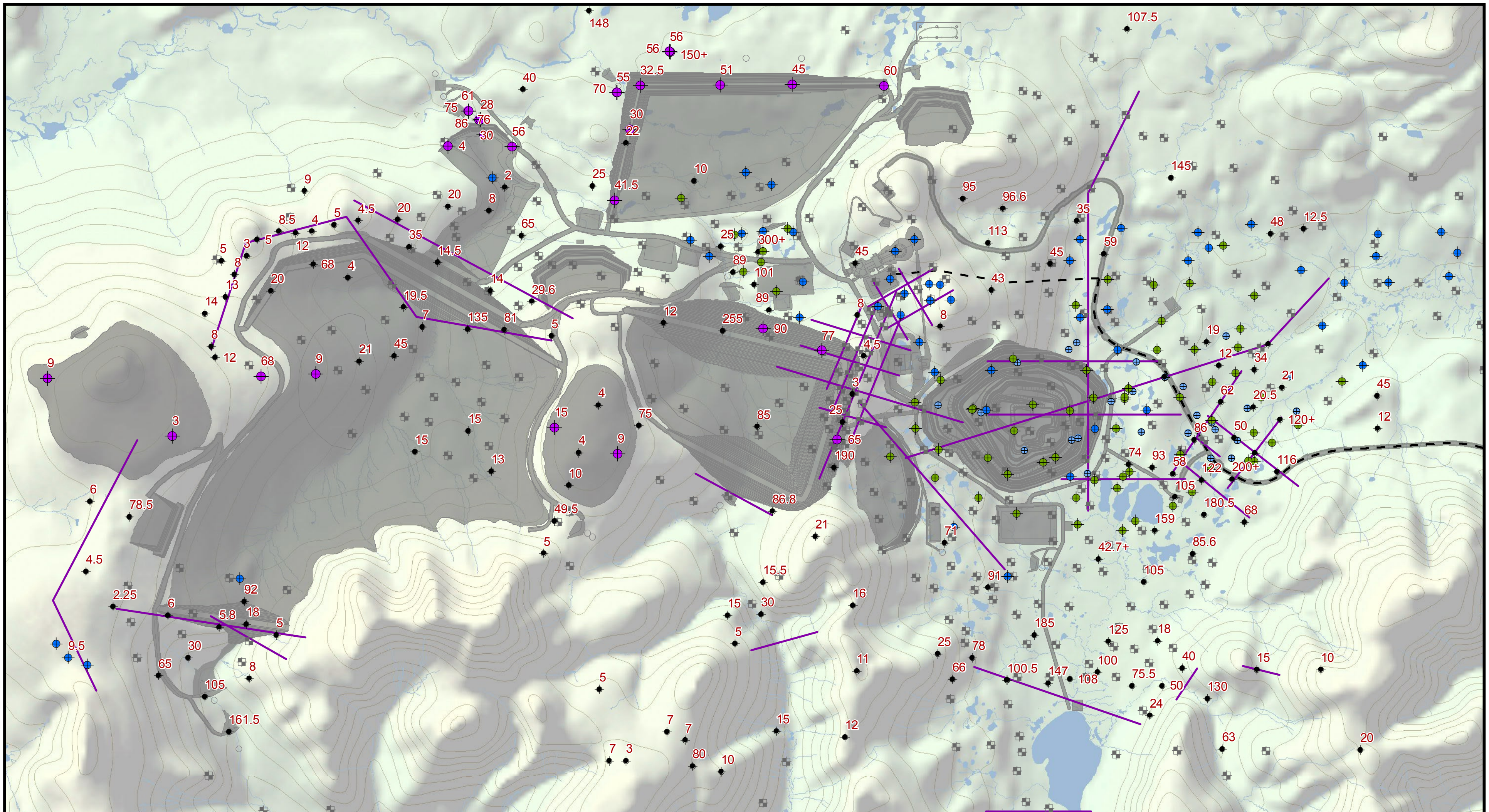
3.15.2 Geotechnical Conditions

Subsurface geotechnical conditions form the basis of foundation design and stability analysis of major structures such as dams, buildings, tanks, facilities, bridges, docks, and fills. Geotechnical conditions are summarized below where important to the analysis of potential geohazard effects on the project, including discussion of features (e.g., roads and port sites) described in alternatives (see Chapter 2, Alternatives), and related environmental impacts.

3.15.2.1 Mine Site

Geotechnical data from site-wide geologic reconnaissance and mapping, drill holes, test pits, and geophysical (seismic) surveys were collected at the mine site between 2004 and 2018 (Knight Piésold 2011c; PLP 2013a; PLP 2018-RFI 014). The mine site was divided into several study areas by Knight Piésold (2011a) based on geomorphology and watershed divisions for the purposes of baseline characterization. These areas are shown on Figure 3.15-3 along with geotechnical data locations and the mine site footprint, and are described below. The number of drill holes, test pits, and seismic survey lines beneath locations of major facilities in each area are provided in Appendix K3.15. As discussed in Section 3.14, Soils, permafrost has not been encountered at the mine site. Depths to moderately weathered bedrock are also shown on Figure 3.15-3, as provided in PLP (2018-RFI 014) for 2018 drillholes and in Knight Piésold (2011c: Appendix 6B) for earlier drillholes. In some cases, these depths are below the base of overburden due to the presence of a highly weathered zone in upper bedrock characterized by intense fracturing and frost disturbance (Knight Piesold 2018a).

- **North Fork Koktuli (NFK) West.** Most of the data collected in this north-draining watershed, which contains the bulk TSF main embankment and impoundment footprint, are in the northern part of the watershed, with fewer data points beneath the southern part of the impoundment. Overburden deposits consist of frost-shattered angular boulders, glacial drift and colluvium containing mostly sand and gravel with varying amounts of silt, and peat in the valley bottom. Overburden overlies sedimentary, volcanic, or intrusive bedrock in this area. Depths to bedrock are variable, ranging from 3 to 135 feet. Bedrock quality, measured using a Rock Mass Rating (RMR) system on a scale of 0 to 100, with higher numbers representing stronger rock quality (Bieniawski 1989), ranges from 35 to 66 (poor to good). Weathered bedrock tends to be deeper in the southern part of this area than the northern part.
- **NFK East.** Field investigations in this north-draining watershed that contains the pyritic TSF and associated ponds indicate that depth to bedrock ranges from 3 feet on hilltops to 255 feet in the valley. In the NFK East, bedrock is generally more fractured and has deeper weathering than beneath the bulk TSF area in NFK West. Overburden consists of sand and gravel with variable amounts of silt.
- **NFK North.** This area contains seepage and sediment ponds downstream of the bulk TSF main embankment and the main water management pond (WMP). Overburden consists mainly of alluvial and morainal gravel and sand deposits. Depths to bedrock range from 4 feet to more than 150 feet. Bedrock in this area consists of basalt with RMRs in the range of 52 to 65 (fair to good).
- **Pit Area**. Geotechnical data in the area of the open pit and rim indicate the presence of overburden consisting of varying mixtures of gravel, sand, silt, and clay of glacial origin, with occasional peat. Depths to bedrock range from about 25 to 150 feet (Knight Piésold 2011c, Figure 6-9). Bedrock types consist primarily of volcanic and sedimentary rock, with average RMRs ranging from 45 to 55 (fair).



Sources:Knight Piesold 2011c; PLP 2013a; PLP 2018 - RFI 014
Note: 1. For 2004-2008 drillholes, denotes depth to bedrock from Knight Piesold (2011c) Appendix 6B; for 2018 drillholes, denotes depth to moderately weathered bedrock in PLP 2018-RFI014.

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Geotechnical Investigations

- 2004 to 2008 Geotechnical Drillhole
- 2010 to 2012 Geotechnical Drillhole
- 2011 to 2012 Sonic Drillhole
- 2018 Geotechnical Drillhole
- Oriented Geotechnical Drillhole
- Test Pit
- Seismic Line
- 96 Depth to Bedrock (feet)[1]

Alternative 1

- Natural Gas Pipeline
- Mine Site Footprint

Other Features

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

GEOTECHNICAL DATA COVERAGE AND DEPTH TO BEDROCK

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FIGURE 3.15-3

- **Bulk TSF South**. The northern portion of this south-flowing watershed contains the footprints of the bulk TSF southern embankment and associated seepage and sediment ponds. Previous investigations indicate depths to bedrock ranging from about 2 to 160 feet, with thicker overburden deposits in the valley bottom consisting of primarily sand and gravel with variable amounts of fines. Bedrock is of similar type and quality to the southern part of NFK West.
- **South of Pit Area.** The northern end of this south-flowing tributary, which drains towards Frying Pan Lake, contains the open pit WMP, pit overburden stockpile, and sediment ponds related to these facilities. Depths to bedrock range from about 25 feet on lower slopes up to 185 feet in the valley. Overburden consists of mostly silty sand and gravel glacial deposits with peat in the valley bottom.

3.15.2.2 Other Project Components

Surficial deposits, near-surface soils, and stream substrates along the transportation corridor are described in Sections 3.13, Geology; 3.14, Soils; and 3.18, Water and Sediment Quality, respectively. Geotechnical conditions along the northern part of the mine access road would be similar to those described above for the mine site. Surficial deposits along the southern part of the mine access road, Iliamna spur road, and the western part of the mine access road (Alternative 2) or north access road (Alternative 3) consist primarily of glacial and alluvial deposits. Surficial deposits along the eastern part of the mine access road (Alternative 2) or north access road (Alternative 3) and the port access road are sparse, and bedrock outcrops near ground surface (Detterman and Reed 1973). Surficial deposits between Pedro Bay and Williamsport (Alternative 2 and Alternative 3) consist mainly of alluvium and alluvial fan deposits along lower slopes of steep-sided valleys.

Surficial units mapped beneath the terminal footprint at the Amakdedori port site consist of Holocene marine terrace and modern beach deposits containing mostly pebbles, cobbles, and sand (Detterman and Reed 1973). Zonge (2017) geophysical data suggest that overburden is on the order of 50 to 100 feet thick in the terminal area. Topographic and stratigraphic relationships in Amakdedori Valley indicate that alluvium, alluvial fan, and beach deposits fill a bedrock-sided valley about 2 miles across between Chenik Mountain to the south, and peak "1996" to the north. These deposits may extend to several tens of feet below sea level in the port and wharf areas, where valley fill and nearshore delta fan material have been deposited towards the east and southeast, following trends of deepening bathymetric contours between Augustine Island and Douglas Reef (NOAA 2015; PLP 2018-RFI 039). Based on geophysical survey data and marine vibracores consisting of silty sand and gravel to 3 feet below mudline (PLP 2018-RFI 039; Zonge 2017), sand and gravel likely exist in Kamishak Bay to the depth of sheetpile or pile-supported dock installation. Boulders derived from sloughing of rocky cliffs and ice-raft movement may also be present in subsurface deposits at the port site.

Surficial deposits mapped beneath the footprint of the Diamond Point terminal site consist of thin alluvial fan deposits on top of shallow bedrock (Detterman and Reed 1973). Offshore deposits in the Diamond Point area, and along the road corridor between Diamond Point and Williamsport, consist primarily of silt and fine sand, with extensive mudflats in the upper reaches of Cottonwood and Iliamna bays. Boulders lie on the mudflats, and extensive reefs, shoals, and offshore rocks occur at the entrance to the bays (Pentec/Hart Crowser and SLR 2011). A combination of marine siltation and tectonic uplift is raising the seafloor near Williamsport at a rate of about 0.3 inch per year (ADNR 2014a).

Site-specific geotechnical information is not available for the eastern landfall pipeline section that is planned to be installed by horizontal directional drilling (HDD) beneath Cook Inlet bluff. The coastal bluff is about 230 feet high at this location; has a relatively steep slope angle of about 1.4H:1V; and is composed primarily of Pleistocene glacial deposits (Reger and Petrik 1993; Karlstrom 1964). A stratigraphic section of the bluff, 2 miles south of the pipeline landfall, contains sand and gravel with occasional boulders, overlying a 50-foot-thick glaciolacustrine clay-silt unit (Reger and Petrik 1993). Perched groundwater is known to seep out of the bluff above similar fine-grained units along eastern Cook Inlet. Tertiary sedimentary rocks of the Beluga Formation are exposed in the lower sea cliff several miles further to the south, and may underlie glacial deposits at the pipeline landfall in the depth of the HDD. These rocks consist of weakly indurated, interbedded sandstone, siltstone, and shale with thin layers of coal (Reger and Petrik 1993). The potential for slope stability impacts on the project from these deposits is provided in Section 4.15, Geohazards.

3.15.3 Unstable Slopes

Unstable slopes typically occur under combined conditions of steep terrain, heavy precipitation, and certain types of surficial deposits, weathered bedrock, or weak stratified layers. The terrain and geomorphology of the mine site consists primarily of gently rolling hills with rounded exposed bedrock hilltops, and valleys of glacial deposits with low-angle slopes and mostly low potential for slope instability. Surficial deposits that have the potential to produce unstable slopes occur sporadically around the mine site, and include the following (Hamilton and Klieforth 2010):

- Colluvium, consisting of rock rubble and debris with fines deposited at the base of slopes, may be subject to frost creep and gradual mass wasting slope processes related to freeze-thaw activity (solifluction). These deposits have been mapped throughout much of the bulk TSF footprint: on slopes adjacent to the bulk TSF south embankment, beneath the southern sediment pond, on the western side of the pyritic TSF, beneath several overburden and growth media stockpiles, and in the northeastern corner of the pit.
- Solifluction deposits, consisting of moderately sloped sheets of stony and organic silt, are subject to gradual downslope movement related to freeze-thaw action. These have been mapped on the eastern side of the pyritic TSF footprint.
- Active talus rubble deposits have been mapped on the northern slope of Kaskanak Mountain on the southeastern slope of the bulk TSF impoundment.

Small areas of colluvium and solifluction deposits have also been mapped along the mine access road and Iliamna spur road. These occur about 2 miles east of the mine site; about 6 miles east of the mine site on the northern side of Koktuli Mountain; and near the junction between the two roads (Detterman and Reed 1973; Hamilton and Klieforth 2010). Steep alluvial fan and talus deposits occur in incised valleys crossed by the eastern portion of the North Route, and along the lake front south of Knutson Mountain. Landslide and solifluction deposits have been mapped near the North Route corridor at the head of Lonesome Bay, and on the flanks of Roadhouse and Knutson mountains. Steep alluvial fan deposits have also been mapped at the southern end of the port access road, about 1 mile north of the port site (Detterman and Reed 1973).

Factors that contribute to unstable coastal bluffs near the pipeline landfall on the eastern side of Cook Inlet are described above in the “Other Project Components” section. The bluffs in this area have a history of erosion problems caused by wave action, tidal currents, groundwater seepage, and overland flow. The bluffs have experienced gullying, periodic landsliding, and debris flows following major storms (Reger and Petrik 1993; USACE 2008). Bluff retreat estimates range from 0.3 to 0.5 feet per year (ft/yr) in lower Cook Inlet near Kachemak Bay, to as much as 3 ft/yr near the town of Kenai (Adams et al. 2007; USACE 2007a).

Large earthquakes can also trigger landslides. The 1964 Great Alaskan Earthquake caused numerous landslides, rockslides, debris flows, soil slumps, and avalanches on the slopes of Kodiak Island and shoreline of Cook Inlet. The earthquake also caused translational landslides, tension cracks, and earth fissures on the top of bluffs; and rotational slides in Tertiary sedimentary rocks such as those that outcrop along the eastern coast of Cook Inlet (Plafker and Kachadoorian 1966; Waller 1966).

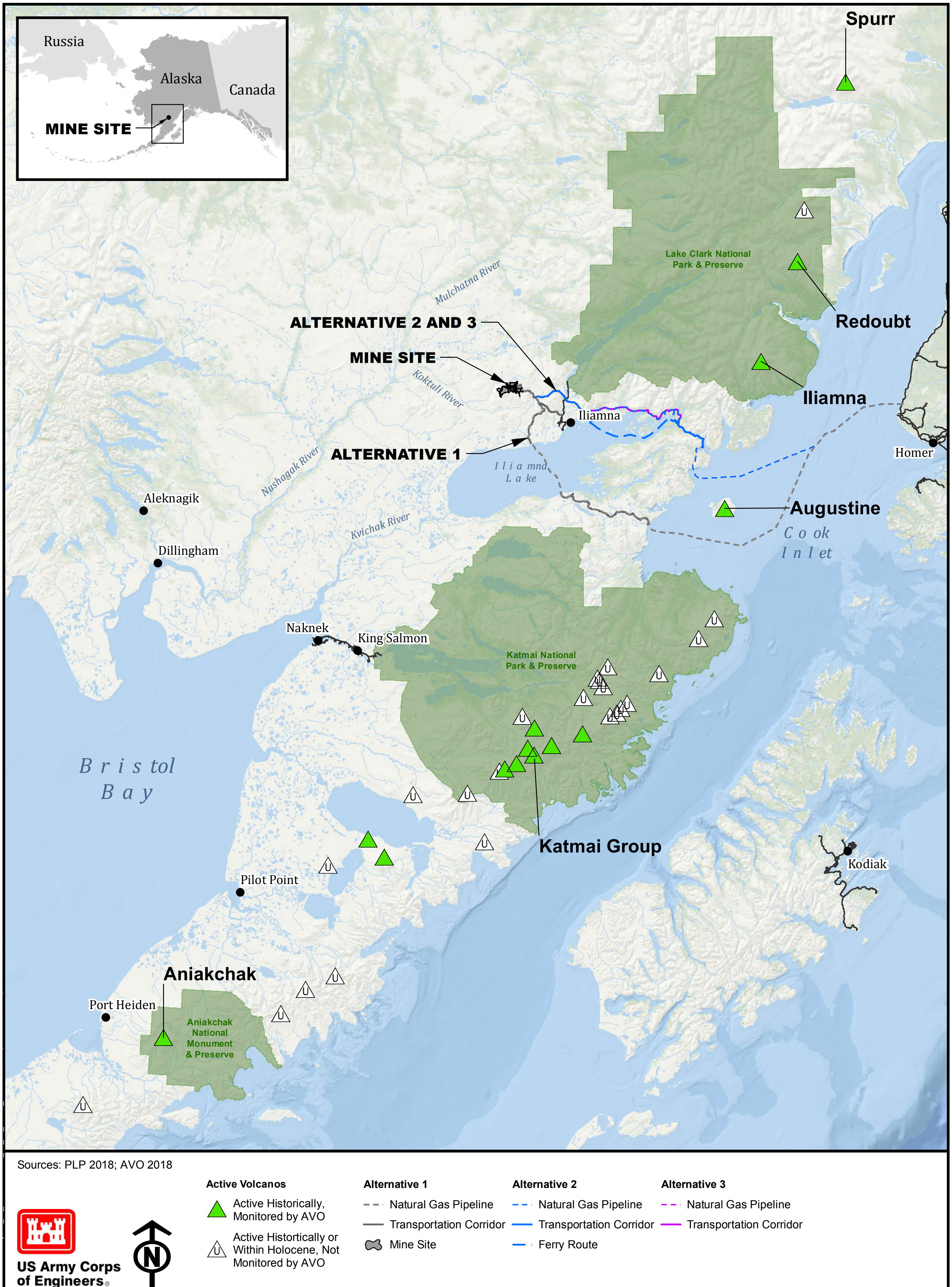
3.15.4 Volcanoes

Alaska contains more than 50 volcanoes considered to be historically active, having erupted in the last few hundred years (Alaska Volcano Observatory [AVO] 2018a). Several are within about 100 miles of proposed project infrastructure (Figure 3.15-4), including Augustine, 20 miles east of the Amakdedori port site; Iliamna and Redoubt volcanoes, north of the project area; and a cluster of volcanoes on the northern Alaska Peninsula.

Augustine Volcano is the most historically active volcano in the Cook Inlet region (Miller et al. 1998) and was last active in 2015. Past eruptions of Augustine caused ashfall accumulations of up to about ¼ inch on the Alaska and Kenai peninsulas, floating rafts of pumice that interfered with boat traffic in Cook Inlet, and ash clouds that disrupted air travel as far away as the Lower 48 (Waythomas and Waitt 1998). Volcanic debris avalanches that flow into Cook Inlet are known to occur with an average recurrence interval of about 150 to 200 years (Beget and Kienle 1992). It is estimated that as many as 12 to 14 of these have reached the sea in the last 2,000 years, with flow paths extending in all directions around the volcano (see Figure 3.15-5). Derived from the collapse of summit lava domes and flows, these deposits consist of bouldery rock debris, gravel, sand, and silt (Waitt et al. 1996; Waythomas et al. 2006).

Redoubt and Iliamna volcanoes were last active in 2015 and 2016, respectively. Redoubt has had three major eruptions in the last 100 years, the most recent of which created significant ash plumes that disrupted air traffic on and off for months, and trace amounts of ashfall in Southcentral Alaska communities. Iliamna Volcano is mainly known for active steam vents and avalanches related to seismic activity (AVO 2018a).

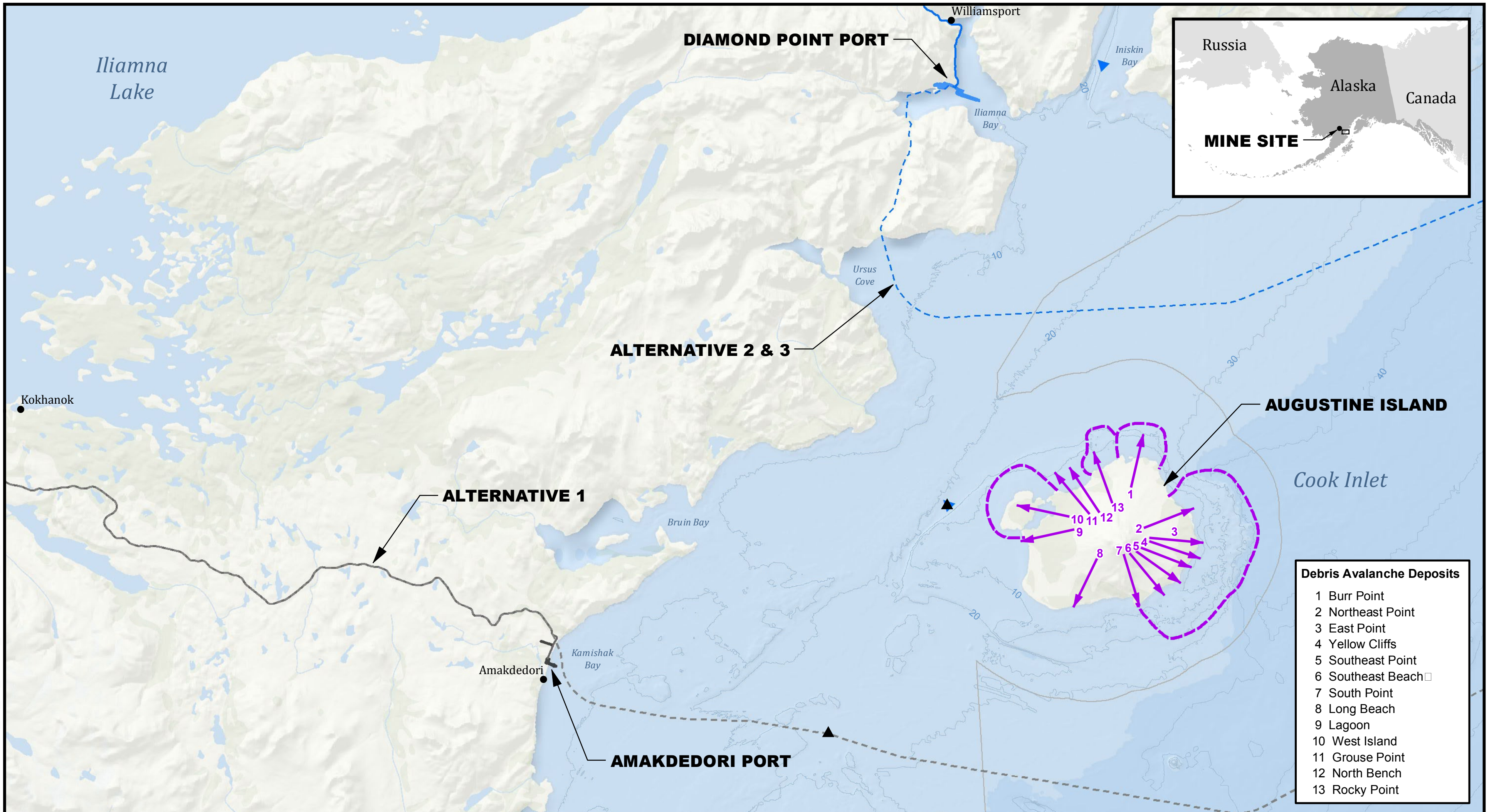
The Katmai group of seven volcanoes on the northern Alaska Peninsula includes three that have experienced historical eruptions (Katmai, Novarupta, and Trident), and four that are primarily known for steaming fumaroles (Snowy, Griggs, Martin, and Mageik) (AVO 2018a). The largest historical eruption in this group occurred at Katmai and Novarupta in 1912, resulting in deposition of approximately 1 foot of ash in Kodiak, 100 miles away (Fenner 1920). Trident's last eruption began in 1953, producing ballistic blocks about 2 miles away from the vent, and intermittent ash clouds over a period of 21 years (AVO 2018a).



ACTIVE VOLCANOES

PEBBLE PROJECT EIS

FIGURE 3.15-4



Sources: Waythomas et al. 2006; ADNR

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Approximate offshore extent of debris-avalanche deposits

Approximate drbris avalanche flow path

Alternative 1

Lightering Location

Natural Gas Pipeline

Transportation Corridor

Alternatives 2 and 3

Lightering Location

Natural Gas Pipeline

Transportation Corridor

Other Features

Bathymetric Contour (meters)

Three Nautical Mile Line

HISTORICAL DEBRIS AVALANCHES ON AUGUSTINE ISLAND

PEBBLE PROJECT EIS

FIGURE 3.15-5

3.15.5 Tsunamis, Seiches, and Coastal Hazards

Tsunamis and seiches are different phenomena. Tsunamis are a series of water waves that are caused by displacement of large bodies of water due to seismic disturbances and underwater landslides. Seiches are large waves triggered by earthquakes that occur in enclosed bodies of water such as lakes and harbors, which can damage shoreline structures, boats, and moored vessels (e.g., Kabiri-Samani 2013).

Lower Cook Inlet has the potential for tsunamis and related coastal geohazards from seismic events. Impacts from tsunamis are dependent on bathymetry, coastline configuration, and tidal interactions. The 1964 Great Alaskan Earthquake generated numerous tsunami waves, including several that destroyed the harbor at Kodiak (Plafker and Kachadoorian 1966). Recent tsunami modeling by American Society of Civil Engineers (ASCE) (2017b) predicts a runup elevation of 28.5 feet above mean high water (MHW) for a 2,500-year return period event at high tide at the Amakdedori port site. This is equivalent to a runup elevation of roughly 42 feet mean lower low water (MLLW)[1]. Lower tsunami runup elevations are predicted for the Diamond Point port site (22 to 25 feet MHW, or 36 to 39 feet MLLW[2]), and the eastern end of the pipeline on Kenai Peninsula (18.6 feet MHW, or about 36 feet MLLW) (ASCE 2017b).

Older tsunami modeling by Crawford (1987) provides information on smaller, more frequent tsunamis that could occur. For example, wave height predictions for 100- to 500-year return period events (combined with high tide) are estimated to be 12 to 23 feet above mean sea level (MSL) (about 19 to 30 feet MLLW[3]) in the Amakdedori area of Kamishak Bay, and 13 to 15 feet MSL (21 to 23 feet MLLW) near the eastern end of the pipeline on Kenai Peninsula.

Volcanic eruptions can also produce tsunamis from catastrophic dome collapses and rapidly moving pyroclastic flows entering the sea (Allen 1994; Armes 1996; Waythomas and Neal 1998; Waythomas et al. 2009; AVO 2018a). One of the debris avalanches at Augustine volcano created West Island on the western side of Augustine Island 300 to 500 years ago (Figure 3.15-5). Based on numerical modeling of this deposit by Waythomas et al. (2006), it is estimated that a tsunami with a maximum wave amplitude of about 30 to 55 feet may have struck the mainland shore south of Ursus Cove, reaching about 10 feet near the Amakdedori port site. A secondary 60-foot wave may have occurred near West Island during this event. (For context, maximum wind-generated storm waves in lower Cook Inlet can reach 40 feet.) The 1883 eruption of Augustine Volcano produced a debris avalanche-generated wave that affected areas up to 55 feet above high tide on the northern side of the island, and 23 feet above high tide on Kenai Peninsula (Begét et al. 2008). Numerical modeling suggests that this event may have produced a tsunami in the range of 5 to 20 feet near Diamond Point and the mouth of Iniskin Bay. These events are estimated to have been capable of transporting gravel- to cobble-sized sediment in northern Kamishak Bay, Ursus Cove, and Iliamna Bay (Waythomas et al. 2006).

Occurrence of seiches has not been monitored in the region, and the occurrence of seiches in Iliamna Lake during past large earthquakes is unknown (PLP 2018-RFI 013). During the 1964

[1] MHW is estimated to be in the range of 13 to 14 feet MLLW at Amakdedori, based on an interpolation of tide gage data from Iniskin Bay (Pentec/Hart Crowser and SLR 2011; Hart Crowser 2015a), northern Shelikof Strait, and southern Kenai Peninsula (NOAA 2018f; PLP 2019-RFI 112). A site-specific MHW for Amakdedori would be determined from ongoing field data collection (PLP 2019-RFI 112).

[2] MHW is 13.8 feet MLLW at Diamond Point (Iniskin Bay) and 17.6 feet MLLW at Anchor Point (Pentec/Hart Crowser and SLR 2011; Hart Crowser 2015a; NOAA 2018f).

[3] MSL is estimated to be about 7.3 to 7.4 feet MLLW at Amakdedori, based on an interpolation of tide gage data from Iniskin Bay and northern Shelikof Strait (Pentec/Hart Crowser and SLR 2011; Hart Crowser 2015a; NOAA 2018f); MSL is 8.2 feet MLLW at Anchor Point (NOAA 2018f).

Great Alaskan and 2002 Denali earthquakes, seiches several feet high occurred in the intracoastal waterways of Southeast Alaska, and in a number of lakes and reservoirs in the Lower 48 (McGarr et al. 1968; Barberopoulou et al. 2004; City and Borough of Juneau [CBJ] 2018). Damage to houseboats on Lake Union in Seattle from seiches was documented during both of these events. Modeling of an earthquake-induced landslide into Bradley Lake in Southcentral Alaska predicted that a 10-foot seiche would occur (Stone & Webster 1987); Bradley Lake is in a similar seismic zone, but is much smaller than Iliamna Lake. Coastal planning in Southeast Alaska anticipates that seiches up to 20 feet high could occur from large distant earthquakes originating in Southcentral Alaska (Community and Systems Analysis [CASA] 1982). For context, storm-driven waves on Iliamna Lake have been documented as high as 6 feet in the community of Iliamna, where they have caused shoreline erosion and damage to the dock and boats (USACE 2009a).

The 1964 Great Alaskan Earthquake generated additional coastal hazards in Cook Inlet—such as tectonic uplift and subsidence, ground fissuring, and submarine landslides—that destroyed the Homer Harbor breakwater. Vertical uplift was on the order of 1 to 2 feet along the western shore of lower Cook Inlet, and subsidence in the range of 0.5 to 4 feet along the eastern shore of lower Cook Inlet (Foster and Karlstrom 1967). Ground cracking, liquefaction, and local subsidence up to several feet occurred in saturated beach and alluvial deposits around Kodiak Island, along Cook Inlet shorelines, and around large lakes in the area (Plafker and Kachadoorian 1966). Along the western shore of Cook Inlet, stream mouths were drowned and narrow beaches experienced vigorous erosion at bluff faces (Stanley 1968).

Other coastal and marine hazards in lower Cook Inlet include large sand waves, current scour features, shallow natural gas accumulations, and boulders on the seafloor (BSEE 2018). The boulders originate from coastal bluff slumping or glacial erratics, and can be ice-rafted along shore during winter, causing potential navigation hazards. Boulders and rocky shallows have been mapped along the coast within 1 to 2 miles north and south of the mouth of Amakdedori Creek (PLP 2018-RFI 039), and extend offshore in an east-trending ridge from 1 to 5 miles due east of the creek. Rocky areas and boulders are common on mudflats in the upper reaches of Cottonwood and Iliamna bays (Pentec/Hart Crowser and SLR 2011). Reconnaissance geophysical surveys indicate the presence of rocks and boulders on the seabed and buried in shallow sediment in the vicinity of Diamond Point, reaching a maximum density near the mouth of Iliamna Bay (PLP 2018-RFI 063). Boulders are also common along the eastern Cook Inlet shoreline near the pipeline landfall (NOAA 2015).

3.16 SURFACE WATER HYDROLOGY

This section describes the affected environment for existing surface water conditions in the Environmental Impact Statement (EIS) analysis area, including the mine site, transportation corridor, port, and pipeline corridor for all alternatives and associated variants. The EIS analysis area (hereafter, analysis area) includes watersheds (i.e., drainage basins), numerous streams, lakes (including Iliamna Lake), marine water (Cook Inlet), and wetlands (see Section 3.22, Wetlands and Other Waters/Special Aquatic Sites) that have the potential to be impacted by the proposed project. The discussion below addresses potentially affected waterbodies, baseline water balance models, flood hazards, floodplain values, tides, and water use (both surface and groundwater). Drainage basins (synonymous in this document with catchments, watersheds, sub-catchments), flow patterns, circulation, discharge/recharge, and interaction with groundwater are described. Section 3.17, Groundwater Hydrology, provides more information regarding groundwater conditions. Section 3.18, Water and Sediment Quality, addresses quality of surface water, groundwater, and sediment/substrate in waters and wetlands.

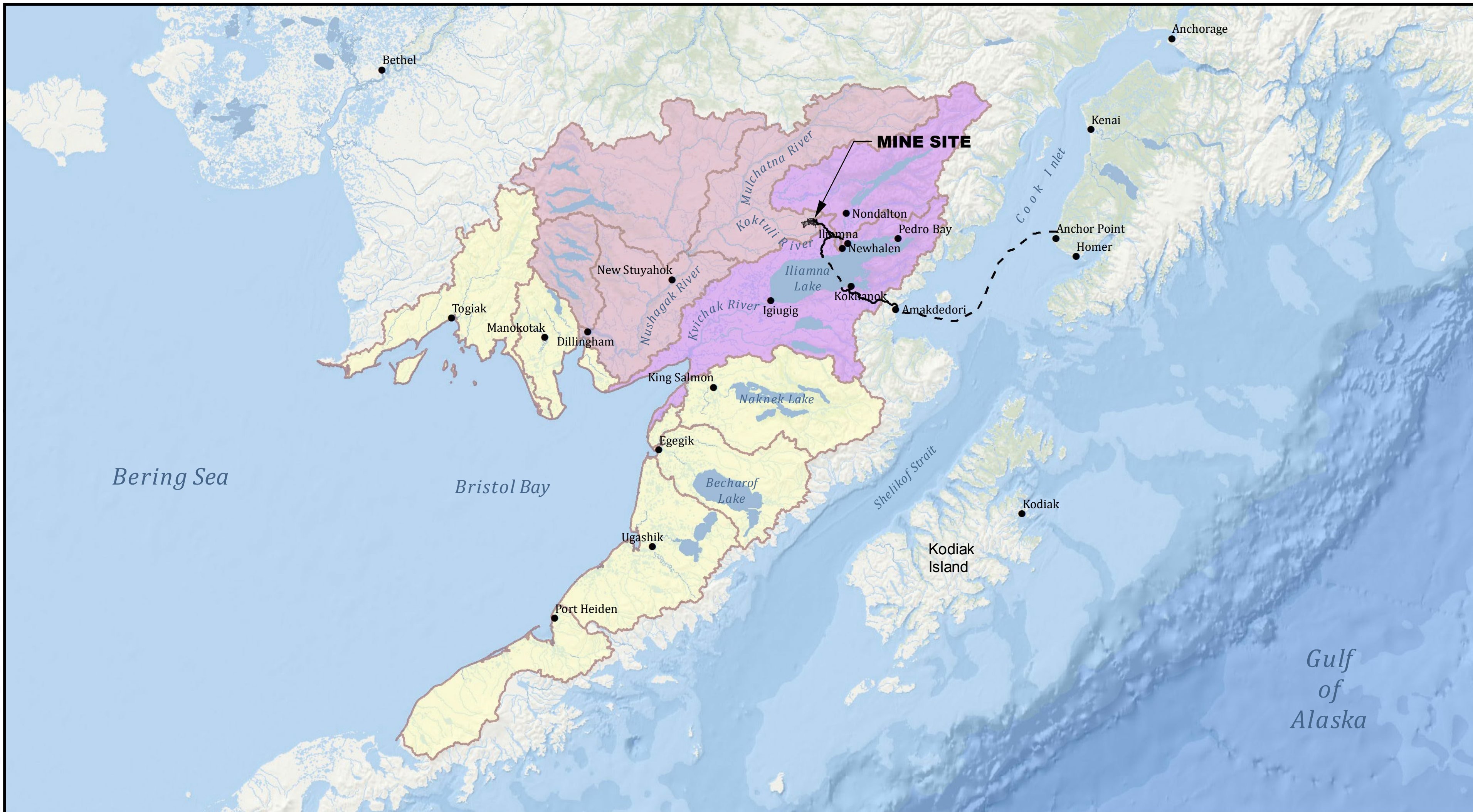
Baseline surface water conditions have been characterized by studies conducted from 2004 through 2012 (Knight Piésold et al. 2011a, 2015b). These baseline studies also considered previous studies and data collected by the US Geological Survey (USGS) and US Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), which are described in greater detail in the Knight Piésold baseline reports referenced above.

In particular, Knight Piésold et al. 2011a provides an overview of regional hydrology in the Bristol Bay drainages and hydrologic context for the mine study area[1] and transportation and pipeline corridors. The baseline studies are summarized in this section, and more details regarding meteorological inputs to water balance models and water balance calibration are provided in Appendix K3.16.

The combined Bristol Bay drainage area is approximately 41,900 square miles—an area bound by the Aleutian Range to the east and southeast, the Kuskokwim Mountains to the west, and the Kuskokwim River watershed boundary to the north (see Figure 3.16-1). The largest rivers draining into Bristol Bay are the Nushagak and Kvichak rivers. These two rivers comprise 49 percent of the Bristol Bay drainages. The Koktuli River forms at the confluence of the North Fork Koktuli (NFK) and South Fork Koktuli (SFK) rivers, approximately 17 miles west of the mine site. The Koktuli River flows into the Mulchatna River, a tributary of the Nushagak River. The Pebble deposit straddles two regional watersheds, but nearly all the project mine site footprint is in the Nushagak River watershed (12,700 square miles). Most of the transportation and pipeline corridors from the mine site toward the east are within the Kvichak River watershed to the Cook Inlet watershed boundary defined by the Alaska Range. The remaining onshore transportation and pipeline corridors and port sites are in the Cook Inlet watershed.

Most of the mine site is hydrologically connected to Bristol Bay via the NFK and SFK rivers, which join the Mulchatna River west of the mine site. The Mulchatna River flows to the confluence with the Nushagak River about 65 miles from its mouth at Bristol Bay.

[1] The mine study area (Knight Piésold et al. 2011a) described in this section is in the EIS analysis area.



Sources: USGS 2017

US Army Corps of Engineers

25 0 25 50

Miles

Alternative 1

- Mine Site
- Transportation Corridor
- Natural Gas Pipeline

Watersheds

- Nushagak Drainage
- Kvichak Drainage
- Subbasin (HUC8) Bristol Bay
HUC = Hydrologic Unit Code

BRISTOL BAY WATERSHED

PEBBLE PROJECT EIS

FIGURE 3.16-1

3.16.1 Alternative 1 – Applicant's Proposed Alternative

Chapter 2, Alternatives, provides a detailed description of Alternative 1 and associated variants.

3.16.1.1 Mine Site

The mine site is within the upper portions of the NFK, SFK, and Upper Talarik Creek (UTC) watersheds (see Figure 3.16-2 and Figure 3.16-3). Figure 3.16-4 and Figure 3.16-5 depict stream gaging stations in the mine study area[2] and in the vicinity of the mine site, respectively. The majority of the mine site facilities would be in the NFK watershed. The open pit, as well as the overburden stockpile, open pit water management pond (WMP), and water treatment plant (WTP) #1 discharge – south, would be in the SFK watershed. Only the WTP #1 discharge – east and a short portion of the mine access road would be in the UTC watershed.

Drainage Basins

Drainage basin characteristics of the NFK and SFK rivers and UTC are described in this section, and general features are listed in Table 3.16-1. The affected environment discussion of watersheds is largely based on baseline studies (Knight Piésold et al. 2011a, 2015b). The reader is referred to these publically available documents for further reading and additional detail.

The topography of the drainage basins listed in Table 3.16-1 consists of low, rolling hills and wide, shallow valleys (Knight Piésold et al. 2011a). Section 3.13, Geology, addresses geologic units and geologic history and processes of the region and project vicinity.

General characteristics common to the drainage basins listed in Table 3.16-1 include:

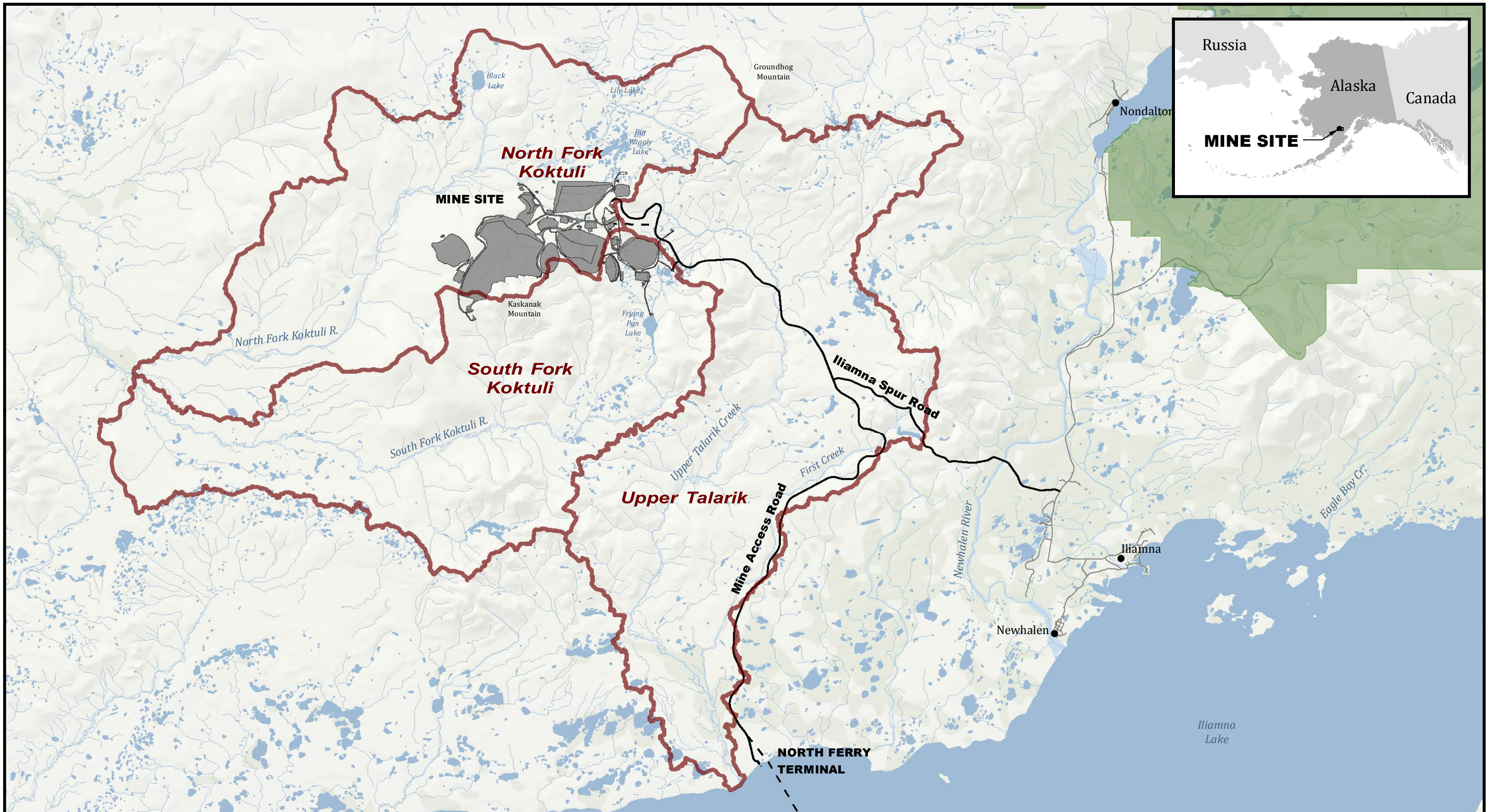
- Main streams occupy valley bottoms 0.5 to 2 miles wide.
- Tributaries to the main streams are incised into the hilly terrain and typically occupy narrow valleys with bottom widths of only 0.1 to 0.2 mile.
- The three main stream channels in the EIS analysis area are highly sinuous and flow within floodplains containing wetlands and oxbow lakes.
- The upper parts of the three main basins are represented by flat, poorly drained terrain.
- Areas of glacial drift (sediment of glacial origin) deposits occur along lower hillslopes and near the headwaters of the main stream valleys, characterized by undulating terrain and numerous kettle lakes.

Table 3.16-1: Mine Site Drainage Basins

Drainage Basin	Drainage Area (mi^2)	Channel Length (miles)	Basin Relief (feet)	Mean Basin Elevation (feet amsl)
NFK River	113	36	580 to 3,074	1,300
SFK River	107	40	580 to 2,760	1,150
UTC	135	39	46 to 3,074	1,000

Notes:
amsl = above mean sea level
mi^2 = square miles
Source: Knight Piésold at al. 2011a

[2] The mine study area (Knight Piésold et al. 2011a) described in this section is within the EIS analysis area.



Sources: PLP 2018d; ADNR

US Army Corps of Engineers®

2 0 2 4

Miles

Alternative 1

- Natural Gas Pipeline
- Transportation Corridor
- Mine Site

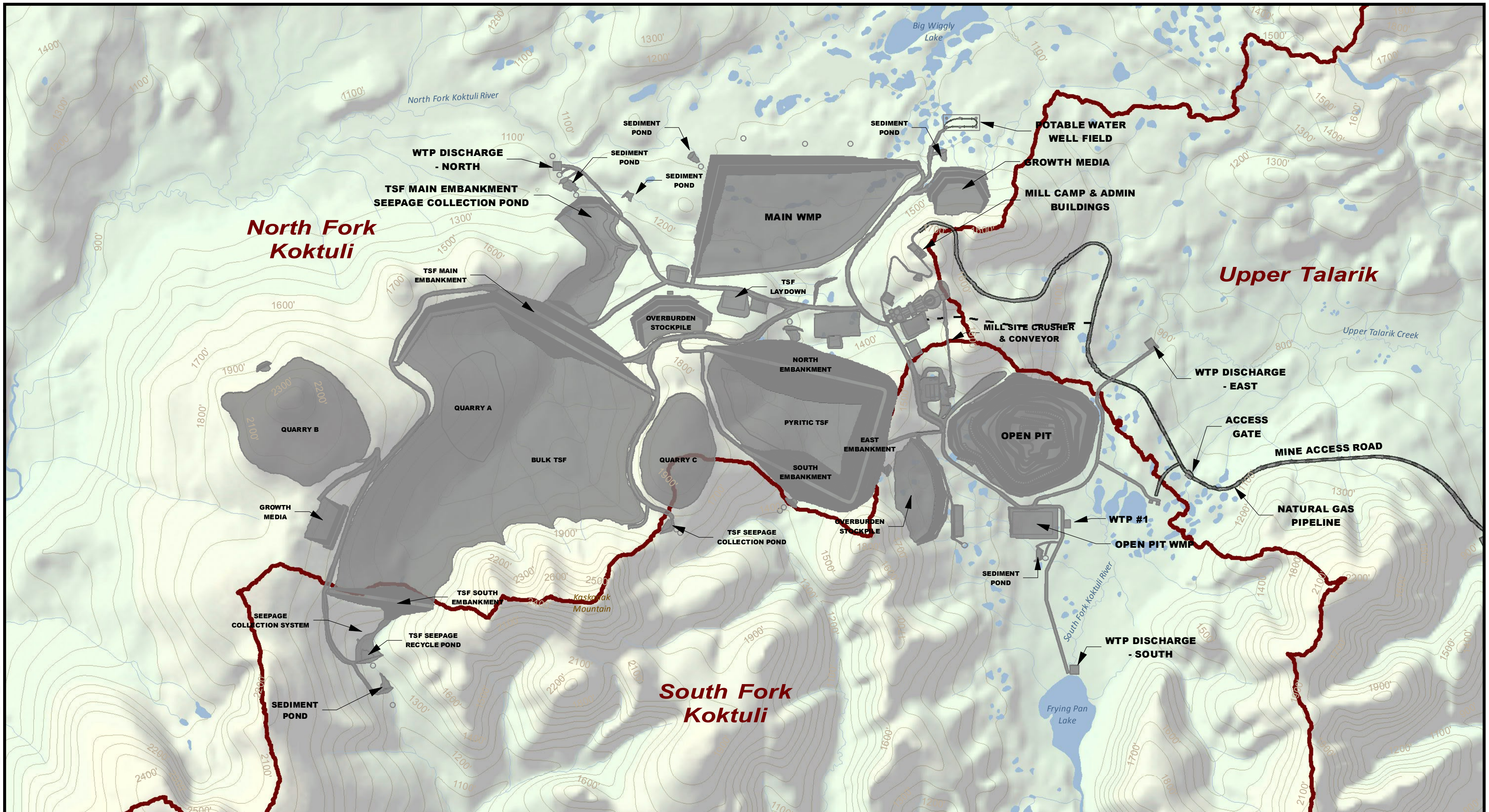
Other Features

- Local Roads
- Major Drainage Boundary
- National Park

WATERSHEDS IN THE MINE STUDY AREA

PEBBLE PROJECT EIS

FIGURE 3.16-2



Sources: PLP 2018-RFI 032; USGS; ADNR

Alternative 1

Natural Gas Pipeline

Mine Site

Other Features

100' Contour (Existing)

River/Stream

Lake/Pond

Major Drainage Boundary

US Army Corps of Engineers®

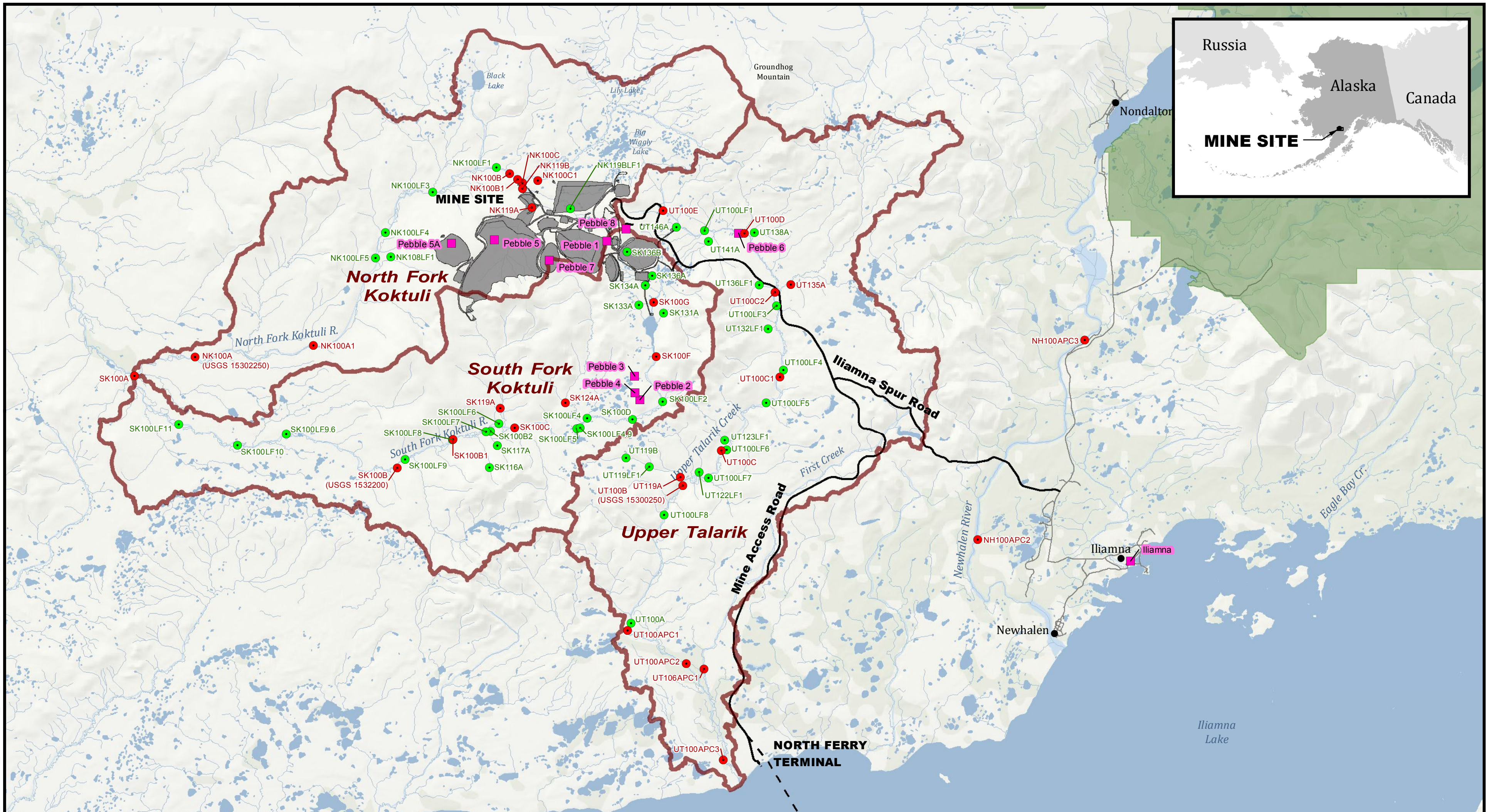
0.5 0 0.5 1

Miles

WATERSHEDS AND MINE SITE FOOTPRINT

PEBBLE PROJECT EIS

FIGURE 3.16-3



Sources: PLP 2018d; ADNR

US Army Corps of Engineers

2 0 2 4
Miles

Continuous Monitoring Gage Stations
Early Spring Low-Flow Measurement Sites
Meteorological Stations

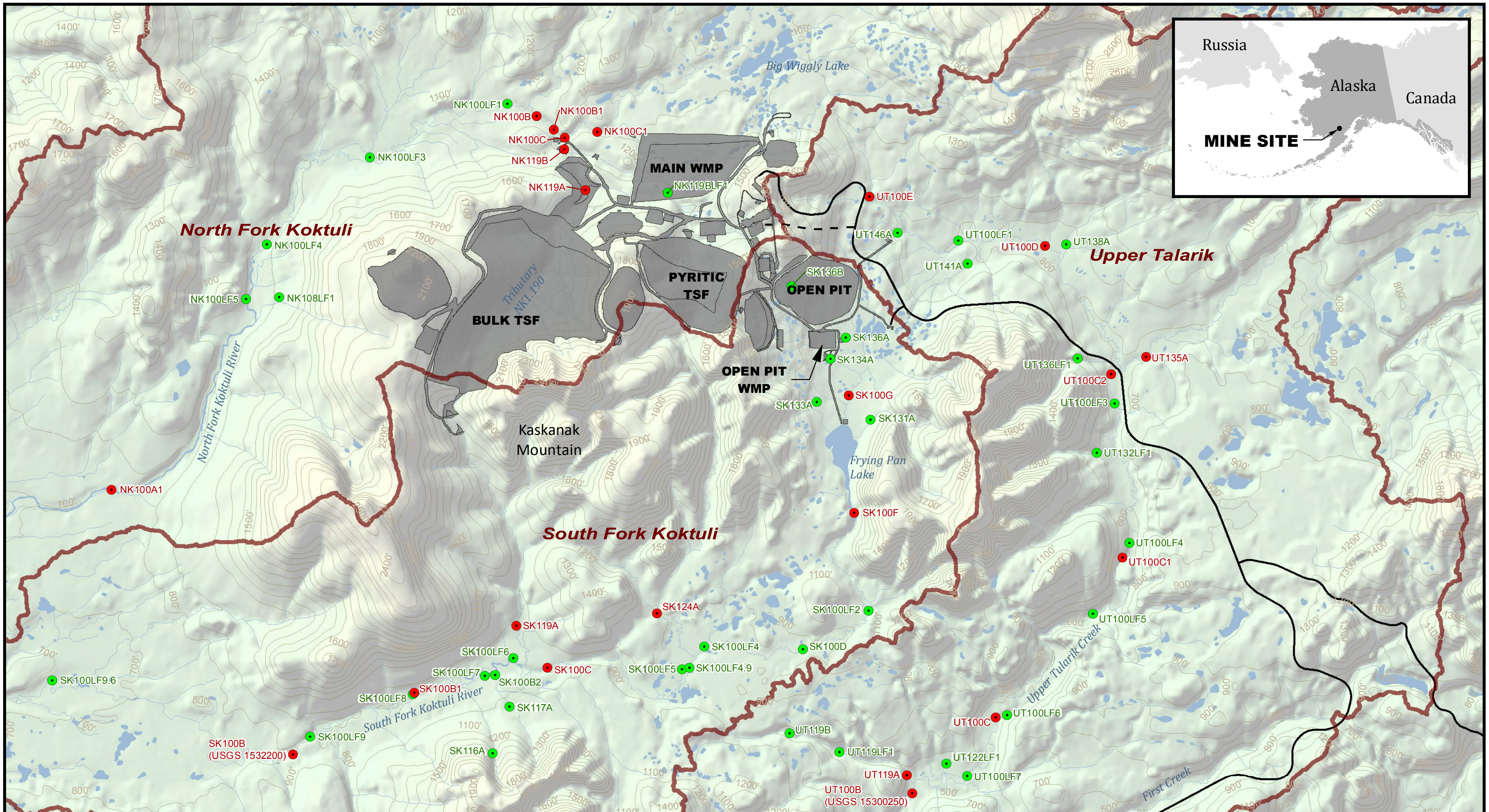
Alternative 1
Transportation Corridor
Natural Gas Pipeline
Mine Site

Other Features
Local Roads
Major Drainage Boundary
National Park

STREAM GAGING STATIONS IN MINE STUDY AREA

PEBBLE PROJECT EIS

FIGURE 3.16-4



Sources: HDR 2012; PLP 2013

Continuous Monitoring Gage Stations

Early Spring Low-Flow Measurement Sites

Alternative 1

Transportation Corridor

Natural Gas Pipeline

Mine Site

Other Features

100' Contour (Existing)

River/Stream

Lake/Pond

Major Drainage Boundary

US Army Corps of Engineers®

N

0.5 0 0.5 1

Miles

STREAM GAGING STATIONS IN VICINITY OF MINE SITE

PEBBLE MINE EIS

FIGURE 3.16-5

North Fork Koktuli River

The NFK River watershed extends northeast from the confluence with SFK River to Groundhog Mountain; approximately 7 miles northeast of the mine site (see Figure 3.16-2). The NFK River drainage area topography is relatively gentle, with elevations ranging from around 600 feet above mean sea level (amsl) near the confluence with SFK River to roughly 3,000 feet amsl at Groundhog Mountain. Lakes and small ponds are common in the upper portions of the NFK watershed, including Big Wiggly Lake, Lilly Lake, and Black Lake. Fewer lakes and ponds exist in the middle and lower portions of the watershed.

South Fork Koktuli River

SFK River extends east and north from the NFK River confluence (see Figure 3.16-2). The watershed topography is relatively gentle, with elevations ranging from approximately 600 feet amsl near the NFK/SFK confluence to 2,760 feet amsl on Kaskanak Mountain, a high point along the NFK/SFK watershed boundary. Lakes and small ponds are common in the upper and lower portions of the watershed, and are less common in the central portion. Frying Pan Lake, approximately 1.5 miles south of the open pit location, is a shallow residual waterbody in the upper SFK River valley (Knight Piésold et al. 2011a). Frying Pan Lake is approximately 1 mile long and 0.5 mile wide, with a relatively uniform depth of approximately 3 feet.

Upper Talarik Creek

The UTC watershed extends north from the creek outlet at Iliamna Lake to the southern side of Groundhog Mountain (see Figure 3.16-2). UTC flows south from its headwaters to Iliamna Lake, roughly 10 miles west of the Newhalen River outlet. The UTC watershed topography is relatively gentle, with elevations ranging from approximately 46 feet amsl at Iliamna Lake to 3,074 feet amsl at Groundhog Mountain. Lakes and small ponds exist throughout the watershed, in relatively flat, poorly drained terrain.

Streamflow

Streamflow in the Bristol Bay region is generated primarily from spring snowmelt runoff and runoff from fall rain events. The mine site watersheds are undisturbed; therefore, baseline streamflow presented in this section is representative of existing natural conditions. The annual pattern of streamflow in the mine site watersheds is characterized by high flows in spring due to snowmelt; lower flows during early to mid-summer; and a high-flow period during late summer to fall derived from rain events (Knight Piésold et al. 2011a). Baseline surface water quality conditions at the mine site are presented in Section 3.18, Water and Sediment Quality.

Groundwater/surface water interaction in the mine site watersheds is controlled by glacial and fluvial deposits of varying thicknesses that occur over most of the analysis area below elevations of approximately 1,400 feet amsl (see Section 3.13, Geology, and Section 3.17, Groundwater Hydrology). Section 3.17, Groundwater Hydrology, describes interaction, importance, and function of these deposits related to surface water runoff, groundwater storage, and exchange between surface water and groundwater.

In Section 3.17, Groundwater Hydrology, the introduction provides an expanded explanation of surface water/groundwater interaction in the EIS analysis area; factors that cause a stream to lose or gain water (i.e., losing or gaining streams); and other terminology.

Gaging Stations

Since 2004, streamflow monitoring has been conducted at gaging stations on the NFK and SFK rivers and the UTC, as well as tributary streams in each watershed. Figure 3.16-2 depicts all gaging station locations in the three watersheds, and Figure 3.16-3 provides a focused view of gaging stations with regard to the mine site. Three gaging stations are operated by the USGS (NK100A, SK100B, and UT100B), and the remaining 25 are operated by Pebble Limited Partnership (PLP). Table 3.16-2 lists stream gaging stations, organized by watershed, that collect continuous flow data (i.e., continuously collecting data) during the open water season, and the number of years in which data were collected at each station. Table 3.16-3 presents a summary of the early spring, low-flow discharge measurements collected at both continuous and non-continuous data collection sites in each watershed. The following summaries provide a description of streamflow at gaging stations closest to the mine site, by watershed. The specific gaging stations selected for discussion in the sections below represent streamflow in the upper portion or at the mouth (downstream end) of each watershed near the mine site.

Table 3.16-2: Streamflow Gaging Stations (Continuous Flow Data)

Drainage[1]	Gaging Station		Drainage Area (mi^2)	Period of Measurement Record[2]	Record Length[3] (Years)
	Pebble ID	USGS ID			
NFK River	NK100A	15302250	105.86	2004-2015, 2018 - present	11
	NK100A1	N/A	85.34[4]	2007-2010	4
	NK100B	N/A	37.32	2007-2013	7
	NK100B1[5]	N/A	37.18	2011-2012	2
	NK100C	N/A	24.35	2004-2013	9
	NK100C1[5]	N/A	24.05	2011-2012	2
	NK119A	N/A	7.76	2004-2013	9
	NK119B	N/A	3.97	2007-2013	6
SFK River	SK100A	N/A	106.92	2004-2007	3
	SK100B	1532200	69.33	2004-2015, 2017 - present	11
	SK100B1	N/A	54.41	2006-2007	2
	SK100C	N/A	37.50	2004-2013	9
	SK100F	N/A	11.91	2004-2013	6
	SK100G	N/A	5.49	2004-2007	3
	SK119A	N/A	10.73	2004-2012	8
	SK124A	N/A	8.52	2005-2010	6
UTC	UT100-APC3	N/A	134.16	2007-2012	5
	UT100-APC2	N/A	110.16	2007-2012	5
	UT100-APC1	N/A	101.51	2007-2012	5
	UT100B	15300250	86.24	2004-2016	12
	UT100C	N/A	69.47	2007-2012	6

Table 3.16-2: Streamflow Gaging Stations (Continuous Flow Data)

Drainage[1]	Gaging Station		Drainage Area (mi^2)	Period of Measurement Record[2]	Record Length[3] (Years)
	Pebble ID	USGS ID			
	UT100C1	N/A	60.37	2007-2010	4
	UT100C2	N/A	48.26	2007-2012	6
	UT100D	N/A	11.96	2004-2013	9
	UT100E	N/A	3.10	2004-2012	8
	UT106-APC1	N/A	14.14	2008-2013	3
	UT119A	N/A	4.05	2004-2013	9
	UT135A	N/A	20.42	2007-2010	0

Notes:
mi^2 = square miles
N/A = Not Applicable
[1] Gaging stations listed include main stem and tributaries.
[2] Calendar years that stream stage data were collected.
[3] Complete water years of record (measured) – Refers to the number of years that stream stage data were collected for at least 3 months and used to compute discharge.
[4] Station NK100A1 reported drainage area: Drainage area on Knight Piésold (2013) Table 7-2 is 85 mi^2; on Table 7-4, drainage area is 81.97 mi^2.
[5] Station NK100B1 and NK100C1 were installed in 2011 for the purpose of verifying measured flows at NK100B and NK100C.
Shaded rows are stations that represent streamflow in the upper portion, or at the mouth, of each watershed near the mine site and subject of more detailed discussion in the narrative.
Source: Knight Piésold 2015b, Table 7-2, and Knight Piésold 2018g, Table 2.4

Table 3.16-3: Early Spring Low-Flow Measurements Summary 2005-2012[1]

Stream	Station or Low Flow (LF) Measurement	Drainage Area (mi^2)	Record Length (yrs)	Lowest Measured Flow (cfs)	Median Measured Flow (cfs)	Highest Measured Flow (cfs)
NFK River	***Main Stem***					
	NK100A (USGS gage)	105.86	8	11.9	47.6	84.5
	NK100A1	85.34	3	43.0	44.3	45.3
	NK100LF5	71.91	2	43.7	45.9	48.0
	NK100LF4	67.28	4	38.7	44.7	53.1
	NK100LF3	53.49	4	4.1	14.9	22.0
	NK100LF1	40.17	3	9.1	15.8	15.9
	NK100B	37.32	8	7.7	14.7	65.0
	NK100B1[3]	37.18	1	9.4	9.4	9.4
	NK100C	24.35	8	8.3	12.9	21.5
	NK100C1[3]	24.05	1	3.8	3.8	3.8
	Tributaries					
	NK108LF1	1.33	1	0.1	0.1	0.1
	NK119A	7.76	8	2.3	2.7	3.7
	NK119B	3.97	5	0.0	0.0	4.3

Table 3.16-3: Early Spring Low-Flow Measurements Summary 2005-2012[1]

Stream	Station or Low Flow (LF) Measurement	Drainage Area (mi^2)	Record Length (yrs)	Lowest Measured Flow (cfs)	Median Measured Flow (cfs)	Highest Measured Flow (cfs)
	NK119BLF1	3.37	1	1.4	1.4	1.4
SFK River	***Main Stem***					
	SK100A	106.92	6	63.5	76.6	125.0
	SK100LF11	90.00	1	13.9	13.9	13.9
	SK100LF10	87.17	4	11.6	13.9	24.6
	SK100LF9.6	80.68	1	0.2	0.2	0.2
	SK100B (USGS gage)	69.33	8	14.7	28.6	45.7
	SK100LF9	68.56	4	30.7	33.8	36.3
	SK100LF8	54.41	1	26.8	26.8	26.8
	SK100B1	54.41	7	12.1	17.3	34.4
	SK100LF7	51.76	1	9.6	9.6	9.6
	SK100B2	51.57	6	0.0	0.0	0.1
	SK100LF6	49.70	1	0.3	0.3	0.3
	SK100C	37.50	7	0.0	0.0	0.0
	SK100LF5	0.29	2	0.0	0.0	0.0
	SK100LF4.9	28.34	1	0.0	0.0	0.0
	SK100LF4	28.91	1	4.9	4.9	4.9
	SK100D	16.22	4	0.0	0.4	6.1
	SK100LF2	15.14	1	4.1	4.1	4.1
	SK100F	11.91	7	1.2	3.5	8.3
	SK100G	5.49	5	2.1	3.6	6.0
	Tributaries					
	SK116A	0.34	2	0.0	0.1	0.1
	SK117A	0.71	3	0.0	0.0	0.0
	SK119A	10.73	6	1.8	2.7	7.6
	SK124A	8.52	6	0.0	0.0	3.0
	SK131A	2.37	4	0.0	0.8	1.1
	SK133A	0.74	3	0.2	0.2	0.3
	SK134A	1.14	4	0.2	0.7	2.4
	SK136A	1.15	4	0.9	1.0	1.2
	SK136B	0.19	3	0.0	0.3	0.4
UTC	***Main Stem***					
	UT100APC3	134.16	3	85.3	135.3	166.4

Table 3.16-3: Early Spring Low-Flow Measurements Summary 2005-2012[1]

Stream	Station or Low Flow (LF) Measurement	Drainage Area (mi^2)	Record Length (yrs)	Lowest Measured Flow (cfs)	Median Measured Flow (cfs)	Highest Measured Flow (cfs)
	UT100APC2	110.16	4	86.1	95.8	114.0
	UT100APC1	101.51	5	43.1	93.9	127.4
	UT100A	101.45	3	89.3	94.7	175.0
	UT100LF8	89.60	4	84.4	105.9	137.8
	UT100B (USGS gage)	86.23	7	87.7	97.5	132.7
	UT100LF7	71.72	4	34.8	69.5	97.5
	UT100C	69.46	6	18.1	50.4	136.5
	UT100LF6	70.72	2	46.1	62.1	78.1
	UT100LF5	65.35	3	47.8	49.1	50.2
	UT100C1	60.37	3	32.4	33.7	43.2
	UT100LF4	59.57	1	28.2	28.2	28.2
	UT100LF3	48.55	1	27.1	27.1	27.1
	UT100C2	48.26	5	10.3	24.0	26.0
	UT100D	11.96	8	5.7	8.1	10.5
	UT100LF1	6.36	1	6.8	6.8	6.8
	UT100E	3.10	8	3.3	3.9	4.6
	Tributaries					
	UT119A	4.05	8	21.5	23.8	28.0
	UT119B	1.72	4	0.1	0.4	1.2
	UT119LF1[1]	2.32	1	15.7	15.7	15.7
	UT122LF[1]	0.06	1	1.1	1.1	1.1
	UT123LF1[1]	1.49	1	1.1	1.1	1.1
	UT132LF1	1.24	1	0.5	0.5	0.5
	UT135A	20.42	3	7.6	13.7	22.3
	UT136LF1	1.57	1	0.6	0.6	0.6
	UT138A	2.75	3	0.6	1.0	1.1
	UT141A	1.66	4	1.0	1.1	1.4
	UT146A	1.86	3	0.0	0.6	2.7

Notes:
mi^2 = square miles
cfs = cubic feet per second
yrs = years
[1] The data used to prepare this table are sourced from Knight Piésold (2015a, Table 7-4). The original table presents the individual flow measurements made in each year.
One low flow measurement was made between March 7 and April 2 in each year in which measurements were made. All sites were not measured every year.
Station NK100B1 and NK100C1 were installed in 2011 for the purpose of verifying measured flows at NK100B and NK100C.

Shaded rows are stations that represent streamflow in the upper portion or at the mouth of each watershed near the mine site and are the subject of more detailed discussion in the narrative.
Source: Knight Piésold 2015b, Table 7-4, Figures 7.2-2 and 7.2-5.

North Fork Koktuli River

There are six gaging stations along the main stem of the NFK River (Figure 3.16-4). Station data from NK100C (main stem of the river) and NK 119A (Tributary NK 1.190) are discussed below.

NK100C, Main Stem (main channel of the NFK River) (see Figure 3.16-5): Station NK100C is in the upper reaches of the NFK River, approximately 20 miles upstream (river miles) of the SFK River confluence. NK100C is the gaging station closest to the mine site on the main stem of the NFK River, roughly 3.5 miles west of the NFK/SFK rivers watershed divide. At NK100C, the river drains an area of approximately 24 square miles, including a large complex of lakes and wetlands, and flows through a narrow valley cut through glacial outwash and drift deposits (see Section 3.13, Geology, for explanation of outwash and drift). The channel above NK100C is dominated by riffles and runs, and the streambed is composed primarily of coarse gravel. Flows at NK100C are buffered by upstream lakes and wetland storage (Knight Piésold et al. 2011a). Based on 8 years of records, the long-term average annual discharge[3] at NK100C is 48 cubic feet per second (cfs) (Table 3.16-4). The lowest average annual discharge recorded was 37 cfs, and the highest average annual discharge recorded was 63 cfs. Streamflow measurements were recorded at NK100C during March and early April to characterize low-flow conditions (see Table 3.16-3). Low-flow discharge measurements ranged from 8 to 22 cfs during the 8-year period of record. Spring and fall instantaneous peak discharge measurements[4] were obtained over a 5-year period (see Table 3.16-5). The lowest instantaneous peak discharge recorded was 117 cfs, during fall 2011. The highest annual instantaneous peak discharge recorded was 586 cfs, during spring 2009.

NK119A, Tributary: Station NK119A is in the western tributary of the NFK River (the tributary is designated in baseline studies as NK 1.190) (see Figure 3.16-5). The bulk tailings storage facility (TSF) and bulk TSF seepage control pond (SCP) would be in the NK 1.190 catchment (see Figure 3.16-5). This tributary is a relatively steep, upland stream, with headwaters along the NFK/SFK rivers watershed divide. The drainage area above NK119A is approximately 8 square miles. The channel above NK119A is dominated by short rapids with irregular scour pools; the streambed is composed primarily of coarse gravels, some cobbles, and numerous boulders (Knight Piésold et al. 2011a). Based on 8 years of record, the long-term average annual discharge at NK119A is 24 cfs (see Table 3.16-4). The lowest average annual discharge recorded was 15 cfs, and the highest average annual discharge recorded was 36 cfs. Streamflow measurements were recorded at NK119A during March and early April to characterize low-flow conditions (Table 3.16-3). Low-flow discharge measurements ranged from 2 to 4 cfs during the 8-year period of record. Spring and fall instantaneous peak discharge measurements were obtained over an 8-year period (Table 3.16-5). The lowest instantaneous peak discharge recorded was 110 cfs, during the spring of 2007. The highest instantaneous peak discharge recorded was 690 cfs, during the fall of 2004.

[3] Average annual discharge = the mathematical average of all discharge measurements (i.e., flow) recorded over a year.
[4] Instantaneous peak discharge (or flow) = the maximum instantaneous discharge occurring during the designated period.

Table 3.16-4: Mine Site Average Annual Streamflow Summary 2004 – 2012

Drainage	Station	Drainage Area (mi^2)	Record Length (years)	Average Annual Discharge (cfs)			
				Lowest Year	Median Year	Average Year	Highest Year
North Fork Koktuli River	NK100A	105.86	8	198.2	239.1	247.2	316.5
	NK100A1	85.34	8	169.0	198.3	205.0	260.9
	NK100B	37.32	8	64.2	81.6	84.3	112.8
	NK100B1[1]	37.18	0	-	-	-	-
	NK100C	24.35	8	36.7	47.2	47.5	63.2
	NK100C1[1]	24.05	0	-	-	-	-
	NK119A	7.76	8	14.8	22.0	23.8	35.5
	NK119B	3.97	8	2.5	4.1	4.3	6.5
South Fork Koktuli River	SK100A	106.92	8	215.1	267.4	259.3	303.9
	SK100B	69.33	8	145.4	188.5	183.7	229.0
	SK100B1	54.41	8	98.8	135.6	130.3	166.3
	SK100C	37.5	8	32.8	50.7	47.7	65.7
	SK100F	11.91	8	24.1	30.3	30.1	37.4
	SK100G	5.49	8	10.3	13.0	13.2	16.3
	SK119A	10.73	8	26.9	34.1	35.2	50.9
	SK124A	8.52	8	14.0	19.3	19.4	26.2
Upper Talarik Creek	UT100-APC3	134.16	8	286.0	326.2	324.1	351.1
	UT100-APC2	110.16	8	253.6	293.3	293.6	333.0
	UT100-APC1	101.51	8	230.0	264.5	261.8	288.5
	UT100B	86.24	8	190.0	223.0	221.4	251.0
	UT100C	69.47	8	134.2	155.0	157.5	185.7
	UT100C1	60.37	8	103.2	121.2	121.3	144.2
	UT100C2	48.26	8	87.6	105.5	104.7	125.1
	UT100D	11.96	8	23.8	28.4	27.8	31.9
	UT100E	3.1	8	7.5	9.1	9.0	10.5
	UT106-APC1	14.14	8	39.5	43.8	43.8	48.5
	UT119A	4.05	8	26.5	29.0	29.2	31.6
	UT135A	20.42	8	32.6	38.7	39.9	47.8

Notes:
cfs = cubic feet per second
mi^2 = square miles
[1]Station NK100B1 and NK100C1 were installed in 2011 for the purpose of verifying measured flows at NK100B and NK100C.
Shaded rows are stations that represent streamflow in the upper portion or at the mouth of each watershed near the mine site and are the subject of more detailed discussion in the narrative.
Source: Knight Piésold 2015b, Table 7-3. The original table presents discharge and unit runoff values for each year of record.

Table 3.16-5: Seasonal Maximum and Annual Instantaneous Peak Discharge at Select Gaging Stations – Mine Site, 2004-2012[1]

Parameter	North Fork Koktuli River				South Fork Koktuli River					Upper Talarik Creek			
	NK100A	NK100B	NK100C	NK119A	SK100A	SK100B	SK100C	SK100F	SK119A	UT100-APC2	UT100B	UT100 C2	UT100D
April - July Maximum Instantaneous Discharge (Spring)													
Record Length (yrs)	8	2	5	8	3	8	1	3	6	N/A	8	1	1
Lowest Recorded Peak (cfs)	687	230	132	110	489	380	116	54	158	N/A	404	598	156
Median Recorded Peak (cfs)	1,525	443	284	271	1,199	1,140	116	172	335	N/A	1,011	598	156
Highest Recorded Peak (cfs)	2,310	655	586	404	1,781	1,710	116	249	484	N/A	1,340	598	156
August-November Maximum Instantaneous Discharge (Fall)													
Record Length (yrs)	9	6	6	8	4	9	8	4	9	4	9	6	8
Lowest Recorded Peak (cfs)	793	403	117	241	1,100	496	156	151	196	650	475	282	103
Median Recorded Peak (cfs)	1,560	470	202	349	1,208	1,090	289	168	475	1,005	926	483	185
Highest Recorded Peak (cfs)	2,240	760	404	690	1,484	1,510	331	233	606	1,404	1,620	825	272

Table 3.16-5: Seasonal Maximum and Annual Instantaneous Peak Discharge at Select Gaging Stations – Mine Site, 2004-2012[1]

Parameter	North Fork Koktuli River				South Fork Koktuli River					Upper Talarik Creek			
	NK100A	NK100B	NK100C	NK119A	SK100A	SK100B	SK100C	SK100F	SK119A	UT100-APC2	UT100B	UT100 C2	UT100D
Calendar Year Maximum Instantaneous Discharge													
Record Length (yrs)	9	2	4	8	4	9	2	3	7	N/A	9	1	2
Lowest Recorded Peak (cfs)	1,430	438	163	306	1,197	782	293	161	278	N/A	796	598	157
Median Recorded Peak (cfs)	1,920	547	294	384	1,209	1,440	304	172	484	N/A	1,230	598	212
Highest Recorded Peak (cfs)	2,310	655	376	690	1,781	1,710	315	249	606	N/A	1,620	598	267

Notes:
cfs = cubic feet per second
yrs = years
N/A = Not Available
[1]Initial gaging station installation occurred July 2004. Discharge data from a September 2004 event resulted in the largest daily and instantaneous discharges on record at some of the stations, including USGS station UT100B. For frequency analysis purposes, the September 2004 event was taken to represent the maximum discharge for the 2004 calendar year at all stations, with the assumption that an even larger peak flow was unlikely to have occurred in the spring of 2004 prior to the start of the gaging program (Appendix 7C, Knight Piésold 2015b).
Shaded columns indicate stations that represent streamflow in the upper portion or at the mouth of each watershed near the mine site, and are the subject of more detailed discussion in the narrative.
Source: Knight Piésold 2015b, Table 2, Appendix 7B. The original table presents the values for each year in which measurements were made.

South Fork Koktuli River

There are six gaging stations along the main stem of the SFK River (Figure 3.16-4). Station data from SF 100F (main stem of the river) and SK 119A (Tributary SK 1.190) are discussed below.

SF 100F, main stem (Figure 3.16-5): Station SK100F is in the upper reaches of the SFK River, approximately 29 miles upstream of the NFK River confluence. SK100F is roughly 2.5 miles south of the mine site, just downstream from the outlet of Frying Pan Lake, and drains an area of approximately 12 square miles. The river at SK100F flows in a narrow valley between hillslopes of moraine deposits and weathered bedrock. The channel in this reach (immediately downstream of Frying Pan Lake) is characterized by riffles, runs, and pools. The streambed is composed primarily of very coarse angular gravels and some cobbles. Based on 8 years of records, the long-term average annual discharge at SK100F is 30 cfs (see Table 3.16-4). The lowest average annual discharge recorded was 24 cfs, and the highest average annual discharge recorded was 37 cfs. Streamflow measurements were recorded at SK100F during March and early April to characterize low-flow conditions (Table 3.16-3). Low-flow discharge measurements ranged from 1 to 8 cfs during the 7-year period of record. Spring and fall instantaneous peak discharge measurements were obtained over a 3- and 4-year period, respectively (see Table 3.16-5). The lowest instantaneous peak discharge recorded was 54 cfs, during the spring of 2007. The highest instantaneous peak discharge recorded was 249 cfs, during the spring of 2006.

SK 119A, Tributary (see Figure 3.16-5): Station SK119A is in an SFK River tributary (designated in baseline studies as tributary SK 1.190), approximately 3.5 miles south of Kaskanak Mountain, a high point along the NFK/SFK rivers watershed divide along the southern side and within 0.5 mile or less of the mine site (see Figure 3.16-5). Tributary SK 1.190 enters SFK River approximately 21 miles upstream of the NFK River confluence. The tributary at the gaging station drains approximately 11 square miles near the outlet of a relatively steep, narrow tributary valley. At the gaging station, the creek flows within a narrow alluvial plain bounded by low terraces and colluvial hillslopes. The channel in this reach is characterized by riffles and runs, and the streambed is composed primarily of coarse gravels and cobbles. Based on 8 years of records, the long-term average annual discharge at SK119A is 35 cfs (see Table 3.16-4). The lowest average annual discharge recorded was 27 cfs, and the highest average annual discharge recorded was 51 cfs. Streamflow measurements were recorded at SK119A during March and early April to characterize low flow conditions (see Table 3.16-3). Low-flow discharge measurements ranged from 2 to 8 cfs during the 6-year period of record. Spring and fall instantaneous peak discharge measurements were obtained over a 6- and 9-year period, respectively (see Table 3.16-5). The lowest instantaneous peak discharge recorded was 158 cfs, during the spring of 2007. The highest instantaneous peak discharge recorded was 606 cfs, during the fall of 2005.

Upper Talarik Creek

There are nine gaging stations along the main stem of UTC (see Figure 3.16-4). Station data from UT 100D (main stem of the river) are discussed below.

UT 100D, main stem (Figure 3.16-5): Station UT100D is in the upper reaches of UTC, approximately 26 miles upstream of the mouth at Iliamna Lake, and roughly 2.5 miles east of the mine site. The drainage area above the station is approximately 12 square miles, consisting of mostly low-gradient wetlands and some adjacent upland, including the general deposit location. UTC meanders through floodplains and associated low terraces within a glaciolacustrine (former glacial lake) basin. The channel in this reach is characterized by riffles and pools, and the streambed is composed primarily of medium gravel. Based on 8 years of records, the long-term average annual discharge at UT100D is 28 cfs (see Table 3.16-4). The lowest average annual discharge recorded was 24 cfs, and the highest average annual discharge recorded was 32 cfs. Streamflow measurements were recorded at UT100D during March and early April to characterize low-flow conditions (see Table 3.16-3). Low-flow discharge ranged from 6 to 11 cfs during the 8-year period of record. Instantaneous peak discharge measurements were obtained at UT100D for spring (over a 1-year period) and for fall (over an 8-year period (see Table 3.16-5). The lowest instantaneous peak discharge recorded was 103 cfs, during the fall of 2009. The maximum instantaneous peak discharge recorded was 272 cfs, during the fall of 2007.

Groundwater is an important component of streamflow in each watershed described above, and results of streamflow data analysis suggested potential cross-watershed boundary interaction between the SFK and UTC watersheds. Streamflow becomes seasonally dry at gage site SK100C (SFK watershed) (see Figure 3.16-4) because of upstream losses of streamflow to groundwater. In the UTC watershed, streamflow at gage UT119A (see Figure 3.16-4) gains substantial flow from groundwater within the SFK watershed to the extent that the hydrograph is dominated by baseflow (Knight Piésold et al. 2011a). The high annual unit runoff values recorded at UT119A are related to a portion of streamflow being generated outside the topographic watershed boundaries that enters via subsurface pathways that cross the topographic divide. Conversely, low annual unit runoff values were recorded at SK100C due to upstream losses of groundwater to the UTC watershed, and from the bypassing of additional groundwater beneath the gage prior to upwelling into the channel further downstream (Knight Piésold et al. 2011a).

Water Balance

A mine site water management plan is essential to: 1) understanding fresh water and mine process water requirements in relation to natural runoff timing; 2) estimating pit dewatering requirements; 3) designing water management and treatment systems; 4) minimizing the potential for an uncontrolled discharge of untreated contact or tailings water; and 5) predicting the impact of mining on streamflow in nearby streams. As part of the water management plan for the mine, a water balance model was developed, and is composed of three modules: the watershed module, the groundwater module, and the mine plan module (Knight Piésold 2018a).

A key component of the modules was the development of a 76-year synthetic precipitation and temperature record that could be used as input to the modules. The synthetic record was developed by adjusting the 76-year temperature and precipitation record (1942-2017) from the Iliamna Airport based on the 8-year (2005-2013) temperature and precipitation record collected at the meteorological monitoring station Pebble 1, located in the mine site (Knight Piésold 2018a) (see Section 3.20, Air Quality, Figure 3.20-1). Details of the procedures used to generate the long-term synthetic temperature and precipitation record are presented in Knight Piésold (2018g). Average monthly temperature and precipitation values were estimated for various locations in the analysis area by adjusting the Pebble 1 average monthly values according to temperature, orographic, and location factors (Knight Piésold 2018a). In general, the magnitude of the factors was determined from hydrometeorological data collected in the EIS analysis area, and/or calibration of the baseline (i.e., pre-mine) watershed module to available surface and groundwater data (Knight Piésold 2018a).

The watershed module is a semi-distributed spreadsheet-based precipitation-runoff model (Knight Piésold 2018a) that incorporates the key components of the hydrologic cycle, including: precipitation as rain and snow, evaporation, sublimation, runoff, surface storage; and groundwater recharge, discharge, and storage (Knight Piésold 2018i; Schlumberger 2011a). The module was developed by Knight Piésold from first principles (AECOM 2018o) in Microsoft

Excel (Knight Piésold 2018i), and run with a monthly time step. The pre-mine model was calibrated to 60 months of streamflow data (starting in mid-2004) at nodes corresponding to established streamflow gauging stations (Knight Piésold 2018i). Once calibrated, the pre-mine model was used with the 76-year synthetic precipitation and temperature record to predict average monthly streamflows at selected locations in the NFK River, the SFK River, and UTC for each month of the 76-year record. The pre-mine model was then altered to reflect end-of-mine conditions, and rerun with the 76-year synthetic temperature and precipitation record. Finally, the model was altered to reflect post-mine closure conditions, and run with the 76-year synthetic temperature and precipitation record.

The results from the model and the impacts on streamflow in the NFK River, the SFK River, and UTC are presented in Section 4.16, Surface Water Hydrology. Additional information regarding the development of the 76-year synthetic record, including calibration and validation of the watershed Module, are presented in Appendix K 3.16.

The mine plan module models the movement of water within the mine site, using inputs from the watershed module and the groundwater module (Knight Piésold 2018a). The model was developed with GoldSim® software, and is based on a 20-year conceptual mine life (Knight Piésold 2018a). The output of the model is average monthly flow. Climate variability was incorporated into the model by using the 76-year average monthly synthetic temperature and precipitation record. The model was run with 20 years of consecutive data at a time. Seventy-six 20-year runs were made, each starting with a different year in the 76-year synthetic record. This method of analysis was used to preserve the inherent cyclical nature of the climate record (Knight Piésold 2018a), and resulted in 76, 20-year period evaluations of water flow and storage. The results from the model and the implications for mine operation are presented in Section 4.16, Surface Water Hydrology.

The groundwater module is discussed in more detail in Section 3.17, Groundwater Hydrology.

Flood Magnitude and Frequency

Flood-peak magnitude and frequency were estimated at five key stream gage stations and eight supplemental stations (Table 3.16-6) in the mine study area[5] (Knight Piésold 2018g). Three of the key stations are USGS stream gage stations: NFK100A, SFK100B, and UT100B. The magnitude of the flood peaks with return periods[6] of 2 to 10 years was estimated based on a Log-Pearson[7] type III distribution and the stream gage record at each site (Knight Piésold 2018g). The magnitude of the flood peaks with return periods of 25 to 200 years was based on an evaluation of the flood peak characteristics at each station and index flood ratios (Knight Piésold 2018g). To evaluate the flood peak characteristics, the 2-, 5-, and 10-year flood peak discharges for each of the 13 stations were plotted against drainage area (Knight Piésold 2018g). The plots revealed three distinct groups, each containing one of the USGS stream gage stations. Index flood ratios were then developed based on the weighted estimates[8] of the magnitude of the 25-, 50-, 100-, and 200- year flood-peaks at the three USGS stream gage sites (Knight Piésold 2018g). The index ratios developed for each USGS stream gage station were

[5] The mine study area (Knight Piésold et al. 2011a) described in this section is within the EIS analysis area.
[6] The return period of an event is based on the probability of occurrence of that event in any given year. For example, if an event has an annual probability of occurrence of 0.10, or 10 percent, it is referred to as having a 10-year return period; the 25-year return period refers to an event having an annual probability of occurrence of 0.04, or 4 percent, and so on.
[7] Log-Pearson type III is a statistical technique for fitting frequency distribution data to predict the design flood for a river at a location.
[8] The weighted estimates were prepared according to the recommendations in Curran et al. (2016).

then used to estimate the 25- through 200-year flood-peak discharges at other stations in the group containing the USGS stream gage station.

Table 3.16-6 Return Period Peak Flows in Mine Study Area

		Estimated Instantaneous Peak Flows (cfs)[1]						
Watershed	**Station**	**Q_2**	**Q_5**	**Q_{10}**	**Q_{25}**	**Q_{50}**	**Q_{100}**	**Q_{200}**
NFK River	NK100A	1,923	2,511	2,956	3,569	4,082	4,649	5,270
	NK100B	678	901	1,037	1,252	1,432	1,631	1,849
	NK100C	343	495	602	663	705	748	791
	NK119A	385	529	648	782	895	1,019	1,155
SFK River	SK100A	1,517	1,870	2,80	2,512	2,873	3,272	3,709
	SK100B	1,291	1,597	1,773	2,141	2,450	2,970	3,162
	SK100C	422	547	628	691	739	780	825
	SK100F	207	264	300	330	351	372	394
	Sk119A	480	617	688	831	950	1,082	1,227
UTC	UT100-APC2	1,647	2,018	2,237	2,462	2,622	2,778	2,940
	UT100B	1,191	1,483	1,646	1,811	1,928	2,044	2,163
	UT100C2	649	776	855	941	1,002	1,061	1,123
	UT100D	200	242	265	292	311	330	349

Notes:
cfs = cubic feet per second
[1] QT refers to peak streamflow with average recurrence interval of "T" (a number of) years.
Source: Knight Piésold 2018g, Table 6.14

Long-Term Climate Change

It is prudent to consider whether the use of historical streamflow and climate records, which are being used to evaluate the hydrology and impacts to hydrology (e.g., water balance, average monthly streamflow, and flood magnitude and frequency), are representative of conditions that may occur over the next several decades.

Four analyses prepared by others were evaluated, and are discussed below:

- Knight Piésold (2009, 2018g) – Historical trends in annual temperature, precipitation, and discharge were reviewed at locations within or close to the EIS analysis area.
- National Weather Service (2012) – Evaluated whether there were statistically significant trends in the annual maximum precipitation data used by the National Weather Service to develop new precipitation-duration-frequency statistics for Alaska. These statistics are often used to predict flood-peak discharge for the design of infrastructure.
- USGS (Curran et al. 2016) – Evaluated whether there were statistically significant trends in the annual maximum flood-peak discharges used by the USGS to develop regional regression equations for the prediction of flood-peak discharge in Alaska.
- Projections from the Scenarios Network for Alaska and Arctic Planning (SNAP 2018).

The following is a summary of the long-term climate change analysis; additional details are provided Appendix K3.16.3. There appears to be general agreement that average annual temperature has been increasing; both near the mine site and throughout Alaska. However, the reason for the increase may be long-term climatic change, a shift in the Pacific Decadal Oscillation (PDO), or most likely, a combination of the two. Because the PDO is expected to shift again, the rate of the temperature increase since about 1977 may not continue long term. With regard to precipitation changes, Knight Piésold (2009) found that there was no common trend in the annual total precipitation at three long-term weather stations located near the mine site. Knight Piésold (2009, 2018g) also evaluated the likelihood of a trend in the magnitude of the annual 1-day maximum daily precipitation at Iliamna, and concluded that there may be a trend of increasing magnitude. A study by the National Weather Service (2012) indicated that there probably was not a trend of either increasing or decreasing annual 1-day maximum daily precipitation at the three sites closest to the mine site, or within the state of Alaska as a whole. With regard to changes in streamflow, Knight Piésold (2009) evaluated the discharge records for three long-term USGS sites within the region, and found no common trend in the magnitude of the mean annual discharge. Similarly, the USGS made an evaluation of the peak-flow data associated with 387 stream gage stations throughout Alaska, and found no universal trend.

Predictions of changes in average annual temperature and precipitation are less useful in predicting hydrologic changes than predictions of changes associated with specific times of the year. Similarly, trends in average annual conditions do not necessarily indicate trends in less frequent events, as are typically used for design. Most of the predictions regarding long-term climatic change are based on average annual temperature and/or precipitation conditions over relatively large areas. Additionally, increasing temperatures result in increased evapotranspiration. Even if the precipitation increases, the streamflow could decrease as a result of increased evapotranspiration. Therefore, both the timing and the magnitude of changes in temperature and precipitation, and the surface conditions on a watershed (e.g., vegetative cover; percent of watershed covered by lakes) would determine whether streamflow increases or decreases. At this point, although there seems to be a common trend in temperature, there does not seem to be a common trend in either precipitation or streamflow at long-term monitoring sites in the vicinity of the mine site. The impact of the uncertainties associated with estimates of hydrologic conditions at the mine site is discussed in Section 4.16, Surface Water Hydrology.

Flood Hazards

For the purpose of this document, a flood hazard exists when existing infrastructure is subject to inundation during a 100-year flood (i.e., probability of inundation in any given year is 1 percent). Because the NFK, SFK, and UTC watersheds are essentially undeveloped, a pre-mine flood hazard does not exist.

Floodplain Functions and Values

Undeveloped floodplains provide many functions of economic, social, and environmental value, including those related to biological resources (see Section 3.22, Wetlands/Special Aquatic Sites). With regard to water resources, undeveloped floodplains often provide flood storage and conveyance; and reduce flood velocities, flood water surface elevations, and flood-peak discharge and sediment transported by the water. Additionally, undeveloped floodplains can have a positive effect on surface water quality and groundwater recharge.

In general, the NFK, SFK, and UTC watersheds consist of low rolling hills and wide shallow valleys. The main channels are highly sinuous and occupy valley bottoms that are 0.5 to 2 miles wide. They flow within floodplains containing wetlands and oxbow lakes. The upper portions of the NFK, SFK, and UTC watersheds are represented by generally flat, poorly drained terrain.

It is likely that the floodplains in the NFK, SFK, and UTC watersheds provide flood storage and conveyance, and reduce flood velocities, water surface elevations, flood-peak discharge, and sediment transported by the water. The impact of the project on these functions and values is discussed in Section 4.16, Surface Water Hydrology.

3.16.1.2 Transportation Corridor

This section describes baseline surface water conditions across the transportation corridor in Alternative 1. The ferry route is addressed under natural gas pipeline corridor.

The road corridor spans multiple watersheds, from its starting point at the southeastern edge of the Nushagak watershed in the mine site, across the greater Kvichak watershed, including Iliamna Lake, to the Aleutian Range watershed divide, and finally entering the greater Cook Inlet watershed east of the divide (Figure 3.16-1). The transportation corridor is described in greater detail in Chapter 2.

The surface water hydrology in the watersheds surrounding the mine site is well characterized, as described above (e.g., Knight Piésold et al. 2011a, 2015b). The mine access road is in the well-studied UTC watershed, for which hydrologic, meteorological, and biological data are available. Limited data are available for the Iliamna spur road (and the port access road. Available information regarding streams containing fish and fish habitat is provided in Section 3.24, Fish Values.

Climatic factors influencing surface water across the corridor are the same or similar to those described above for the mine site. The maximum elevation of the transportation corridor is approximately 1,700 feet amsl; there are no glaciers in the road corridor watersheds. There is no known permafrost in the transportation corridor; however, permafrost has been observed in the general area (Detterman and Reed 1973), and may be present at depth in isolated zones, such as on north-facing slopes. Section 3.14, Soils, addresses the occurrence of permafrost.

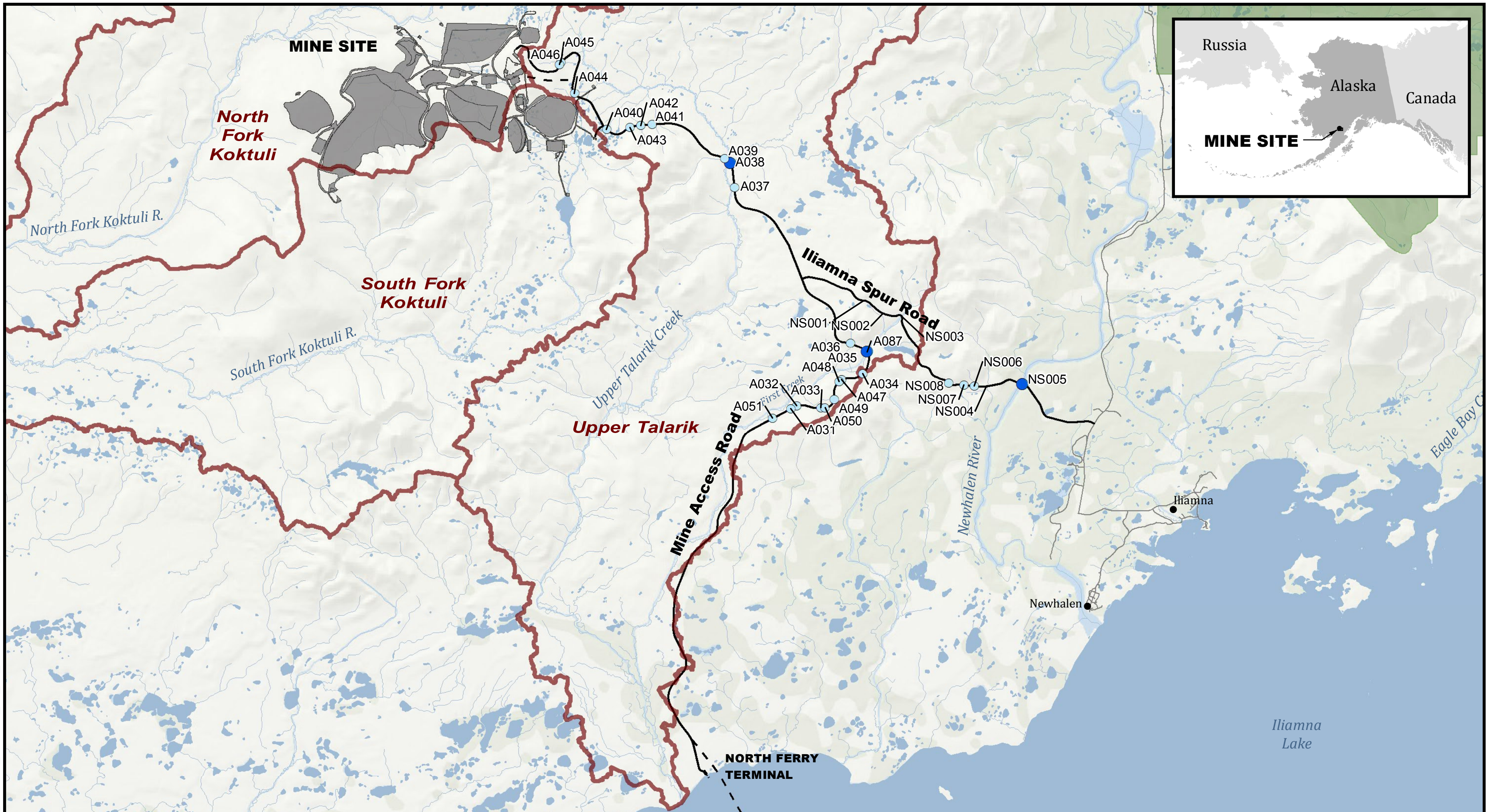
<u>Drainage Basins</u>

Mine Access Road

The mine access road at the mine site is at an elevation of approximately 1,700 feet amsl. The area between the mine site and Iliamna Lake is characterized by gently rounded hills and wide valleys. The mine access road would be relatively close to and roughly parallel the UTC watershed boundary for the majority of its length. Culverts would be used for the road to cross approximately 20 small tributaries (Figure 3.16-6). Two bridges would be used for stream crossings: one to span UTC, and one to span First Creek. The mine access road terminates at the north ferry terminal at Iliamna Lake.

Iliamna Spur Road

The Iliamna spur road corridor starts at the mine access road, at an elevation of approximately 950 feet amsl, and heads eastward out of the UTC drainage. The road corridor crosses First Creek, which flows southward and drains into Iliamna Lake just south of the north ferry terminal, and then enters the Newhalen River watershed. The Newhalen River is one of the larger rivers in the area, with a drainage area of 3,451 square miles at its mouth (Knight Piésold et al. 2011a). It drains glaciated mountainous headwaters; is the main outlet for the large glacial Lake Clark; and has a high suspended sediment load. The Newhalen River flows southward through poorly drained lowland/wetland areas with abundant kettle ponds. Numerous small tributaries feed into the river before it reaches its outlet at Iliamna Lake, 3 miles southwest of the village of Iliamna.



Sources: PLP 2018d; ADNR

US Army Corps of Engineers

2 0 2 4
Miles

Proposed Crossings
- Bridge
- Culvert

Alternative 1
- Transportation Corridor
- Natural Gas Pipeline
- Mine Site

Other Features
- Local Roads
- Major Drainage Boundary
- National Park

STREAM CROSSINGS AT MINE ACCESS AND ILIAMNA SPUR ROADS

The corridor drops in elevation southward as the terrain flattens out over glacial and fluvial deposits, with abundant kettle ponds and wetlands (Wahrhaftig 1965, 1994). The Iliamna spur road corridor would end at an existing road near Iliamna, at an elevation of approximately 200 feet amsl. Culverts would be used to cross approximately 7 small streams, and a bridge would be used to cross the Newhalen River (see Figure 3.16-6).

Port Access Road

The port south access road corridor starts at the south ferry terminal on Iliamna Lake and ends at Amakdedori port. The northern two-thirds of the port access road and the Kokhanok Airport spur road are in the Kvichak watershed, west of the Bristol Bay/Cook Inlet drainage divide (see Figure 3.16-1). The terrain along the road corridor west of the divide consists of low, rounded ridges of exposed bedrock, and valley bottoms dominated by wetlands, streams, and abundant kettle ponds (Wahrhaftig 1965, 1994). Bedrock exposures are common; with less-abundant surficial deposits of ground moraine and alluvium (Detterman and Reed 1973; AECOM 2018h) (see Section 3.13, Geology). Elevations range from 50 feet amsl at the shores of Iliamna Lake, to about 800 feet amsl near the Bristol Bay/Cook Inlet watershed divide.

West of the Bristol Bay/Cook Inlet drainage, streams flow north in sinuous patterns through the varied upland terrain, eventually meandering downgradient into Iliamna Lake. The port access road corridor passes within a mile of Gibraltar Lake, a prominent elongate lake approximately 7 miles long by 0.5 mile wide, of unknown depth. Gibraltar Lake is fed by small streams on the southern and western sides, including Dream Creek and Emerald Creek. The lake drains north into the Gibraltar River and then into Iliamna Lake. On this segment of the port access road, culverts would be used to cross approximately 26 small streams (see Figure 3.16-7). Bridges would be used to cross four unnamed streams and rivers, including the Gibraltar River.

East of the Bristol Bay/Cook Inlet drainage divide, the port access road drops into the greater Cook Inlet watershed. The terrain east of the divide is rocky and undulating, with elevations close to 800 feet amsl at the divide, dropping down to more gentle slopes and wetlands nearing the coast at sea level. There are fewer kettle ponds east of the divide. Streams flow in sinuous patterns through the varied terrain, eventually draining south and east into Kamishak Bay. The road corridor would end at Amakdedori port, which is north of Amakdedori Creek, and would not cross Amakdedori Creek. On this segment of the port access road, culverts would be used to cross approximately 33 small streams (see Figure 3.16-7). Bridges would be used to cross two larger unnamed streams.

Sources: PLP 2018d; ADNR

US Army Corps of Engineers

2 0 2 4

Miles

Proposed Crossings

- Bridge
- Culvert

Alternative 1

- Transportation Corridor
- Natural Gas Pipeline

Kokhanok East Ferry Terminal Variant

- Transportation Corridor
- Natural Gas Pipeline

Other Features

- Borough Boundary
- Local Roads
- National Park
- State Game Refuge/Sanctuary
- Major Drainage Boundary

STREAM CROSSINGS AT PORT ACCESS ROAD

PEBBLE PROJECT EIS

FIGURE 3.16-7

Streamflow

Mine Access Road

The mine access road would cross 22 streams in the UTC watershed. Culverts would be used to cross 20 streams, and bridges would be used to cross the main channel of UTC and First Creek (see Figure 3.16-6). Streamflow information collected within the UTC watershed is presented above in the description of the mine site.

Iliamna Spur Road

The Iliamna spur road would cross seven small streams and the Newhalen River. Culverts would be used to cross the seven small streams, and a bridge would be used to cross the Newhalen River. These seven streams are un-gaged; however, where sufficient streamflow data are not available, it is standard practice in Alaska to design the drainage structures using regional regression equations to predict the design. An example of regional regression equations that might be used for this project is the USGS regression equations published in 2016 (Curran et al. 2016). The Newhalen River has a drainage area of 3,451 square miles at its mouth, and is one of the largest rivers in the area (Knight Piésold et al. 2011a). A USGS gaging station was installed at the Newhalen River (ID 15300000) close to the village of Iliamna in 1951, and was active through 1986. PLP installed two new gaging stations in 2008: one at the same USGS site (NH100-APC3), and the other 8 river miles downstream (NH100-APC2). The watershed contains mountainous terrain, and a large portion of annual runoff occurs during spring and summer snowmelt. Additionally, a secondary hydrograph peak occurs in response to frontal rainfall during late summer and early fall (typically August through October). Unlike the smaller watercourses draining the area around the deposit location, the Newhalen River lacks a distinct low-flow period in the summer due to the effects of summer snow melt and storage in several large lakes, including Lake Clark. Winter flows in the Newhalen River are fed by the upstream lakes, and baseflows remain significant through the winter (Knight Piésold et al. 2011a). The Newhalen River has a mean annual unit runoff of 2.6 cubic feet per square mile (or approximately 35 inches of annual basin runoff depth) (Knight Piésold et al. 2011a). Streamflow information for the other streams crossed by the road is not available at the time of this writing.

Port Access Road

The port road would cross 65 rivers and streams. Culverts would be used to cross 59 small streams, and bridges would be used to cross six larger rivers and streams (see Figure 3.16-7). Drainages in the analysis area south of Iliamna Lake have not been the focus of any known hydrologic studies to date. Streams and tributaries along the port access road corridor are likely fed by spring snowmelt, rainfall runoff, and groundwater. There are no known stream gage data in proximity to the port access road corridor. The closest known stream gage data are from Williams Creek and an unnamed creek in locally named Y Valley, about 30 miles northeast. The Gibraltar River, at the port access road crossing, meanders within a floodplain containing oxbow lakes at wetlands. Data from these streams are limited, and the watersheds are more mountainous and likely hydrologically different from the road corridor area. Where sufficient streamflow data are not available, it is standard practice in Alaska to design the drainage structures using regional regression equations to predict the design. Regional regression equations that might be used for this project are the USGS regression equations published in 2016 (Curran et al. 2016).

Floodplain Function and Values

Floodplain function and values are anticipated to be similar to those discussed above for the streams in the immediate vicinity of the mine.

Flood Magnitude and Frequency

Flood magnitude and frequency have not been estimated for the streams and rivers crossed by the Alternative 1 transportation corridor. However, where sufficient streamflow data are not available, it is standard practice in Alaska to design the drainage structures using regional regression equations to predict the design. Regional regression equations that might be used for this project are the USGS regression equations published in 2016 (Curran et al. 2016).

Surface Water Extraction Sites during Construction

Figure 4.16-7 (Section 4.16, Surface Water Hydrology) depicts surface water extraction sites that would be used to support construction and maintenance of the access roads (PLP 2018-RFI 022).

Stream Crossing Bank Erosion/Scour

Erosion of stream banks is generally caused by an increase in flow during flooding events. There are no known studies of baseline stream bank erosion along the transportation corridor. Bank erosion and scour potential at each stream crossing would be evaluated prior to selecting the final stream crossing locations along the transportation corridor.

Fish habitat field studies conducted in summer of 2018 included collection of substrate composition (e.g., sand, silt, and gravel) and water turbidity (PLP 2018-RFI 036). This information is discussed in Section 3.18, Water and Sediment Quality.

3.16.1.3 Amakdedori Port

Drainage Basins

Amakdedori port is located in Kamishak Bay of Cook Inlet (see Figure 2-2). The Aleutian Range west of the port forms the divide between the Kvichak River watershed (Iliamna Lake outlet) and Cook Inlet watersheds. The terrain along the divide is rocky and undulating, with an elevation of about 800 feet amsl; then drops down to more gentle slopes containing numerous lakes and wetlands east towards the port area. The port would be constructed just north of the Amakdedori Creek outlet. Amakdedori Creek is a small stream that forms from several small lakes.

Streamflow

No streamflow gaging stations are present in the port area (USGS 2018c). Where sufficient streamflow data are not available, it is standard practice in Alaska to design drainage structures using regional regression equations to predict the design. Regional regression equations that might be used for this project are the USGS regression equations published in 2016 (Curran et al. 2016).

Floodplain Function and Values

Floodplain function and values are anticipated to be similar to those discussed above for the streams in the immediate vicinity of the mine. Floodplain values are related to biologic and water resources. Biological resources related to wetlands are described in Section 3.22, Wetlands and Other Waters/Special Aquatic Sites. Water resources include those resources and functions of floodplains related to natural moderation of floods, water quality maintenance, and groundwater recharge. The area is not populated, and there is currently no infrastructure in the area that would be in the floodplain.

Flood Magnitude and Frequency

The port would be developed based on a design flood event for Amakdedori Creek. Where sufficient streamflow data are not available, it is standard practice in Alaska to design drainage structures using regional regression equations to predict the design. An example of regional regression equations that might be used for this project is the USGS regression equations published in 2016 (Curran et al. 2016).

Surface Water Use

There is no known or documented surface water use at the proposed port site. The mouth of Amakdedori Creek is just south of the proposed port. The creek has been advertised as a destination for recreational fishing, but its use has not been documented.

Marine Water – Western Marine Landfall of Natural Gas Pipeline

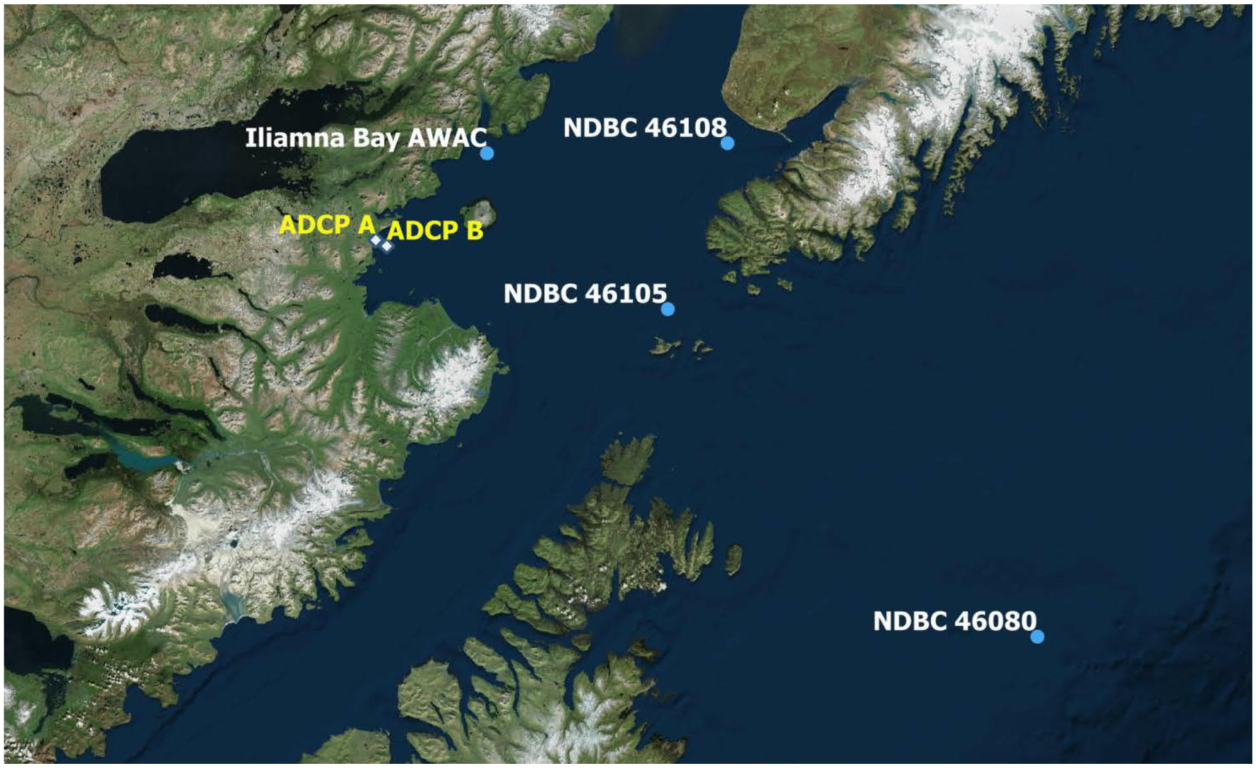
Available Information

Environmental baseline data for the proposed western landfall of the natural gas pipeline were collected in the Iliamna and Iniskin bays area, 25 to 30 miles north of the proposed Amakdedori port site (Pentec Environmental/Hart Crowser and SLR 2011). Amakdedori lies on the western shore of Kamishak Bay, with meteorology and oceanography characteristics more similar to Cook Inlet than the more sheltered locations where the baseline data were collected. Consequently, the baseline data relate to a distinctly different marine environment, and could not be used to describe the Amakdedori port site.

Available site-specific data regarding oceanographic conditions at and near the Amakdedori port site are described in PLP 2018-RFI 039. Publicly available information includes regional wave data from three National Oceanographic and Atmospheric Administration (NOAA) buoys, two of which are in Lower Cook Inlet (NDBC 46108 and NDBC 46105), and the third (NDBC 46080) in the Gulf of Alaska, southeast of Kennedy Entrance, about 175 miles southeast of Amakdedori port. An acoustic wave profiler (AWAC) was deployed near the entrance to Iliamna Bay between 2010 and 2012. Two acoustic Doppler current profilers have been deployed near Amakdedori port site in a metocean program[9], which is scheduled for completion in March 2019 (PLP 2018-RFI 039). Locations of these instruments are shown on Figure 3.16-8.

[9] A metocean measurement program is currently under way in Kamishak Bay at locations denoted by ADCP A and ADCP B (see Figure 3.16-6). The program began in March 2018, and will run until March 2019 to provide site-specific metocean data for the detailed design phase of the port. Two acoustic doppler current profilers (ADCPs) and a shallow water ice profile (SWIP) have been deployed to date (PLP 2018-RFI 039.

Figure 3.16-8: Locations of Available Wave Instrumentation



Source: PLP 2018-RFI 039, Figure 1

Regional Wave Climate

With regard to the suitability of Amakdedori as a port site, the most important meteorological aspects are exposure to wind and the resultant waves (especially from the northeast and east), as well as the presence of sea ice. Wave data from the three NOAA buoys were analyzed to determine "return periods" (see flood magnitude and frequency under "Mine Site" section above for explanation of return period) of various magnitudes of the "significant wave height." The "significant wave height" is defined as the mean height of the highest one-third of the waves. These data were used to evaluate wave conditions at Amakdedori, and also at Lightering Locations A and B (Alternative 1) and Iniskin Bay (Alternatives 2 and 3) (see Chapter 2, Alternatives).

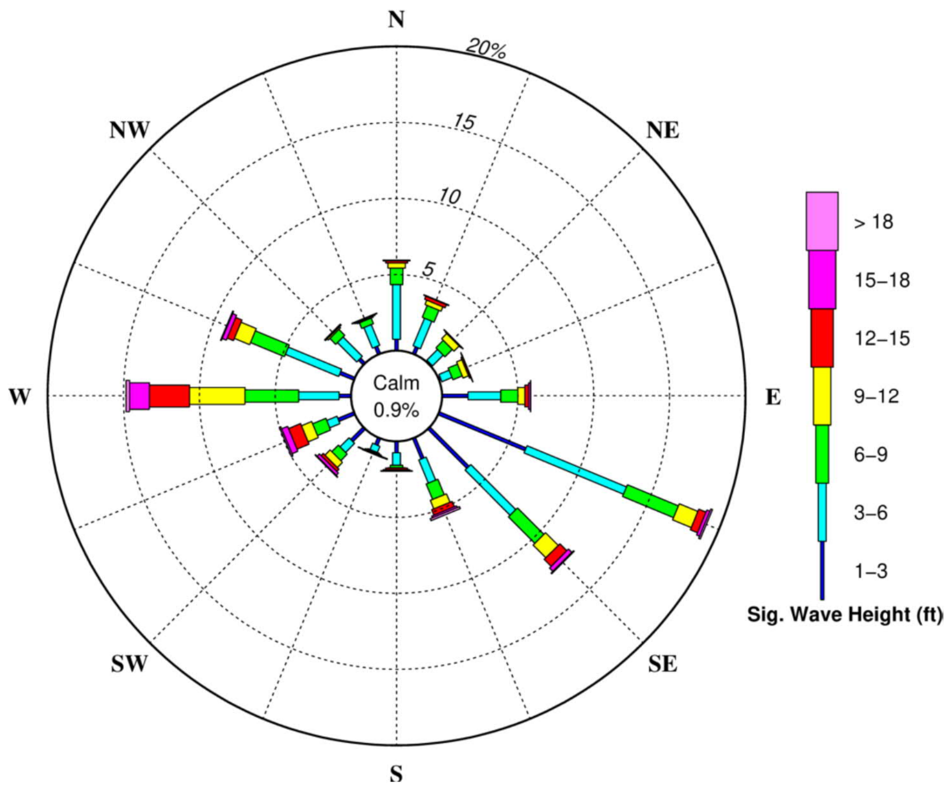
Table 3.16-7 lists return periods from 2 to 25 years of significant wave heights from all three NOAA buoys and the Iliamna Bay AWAC. Figure 3.16-9 and Figure 3.16-10 are wave "roses" for buoys NDBC 46105 and NDBC 46108 that show the directions from which waves were observed as percentages of total observations for ranges of significant wave heights measured by each buoy. NDBC 46105 is fully exposed to waves from the east and southeast, but also receives significant wave activity from the west due to locally generated storms.

Table 3.16-7: Offshore Data Available from NBDC and External Sources

Source	Dates of Data Available	Return Period H_s (feet)				T_p(s) for large events
		2-Year	5-Year	10-Year	25-Year	
NBDC 46080	2002 – 2012	26	32	34	36	11-14
NBDC 46105	2008, 2011 – 2012	23	25	27	-	9-12
NBDC 46108	2011 – 2013, 2015 – 2018	9	10	11	12	8-11
Iliamna Bay AWAC	2010 – 2012	15	17	18	-	8-9

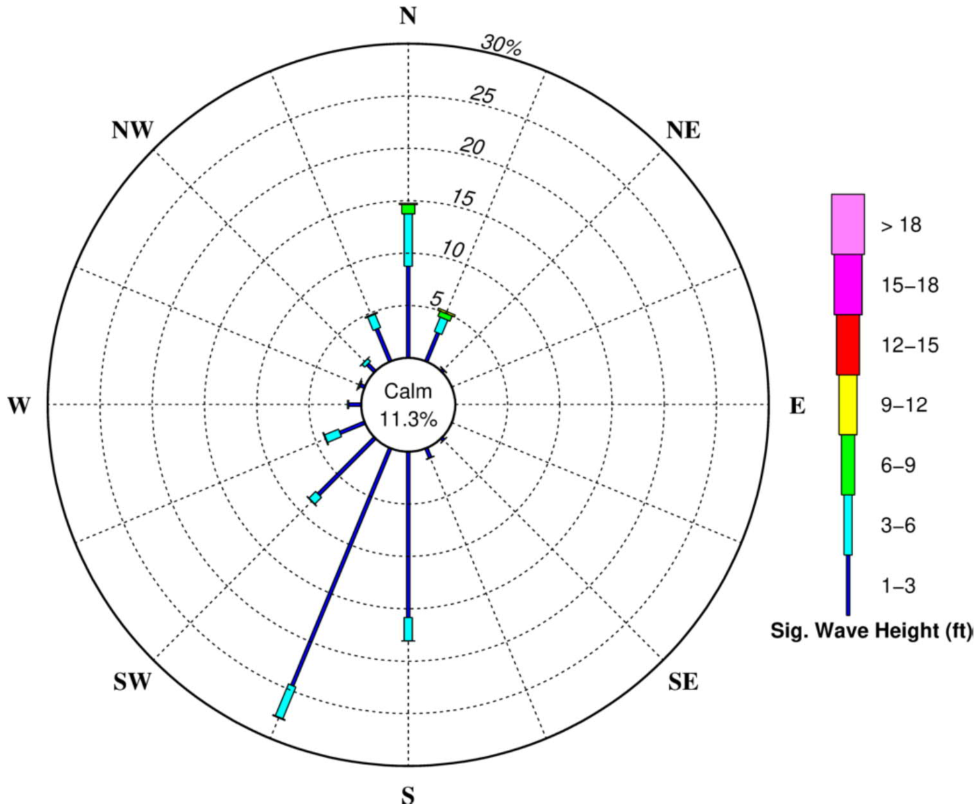
Notes:
H_s = significant wave height (in feet)
T_p(s) = peak wave period
Source: PLP 2018-RFI 039, Table 1

Figure 3.16-9: Wave Rose of Wave Conditions from Buoy NBDC 46105



Source: PLP 2018-RFI039, Figure 3

Figure 3.16-10: Wave Rose of Wave Conditions from Buoy NDBC 46108



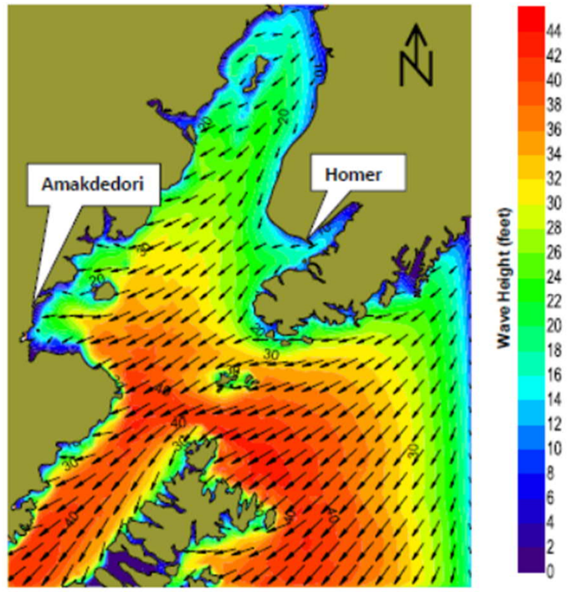
Source: PLP 2018-039, Figure 4

Local Wave Climate

As waves travel into the immediate vicinity of Amakdedori port, they are transformed both in height and direction by processes of "shoaling" and "refraction" due to the decreasing water depth and varying seabed topography. Evaluation of port options included running of numerical wave models (simulating waves nearshore [SWAN] and Delft3D) that are widely used by port designers for this purpose. Figure 3.16-11 and Figure 3.16-12 show SWAN model outputs for waves from east-northeast and east-southeast, respectively. The results of modeling indicates that long-period swell from the Gulf of Alaska is able to penetrate Kamishak Bay and reach the Amakdedori port site. Results also showed that waves from northeast have slightly smaller significant wave height than waves from southeast.

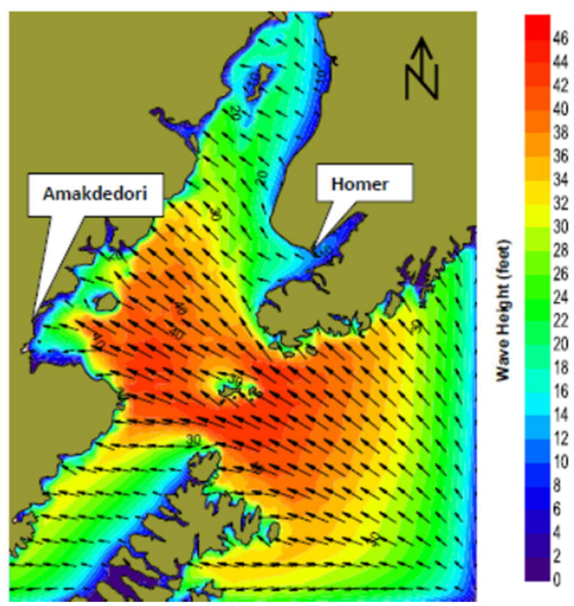
Numerical results from the model runs (see Table 3.16-8) enabled determination of wave conditions (significant heights, periods, and direction) for a range of wind speeds from the northeast (058^0), east (090^0), and east-southeast (116^0). Also shown is the percent reduction in significant wave height due to shoaling and refraction as waves travel from offshore to nearshore.

Figure 3.16-11: SWAN Model Outputs for Waves from the East-Northeast



Source: PLP 2018-RFI039, Figure 5

Figure 3.16-12: SWAN Model Outputs for Waves from East-Southeast



Source: PLP 2018-039, Figure 6

Table 3.16-8: Results of Numerical Modeling at Amakdedori Port Site

Run #	Input					Output		
	Wind		Wave			Percent Reduction in Hs		
	Wind Speed (m/s)	Direction (deg)	H_s (feet)	T_p (s)	Direction (deg)	Nearshore	Approach	Offshore
1	10	58	1.6	3.5	58	81%	81%	100%
2	20	58	5.6	6	58	70%	82%	93%
3	40	58	20	9	58	54%	71%	82%
4	60	58	32.8	12	58	37%	69%	80%
5	10	90	1.6	3.5	90	94%	94%	100%
6	20	90	5.9	6	90	83%	88%	95%
7	40	90	20.1	9	90	57%	77%	85%
8	60	90	36.1	13	90	35%	68%	78%
9	10	116	1.6	3.5	116	94%	94%	100%
10	20	116	5.9	6	116	83%	88%	95%
11	40	116	22.3	11	116	53%	75%	79%
12	60	116	39.4	14	116	32%	64%	73%

Notes:
m/s – meters per second
deg = compass direction in degrees
H_s = significant wave height (in feet)
T_p = peak wave period
Source: PLP 2018-RFI 039, Table 5

During scoping meetings in April 2018, the following remarks were recorded from Mr. Chester Passic, Commander in the US Coast Guard (Peninsula Reporting 2018):

> *I'm a commander in the United States Coast Guard. I'm the captain of a Coast Guard vessel Hickory stationed here in Homer. I do all of the aids to navigation in the Cook Inlet, the buoys and the lights…. We do not keep buoys in Cook Inlet for six months a year because of the weather and ice, and we can't keep buoys in Cook Inlet at that time. Kamishak Bay where the deepwater port is proposed is one of the worst places in the world to operate in terms of combination of tide, current, winds, weather. And I don't know if -- I think the Corps needs to investigate the deepwater port there. My concern would be that we can't keep aids to navigation for the vessels going in and out of there.*

Marine Water Dynamics – Tides, Currents, and Storm Surge

At Nordyke Island (about 6 miles south-southeast of Amakdedori), the mean tide range is 13.0 feet, while the maximum diurnal range is 15.3 feet. Prevailing currents are those associated with the tide, and are generally aligned with bottom contours of the seabed.

Storm surge occurs when strong winds cause a change in local mean sea level. An elevation of sea level is called a “positive” surge, while a depression of sea level is a “negative” surge. Strong winds from the northeast or east could produce a positive storm surge in Kamishak Bay. However, the relatively steep slope of the seabed near the port site would minimize the effects of a storm surge at the port site if it occurred. Due to the prevailing wind direction, negative storm surge is not expected to occur.

Sea Ice

Two compilations of sea ice information for Cook Inlet are available: The Marine Ice Atlas for Cook Inlet (Mulherin et al. 2001), and Pebble Project Ice Database 1997 to 2016 (Dickins 2018). Mulherin et al. (2001) included maps depicting various measures of ice conditions for each biweekly interval between December 1 and March 31 for the period from January 1986 to April 1999 (14 winters), which were based on ice charts constructed by the NWS using aerial and satellite photography, as well as visual reports. The Dickins (2018) study was undertaken to create an updated database that is representative of current climatic conditions, and to provide more locally relevant sea ice information for three locations near the proposed project: 1) Amakdedori port site; 2) lightering location A in middle of Kamishak Bay; and 3) the alternative Diamond Point port site, accessed through Iliamna Bay (see Chapter 2, Alternatives).

The database developed by Dickins (2018) is based on the US National Ice Center archive of 359 Cook Inlet ice charts that span the 19-year period from 1997 to 2016. Data are summarized in tables for each of the study sites, showing dates of first and last observed ice of any severity, the number of weeks of “significant” ice, and maximum concentration of any ice thicker than 4 inches, excluding new ice, which is easily broken up by wind, waves, and vessel operations. The following paragraphs provide the conclusions drawn from the independent review of Dickins (2018) report.

The database shows that ice conditions at the Amakdedori and Diamond Point port sites are very different. Over the 19 ice seasons during the period 1997 to 2016, the Amakdedori port site rarely experienced compact ice for any extended period, and averaged only 3 weeks per year of “significant” ice; while Diamond Point saw ice nearly twice as long, with an average of 5 to 6 weeks per year. In general, the Diamond Point port site had thicker ice in higher concentrations for longer periods than the Amakdedori port site.

Ice cover at lightering location “A” was sporadic during each season, and from year to year. In 5 of the 19 winters studied, there was no ice at this location. The maximum duration of “significant” ice at lightering location “A” was 5 weeks in two seasons. In the other 17 seasons, “significant” ice was present for 2 weeks or less.

A preliminary comparison suggests that ice severity at Amakdedori port site and lightering location “A” might have decreased in last 2 decades, as compared to the 1984 to 1999 period studied by Mulherin et al. (2001). For example, the 2-week period from March 1 to March 15, studied by Mulherin (2001), showed probabilities of ice concentrations[10] (using concentration criterion of greater than or equal to 5/10) of 75 to 100 percent at Amakdedori port site; and 50 to 75 percent at lightering location “A.” For the period from 1997 to 2016, and using the same greater than or equal to 5/10 concentration criterion, the Dickins (2018) database showed probabilities of 58 percent and 26 percent at Amakdedori and Diamond Point, respectively. However, Dickins (2018) reported that there is no clear trend for any of the sites over the 19 ice seasons covered in the more recent database. Because there is no clear trend, it is not possible to conclude that one site is more favorable than the other.

[10] Ice concentration is the amount of ice covering an area, written as either a fraction or percentage of ice coverage. In general 3/10 (30 percent) is navigable by ship; 9/10 (90 percent) is considered solid ice (http://seaiceatlas.snap.uaf.edu/glossary).

Iliamna Lake

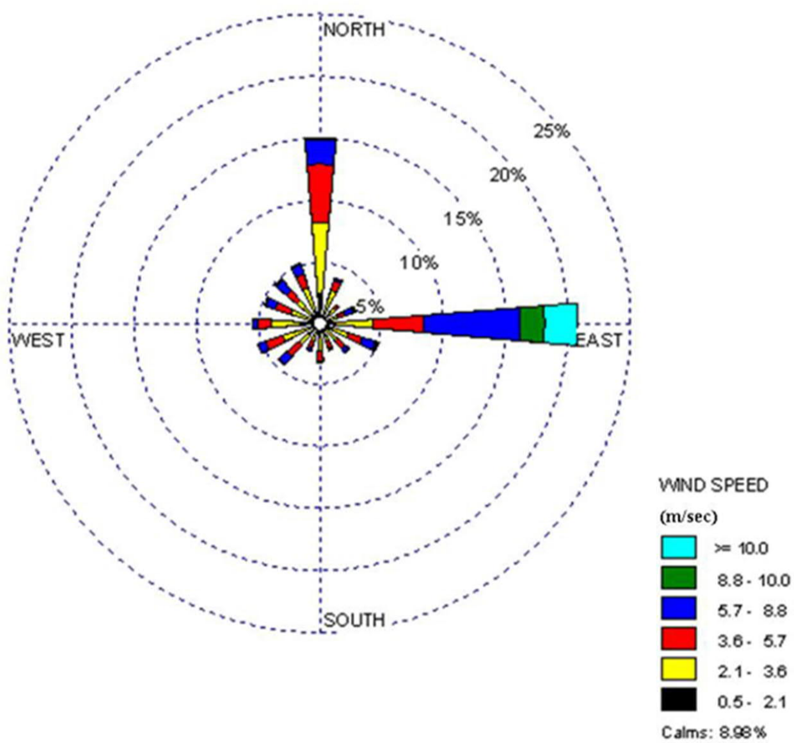
Available Information

Iliamna Lake is the largest lake in Alaska. Approximately 75 miles long by 22 miles wide, its surface area is about 1,000 square miles. Its greatest depth is more than 980 feet, but its mean depth is only about 144 feet. HDR (2011a) provides baseline information regarding water quality, sediment, and biological components for Iliamna Lake (see Section 3.18, Water and Sediment Quality).

Meteorology and Wave Climate

Regarding the ferry terminal locations (and alternative locations described in Chapter 2, Alternatives) on Iliamna Lake and the ferry route(s), the most important meteorological aspects are exposure to wind and the resultant waves (especially from the northeast and east), and the presence of lake ice. Meteorological data for Iliamna Lake are available from Iliamna Airport, for which the record extends from the 1940s; however, no statistical summary other than the Iliamna wind rose (for 2000 through 2008) was located (see Figure 3.16-13).

Figure 3.16-13: Iliamna Airport Wind Rose, 2000 through 2008



Notes:
m/sec = meters per second. 1 m/sec = 2.2 miles per hour.
Source: Hoefler 2010a, Figure 2-2

Figure 3.16-13 indicates that winds at Iliamna are essentially bimodal, either from the east or north, with direction likely governed by local terrain. For the 4 years of meteorological studies included in Hoefler (2010a), for the period of measure 2005 to 2008, maximum hourly mean wind speeds ranged from 20 to 22 miles per hour (mph) (summer), to 43 to 47 mph (winter) for 2005 to 2007, but were somewhat less at 16 to 25 mph in the least windiest year of 2008.

A cursory (i.e., non-statistical) review of data from both Iliamna and Igiugig (at the western end of Iliamna Lake), available at National Climatic Data Center (https://www.ncdc.noaa.gov/data), showed that maximum wind speed of 40 mph is common.

Using wave forecasting equations from the US Army Corps of Engineers (USACE) Coastal Engineering Manual (USACE 2002), for a wind speed of 60 mph and fetch length of 35 miles from the proposed ferry crossing to the northeastern end of Iliamna Lake, a significant wave height of 10 feet and dominant wave period of 6.5 seconds were calculated. Anecdotal information, collected at scoping meetings, suggests that even 60 mph might be an underestimate of maximum wind speeds experienced on Iliamna Lake, as noted below (Midnight Sun Court Reporters 2018):

> *I spent many years in Igiugig in the fall, and it probably blows 100 miles an hour at Lake Iliamna three to five times a year. 100 miles an hour. They want to cross it all the time.*

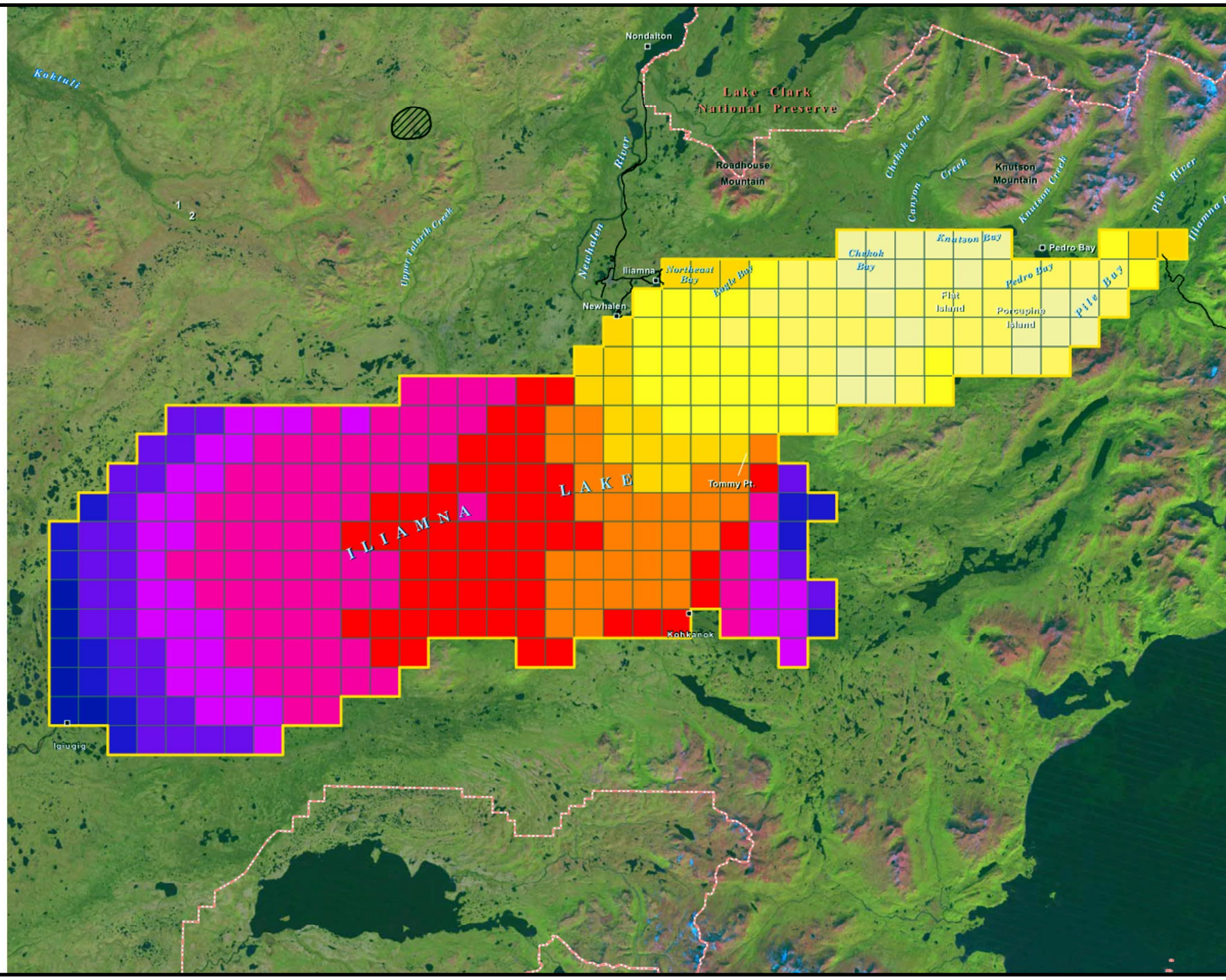
Lake Ice Hazards

The ice-covered season at Iliamna Lake is highly variable. Complete freeze-over occurs between late October and mid-March, and can last for 2 to 5 months before break-up. The average length of the ice-covered season is expected to be about 115 days, based on 15 years of data collected in several southwestern Alaska lakes (Verrier and Kirchner 2016). Limited data are available on ice thickness in Iliamna Lake; anecdotal reports indicate that it can be about 4 feet thick in late spring (Billmeier 2015), but can range from several inches to several feet at the same time over a short distance (ADF&G 2008). The variation in lake ice thickness may be at least partially attributable to stacking of ice floes. Lake ice hazards, such as pressure ridges driven by wind, are known to occur in Iliamna Lake (Billmeier 2015; Andrew 2017).

Ice coverage areas of Iliamna Lake were compiled and georeferenced, using Moderate Resolution Imaging Spectroradiometer (MODIS) imagery for the period from December 1 through June 1 for each winter from 1999/2000 through 2017/2018 (ABR 2018a). Daily images of the lake were reviewed to identify areas of ice cover or open water to develop a time series of ice cover for each winter. The plotted time series showed timing and speed of ice cover formation, as well as the range of uncertainty due to cloud cover. Ice duration (days with ice) was calculated for each of 340 square grid cells, and used to determine median durations for the entire time series.

The analysis spanned 19 winters, with 15 that had prolonged periods of complete or nearly complete ice cover. Four winters had minimal or no periods of complete ice cover. During one winter (2015/2016), only trace ice cover was observed during the entire winter. Often, there were weeks of uncertainty regarding ice conditions because of cloud cover.

Figure 3.16-14 (ABR 2018a) is a map of median ice duration that shows the pattern of shortest duration (less than 105 days) in the eastern portion of the lake, as far west as Iliamna. Median ice duration is intermediate across the lake to Kokhanok (96 to 110 days), except along the shore in the bays and islands east of Kokhanok. Farther west, the median ice duration increases gradually, ranging from 106 to 140 days.



Source: PLP 2018 RFI 013; ABR 2018 Figure 3

US Army Corps of Engineers®

N

Study Area

Existing Road

Median Ice Duration (days)

88 - 90
91 - 95
96 - 100
101 - 105
106 - 110
111 - 115
116 - 120
121 - 125
126 - 130
131 - 135
136 - 140

MEDIAN ICE DURATION ON ILIAMNA LAKE - WINTERS 2000/2001 THROUGH 2017/2018

3.16.1.4 Natural Gas Pipeline Corridor

Available surface water data in the natural gas pipeline corridor are the same as those described for the transportation corridor, with the exception of the Cook Inlet crossing and the eastern Cook Inlet pipeline landfall north of Anchor Point. The marine portion of the pipeline corridor is addressed above under Amakdedori port, Marine Water – Western Cook Inlet Landfall.

Drainage Basins

The drainage basin descriptions for most of the natural gas pipeline corridor are the same as those provided for the transportation corridor.

3.16.2 Alternative 2 – North Road and Ferry with Downstream Dams

Chapter 2, Alternatives, provides a detailed description of Alternative 2 and associated variants.

Drainage Basins

The proposed compressor station would be located north of Anchor Point, on the eastern side of Cook Inlet (see Chapter 2, Alternatives, Figure 2-34). The compressor station would be constructed within the Granoos Creek watershed, a small coastal stream that drains into the Anchor River just upstream of where Anchor River drains into Cook Inlet. The Granoos Creek watershed is low lying, containing small lakes and wetlands that make up its headwaters east of the coast. Granoos Creek is an ungaged stream; no streamflow data are available.

On the western side of Cook Inlet, the principle (named) streams along the transportation corridor between Diamond Point port site and the mine site include Williams Creek, Chinkelyes Creek, Iliamna River, Long Lake Creek, Pile River, Knutson Creek, Canyon Creek, Chekok Creek, Roadhouse Creek, and the Newhalen River. Williams Creek flows into Iliamna Bay in Cook Inlet, and all the other watercourses flow directly or indirectly into Iliamna Lake. Between the Diamond Point port and Iliamna Lake, steep mountainous terrain of the Aleutian Range bounds the pipeline corridor. Further west, along the northeastern side of Iliamna Lake, the pipeline corridor follows topography that is less steep, with watersheds containing wider valleys and numerous lakes.

East of the Newhalen River crossing, the mine access road and pipeline corridor cross into the UTC watershed, and follow the route described under Alternative 1 to the mine site. The onshore pipeline segment that would cross between Ursus Cove and Cottonwood Bay would follow a glacial valley bounded by steep terrain. There are no principle (named) streams along this segment of the route.

The Diamond Point port site is on the eastern side of the Aleutian Mountain Range (in the Cook Inlet watershed), a coastal mountainous terrain with a maritime climate. Along these coastal mountains, rapid snowmelt and rainstorm runoff is facilitated by the steep terrain, and thin surficial sediments on mountain slopes. Closer to the mine site, peak flow attenuation and baseflow augmentation are facilitated by gentler terrain, increased thickness of surficial sediments, and increased number of surface waterbodies (Knight Piésold et al. 2011a).

Streamflow

Along the Alternative 2 ferry access route between Diamond Point port and Pile Bay ferry terminal, the USGS operates one crest gaging station on Chinkelyes Creek Tributary (see Figure 3.16-15 and Table 3.16-9). Along the Alternative 2 pipeline route between Pile Bay and the mine site, the USGS operates one continuous streamflow gaging station on Roadhouse Creek, and one on the Newhalen River. Newhalen River streamflow is described under Alternative 1.

Sources: Knight Piesold et al. 2011a

US Army Corps of Engineers

3 0 3 6
Miles

Surface Water Gage Station (Pebble Project)

Surface Water Gage Station (USGS)

Alternative 1

Transportation Corridor

Natural Gas Pipeline

Mine Site

Alternative 2

Transportation Corridor

Ferry Route

Alternative 3

Transportation Corridor

Other Features

Local Roads

Borough Boundary

National Park

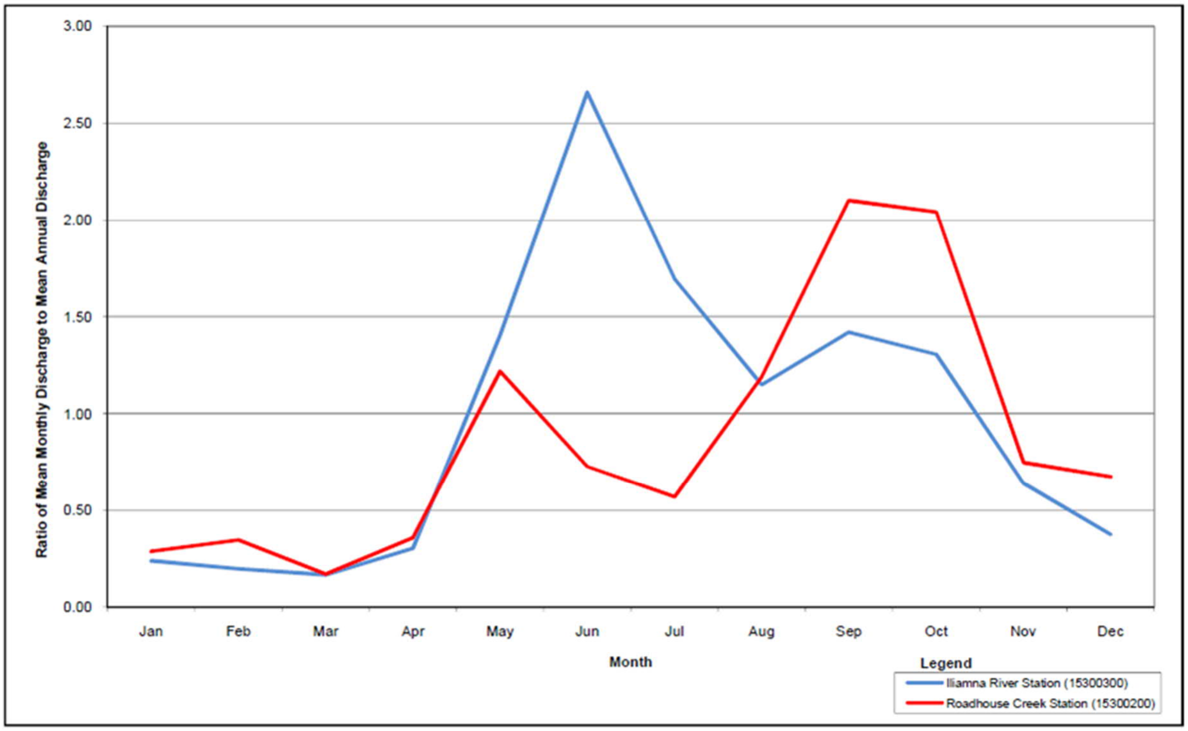
STREAM GAGING STATIONS - TRANSPORTATION CORRIDOR, ALTERNATIVES 2 AND 3

Table 3.16-9: USGS Gaging Stations in Transportation and Natural Gas Pipeline Corridors – Alternative 2

Station			Location		Period of Record				Drainage Area (m^2)	Mean Annual Peak Discharge		Mean Annual Peak Disharge	
USGS ID	USGS Name	Type	Lat (N)	Long (W)	Start Year	End Year	No. Complete Water Years	No. Annual Peaks		Absolute Discharge (cfs)	Unit Discharge (cfs/mi^2)	Absolute Discharge (cfs)	Unit Discharge (cfs/mi^2)
15300200	Roadhouse Creek Near Iliamna AK	Crest	59°45’26”	154°50’49”	1973	1983	N/A	10	20.8	N/A	N/A	128	6.2
15300200	Roadhouse Creek Near Iliamna, AK	Continuous	59°45’26”	154°50’49”	2005	2008	3	4	19.2	29.1	1.4	198	9.5
15300300	Iliamna River Near Pedro Bay, AK	Continuous	59°45’31”	153°50’41”	1996	2008	12	13	129	914	7.1	15,900	124.2
15300350	Chinkelyes Creek Tributary Near Pedro Bay. AK	Crest	59°44’02”	153°48’40”	1997	2008	N/A	12	0.6	N/A	N/A	84.4	211.0

Notes:
AK = Alaska
cfs = cubic feet per second
Lat (N) = Latitude (North)
Long (W) = Longitude (West)
m^2 = square mile(s).
N/A = Not Available
Source: Knight Piésold et al. 2011a, Table 7.3-1

Figure 3.16-16: Mean Annual Hydrograph Comparison – Iliamna River and Roadhouse Creek USGS Gaging Stations



Source: Knight Piésold et al. 2011a (Figure 7.3-2)

In addition to the USGS gaging stations, instantaneous discharge measurements were recorded on select streams along the Alternative 2 transportation and natural gas pipeline corridors. Instantaneous discharge measurements were collected for: Summer 2004 (Table 3.16-10), winter 2005 (Table 3.16-11), and summer 2005 (Table 3.16-12).

Floodplain Function and Values

Floodplain function and values are anticipated to be similar to those discussed above for the streams in the immediate vicinity of the mine.

Floodplain Hazards

For the purpose of this document, a flood hazard exists when existing infrastructure is subject to inundation during a 100-year flood (i.e., probability of inundation in any given year is 1 percent). Because watersheds along the Alternative 2 transportation corridor are essentially undeveloped, a pre-mine flood hazard does not exist.

Flood Magnitude and Frequency

Peak streamflow on streams along the Alternative 2 transportation and natural gas pipeline corridors were estimated using USGS regional regression equations (Knight Piésold et al. 2011a). Estimated peak streamflow values for Alternative 2 stream crossings are presented in Table 3.16-13.

Table 3.16-10: Summer 2004 Instantaneous Discharge Measurements in Transportation and Natural Gas Pipeline Corridors – Alternative 2

2004 Instantaneous Discharge Measurements Sample Location (West to East)		July 2004		August 2004		September 2004		August 2004	
		Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
GS-23	Chinkelyes Creek	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GS-3a	Iliamna River	N/A	N/A	19-Aug	338.7	25-Sep	85.7	15-Oct	1,200.0
GS-4a	Pile River	N/A	N/A	2-Aug	1,533.1	25-Sep	212.4	20-Oct	764.0
		N/A	N/A	19-Aug	1,375.2	N/A	N/A	N/A	N/A
GS-4b	Unnamed Outlet Creek from Long Lake	N/A	N/A	N/A	N/A	25-Sep	0.2	15-Oct	20.6
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	21-Jul	4.2	20-Aug	2.2	24-Sep	2.3	15-Oct	6.2
GS-7a	Unnamed Creek near Pedro Bay Townsite	21-Jul	Dry	19-Aug	Dry	N/A	N/A	16-Oct	4.7
GS-8a	Knutson Creek	21-Jul	128.6	18-Aug	63.5	24-Sep	69.6	16-Oct	282.4
GS-11a	Canyon Creek	20-Jul	107.9	17-Aug	54.2	23-Sep	92.0	16-Oct	261.1
GS-12a	Chekok Creek	N/A	N/A	1-Aug	75.7	22-Sep	111.9	16-Oct	209.0
		N/A	N/A	17-Aug	43.1	N/A	N/A	N/A	N/A
GS-14a	Unnamed Creek East of Eagle Bay Creek	19-Jul	19.5	17-Aug	12.3	22-Sep	86.1	17-Oct	66.4
GS-14b	Unnamed Creek West of Chekok Creek	20-Jul	7.6	17-Aug	4.0	22-Sep	20.3	16-Oct	27.9
GS-17a	West Fork Eagle Bay Creek	19-Jul	6.6	17-Aug	5.1	22-Sep	10.8	16-Oct	28.9
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	19-Jul	1.5	N/A	N/A	21-Sep	0.5	16-Oct	0.5
GS-20	Roadhouse Creek	22-Jul	15.0	3-Aug	9.0	26-Sep	38.3	14-Oct	46.4

Notes:
cfs = cubic feet per second
N/A = Not Available
Source: Knight Piésold et al. 2011a, Table 7.3-8

Table 3.16-11: Winter 2005 Instantaneous Discharge Measurements within Transportation and Natural Gas Pipeline Corridor – Alternative 2

2005 Winter Instantaneous Discharge Measurements Sample Location (West to East)		February 2005		March 2005		April 2005	
		Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
GS-23	Chinkelyes Creek	N/A	N/A	N/A	N/A	N/A	N/A
GS-3a	Iliamna River	15-Feb	53.8	N/A	N/A	N/A	N/A
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	16-Feb	3.6	N/A	N/A	3-Apr	3.0
GS-7a	Unnamed Outlet Creek from Long Lake	N/A	N/A	N/A	N/A	N/A	N/A
GS-8a	Knutson Creek	17-Feb	27.3	N/A	N/A	3-Apr	16.0
GS-11a	Canyon Creek	17-Feb	8.8	N/A	N/A	1-Apr	7.7
GS-12a	Chekok Creek	19-Feb	16.9	N/A	N/A	1-Apr	14.0
GS-14a	Unnamed Creek East of Eagle Bay Creek	19-Feb	7.5	31-Mar	3.9	N/A	N/A
GS-14b	Unnamed Creek West of Chekok Creek	17-Feb	3.1	N/A	N/A	N/A	N/A
GS-17a	West Fork Eagle Bay Creek	18-Feb	1.1	31-Mar	0.8	N/A	N/A
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	18-Feb	0.1	31-Mar	0.1	N/A	N/A
GS-20	Roadhouse Creek	18-Feb	13.0	N/A	N/A	1-Apr	2.8
GS-20a	Upper Roadhouse Creek	18-Feb	0.2	30-Mar	1.8	N/A	N/A

Notes:
cfs = cubic feet per second
N/A = Not Available
Source: Knight Piésold et al. 2011a, Table 7.3-8

Table 3.16-12: Summer 2005 Instantaneous Discharge Measurements in Transportation and Natural Gas Pipeline Corridors – Alternative 2

Summer 2005 Instantaneous Discharge Measurements Sample Location (West to East)		May 2005		June 2005		July 2005	
		Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
GS-23	Chinkelyes Creek	N/A	N/A	N/A	N/A	14-Jul	295.3
GS-3a	Iliamna River	N/A	N/A	14-Jun	2070.0	15-Jul	1160.0
GS-4a	Pile River	4-May	786.1	14-Jun	1641.1	15-Jul	1522.6
GS-4b	Unnamed Outlet Creek from Long Lake	N/A	N/A	N/A	N/A	N/A	N/A
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	N/A	N/A	N/A	N/A	N/A	N/A
GS-7a	Unnamed Creek near Pedro Bay Townsite	N/A	N/A	N/A	N/A	N/A	N/A
GS-8a	Knutson Creek	4-May	247.7	14-Jun	316.9	15-Jul	167.3
GS-11a	Canyon Creek	3-May	246.7	15-Jun	526.6	16-Jul	196.3
GS-12a	Chekok Creek	N/A	N/A	N/A	N/A	N/A	N/A
GS-14a	Unnamed Creek East of Eagle Bay Creek	N/A	N/A	N/A	N/A	N/A	N/A
GS-14b	Unnamed Creek West of Chekok Creek	3-May	45.3	15-Jun	13.8	15-Jul	3.1
GS-17a	West Fork Eagle Bay Creek	5-May	46.5	15-Jun	14.2	16-Jul	8.4
GS-18a	Upper Creek on South Slope of Roadhouse Mountain	N/A	N/A	N/A	N/A	N/A	N/A
GS-20	Roadhouse Creek	24-May	26.0	18-Jun	45.0	2-Jul	33.0
GS-20a	Upper Roadhouse Creek	N/A	N/A	N/A	N/A	N/A	N/A

Table 3.16-12: Summer 2005 Instantaneous Discharge Measurements in Transportation and Natural Gas Pipeline Corridors – Alternative 2 – (continued)

Summer 2005 Instantaneous Discharge Measurements Sample Location (West to East)		August 2005		September 2005		October 2005	
		Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
GS-23	Chinkelyes Creek	9-Aug	94.5	10-Sep	468.0	6-Oct	151.5
GS-3a	Iliamna River	10-Aug	500.0	10-Sep	2,530.0	6-Oct	565.0
GS-4a	Pile River	10-Aug	1,272.5	10-Sep	N/A	7-Oct	525.4
GS-4b	Unnamed Outlet Creek from Long Lake	N/A	N/A	N/A	N/A	N/A	N/A
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	N/A	N/A	N/A	N/A	N/A	N/A
GS-7a	Unnamed Creek near Pedro Bay Townsite	N/A	N/A	N/A	N/A	N/A	N/A
GS-8a	Knutson Creek	9-Aug	116.8	9-Sep	N/A	7-Oct	167.5
GS-11a	Canyon Creek	10-Aug	93.2	8-Sep	361.4	7-Oct	183.1
GS-12a	Chekok Creek	N/A	N/A	N/A	N/A	N/A	N/A
GS-14a	Unnamed Creek East of Eagle Bay Creek	N/A	N/A	N/A	N/A	N/A	N/A
GS-14b	Unnamed Creek West of Chekok Creek	10-Aug	7.2	10-Sep	80.4	7-Oct	56.6
GS-17a	West Fork Eagle Bay Creek	10-Aug	6.5	10-Sep	62.2	7-Oct	30.2
GS-18a	Upper Creek on South Slope of Roadhouse Mountain	N/A	N/A	N/A	N/A	N/A	N/A
GS-20	Roadhouse Creek	24-Aug	53.0	10-Sep	282.0	8-Oct	110.0
GS-20a	Upper Roadhouse Creek	N/A	N/A	N/A	N/A	N/A	N/A

Notes:
cfs = cubic feet per second
N/A = Not Available
Source: Knight Piésold et al 2011a, Table 7.3-8

Table 3.16-13: Estimated Peak Streamflows in the Transportation and Natural Gas Pipeline Corridors – Alternative 2

Station	Stream	Peak Flows Estimated from Regression Equations for Region 3 (cfs)						
		Q_2[1]	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}
GS-23	Chinkelyes Creek	826	1,190	1,452	1,797	2,070	2,345	2,646
GS-3a	Iliamna River	3,618	5,276	6,472	8,054	9,311	10,580	11,971
GS-4a	Pile River	4,419	6,447	7,909	9,840	11,373	12,921	14,614
GS-4b	Unnamed Outlet Creek from Long Lake	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	63	94	117	148	173	198	226
GS-7a	Unnamed Creek near Pedro Bay Townsite	143	221	278	355	416	479	549
GS-8a	Knutson Creek	995	1,531	1,925	2,455	2,881	3,319	3,801
GS-11a	Canyon Creek	707	1,112	1,413	1,825	2,159	2,507	2,893
Station	**Stream**	**Peak Flows Estimated from Regression Equations for Region 4 (cfs)**						
		Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}
GS-23	Chinkelyes Creek	645	976	1,230	1,571	1,837	2,106	2,388
GS-3a	Iliamna River	3,038	4,359	5,340	6,621	7,607	8,588	9,609
GS-4a	Pile River	3,697	5,280	6,453	7,981	9,154	10,321	11,532
GS-4b	Unnamed Outlet Creek from Long Lake	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	40	66	87	116	140	165	191
GS-7a	Unnamed Creek near Pedro Bay Townsite	66	111	148	199	240	284	330
GS-8a	Knutson Creek	583	901	1,144	1,472	1,730	1,993	2,271
GS-11a	Canyon Creek	421	654	832	1,072	1,261	1,456	1,661
GS-12a	Chekok Creek	556	850	1,072	1,371	1,605	1,845	2,097
GS-14a	Unnamed Creek East of Eagle Bay Creek	202	323	417	545	647	752	865
GS-14b	Unnamed Creek West of Chekok Creek	155	246	316	413	490	569	654
GS-17a	West Fork Eagle Bay Creek	129	210	274	362	433	506	585
GS-18a	Unnamed Creek on South Slope of Roadhouse Mountain	86	141	184	244	292	342	396
GS-20	Roadhouse Creek	176	273	346	445	524	604	689
GS-20a	Upper Roadhouse Creek	81	130	169	223	266	311	358

Notes:
[1] Q_T refers to peak streamflow with average recurrence interval of T years.
cfs = cubic feet per second N/A = Not Available
Source: Knight Piésold et al. 2011a, Table 7.3-12

3.16.3 Alternative 3 – North Road Only

The affected environment for surface water for Alternative 3 and associated variants is the same as described under Alternative 2.

3.16.4 Surface Water Use

This section addresses surface water use in the analysis area and considers all alternatives and associated variants described above. Affected environment for existing groundwater use is described in Section 3.17, Groundwater Hydrology.

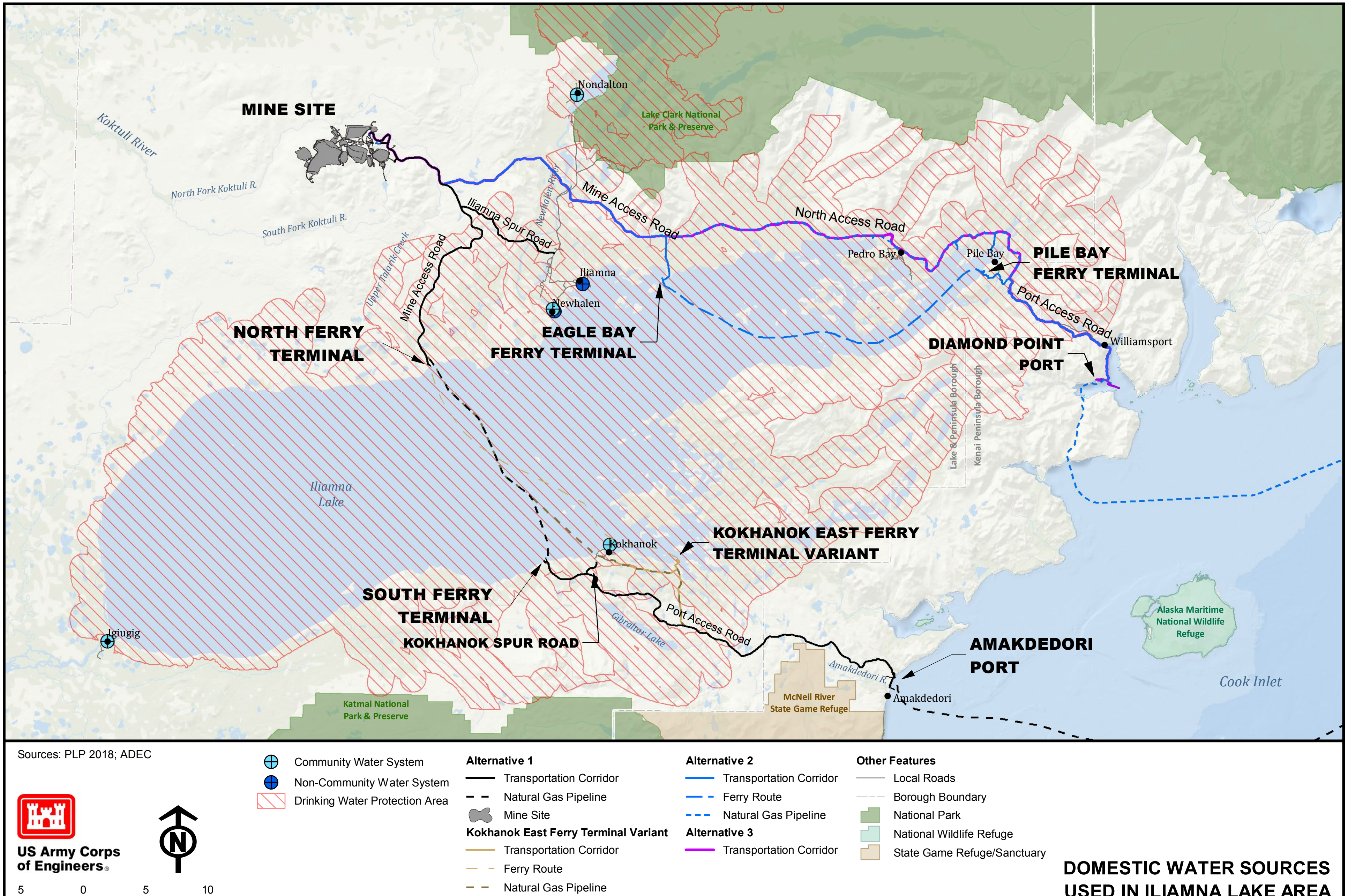
3.16.4.1 Domestic Surface Water Use

Three community water systems in the Iliamna Lake area extract surface water for domestic use: Nondalton, Kokhanok, and Igiugig (see Figure 3.16-15). The Nondalton system uses infiltration galleries[11] from Sixmile Lake (at the southern end of Lake Clark) which drains into the Newhalen River; Kokhanok draws water directly from Iliamna Lake; and Igiugig has one active intake in the Kvichak River, which drains out of the southwestern side of Iliamna Lake (ADEC 2018f). In addition to community water systems that supply surface water, local residents may collect surface water for personal use. To date, no additional traditional ecological knowledge (TEK) regarding collection of surface water for personal use within the analysis area has been received (see Appendix K3.1 for additional information on TEK).

Section 3.18, Water and Sediment Quality, describes current water quality of community water systems relevant to the analysis area, including water quality data on Iliamna Lake. Drinking water wells used in some lake communities are described in Section 3.17, Groundwater Hydrology. No public data are available on drinking water sources for Pile Bay and Williamsport, near the Alternatives 2 and 3 transportation corridors (ADEC 2018f; ADNR 2018a).

To meet the requirements of the Safe Drinking Water Act, elements of the EPA 1986 Wellhead Protection and 1997 Source Water Assessment and Protection (SWAP) programs have been combined under the ADEC Drinking Water Protection Areas (DWPA) program. The DWPA program's intent is to delineate the boundaries of public (community) drinking water sources, identify potential risks from contamination, and determine 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 shores of Lake Clark, Iliamna Lake, and the community surface water systems described above. Zones within the DWPAs reflect buffers around surface drinking water sources and watershed boundaries (see Figure 3.16-17).

[11] Infiltration gallery = a horizontal perforated pipe structure installed to facilitate transfer of water from a shallow aquifer, such as may occur near a lake or river shoreline.



DOMESTIC WATER SOURCES USED IN ILIAMNA LAKE AREA

PEBBLE PROJECT EIS

FIGURE 3.16-17

3.16.4.2 Mine Site Water Use

Surface water within the mine site may be used by local residents for hunting, fishing, and other subsistence activities, but has not been documented. To date, no additional TEK regarding collection of surface water for personal use within the analysis area information has been received (see Appendix K3.1 for additional information on TEK).

PLP has received multiple Temporary Water Use Authorizations (TWUAs) for exploration activities between 2004 and 2013. The TWUAs allow a limited volume to be withdrawn per day, up to a specified annual limit, from specified sources; mostly groundwater wells (see Section 3.17, Groundwater Hydrology).

PLP has applied for surface water rights for some of the main drainages within the mine site area, including the SFK river, the NFK river (designated in baseline studies as tributary NK 1.190), and UTC. All water rights applications filed by PLP are on the ADNR website at: http://dnr.alaska.gov/mlw/mining/largemine/pebble/water-right-apps/ (ADNR 2018c).

3.16.4.3 Port Water Use

There is no known or documented surface water use at either Amakdedori or Diamond Point port sites (ADEC 2018f).

3.16.4.4 Transportation and Natural Gas Corridors Water Use

A hydropower project (Tazimina Hydro) was installed 9 miles upstream from the confluence of the Newhalen and Tazimina rivers, near the transportation corridor (Alternatives 2 and 3). By 2012, the run-of-the-river-type hydropower plant supplied over 95 percent of the power for the communities of Iliamna, Newhalen, and Nondalton (INNEC 2012). The hydropower system uses the natural waterfalls at the site to provide the mechanical energy to spin power-generating turbines, and there is no dam required. Streamflow is therefore not significantly affected, and no water is removed from the drainage for power production.

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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 space) 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, the ability of the subsurface material to transmit water (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.

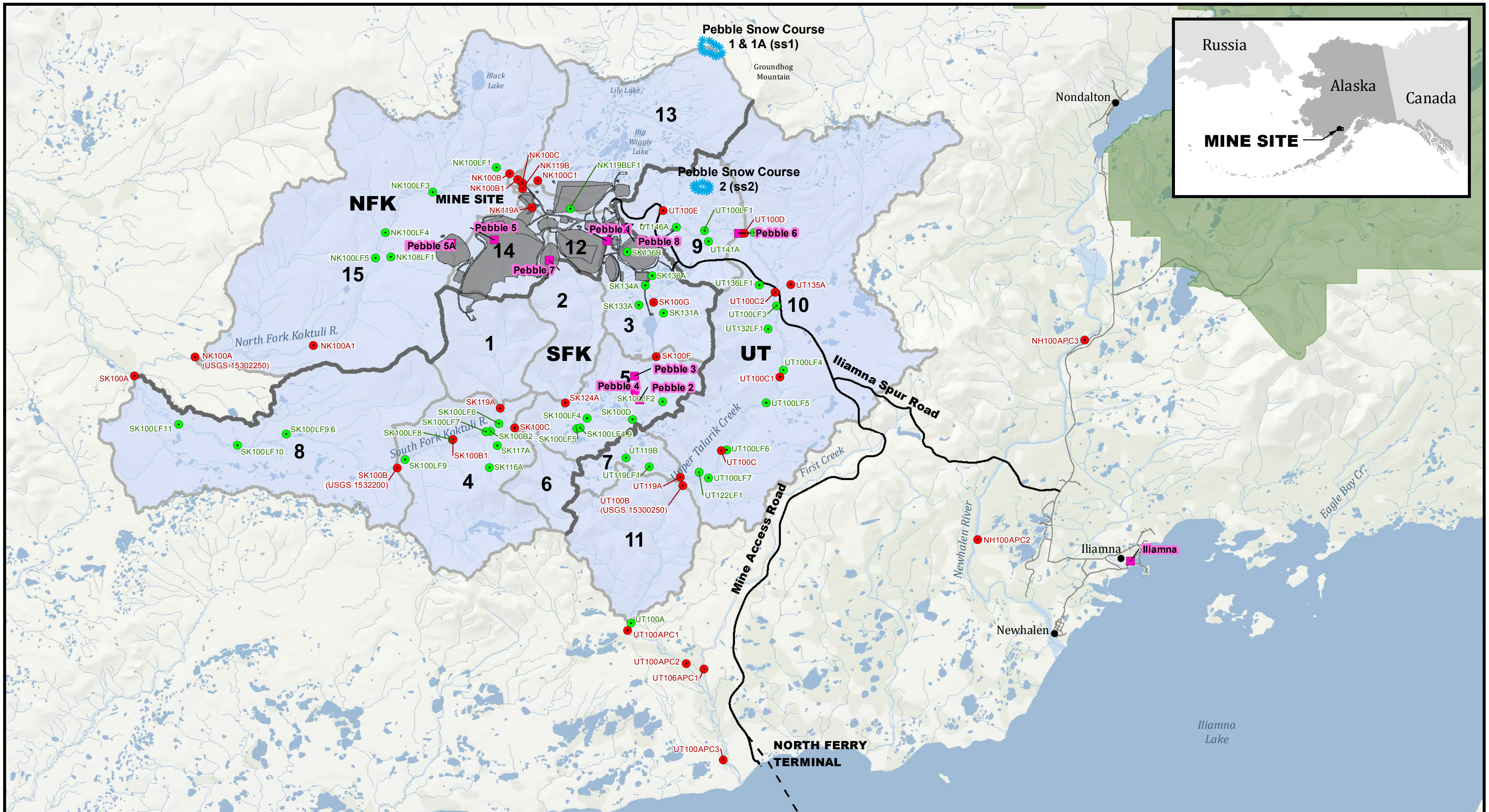
The Environmental Impact Statement (EIS) analysis area (hereafter, analysis area) includes the mine site, transportation corridor, pipeline corridor, and ports for all alternatives and associated variants, and includes the watersheds most likely to be affected by the project The geographic area considered 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, 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 in the EIS that support development of the hydrogeology discussion are cross-referenced.

[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.

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 Alternatives 1, 2, and 3 and associated 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), monitoring of meteoric inputs (e.g., rainfall, snowfall), and routine measurement of groundwater levels.



Sources: PLP 2018d; ADNR

US Army Corps of Engineers

2 0 2 4

Miles

- Snow Course Station
- Continuous Monitoring Gage Stations
- Early Spring Low-Flow Measurement Sites
- Meteorological Stations
- Sub-catchment

Alternative 1

- Transportation Corridor
- Natural Gas Pipeline
- Mine Site

Other Features

- Watershed Boundaries
- Local Roads
- National Park

MINE SITE GROUNDWATER ANALYSIS AREA

PEBBLE PROJECT EIS

FIGURE 3.17-1

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 (physical characteristics of the geologic material) are provided in Table K3.18-17. 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 and rates.
- Relationships between local, intermediate, and regional groundwater flow systems.
- Interaction and seasonality of groundwater and surface water systems.

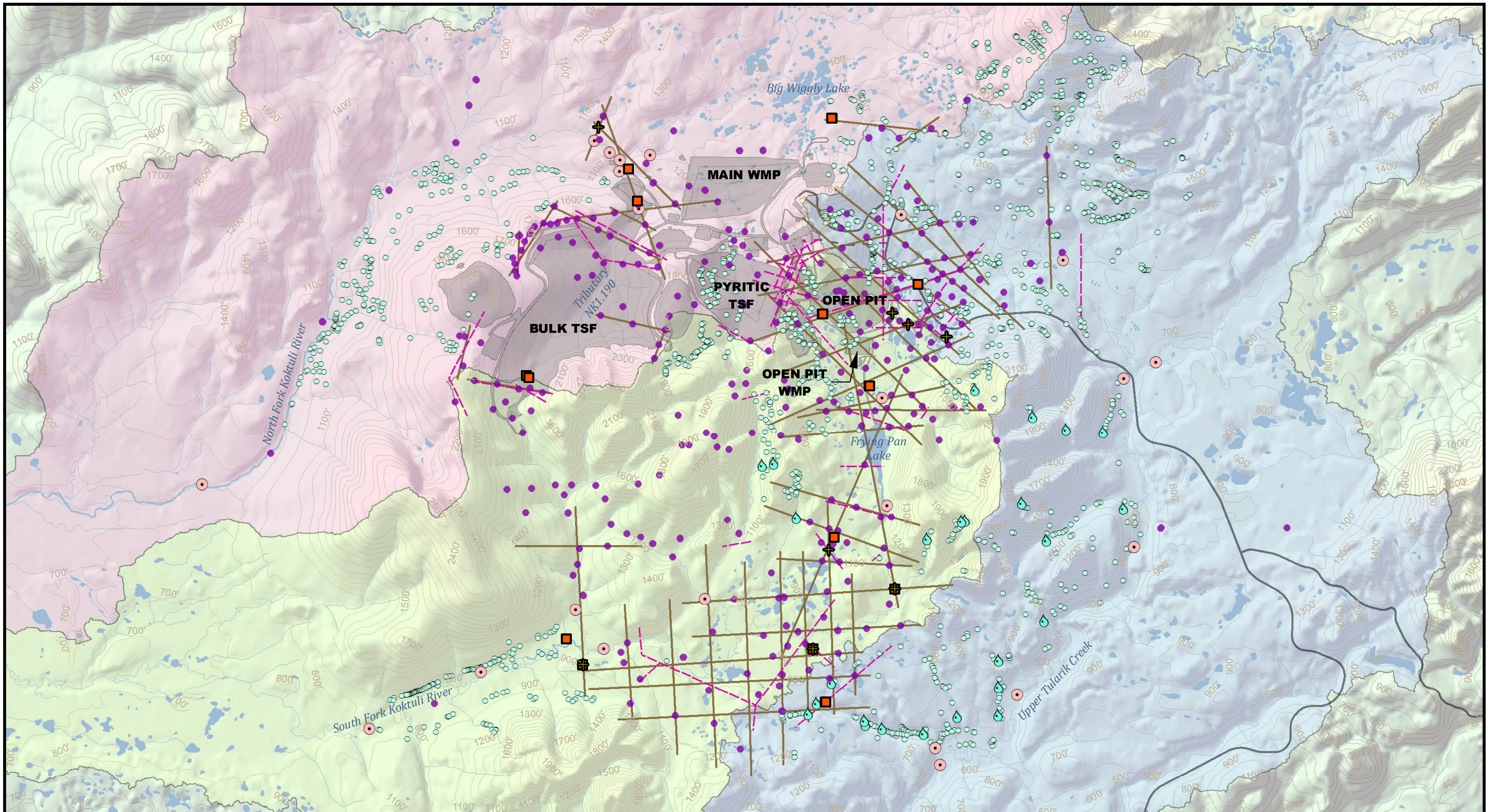
The results of these characterization programs form the basis for a baseline water balance model (Schlumberger 2011a, Appendix 8.1I), a baseline groundwater flow model (Schlumberger 2011a, Appendix 8.1J), a groundwater model at the end of mining operations and post-closure (Piteau Associates 2018a), and water balance and water quality models for operations, closure, and post-closure (Knight Piésold 2018a, 2018d). 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.

3.17.1.1 Aquifers and Confining Units

Topography of the analysis area is characterized by hills separated by wide valleys with elevations ranging to 2,500 feet above mean sea level (amsl) in 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) 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 through a conceptual model incorporating the following units or "layers" (Schlumberger 2015a):

- Surficial aquifer
- Shallow confining unit
- Intermediate aquifer
- Deep confining unit
- Deep aquifer

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



Sources: Schlumberger 2011a, Figures 8.1-4 and 9.1-5

US Army Corps of Engineers

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

Alternative 1
- Mine Site
- Transportation Corridor
- Natural Gas Pipeline

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

The units listed above are discontinuous in the mine vicinity. Aquifers are composed primarily of sand and gravel with minor amounts of silt. Confining units are composed primarily of silt and clay with varying amounts of sand and gravel.

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 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 system 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 Appendix K3.17, Table K3.17-1.

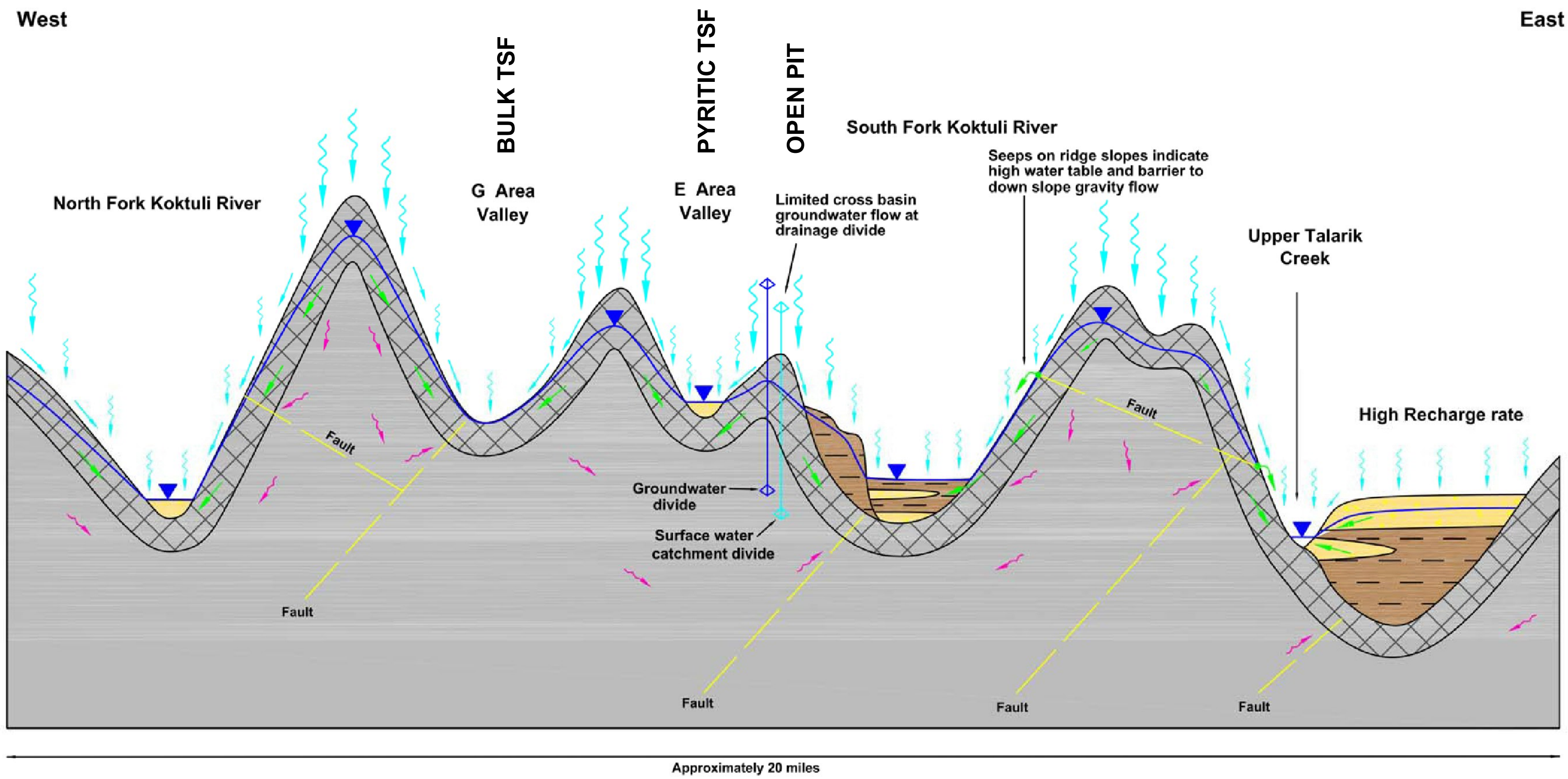
Cross-sections were developed from borehole data to illustrate the subsurface distribution of aquifers and confining units in overburden and bedrock in the mine vicinity (Schlumberger 2015a: Appendix 8.1B). Locations of four representative hydrogeologic cross-sections are shown on Figure 3.17-4. Hydrogeologic cross-sections are provided on Figure 3.17-5 through Figure 3.17-8 as follows:

- Figure 3.17-5: Cross-section E-10 – southwest-northeast section across the area between the Pebble deposit area and Frying Pan Lake.
- Figure 3.17-6: Cross-section L-1 – an approximately 10-mile section from the south side of the Pebble deposit area, along the South Fork Koktuli (SFK) River through Frying Pan Lake, and across the drainage divide to the headwaters of tributary UT1.190 (as named in baseline studies).
- Figure 3.17-7: Cross-section S-1 – north-south cross-section across the SFK River at the western end of the analysis area.
- Figure 3.17-8: Cross-section M1 – northwest-southeast cross-section across the North Fork Koktuli (NFK) River, across the bulk tailings storage facility (TSF) main embankment and seepage collection pond, to the east 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. Shallow groundwater flow patterns in the surficial aquifer at seasonal low and seasonal high water levels are illustrated in Figure 3.17-9a and Figure 3.17-9b, respectively. While flow patterns during these two seasons are similar, seasonal low values best reflect base flow5 to streams and wetlands. Flow patterns in the deeper overburden aquifers and weathered bedrock zone are shown in Figure 3.17-10. The following narrative describes the hydrogeologic characteristics of areas in the mine site that would be most affected by the project.

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

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



Sources: PLP 2011d

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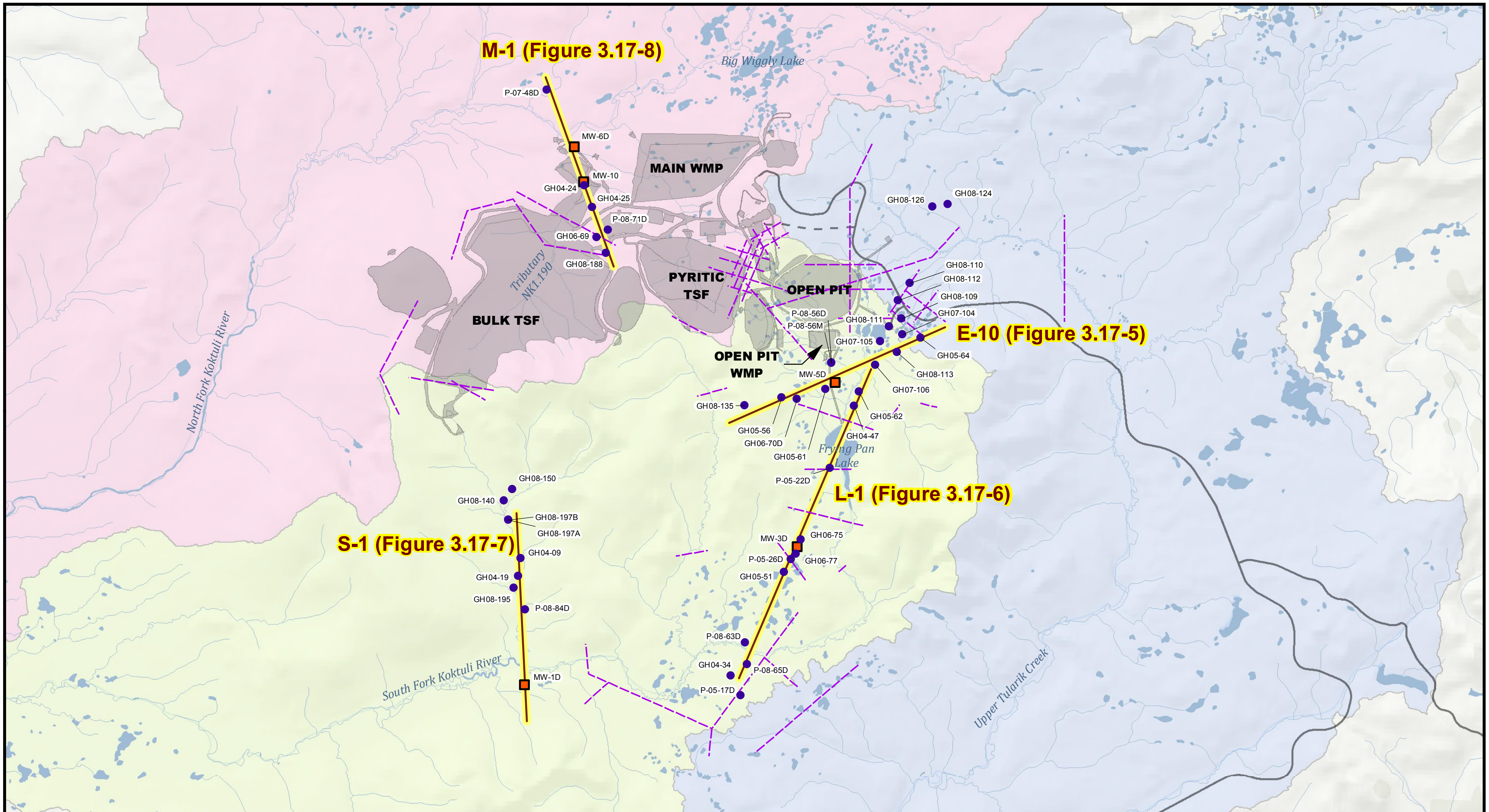
LEGEND

- 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

SCHEMATIC REPRESENTATION OF SITE-WIDE GROUNDWATER SYSTEM



Sources: Schlumberger 2011a, Figure 8.1-4

US Army Corps of Engineers®

1 0 1 2

Miles

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

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

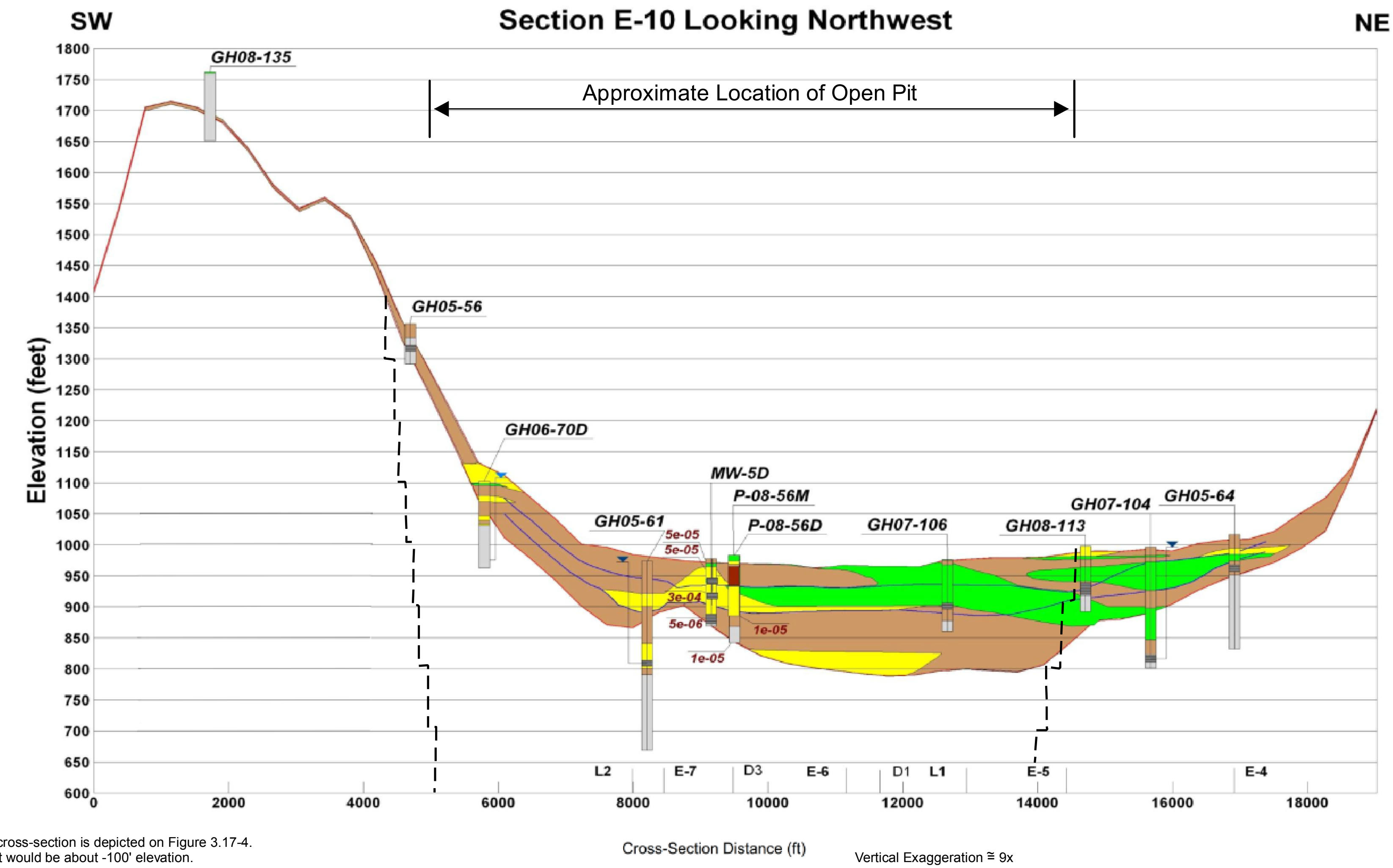
Alternative 1
- Mine Site
- Transportation Corridor
- Natural Gas Pipeline

Other Features
- River/Stream
- Lake/Pond

CROSS-SECTION LOCATION MAP

PEBBLE PROJECT EIS

FIGURE 3.17-4



Notes:
1. Location of cross-section is depicted on Figure 3.17-4.
2. Bottom of pit would be about -100' elevation.

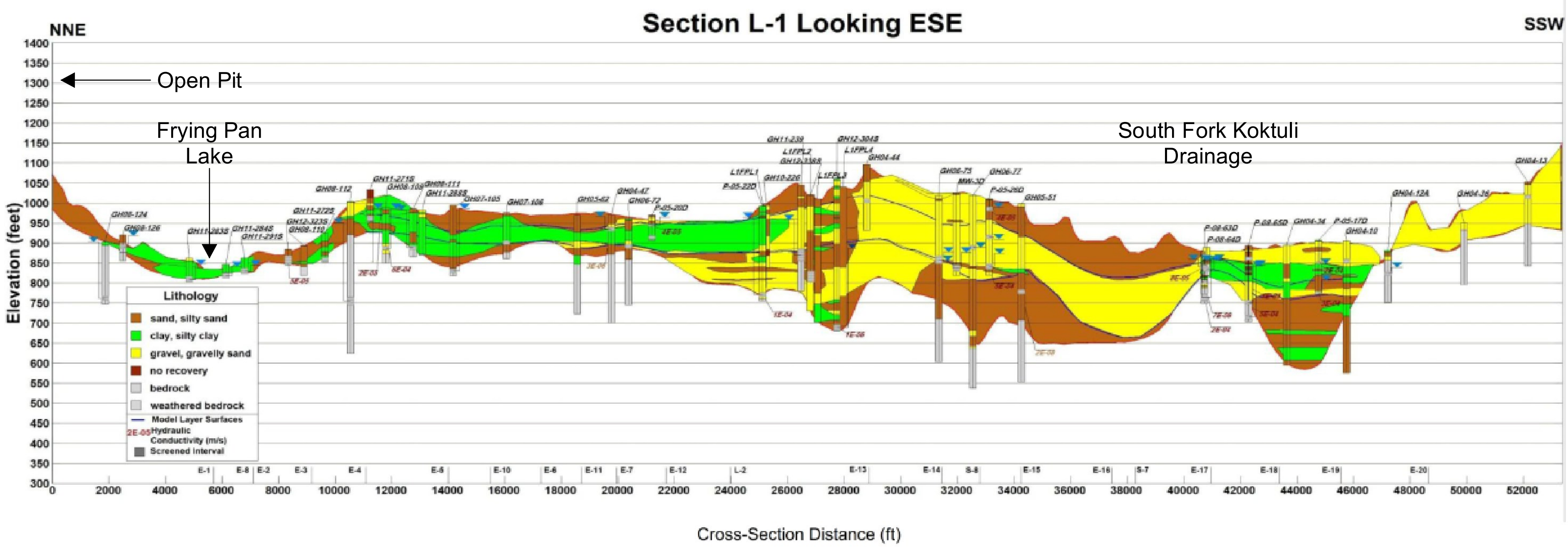
Sources: Schlumberger 2015a, Appendix 8.1B

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
4e-06 Hydraulic Conductivity (m/s)
Screened Interval
GH05-62 Well Name
E-13 Intersecting Cross-Section
Approximate Location of Pit Walls

US Army Corps of Engineers

CROSS-SECTION E-10
PEBBLE DEPOSIT AREA



Note: Location of cross-section is depicted on Figure 3.17-4. Vertical Exaggeration = 14x

Sources: Schlumberger 2015a, Appendix 8.1B

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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

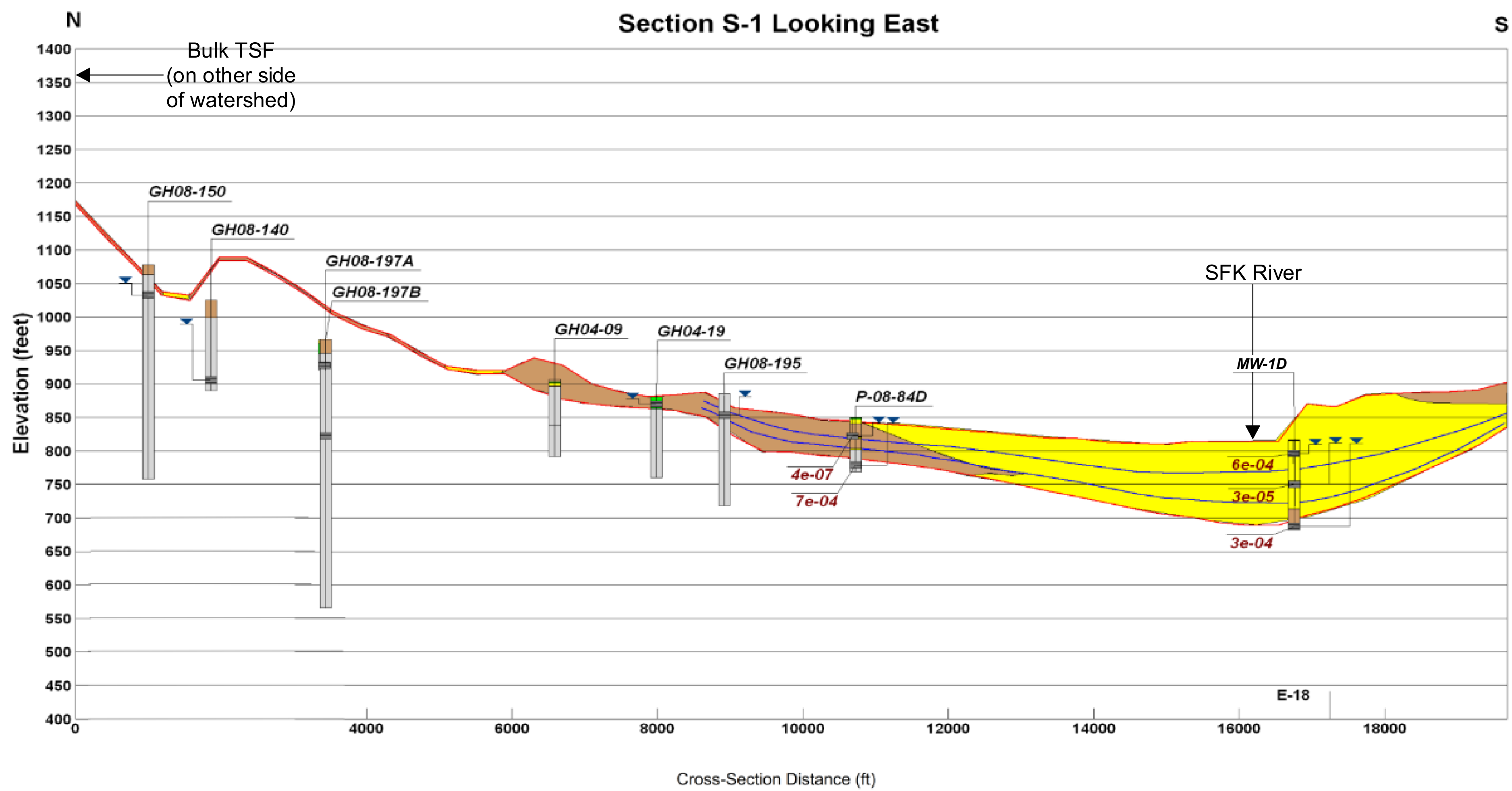
4e-06 Hydraulic Conductivity (m/s)

Screened Interval

GH05-62 Well Name

E-13 Intersecting Cross-Section

CROSS-SECTION L-1
FRYING PAN LAKE AND SOUTH FORK KOKTULI DRAINAGE



Note: Location of cross-section is depicted on Figure 3.17-4. Vertical Exaggeration = 13x

Sources: 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
- 4e-06 Hydraulic Conductivity (m/s)
- Screened Interval
- GH05-62 Well Name
- E-13 Intersecting Cross-Section

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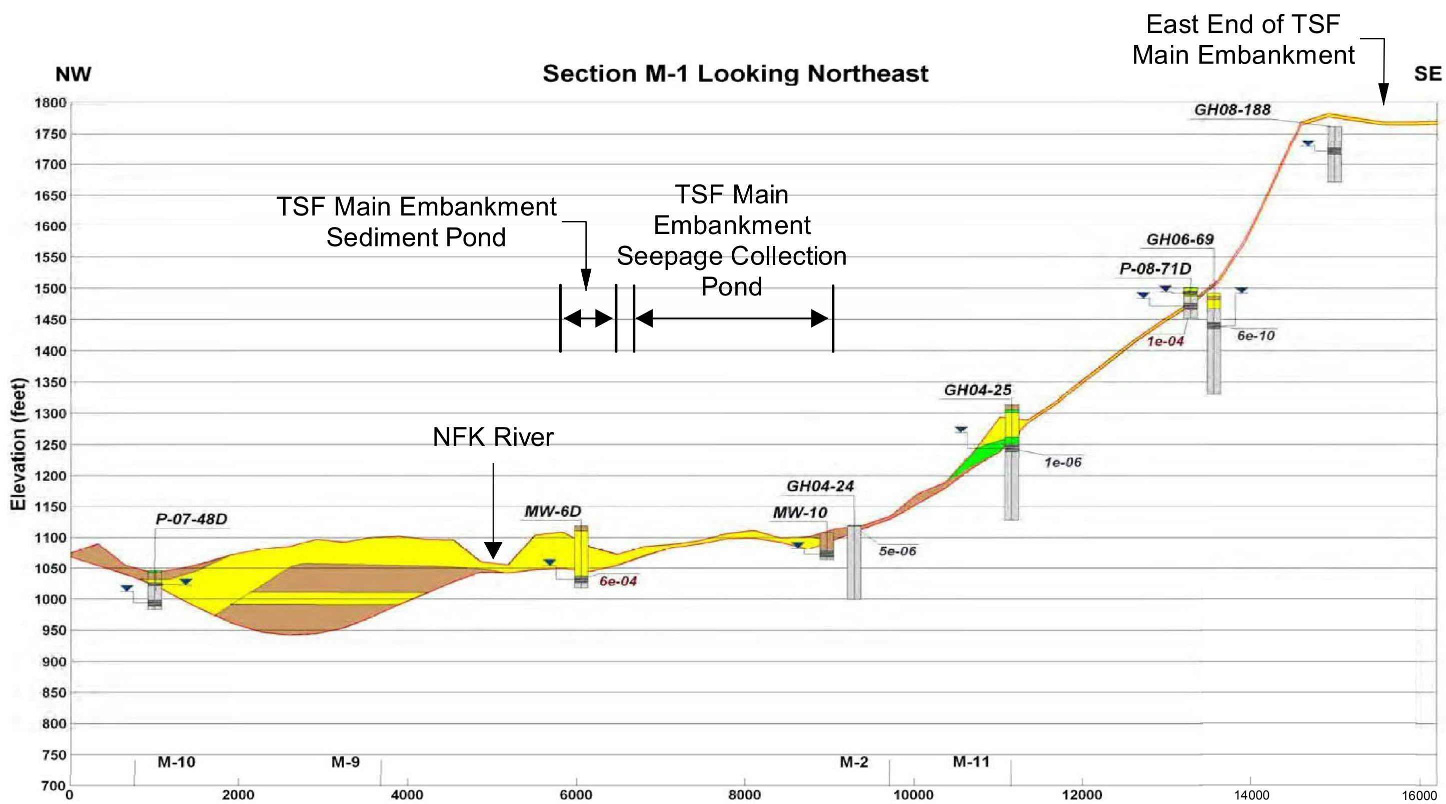
CROSS-SECTION S-1
SOUTH FORK KOKTULI DISCHARGE AREA



Note: Location of cross-section is depicted on Figure 3.17-4. Vertical Exaggeration = 8x

Sources: Schlumberger 2015a, Appendix 8.1B

Lithology

- sand, silty sand
- clay, silty clay
- gravel, gravelly sand
- Model Layer Surfaces
- 4e-06 Hydraulic Conductivity (m/s)
- Screened Interval

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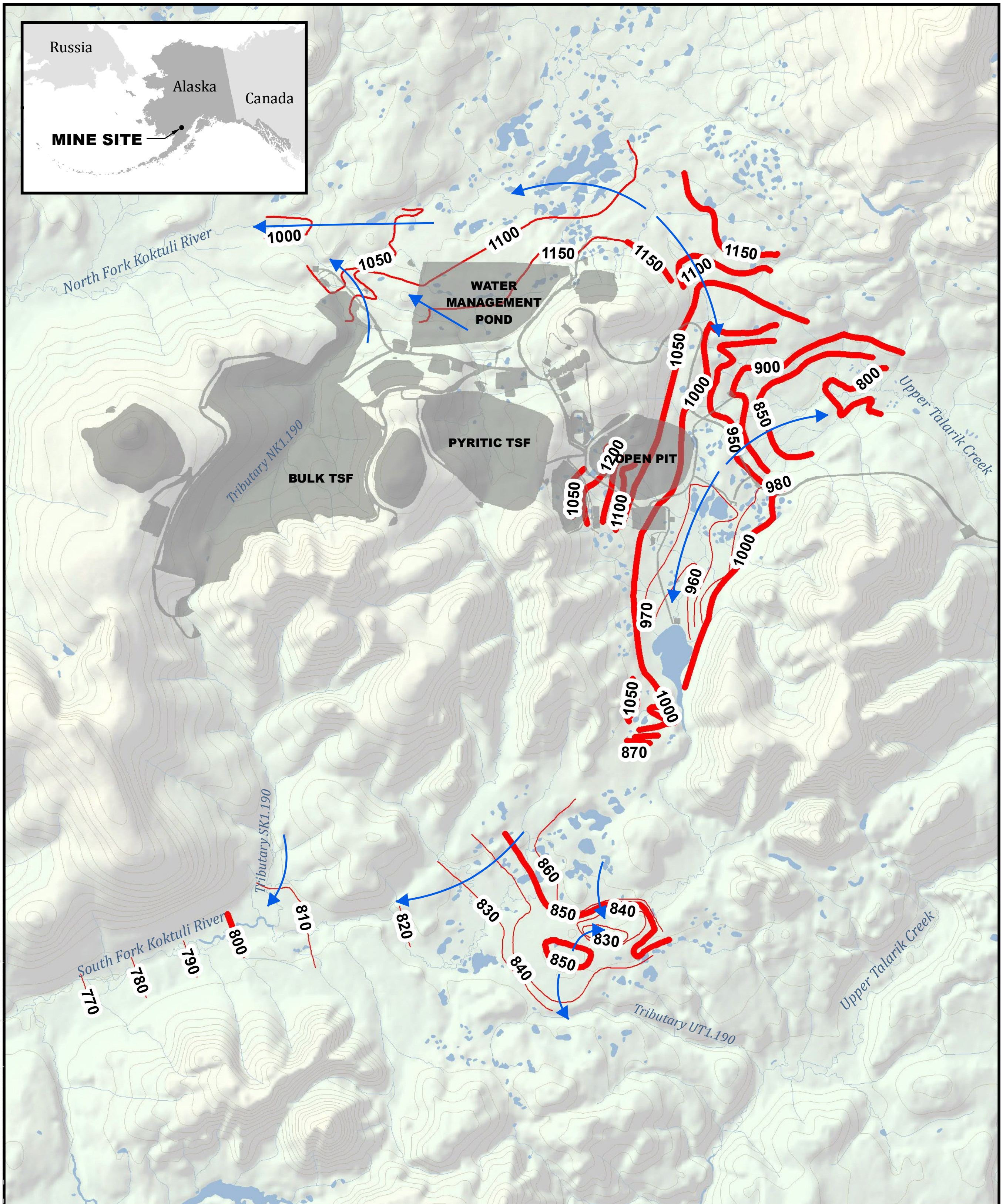
CROSS-SECTION M-1
NORTH FORK KOKTULI DRAINAGE

PEBBLE PROJECT EIS

FIGURE 3.17-8



Sources: Schlumberger 2015a, Figure 8.1E-1
Note: Shallow GWE Contours represents flow in uppermost overburden aquifer.

Shallow GWE Contours
- 10 ft
- 100 & 50 ft
- Groundwater Flow Direction

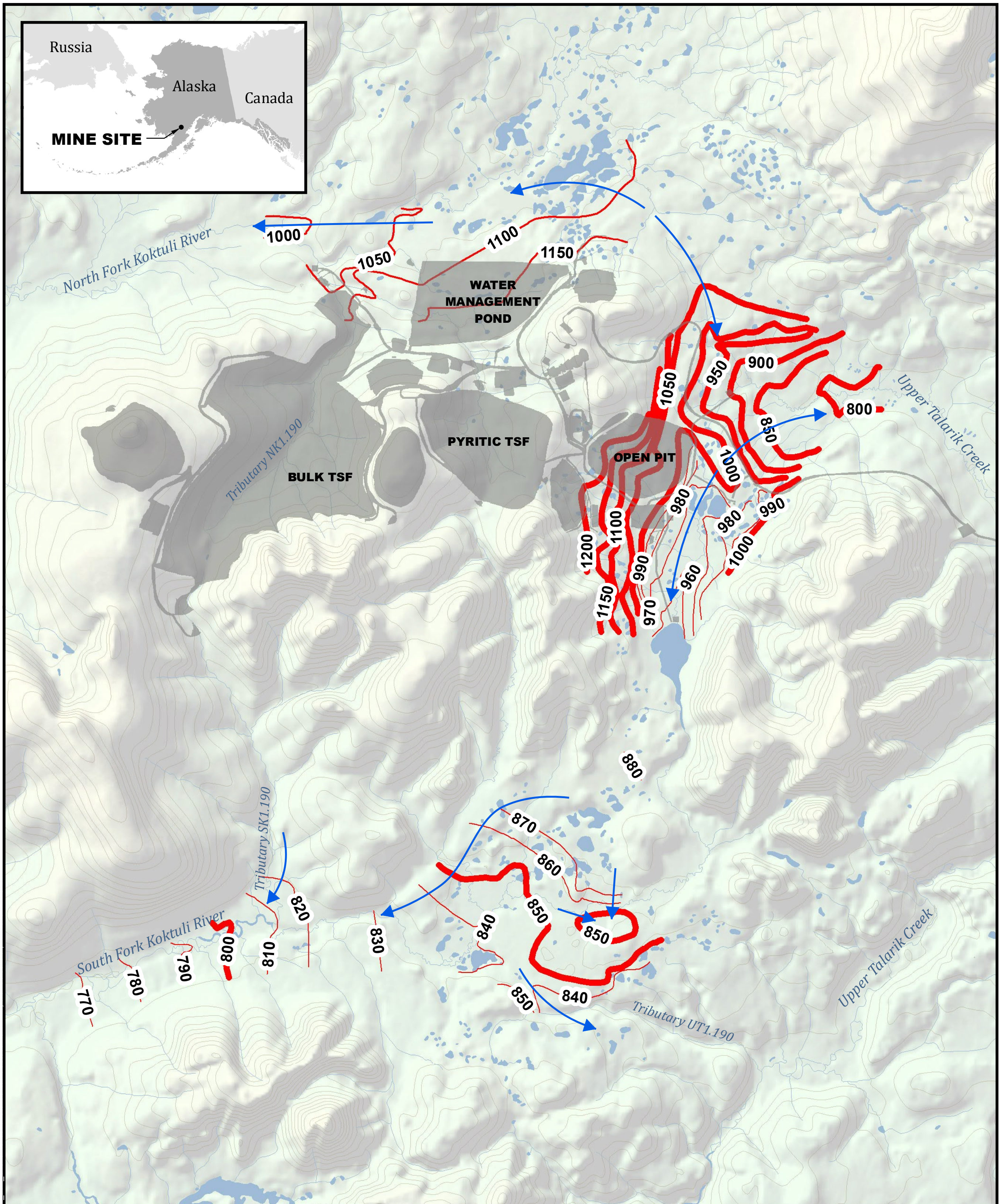
Other Features
- 100' Contour (Existing)
- River/Stream
- Lake/Pond
- Project Features

US Army Corps of Engineers

0.5 0 0.5 1
Miles

SHALLOW GROUNDWATER CONTOURS AND FLOW DIRECTIONS APRIL 2011 SEASONAL LOW WATER

FIGURE 3.17-9A



Sources: Schlumberger 2015a, Figure 8.1E-2

Note: Shallow GWE Contours represents flow in uppermost overburden aquifer.

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0.5 0 0.5 1

Miles

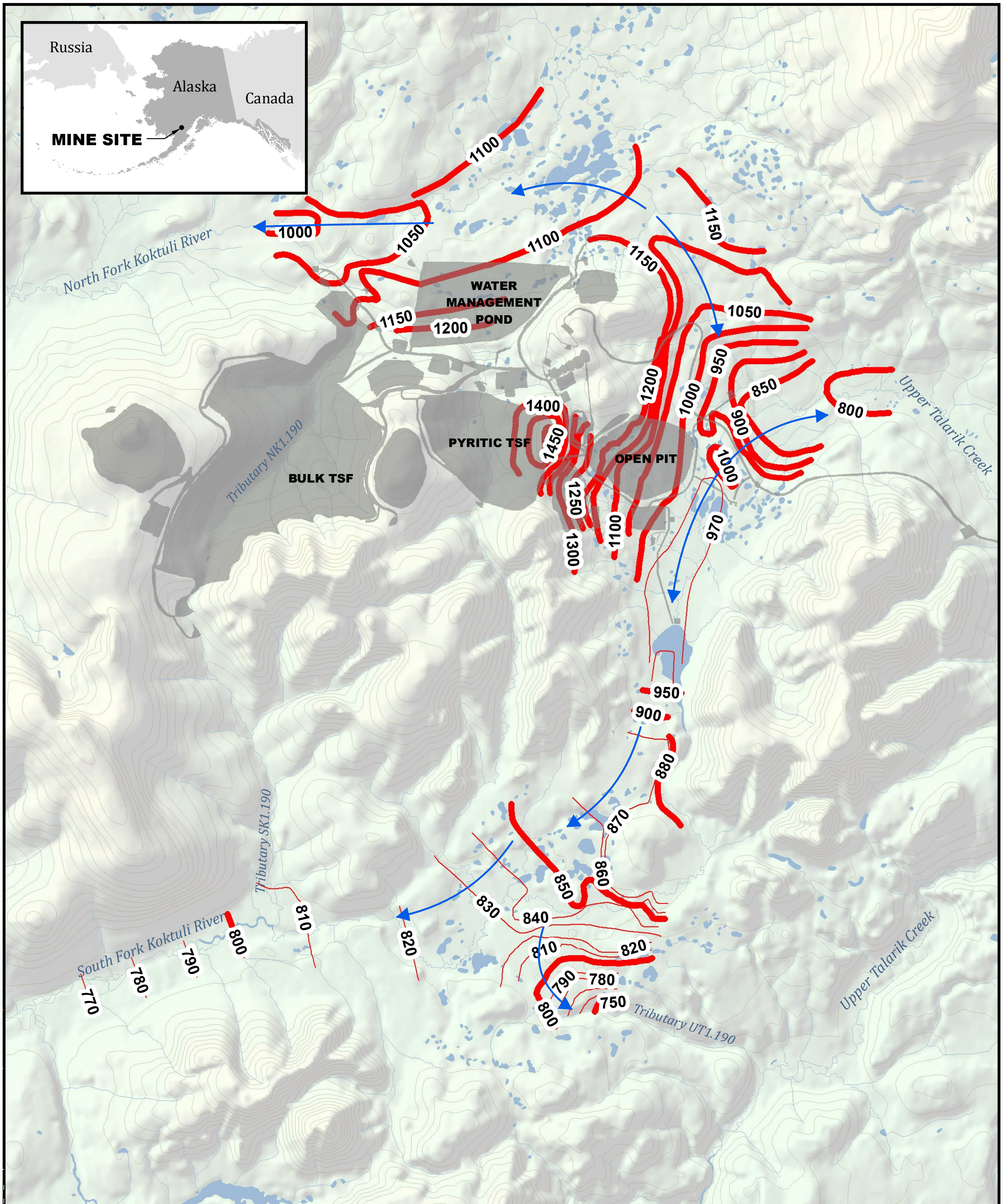
Shallow GWE Contours

- 10 ft
- 100 & 50 ft
- Groundwater Flow Direction

Other Features

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

SHALLOW GROUNDWATER CONTOURS AND FLOW DIRECTIONS OCTOBER 2011 SEASONAL HIGH WATER



Sources: Schlumberger 2015a, Figure 8.1E-2

Note: Deep GWE Contours represents flow in intermediate and deep overburden and weathered bedrock aquifers (Table K3.17-1).

Deep GWE Contours
- 10 ft
- 100 & 50 ft
- Groundwater Flow Direction

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

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0.5 0 0.5 1
Miles

DEEP GROUNDWATER CONTOURS AND FLOW DIRECTIONS APRIL 2011 SEASONAL LOW WATER

PEBBLE PROJECT EIS

FIGURE 3.17-10

3.17.1.2 Overview of Hydrogeological Characterization of the Area

The hydrogeology of the mine site area is largely composed of tributary valleys and adjacent ridges and knobs underlain by permeable weathered and fractured bedrock, talus[6], rubble, and solifluction[7] deposits. The weathered and fractured bedrock, which is up to 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, yielding areas of both enhanced permeability through fractures and reduced permeability where clay-rich fault gouge[8] is present. Some faults are laterally extensive and have the potential to function as barriers to groundwater flow, resulting in 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 compartmentalized flow affect regional flow. Most of the groundwater storage occurs in the overburden, which sustains winter base flow along most of the streams and rivers in the main valleys (Schlumberger 2015a).

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 located 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 on Section 3.13, Geology, Figure 3.13-2; Figure 3.17-5 through Figure 3.17-8; 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.

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 cross-catchment groundwater flow between the SFK River and Upper Talarik Creek (UTC), most of the water remains in each surface water watershed and is eventually discharged to streams along the valley bottoms.

[6] **Talus** is a steep slope deposit formed by the accumulation of broken rock debris.
[7] **Solifluction** refers to the slow creep of surficial soil layers downslope from freeze-thaw action.
[8] **Fault Gouge** is very fine crushed rock (e.g., clay-size) that results from friction caused by movement along a fault plane (between the two sides of a fault).

3.17.1.3 Aquifer Properties – Hydraulic Conductivity and Storativity

Hydraulic conductivity (K) (expressed in meters per second [m/s]) describes ability of 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 much more.

Hydraulic conductivities were measured at wells using response (e.g., slug or packer) and pump tests in areas of the project to characterize groundwater movement and interactions between aquifers and surface waterbodies and wetlands. A slug test is conducted by inserting an object (a slug) of known volume into a well or piezometer, then subsequently extracting it and measuring the rates of rise and/or fall of the water level as it returns to its original level. These data are used to calculate local hydraulic conductivity at an individual well. A pump test involves pumping water from a well and measuring the drawdown of the water level at the well being pumped and in other observation wells or piezometers in the area. Drawdown typically decreases with radial distance from the pumping well and increases as the length of time pumping continues. Packer tests measure the hydraulic conductivity of discrete intervals in a borehole in bedrock that are isolated with movable, inflatable packers. The rate of water injected into the interval between two packers is measured and used to estimate hydraulic conductivity.

Storativity (or specific yield in the case of an unconfined aquifer) is a measure of how much water the aquifer stores (how much water the aquifer will accept or release with changes in water level). Pump tests provide information to estimate storativity and 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 $8x10^{-9}$ m/s to $1x10^{-3}$ m/s (Appendix K3.17, 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 $1x10^{-5}$ (UTC) to $4x10^{-4}$ m/s (SFK River Flats). Hydraulic conductivity values for overburden materials in the Pebble deposit ($3x10^{-5}$ m/s) and UTC ($1x10^{-5}$ 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 and outside the Pebble deposit determined by pump and response tests is shown in Appendix K3.17, Figure K3.17-6. Results of pump tests in overburden indicate hydraulic conductivity was almost 10 times (one order of magnitude) higher than values derived from response tests (Schlumberger 2011a, 2015a). Pump 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 pump tests indicate the overburden aquifers are capable of conveying moderate to large quantities of groundwater. Most pumping rates for the tests ranged from 45 to 85 gallons per minute (gpm), which is a good indicator for the range of expected well yields in 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 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 K3.17-6 through Figure K3.17-9). 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 shallower data collected at depths 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 area ($2x10^{-5}$ 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 pump 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 shown in Appendix K3.17, Figure K3.17-6. Results of packer tests are shown in Figure K3.17-7 through Figure K3.17-9.

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.

3.17.1.4 Groundwater Flow Systems

Gravity-driven groundwater flow systems are commonly classified as local, intermediate, or regional following framework established by Toth (1963). Local flow systems typically deliver locally recharged groundwater to adjacent streams. Intermediate flow systems may deliver groundwater to an adjacent stream catchment. 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, and existing data show that the permeability of deep bedrock on a broad scale is consistently very low.

The topographic relief in the vicinity of the mine 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, the majority of water that recharges the groundwater system in local watersheds generally discharges in the same watersheds.

The water table maps (Figure 3.17-9a and Figure 3.17-9b) and the deep groundwater contours of the bedrock flow system (Figure 3.17-10) illustrate several features of the local and intermediate groundwater flow systems. In general, the water table reflects the ground surface topography; whereby 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 through 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. 3.17-9a, Figure 3.17-9b, and Figure 3.17-10) three groundwater divides in the analysis area as follows:

1. Between the UTC drainage and the NFK River drainage.
2. Near the Pebble deposit between the SFK River drainage and the UTC drainage.
3. Between the SFK River drainage and the tributary UT1.190 drainage.

In bedrock (Figure 3.17-10), deep 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 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 deep groundwater contour maps (Figure 3.17-9a, Figure 3.17-9b, and Figure 3.17-10) also present evidence of an intermediate-scale groundwater flow system. A closed "850" contour on the water table map between tributary UT1.190 and the SFK River in the southern area of the mapped water table indicates that local groundwater flow systems are present, with groundwater flow diverging from the center of the contour, which serves as a local groundwater divide. This groundwater flow is interpreted to be the result of local recharge within the closed contour area and the presence of a surficial aquifer to carry the flow. However, the deep groundwater contours for the same area depict a steady slope of the surface 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.

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 and snowmelt. 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 peak 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 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 (Appendix K3.17, Figure K3.17-10 and Figure K3.17-11) (Schlumberger 2015a). Lowest groundwater levels were recorded in late winter; and highest water levels were typically recorded during spring freshet 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 Site-Wide Water Balance Model

A water balance model is essentially a means to calculate inflow, outflow, and water storage and can be used to predict and manage water supply. The water balance 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 mine site groundwater flow model.

The water balance model is also used to estimate water flows during project operations and during the closure and post-closure phases. The water balance 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 1942 to 2017 based on data from mine site and regional weather stations.

The water balance model results are described in Section 3.16, Surface Water Hydrology, and briefly summarized below. The water balance model is described in detail in Schlumberger (2011a, 2015a) and Knight Piésold (2018a, 2018d). 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 3.17-1) 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 within the same drainage basin, with the exception of groundwater transfer between the SFK Flats Area (Area 5 on Figure 3.17-1) to the UTC drainage along tributary UT1.190 (Area 7) estimated to be 6 inches per year, or about one-third of the total underflow in the SFK Flats Area.

3.17.1.6 Mine Site Groundwater Flow Model

A three-dimensional numerical groundwater flow model was developed to simulate baseline groundwater conditions as described in detail in Schlumberger (2011a: Appendix 8.1J). From 2004 to 2013, the model was progressively updated to better represent the groundwater flow system and improve the match to observed groundwater elevations and streamflows. In 2017 to 2018, updates were incorporated (notably increasing the number of layers representing deep bedrock from one layer to six layers (PLP 2019-RFI 109) to better simulate rates of inter-watershed flow and groundwater discharge for the analysis of site-wide flow-reduction effects (Piteau Associates 2018a; Knight Piésold 2018n). The model setup and calibrations 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 10 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 water balance model and hydraulic conductivities were used as initial model input. Groundwater levels at wells, hydraulic conductivity comparisons to response and pumping tests, and flows to and from streams were used as calibration targets.

Model parameters were calibrated (adjusted) to calibration targets as described above. The model reasonably matched most field-measured water levels from monitoring wells and successfully estimated most flow rates to surface water, indicating that the hydrogeologic model is a feasible simulation of the groundwater system (Schlumberger 2011a, Appendix 8.1J).

The baseline groundwater model is important because it is used to predict potential effects caused by the project 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 proposed mine activities on groundwater and related impacts to surface water, wetlands, and water management activities are discussed in Section 4.17, Groundwater Hydrology.

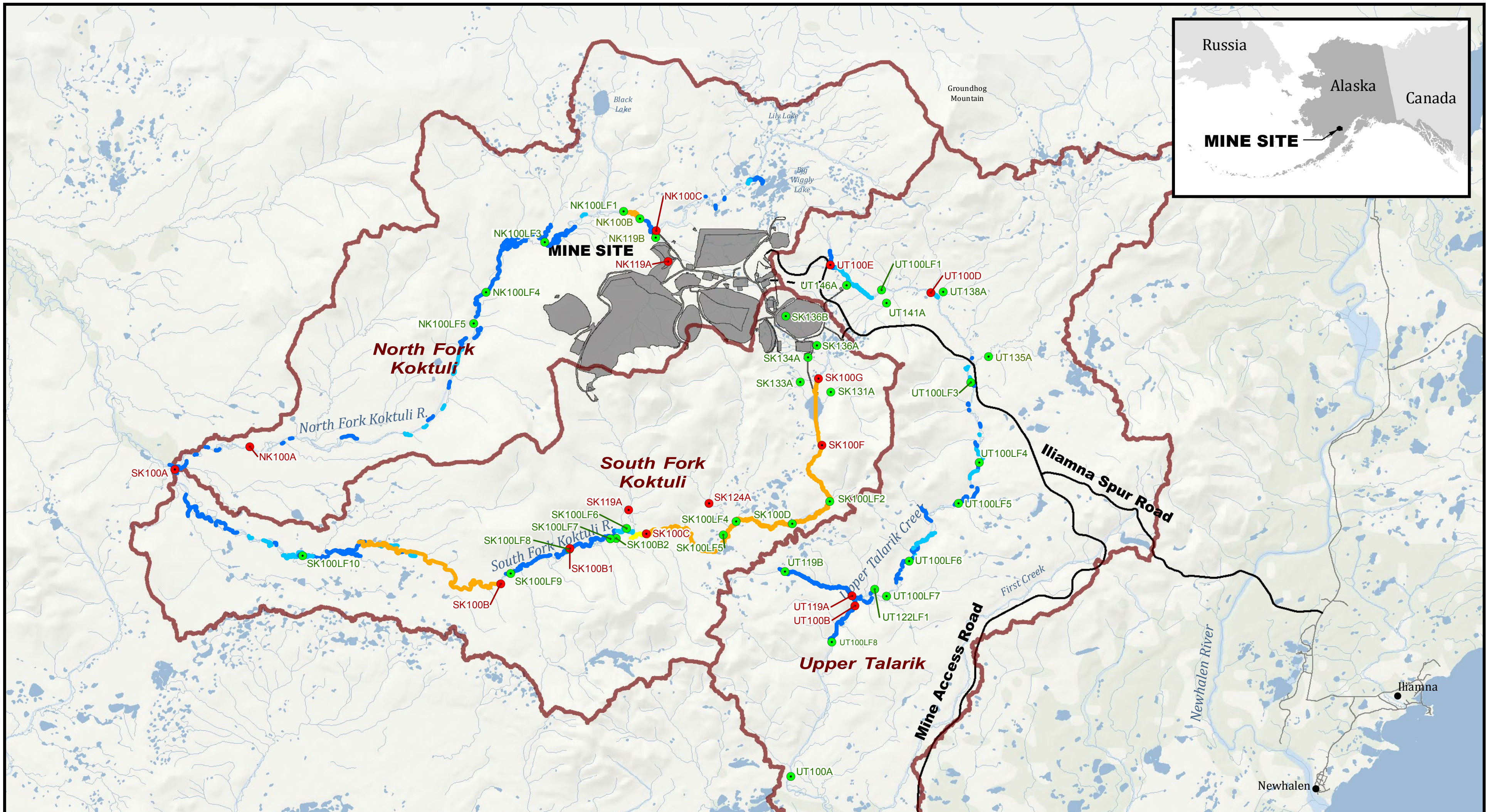
3.17.1.7 Groundwater and Surface Water Interaction

The region surrounding the mine site has significant groundwater-surface water interactions. Groundwater and surface water interaction was characterized based on detailed streamflow surveys and the site-wide water balance model.

The surface water flow surveys were conducted during periods of low streamflow and are described in detail in 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 depicts stream gage locations.

Based on the results of the streamflow surveys, gaining and losing stream reaches were identified, and possible explanations for the variability in flows between gages were provided. The majority of the 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) from SK100G to SK100F, from SK100F to SK100C, and between SK100B and SK100LF10. Figure 3.17-11 shows losing stream segments.



Sources: Knight Piesold et al. 2011a;
Knight Piesold 2015a

US Army Corps of Engineers

2 0 2 4
Miles

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

February 2006 Survey Results
- No Flow
- Intermittent
- Open Water
- Ice Covered/Not Surveyed

Alternative 1
- Transportation Corridor
- Natural Gas Pipeline
- Mine Site

Other Features
- Local Roads
- Major Drainage Boundary

2006 OPEN WATER SURVEY RESULTS DEPICTING LOSING STREAM SEGMENTS

FIGURE 3.17-11

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 Alternatives 1, 2, and 3 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.

The mine access road under Alternative 1, the mine access road under Alternatives 2 and 3, and the western part of the north access road are in the well-studied UTC drainage. Limited data are available for the port access road under Alternative 1, or port access road under Alternatives 2 and 3. 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). The mine access road under Alternative 1, and western part of the north access road under Alternatives 2 and 3, 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 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 the mine access road to the north, with Tertiary 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 within 1 to 2 miles of the north ferry terminal (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 under 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. 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 surface along steep slopes in weathered or fractured bedrock in this area. At the Diamond Point port site, shallow groundwater may be present in alluvial fan material in the small drainage on the north side of Cottonwood Bay (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 airport 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 on the order of 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

The mine access road is in the UTC drainage, where 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 $2x10^{-6}$ m/s to $4x10^{-5}$ 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 $2x10^{-7}$ m/s to $2x10^{-5}$ 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 1 transportation corridor parallels the First Creek tributary basin, which drains southward into the main UTC drainage above Iliamna Lake; the Alternatives 2 and 3 corridors cross 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 as 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 in 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. 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, groundwater likely flows perpendicular through steep slope deposits into the narrow valleys, and then parallels the direction of surface water flow down 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 creek flow south and southeast toward Kamishak Bay. Groundwater at the Diamond Point port site likely flows south towards Cottonwood Bay. Groundwater flow beneath beach 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 is likely to interact 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 corridor and data are the same as those discussed above for the transportation corridor, 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 Tertiary 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 Cook Inlet bluff at elevations of approximately 200 feet, produce water at depths between 8 and 30 feet below ground surface (ADNR 2018a). Deeper aquifers are also locally present in glacial deposits and sedimentary bedrock at depths between 50 and 120 feet (Nelson and Johnson 1981).

3.17.4 Groundwater Use

This section addresses groundwater use in the analysis area for all components and 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 2013. 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 3.17-12, ADNR 2018a[9]). The village of Newhalen has both community and private groundwater wells, while Iliamna and the community of Pedro Bay (along the Alternative 2 and Alternative 3 transportation corridors) rely 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 is available for private groundwater wells. No public data is 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 (DWPA) program. The DWPA program's intent is to delineate the boundaries of public (community) drinking water sources, identify potential risks from contamination, and determine 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 community groundwater supply wells in the villages described above. Various zones in the DWPAs for groundwater wells reflect buffers around wellheads, groundwater travel time, and direction of flow.

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

Pipeline. Residents of Anchor Point, about 5 miles south of the eastern terminus of the natural gas pipeline corridor on the Kenai Peninsula, use private groundwater wells for their domestic water supply. There are 11 private groundwater wells within 0.5 mile of the pipeline infrastructure on the eastern side of Cook Inlet (ADNR 2018) (Figure 3.17-13).

[9] 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 (calculated center of a parcel defined by legal land description boundaries [i.e., the Section, Township, and Range convention]).

Sources: PLP 2018d; ADEC 2018g; ADNR 2018a; ADOT&PF

US Army Corps of Engineers

0.5 0 0.5 1

Miles

Community Water System

Non-Community Water System

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

GPS - Global Positioning System coordinates location

Property Parcel

PLSS Centroid - the calculated center of a property defined by the US Public Land Survey System

Well locations are approximate and plotted based on ADNR data.

Other Features

Local Roads

WATER SUPPLY WELLS IN NEWHALEN AND ILIAMNA

PEBBLE PROJECT EIS

FIGURE 3.17-12

Sources: PLP 2018d; ADEC 2018f;
ADNR 2018c; ADOT&PF

US Army Corps of Engineers

500 0 500 1,000

Feet

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

- GPS - Global Positioning System coordinates location
- Property Parcel
- PLSS Centroid - the calculated center of a property defined by the US Public Land Survey System

Well locations are approximate and plotted based on ADNR data.

Alternative 1

- Project Infrastructure

Other Features

- Local Roads

WATER SUPPLY WELLS NEAR EASTERN PIPELINE TERMINUS

PEBBLE PROJECT EIS

FIGURE 3.17-13

3.18 WATER AND SEDIMENT QUALITY

This section describes existing conditions related to surface water, groundwater, and sediment quality in the Environmental Impact Statement (EIS) analysis area, which includes the proposed project footprint, and areas adjacent to or downstream of, and potentially affected by proposed project elements. In addition to areas potentially affected by the proposed alternative, areas potentially affected by other action alternatives (Alternatives 2 and 3) and variants are also assessed. Geochemistry at the mine site is described as it relates to the potential for release of chemicals into water from mining activities. Information on water and sediment quality criteria that are used to compare to existing and future conditions are provided in Appendix K3.18.

Water quality related evaluation factors to be considered by the US Army Corps of Engineers (USACE) in making determinations under Clean Water Act (CWA) 404(b)(1) Subpart C include the following physical and chemical characteristics of the aquatic ecosystem. These are addressed in this section of the EIS as noted below:

- **Substrate.** Substrate includes sediment at the bottom of waterbodies as well as wetland soils. Baseline characteristics of waterbody substrate (sediment) within the four project components are summarized below and additional details are provided in Appendix K3.18. Baseline information on wetland substrate is provided in Section 3.22, Wetlands and Other Waters/Special Aquatic Sites, and Section 3.14, Soils. Removal and disposal of dredged marine sediment under the northern route is addressed in Section 4.18, Water and Sediment Quality.
- **Suspended Particulates/Turbidity.** Measurements of total suspended solids (TSS) and turbidity in water are summarized in the surface water quality sections of this chapter and additional details are provided in Appendix K3.18.
- **Water Quality.** Water quality data are summarized in the surface water quality sections of this chapter and additional details are provided in Appendix K3.18.
- **Salinity Gradients.** Salinity trends are described below, and additional details are provided in Appendix K3.18.

3.18.1 Mine Site Area

3.18.1.1 Geochemistry

Rock chemistry typically drives water quality, facility design, and water treatment requirements at hard rock mines (ADNR 2014). The open pit, bulk tailings storage facility (TSF), pyritic TSF, and water management ponds at the mine site pose the most significant risk to water quality because they expose fresh rock to oxidation and leaching processes that may generate acidic drainage and leach metals that could impact water. The geochemistry of the rock that would be mined and exposed at the Pebble deposit is described in this section, followed by a summary of existing data for surface water, groundwater, and sediment at the mine site.

The Pebble deposit is a copper-gold-molybdenum porphyry deposit formed when older sedimentary and igneous rocks were intruded by a granitic magma laden with hot fluids carrying dissolved copper, gold, molybdenum, and silver, as well as quantities of rhenium and palladium. As the fluids cooled, concentrations of sulfide minerals, chalcopyrite ($CuFeS_2$), molybdenite (MoS_2), and pyrite (FeS_2), hosting the copper, gold, molybdenum, and silver metals, precipitated in quartz veins and disseminated throughout the granitic and adjacent sedimentary and igneous rocks.

Geochemical Processes

In the natural environment, rocks are broken down to create soil layers through exposure to air and water in a process called chemical weathering. During weathering, minerals in the rocks react with air (oxidation) and water (dissolving into solution) to release some of their constituents (ions) into the surrounding environment. The ions that go into solution may be transported away by overland runoff, streams, and groundwater. Therefore, weathering processes in rock can have a large influence on water quality. If a mineralized deposit is buried beneath other rocks, sediment, and soil, it naturally weathers very slowly. However, when a mineralized deposit is exposed at the surface, the weathering process can increase substantially due to exposure to rain, snow, and air.

Both ore and non-ore rocks contain minerals that can produce acid during weathering, the most common acid-generating mineral being pyrite (FeS_2), which contains iron and sulfur. The sulfur in pyrite reacts with oxygen and water to form sulfuric acid. The resulting acidic water is known as acid rock drainage (ARD), which in turn accelerates the weathering process further. Metals and other potentially harmful constituents can also be released during weathering in a process called metal leaching (ML). Most metals are released more rapidly in acidic water; however, some other constituents, including metalloids such as arsenic, molybdenum, and selenium, and salts such as sulfate, can be released into the environment even if the water draining the rock has a neutral or basic pH (Smith 2007). Acid generation can be counteracted if there are minerals present that neutralize the acid, such as calcite. The neutralization is generated through a reaction of calcite with the sulfuric acid. In the presence of those minerals, acidification is typically delayed until the neutralizing minerals are exhausted.

The purpose of geochemical characterization at the proposed mine site is to identify the potential of the rocks in and surrounding the mineralized deposit to produce ARD and/or ML that could affect water quality in surface water and/or groundwater. The characterization process involves studies of the mineralogy of the rocks, the quantities of minerals with potential to generate or neutralize acid, the amounts of leachable constituents in the rocks, and the rates of weathering and release of these minerals and constituents expected both during mining and after mining ceases. Geochemical characterization was undertaken as part of environmental baseline studies over a number of years to evaluate the potential for ARD and/or ML for the project (PLP 2018a; SRK 2011a, 2018a, 2018b, 2018c). A summary of the results of these studies follows, and additional details are provided in Appendix K3.18.

Geochemical Characterization

The objectives of the geochemical characterization program were to predict the weathering and leaching behavior of rock, tailings, and other materials that would be produced during mining and processing. Data produced from geochemical testing are used to predict the chemistry of waters that contact the rock exposed in the open pit, and the waste rock and tailings stored in the TSFs, and determine their ARD/ML potential.

Sampling and Testing Program. Samples for geochemical testing include representative overburden, rock cores, and metallurgical waste (tailings) samples from the Pebble east and west zones (PEZ and PWZ), and rock core samples from borings drilled in three proposed construction rock quarry areas. Samples were selected from the numerous exploration cores drilled to outline the deposit. A visual analysis was performed to ensure that samples were representative across all geochemical variations. Additionally, a gap analysis was performed and additional samples were manually selected to ensure a representative sampling pattern was used (SRK 2011a). A summary of the geochemical testing program is provided in Table K3.18-2. The samples included all the main Pebble deposit rock types and adjacent rock types that might be removed during mining. As of 2018, the program had included analysis of 1,023 rock samples from the Pebble deposit, and 26 samples of overburden materials. In addition, 64 tailings samples, composed mostly of angular, pyritic, and gold plant tailings, from test processing of ore composites have been characterized. To date, limited geochemical testing has been performed on the representative concentrate because possible designs for metallurgical processes are still at an investigative stage.

The rock samples were tested using industry standard mineralogical and geochemical analysis techniques to assess the chemical and mineralogical makeup of rocks in the project area, and evaluate the potential for the generation of ARD or leaching of mineral constituents into surface or groundwater. Tests included mineral abundance, ARD potential, bulk chemical composition, and constituent mobility. Geochemical tests have included acid-base accounting (ABA), sequential net acid generation, shake flask extractions, meteoric water mobility, humidity cells, subaqueous (saturated) leach columns, and on-site field weathering (barrel and bag) tests to evaluate rates of oxidation, acid generation, acid neutralization, and element leaching. The geologic settings between the two zones are comparable, with the same mineralizing system and the same host rocks. For this reason, data from both the PEZ and PWZ are used, and when appropriate, combined to create a more robust dataset (SRK 2018f). Selected geochemical data are summarized in data tables in Appendix K3.18, and described below.

Acid-Generating Potential. In some mineralized deposits, rock type alone can be a good indicator of whether a rock will potentially produce ARD and/or ML. There are two main geological divisions at the mine site. The mineralization is hosted by sedimentary and volcanic rocks of pre-Tertiary age. After the pre-Tertiary occurrence of mineralization, those rocks were partially eroded, then covered by other sedimentary and volcanic rock later in the Tertiary period. The later Tertiary age rocks at the mine site generally do not contain copper, gold, or other metals that would be economically viable to recover at the present time (SRK 2011a; PLP 2018a).

A summary of ABA data is provided in Table K3.18-3. ABA testing has determined that the pre-Tertiary mineralized sedimentary and plutonic rocks at the mine site are predominantly potentially acid generating (PAG). PAG waste rock is defined as any rock with a neutralization potential (NP) / acid-generating potential (AP) ratio equal to or greater than the local site-based criteria of 1.4 (PLP 2018a). The AP of these rocks is relatively high because they contain several percent pyrite, as indicated by the total sulfur content of greater than 1 percent, and they have limited NP. The distribution of pyrite (and consequently AP) was found to be influenced by the hydrothermal alteration zones overprinted on the deposit. In contrast, the majority of the Tertiary age rocks that comprise the cover and overburden materials at the proposed mine site are considered non-PAG because they have less than 1 percent pyrite, low total sulfur concentrations, and excess NP because carbonate minerals are abundant. However, a small proportion of the Tertiary age volcanic rocks were found to be PAG.

Weathering and Leaching Rates. To develop an understanding of weathering and leaching processes that might affect rocks exposed during mining (e.g., pit walls and stockpiled waste rock and tailings), additional laboratory and field geochemical tests were conducted. Laboratory tests included humidity cell, subaqueous (saturated) column, stored bag, and field barrel tests. Humidity cell test data obtained for periods up to 8 years allow interpretation of long-term acid generation potential and neutralization rates as the rocks are oxidized and leached during wet and dry cycles. Humidity cell test results were used to confirm ABA criteria for segregating PAG from non-PAG rocks and waste, based on the NP/AP ratio. The ABA and humidity cell data indicate that PAG and non-PAG rocks can be distinguished using an NP/AP ratio of 1.4 (PLP 2018a), and are applicable to pre-Tertiary, Tertiary, and overburden materials. The discrete site-specific PAG criteria of 1.4 was determined though analysis of the molar release rate obtained via humidity cell tests (PLP 2018a). The molar release rate is an equivalent to the NP/AP criteria and can be examined to determine the site-specific criteria for potential acid generation (Day et al. 1997). If the molar release ratio is greater than the NP/AP ratio, the waste rock has the potential to generate acid (SRK 2011a). PLP (2018a: Figure 11-28) depicts the molar ratio data from humidity cell test used to determine site specific criteria of 1.4.

Humidity cell tests also help to estimate the potential lag or delay in the onset of ARD using the sulfide oxidation and release rates and pH profiles. The delay occurs because acid-neutralizing minerals (e.g., calcite, feldspars, and micas) are not depleted instantly as acid is formed, but are consumed at different rates depending on their reactivity and abundance. Results show that pre-Tertiary rocks with low NP/AP ratios (less than 0.3) have little neutralization potential and are estimated to generate acid within 1 to 6 years (SRK 2018a). Pre-Tertiary rocks with NP/AP ratios of 1 have higher neutralization potential, which delays the estimated onset of acid generation to 8 to 20 years (SRK 2018a). These estimated times to onset of ARD are considered underestimates because they are based on data developed under ideal laboratory conditions. Actual conditions in the field, with colder temperatures and long winters, are likely to be less conducive to acid formation. Paste pH results for aged rock cores stored at the site suggest that acidification may be delayed up to 40 years for 95 percent of the pre-Tertiary mineralized rock (SRK 2011a). Given differences in the test conditions, laboratory and field tests suggest that oxidized pre-Tertiary mineralized rock may take up to several decades for acidification to occur.

Element release rates determined from kinetic tests, which were performed on both filtered and unfiltered samples, were mainly a function of leachate pH rather than the element content of the samples (SRK 2011a). Leaching of copper accelerated as pH decreased; therefore, the potential for metal release is linked to the potential for acid generation, and ABA data can be used to assess the potential for copper leaching. However, for some elements (arsenic, molybdenum, and selenium), release can be environmentally significant under neutral pH conditions as described in SRK (2011a). Tests on some samples of Tertiary rock showed elevated leaching of these elements under non-acidic conditions. Data analysis from the various geochemical tests performed yielded consistent results. Leaching data from humidity cell tests, barrel tests, and shake flask tests performed on samples collected in both the PWZ and PEZ were used to develop geochemical source terms for predictive water quality (SRK 2018c, 2018f). Additional information regarding how the data were used in water quality modeling is provided in Section 4.18, Water and Sediment Quality.

Tailings. Ore processing based on a conventional flotation process to recover chalcopyrite and molybdenite, the primary copper and molybdenum minerals, followed by treatment of pyrite to recover gold, would result in a low sulfide bulk tailing concentrate and a high-sulfide (pyrite-rich) tailing concentrate, respectively. Metallurgical process testing has produced a range of representative tailings products. Geochemical testing of 64 tailings samples indicates that the most volumetrically abundant product, bulk tailings, which would be produced under most of the processing approaches being considered, typically contains low to moderate total sulfur. Bulk tailings can be categorized as non-PAG if the total sulfur remains below 0.2 percent. Under equivalent conditions (including grain size and exposure to oxidizing conditions), the ARD potential for the bulk tailings is lower than that of mineralized rock, because most of the sulfur is removed to recover the economic minerals and separate out the pyritic tails while concentrating neutralizing minerals in the bulk tailings. Element leaching from the rougher tailings occurred at low rates, and unfiltered process supernatants were found to contain low levels of potential constituents relative to water quality standards. The pyrite and gold plant tailings have higher sulfide contents are often classified as PAG, and leach metals at higher rates. Appendix K3.18

provides additional information on the geochemical characteristics of the tailings and supernatant.

Open Pit Block Model. Because of the geochemical variability in the rocks, assessment of impacts resulting from geochemical processes requires consideration of the disposition and fate of the material that will be mined each year. The annual area and rock types mined can be estimated using the existing geologic block model (i.e., a computer model that shows the three-dimensional location of each type of rock and the likely order of mining). The geologic block model could be updated in the future to incorporate geochemical data so that mineralized and waste rock can be managed appropriately as mining proceeds. During mining, rock materials will be assessed using the block model to determine whether the mined rocks are PAG or non-PAG, and whether the mined material would be processed and disposed as tailings, or not processed and set aside as waste rock. Further information regarding the block model is provided in Appendix K3.18.

Based on the results obtained from the geochemical characterization studies, the majority of the rocks that would be expected to be mined from the PWZ do not have the potential for acid generation, and could be considered substantially acid neutralizing. However, some rocks do have the potential to leach certain non-acid constituents, mainly arsenic and sulfate. These results, and their influence on the existing baseline water quality at the mine site, are discussed in more detail in the next few sections.

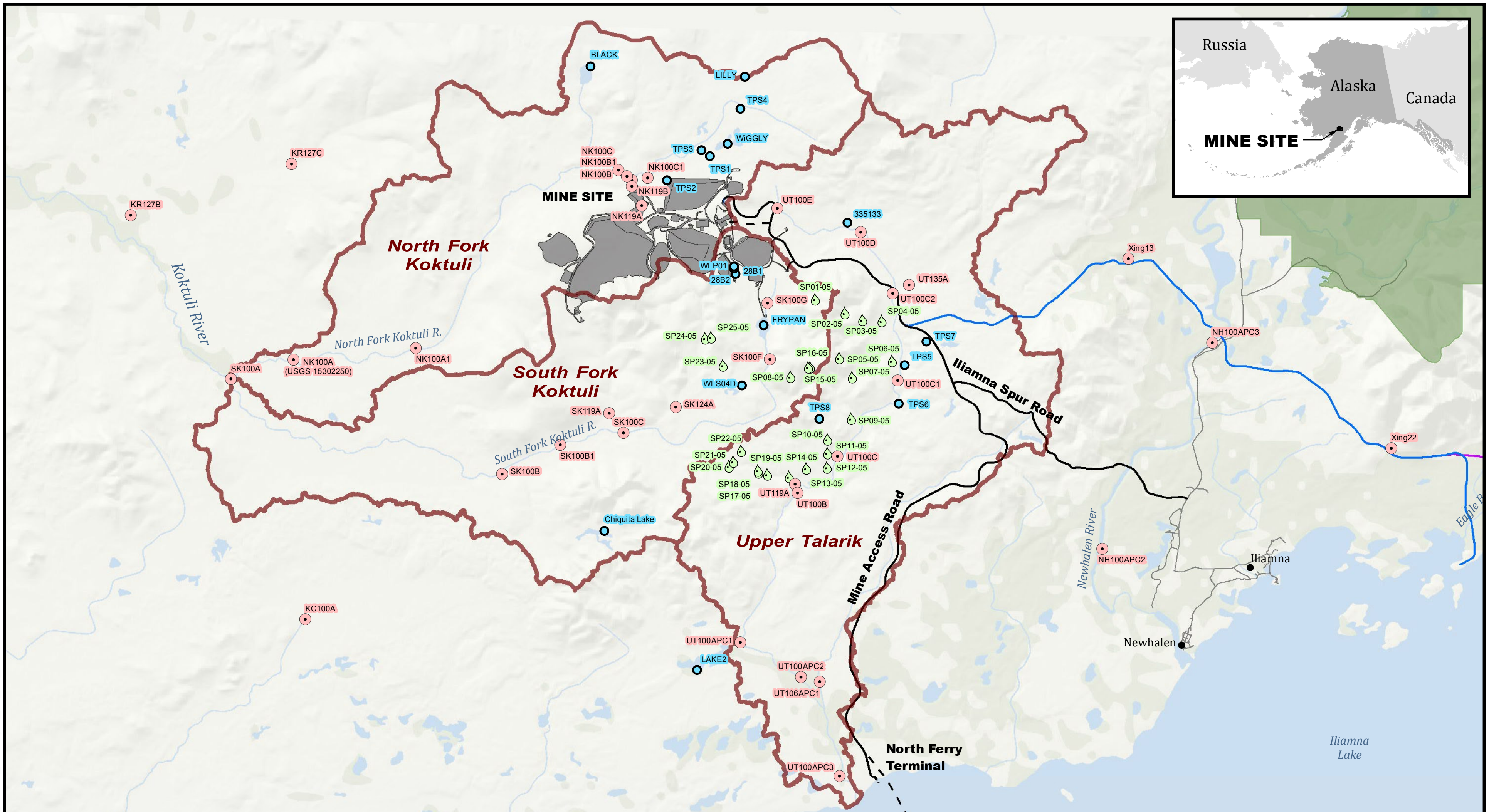
3.18.1.2 Surface Water Quality

The Pebble deposit and project area are located in the headwaters of the Upper Talarik Creek (UTC) and South Fork Koktuli (SFK) River drainages, and adjacent to the headwaters of the North Fork Koktuli (NFK) River drainage. The NFK River is on the north side of the project area. The Kaskanak Creek (KC) drainage lies south of the SFK River drainage.

Sampling Program. Water quality studies were conducted by Schlumberger et al. (2011a) and ERM (2018a) to quantify chemical and physical parameters that describe the quality of the water at the mine site and surrounding areas that would potentially be impacted by the alternatives. Water quality data were collected for rivers, lakes, and seeps in the project area, and throughout a 965 square mile area that includes the NFK River, SFK River, and UTC (Figure 3.18-1).

A comprehensive network of sampling stations was established in the project area for sampling surface water from streams, lakes, and seeps. Stream samples were collected from 44 locations during 50 sampling events from April 2004 through December 2008 (Schlumberger et al. 2011a). Lake and pond samples were collected from 19 lakes once or twice per year during 2006 and 2007. Seep samples were collected from 11 to 127 sample locations (depending on the year), two to five times per year.

Altogether between 2004 and 2008, over 1,000 samples were collected from streams, more than 600 samples from seeps, and approximately 50 samples from lakes. Additional samples were also collected during the supplementary water quality study period, which occurred from 2008 to 2013 (ERM 2018a).



Sources: EBD Chapter 9, Figure 9.1-2

US Army Corps of Engineers

2 0 2 4

Miles

Sampling Locations
- Streams
- Lakes
- Seeps

Alternative 1
- Mine Site
- Transportation Corridor
- Natural Gas Pipeline

Alternative 2
- Transportation Corridor

Alternative 3
- Transportation Corridor

Other Features
- Local Roads
- Major Drainage Boundary
- National Park

SURFACE WATER QUALITY SAMPLE LOCATIONS, MINE SITE AREA

Several tables are provided in Appendix K3.18 showing a summary of surface water quality data compared to criteria for waterbodies most pertinent to potential future impacts at the mine site. These include data for NFK, SFK, UTC, and Frying Pan Lake (Table K3.18-7 through Table K3.18-10). Additional water quality details on seeps and other lakes and streams in the mine site study area are provided in ERM (2018a: Tables 9.1-15 through 9.1-24) and Schlumberger et al. (2011a, Tables 9.1-31 through 9.1-36), and are incorporated by reference into the discussion below.

Overview of Sampling Results. The results of these analyses indicate that the baseline surface water resources can generally be characterized as cool, clear waters with near-neutral pH that are well-oxygenated, low in alkalinity, and generally low in nutrients and other trace elements. Water types ranged from calcium-magnesium-sodium-bicarbonate to calcium-magnesium-sodium-sulfate. Water quality data occasionally exceeded the maximum criteria for concentrations of various trace elements in some individual sample measurements; however, in no instance did the mean concentration of trace elements exceed the most stringent water quality guidelines. Cyanide was occasionally present at detectable concentrations in a limited number of samples. Cyanide detected in those samples is believed to be of natural origin, based on the distribution and lack of anthropogenic sources. Cyanide can occur naturally as a product of anabolism in some plants, bacteria, and fungi (CDC 2006). Additionally, there were consistently detectable concentrations of dissolved organic carbon. No detectable concentrations of petroleum hydrocarbons, polychlorinated biphenyls (PCBs), or pesticides were found.

Some differences in water quality between watersheds and trends in water quality along streams were noted. These are summarized below and in tables in Appendix K3.18. Higher concentrations of copper, molybdenum, nickel, zinc, and sulfate were present in SFK than in NFK, consistent with SFK's proximity to the Pebble deposit area. Total dissolved solids (TDS), pH, sodium, alkalinity, hardness, nitrogen (nitrate+nitrite), and nickel concentrations were greatest in the UTC drainage. The uppermost reach of UTC passes through a portion of the general deposit area, and also had significantly higher concentrations of all of these naturally occurring constituents than in NFK. TSS, potassium, chloride, iron, and arsenic concentrations were highest in KC, while cadmium and lead concentrations were highest in the NFK drainage. These characteristics of KC and NFK likely indicate that these parameters are unrelated to the deposit area, and represent water quality signatures that are distinct from the other drainage areas.

The following paragraphs discuss some of the specifics of the sample results and trends observed in the NFK, SFK, and UTC. Data summaries for these streams are provided in Tables K3.18-7 through K3.18-9, and trend analysis data in Table K3.18-14 through Table K3.18-16.

Total Dissolved Solids. The mean levels for TDS in streams, by watershed, ranged from 37 to 51 milligrams per liter (mg/L), which is 10 percent or less of the most stringent Alaska Department of Environmental Conservation (ADEC) water quality maximum criterion. Of the three streams that originate close to the deposit area, UTC and SFK had significantly higher TDS levels than NFK. Furthermore, a decrease in TDS levels with distance along the stream was more pronounced in the SFK and UTC watersheds than in the NFK watershed. Higher TDS in the UTC and SFK watersheds with decreasing trends downstream were expected, because the deposit area lies within their watersheds, and the oxidation of sulfide minerals associated with the deposit would release dissolved solids. The mean levels for TDS in lakes and seeps were similar to those for streams, with values of 49 and 42 mg/L, respectively.

Total Suspended Solids and Turbidity. Mean TSS values ranged from 1.19 mg/L to 3.21 mg/L in the NFK and UTC, respectively. The highest value for TSS was in KC, and the lowest was in the NFK. Mean TSS values did not exceed the most stringent water quality criteria for any rivers in the mine site area; however, at least one exceedance was recorded in a sample collected at the UTC. The mean for TSS in lakes and seeps was similar to that for streams.

pH. The pH values in surface water were close to neutral. The mean pH for streams by watershed ranged from 6.7 to 7.0. The mean pH values for lakes and seeps were 7.2 and 6.5, respectively. Because of the exposed Pebble deposit and seasonally fluctuating groundwater conditions in the area (see Section 3.17, Hydrogeology), it is possible that the oxidation of sulfide minerals release acid in this area; however, based on the mean pH data, carbonate minerals may be providing some pH buffering. Although the mean pH values fell within the range for pH specified in the most stringent ADEC criteria (6.5 to 8.5), 34 percent of all individual water quality samples did not meet the water quality criteria for pH. Recorded pH values ranged from 3.31 to 9.33 with the lowest pH recorded in the NFK and the highest recorded in UTC. The frequency of this trend in seeps was at least double that of streams, depending on the watershed.

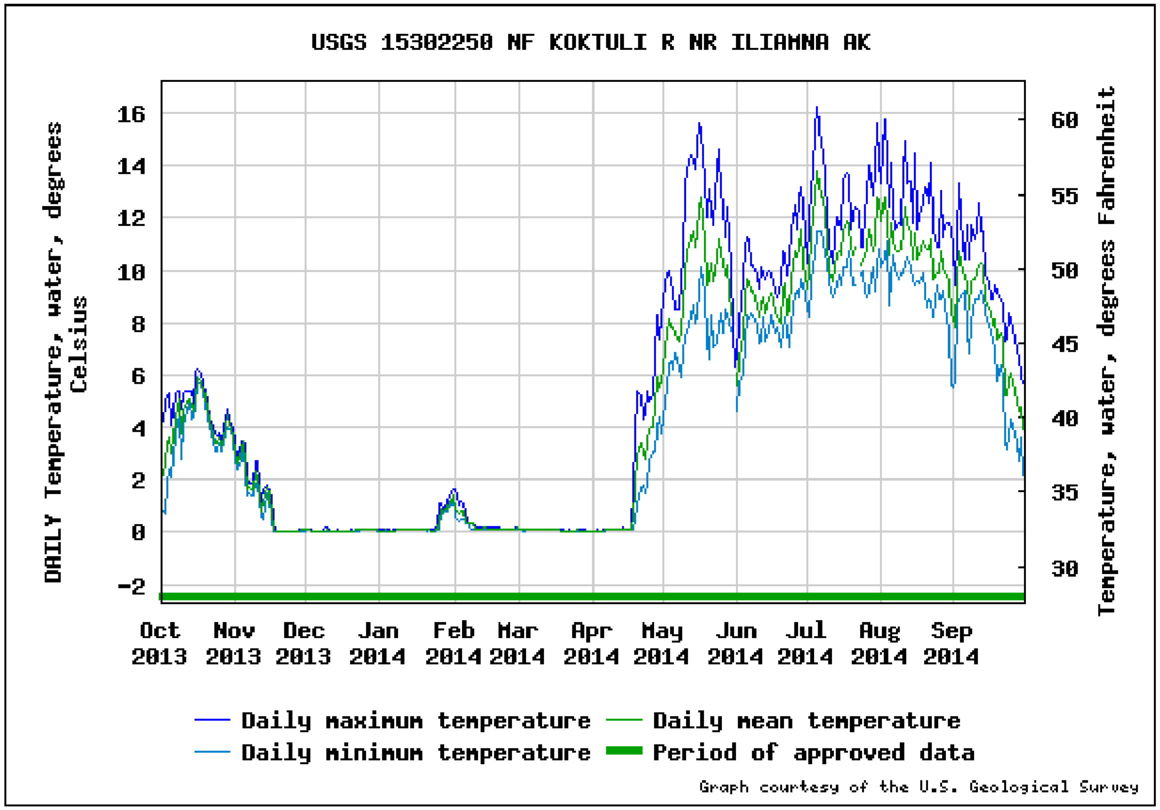
Alkalinity. The alkalinity of the surface water samples was low. Mean alkalinity for streams, by watershed, ranged from 17 to 32 mg/L. Mean alkalinity for lakes and seeps was 19 and 23 mg/L, respectively. Alkalinity was the parameter that was most frequently detected outside the range of the most stringent ADEC criterion. In all, 43 percent of all surface water samples were below the minimum criteria for alkalinity as specified by the ADEC. The frequency with which alkalinity values for lakes and seeps were below the minimum criterion was 10 to 20 percent higher than the frequency for streams.

Temperature. Mean water temperature in streams ranged from 4.0 to 4.8 degrees Celsius (°C), depending on the watershed. The standard deviation of temperature values measured in each watershed was approximately equal to the mean of the values, indicating a high level of variability. Lakes in the mine site area were considerably warmer, with a mean temperature of 12°C, and seeps slightly cooler, with a mean temperature of 3.4°C.

Temperature recording at the US Geological Survey (USGS) gaging station began in October 2013. While long-term water temperature trends are not available, these may vary as a subdued expression of long-term air temperature trends. Mean annual temperature trends in the region indicate that air temperatures have increased approximately 3°C over the past 50 to 60 years related to large-scale climate oscillation (Knight Piésold 2012, 2018a), trends that are predicted to continue into the next century (SNAP 2018). Figure 3.18-2 shows daily water temperatures in the NFK river.

Dissolved Oxygen. Dissolved oxygen (DO) concentrations in streams were very similar in all watersheds, with mean concentrations that ranged from 10.2 to 10.5 mg/L. These values are close to the theoretical solubility of oxygen of 12.3 mg/L at 900 feet above mean sea level (amsl) and a water temperature of 4°C. Although most samples indicated high DO, 7 percent of the samples had DO concentrations lower than the most stringent ADEC minimum criterion.

USGS Water-Year Summary for Site USGS 15302250



Source: USGS 2018

US Army Corps of Engineers

DAILY WATER TEMPERATURES IN NFK RIVER

Major Ions. Groundwater type can be characterized by the presence and predominance of specific ions, including anions and cations. The water type of most samples from streams in the mine site area ranged from calcium-magnesium-sodium-bicarbonate to calcium-magnesium-sodium-bicarbonate-sulfate. The cation composition was dominated by calcium and was relatively consistent. The anion composition had a wider range, with most stream samples being dominated by carbonate. The average water type of the lakes and seeps was generally the same as the streams; however, the seeps had a slightly greater range of water types, and the distribution of water types was slightly different. Specifically, the seeps included samples with a higher proportion of sulfate, and the samples also were distributed more evenly across the spectrum of anion composition, rather than being weighted toward the bicarbonate end of the spectrum.

Nutrients. Nutrients, which included total ammonia, total nitrogen (nitrate+nitrite), total phosphorous, and orthophosphate, had generally low concentrations, especially in lakes and seeps. Orthophosphate was generally not present at detectable levels, with one exception in the KC watershed. Total ammonia was detected in 19 to 36 percent of surface water samples, and mean concentrations ranged from 0.03 to 0.05 mg/L, depending on source (streams, lakes, or seeps). Nitrogen and phosphorous were detected in 66 to 98 percent of surface water samples, depending on the sample source. Mean concentrations of nitrogen ranged from 0.1 to 0.3 mg/L, and mean concentrations of total phosphorous ranged from 0.02 to 0.04 mg/L. None of the nutrient concentrations exceeded the most stringent ADEC maximum criterion. The coefficients of variation for nutrients were high compared to most other parameters, often in the range of 1 to 2.

Trace Elements. The trace elements aluminum, antimony, arsenic, barium, cadmium, copper, iron, lead, manganese, molybdenum, mercury, nickel, and zinc were detected in surface water, although at low concentrations. The frequency of detection depended on the watershed, and on whether the sample was collected from a stream, a lake, or a seep. Total and dissolved aluminum, barium, copper, iron, manganese, and molybdenum were typically the most frequently detected trace elements in the streams and lakes; the frequency of detection generally ranged from 85 to 100 percent, depending on sample source (streams, lakes, or seeps). The most frequently detected elements in the seeps were generally the same as those for the streams and lakes, but the frequency of detection was lower in the seeps (53 to 99 percent, rather than 85 to 100 percent). Exceptions to this general pattern included a frequency of detection for total and dissolved arsenic in KC of more than 98 percent. The trace elements arsenic, lead, nickel, and zinc had an intermediate frequency of detection in most waters sampled, with the exception of zinc, which had a higher frequency of detection (98 percent) in lakes. Cadmium had the lowest frequency of detection.

Some trace element concentrations in stream samples exceeded the most stringent ADEC maximum criteria. These are described below in relationship to watersheds (trend analyses for data within individual watersheds are provided in Appendix K3.18):

- Copper from the SFK watershed exceeded the water quality criterion most frequently, with total and dissolved copper exceeding the criterion in 42 and 34 percent of samples, respectively. In contrast, copper had one of the lowest frequencies of exceedance in other watersheds. The relatively high frequency of exceedance in the SFK watershed is probably related to proximity of the deposit.
- Total aluminum exceeded the most stringent ADEC maximum criterion in 12 to 22 percent of the stream samples from the SFK, UTC, and KC watersheds; and in 6 percent of the samples from the NFK watershed. In contrast, dissolved aluminum exceeded the criterion in only 1 percent of the stream samples, and only in the UTC

watershed; therefore, aluminum exceedances seem to be almost exclusively associated with suspended solids.

- Total lead exceeded the most stringent criterion in 8 to 16 percent of the stream samples, and was generally the next most frequently exceeded criterion after total aluminum. Dissolved lead exceeded the criterion in 1 to 6 percent of the stream samples, and was second only to copper for frequency of exceedance for dissolved elements.
- Total manganese exceeded the criterion in 15 percent of stream samples from the SFK and UTC watersheds, in 3 percent of the samples from the NFK watershed, and in none of the samples from the KC watershed. Similar to aluminum, manganese exceedances appear to be associated with suspended solids.
- Concentrations of total antimony, cadmium, iron, mercury, and zinc for the stream samples rarely exceeded the criteria (0.3 to 4 percent).
- In samples from seeps, exceedances of the most stringent maximum criteria included total and dissolved aluminum (17.2 percent total and 22.94 percent dissolved), total and dissolved copper (30.51 percent total and 42.78 percent dissolved), total and dissolved iron (4.61 percent total and 4.91 percent), total and dissolved nickel (23.21 percent total and 23.58 percent dissolved), total and dissolved lead (17.00 percent total and 36.31 percent dissolved), total and dissolved cadmium (33.14 percent total and 42.78 percent dissolved), total and dissolved silver (14.34 percent total and 34.82 percent dissolved, total and dissolved zinc (11.03 percent total and 31.37 percent dissolved), and dissolved manganese (17.86 percent).

Cyanide was occasionally detected in the surface water samples. Total cyanide was detected in 2 to 15 percent of all samples, depending on sample source (streams, lakes, or seeps), and weak acid dissociable cyanide was detected in 5 to 13 percent of all samples. Concentrations of weak acid dissociable cyanide in samples were compared with the most stringent ADEC maximum criterion, and exceeded this criterion in 1 to 3 percent of the stream samples, depending on the watershed.

Dissolved organic carbon was detected in 93 to 100 percent of the stream samples, and the mean concentrations ranged from 1 to 2 mg/L, depending on the watershed.

Concentrations of petroleum hydrocarbons, volatile and semi-volatile organic compounds, polychlorinated biphenyls, and pesticides were not detected.

3.18.1.3 Groundwater Quality

Mine Site Monitoring Wells. A total of 77 groundwater monitoring wells with depths up to 200 feet below ground surface were installed in the project area. Two additional drill holes (DH-8417 and GH10-220) were used for groundwater sampling in deep bedrock in the deposit area at depths ranging from 210 to 4,050 feet. Table K3.18-17 provides a list of wells completed in and outside of the Pebble deposit area, along with depth and bedrock lithology. The location of the wells is shown on Figure 3.17-2. The results of groundwater quality testing are summarized in Table K3.18-18 and discussed below based on mean values for wells grouped by lithology (ERM 2018a). These data were used in the Knight Piésold (2018a) Operations Water Management Plan to predict the water quality of pit dewatering water going to water management ponds and influent to the water treatment plants (see Section 4.18, Water and Sediment Quality).

Groundwater samples from depths of 200 feet or less were characterized by mean levels of TDS ranging from less than 90 mg/L to over 150 mg/L (higher in bedrock wells); mean pH values between 4.4 and 7.3; mean DO concentrations ranging from 2.6 to 9.1 mg/L; and mean concentrations of dissolved trace elements above the most stringent ADEC water quality maximum criteria for several constituents (aluminum, copper, iron, lead, and manganese).

Concentrations of TDS in groundwater generally decreased with distance from the deposit area, and results from deep drill hole DH-8417 (mean of 835 mg/L) suggest that concentrations of TDS increase with depth (Knight Piésold 2018a). Monitoring wells MW-14D in the SFK watershed and P08-69D in the NFK watershed were the only wells showing a relatively high TDS level that was not consistent with this general pattern. While data from well MW-14D are somewhat anomalous, they could be interpreted to suggest that the deposit has influenced groundwater quality.

Most of the groundwater samples had a composition that ranged from calcium-bicarbonate to calcium-magnesium-bicarbonate and calcium-sodium-bicarbonate. Some samples from relatively close to the deposit area had a higher proportion of sulfate, suggesting that the groundwater in this area is influenced by oxidation of the sulfide minerals that are associated with the deposit. As the sulfide minerals oxidize, iron, sulfuric acid, and probably trace elements are released. The acid is neutralized by carbonate minerals such as calcite and dolomite, which release calcium, magnesium, manganese, carbonate, and usually some trace elements. This series of geochemical reactions increases the concentration of TDS and the proportion of sulfate in the groundwater.

Although sulfides appear to be oxidizing locally in the Pebble deposit area, the groundwater is not acidic overall. The lowest mean pH value of 4.4 was recorded at only one well location in shallow bedrock. In the remaining wells, mean pH values ranged from 6.7 to 7.9, indicating broadly that the groundwater is not acidic. Eight wells (six completed in overburden, two in bedrock) had mean pH values greater than 7.0, and three of these wells (all completed in overburden) had the highest mean TDS concentrations observed.

The DO measured in the groundwater was generally high. Twenty-seven wells had mean DO concentrations of 8 mg/L or greater. Wells with relatively high TDS, measured in filtered samples, also generally showed relatively high concentrations of arsenic, barium, and molybdenum compared with other wells in the analysis area. All of the wells with more than two trace metals at relatively high concentrations were located closer to the deposit area.

Some systematic differences in concentrations were observed with depth, as indicated by the differences in concentration between wells that were completed in overburden and those completed in bedrock (Table K3.18-18). Specifically, the concentrations of antimony, arsenic, copper, iron, manganese, and molybdenum tended to be higher in wells completed in bedrock than in wells completed in overburden. Conversely, the concentrations of DO and nickel tended to be lower in bedrock wells than in overburden wells.

Drinking Water Protection/Drinking Water Wells. Drinking water sources are regulated by federal and state laws and regulations, mainly the Safe Drinking Water Act (SDWA). Under the SDWA, US Environmental Protection Agency (EPA) sets standards for drinking water quality and implements various technical and financial programs to ensure drinking water safety. Alaska has primacy on regulating public drinking water systems with many references to federal regulations. Regulations also contain references to drinking water protection areas that have been mapped for many public drinking water systems. There are currently no designated drinking water protection areas in the project area.

There are currently no drinking water wells at the mine site (ADNR 2018a). During exploration and monitoring activities, personnel typically stay in Iliamna and use local water supplies in that community (described below). With project development, groundwater wells would be installed on the northern side of the mine site to supply potable water. Groundwater testing at that location has shown that minimal treatment would be required (filtration, chlorination and pH adjustment) to develop a potable water source (PLP 2018d).

3.18.1.4 Substrate/Sediment Quality

This section describes baseline information on waterbody substrates at the mine site. Baseline information on wetland substrate is provided in Section 3.22, Wetlands and Other Waters/Special Aquatic Sites, and Section 3.14, Soils. Baseline physical and chemical data on substrate/sediment from the major drainages and other waterbodies at the mine site were collected between 2004 and 2008 (Knight Piésold 2011a; R2 et al. 2011a; HDR 2011a; SLR et al. 2011a; Three Parameters Plus and HDR 2011). Sample locations are shown on Figure 3.18-3. The National Uranium Resource Evaluation (NURE) program also collected a variety of substrate samples across the region in 1977 (Grossman 1998). NURE data include basic physical substrate descriptions and thorough chemical analyses, as well as reporting of potential contaminant sources, and are included below. NURE collected and analyzed data for eleven elements including sodium, titanium, iron, copper, zinc, arsenic, cerium, hafnium, lead, thorium, and uranium (Grossman 1998).

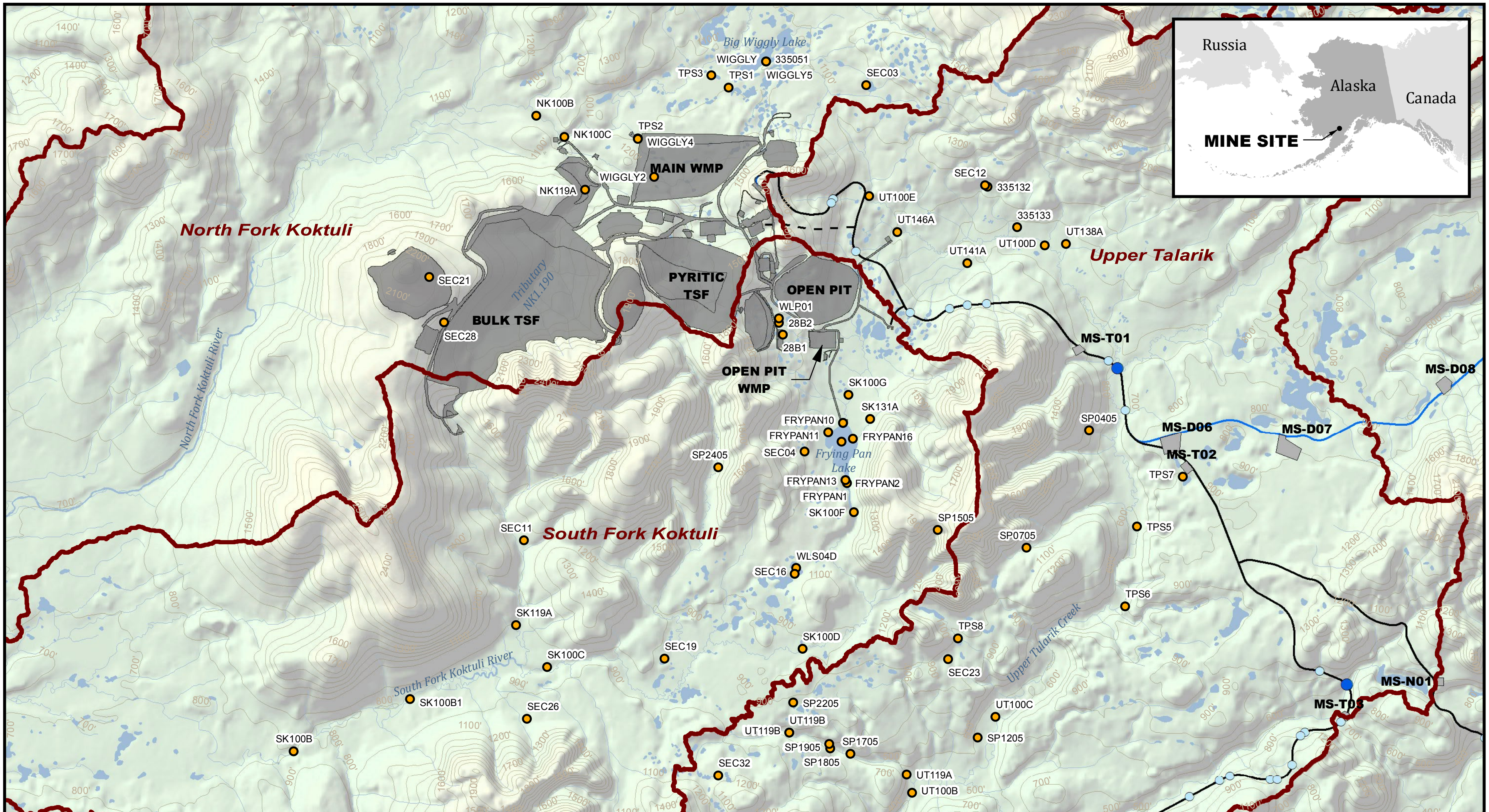
Physical Characteristics. Waterbody substrate data coverage within the mine site includes the SFK, NFK, and UTC drainages. Streambed sediment from these drainages is dominated by medium to coarse gravels, to small cobbles, with boulders present in stretches of rapids. In areas of low water velocity and pools, sands and silts are more common, and organic sediments are present in some areas (Knight Piésold 2011a; R2 et al. 2011a). The NURE data collected from the region include basic physical substrate descriptions and thorough chemical analyses, as well as reporting evidence for potential local contaminant sources. Twelve samples of pond substrate collected by NURE within approximately 20 miles of the mine site were all reported as mud/fine sediment (Grossman 1998). Limited data from the shores of Frying Pan Lake show a sand, silt, and gravel substrate (R2 et al. 2011a).

Chemical Quality. Between 2004 and 2007, a total of 198 samples of sediment from lakes, ponds, seeps, and major and minor drainages in the analysis area were sampled and analyzed for their content of naturally occurring trace elements, anions, cations, and organics (SLR et al. 2011a). A summary of the data is provided in Table K3.18-19. Samples collected from wetland substrates are included in the summary of soil chemical quality in Appendix K3.14, Soils, Table K3.14-2 and Table K3.14-3.

Of the 26 trace elements for which samples were analyzed, all were present above analytical detection limits in at least some of the samples, with aluminum, iron, calcium, and magnesium present at substantially higher concentrations than the other elements. Mercury content of sediment samples from the mine site was the lowest level detected, at a mean concentration of 0.040 milligrams per kilogram (mg/kg). Comparing sediment from the major drainages, copper was the only element showing significant variation, likely due to the difference in rock composition across drainages. Copper concentrations were particularly high in SFK sediment, likely due to copper-rich bedrock at the headwaters. In comparison to federal National Oceanic and Atmospheric Administration (NOAA) sediment quality guidelines (SQGs) (Table K3.18-1), the highest detected concentrations of four metals (arsenic, chromium, copper, and nickel) exceeded concentrations that may have an adverse effect on benthic organisms [both the threshold effects level (TEL) and higher probable effects level (PEL)]. These samples were from sediment in the SFK drainage (for arsenic and copper) and UTC drainage (for chromium and nickel). The mean concentration of arsenic exceeded the TEL across the study area.

Sediment from ponds and minor drainages in the mine site area showed higher concentrations of anions and cations such as sulfate, ammonia, and sodium than did other waterbodies. Total cyanide concentrations were the lowest of the analyzed anions on average, with a mean concentration of 0.39 mg/kg (SLR et al. 2011a). Of the 12 pond sediment samples analyzed by the NURE within 20 miles of the mine site area, none showed evidence of contamination (Grossman 1998).

Analyses of several organic compounds (gasoline range organics [GRO], diesel range organics [DRO], residual range organics [RRO], volatile organic compounds [VOCs], semi-volatile organic compounds [SVOCs], and polynuclear aromatic hydrocarbons [PAHs]) were performed on one mine site pond sample to identify the potential presence of naturally occurring hydrocarbons. Of the compounds analyzed, DRO, RRO, and 12 of 18 PAHs were detected. Because of the remote undeveloped nature of the area, these compounds are likely present due to the biogenic breakdown of aquatic plants, historic wildfires, or volcanic activity (e.g., Abdel-Shafy and Mansour 2015). Total organic carbon was detected in all 34 samples tested, with a mean concentration of 6.05 percent.



Sources: EBD Chapter 10. Figure 10.1-1

US Army Corps of Engineers

0.5 0 0.5 1

Miles

Sediment Quality Sample

Major Drainage Boundary

Alternative 1

Bridge

Culvert

Material Site

Mine Site

Transportation Corridor

Natural Gas Pipeline

Alternative 2/3

Transportation Corridor

Other Features

River/Stream

Lake/Pond

100' Contour (Existing)

SEDIMENT QUALITY SAMPLE LOCATIONS, MINE SITE AREA

PEBBLE PROJECT EIS

FIGURE 3.18-3

3.18.2 Transportation Corridor

The 84-mile long proposed access corridor under Alternative 1 would cross numerous streams within the Bristol Bay and Cook Inlet watersheds, and includes an 18-mile crossing of Iliamna Lake. The corridor originates in the Nushagak watershed at the mine site, and traverses the Kvichak watershed on the north side of the Alaska Peninsula; both are within the greater Bristol Bay watershed (Figure 3.16-1). The south end of the corridor terminates in the Tuxedni-Kamishak bays watershed of the greater Cook Inlet watershed. More detailed descriptions of these watersheds are provided in Section 3.16, Surface Water Hydrology. Additional information specific to Alternatives 2 and 3 is provided in Appendix K3.18.

3.18.2.1 Surface Water Quality

Mine Access Road. Surface water quality data described above for the UTC drainage at the mine site are pertinent to the upper part of the mine access road. Stream data for UTC is summarized in Table K3.18-9, and spatial trends are presented in Table K3.18-16. Although exceedances were measured in some samples, mean concentrations of all measured constituents for the UTC were below the most stringent water quality standards. Additionally, field studies in 2018 included turbidity measurements at stream crossing sites. Field study measurements indicate that all stream crossings along both the mine access road and the Iliamna spur road yield turbidity below the minimum detection level for the instrument used (65 centimeter [cm] turbidity tube; 7-11 Nephelometric Turbidity Units [NTU] detection level) (PLP 2018-RFI 036).

Newhalen River and North Access Road (Alternatives 2 and 3). A total of 16 surface water sampling stations were established and sampled by Schlumberger et al. (2011a) along the north access route extending east from the Newhalen River (Figure 3.18-4). About 12 samples were collected at each station over a 2-year period in 2004 and 2005. One of the stations, located on the Newhalen River upstream of the proposed Newhalen Bridge, is pertinent to both the proposed transportation corridor under Alternative 1 and the northern access route under Alternatives 2 and 3. Table K3.18-11 and Table K3.18-12 provide a summary of the surface water quality data for the western and eastern parts of the northern access route, respectively. Data are described below for both the Newhalen River and collectively for all stations along the north access road.

Sources: EBD Chapter 9, Figure 9.3-1

SURFACE WATER QUALITY SAMPLE LOCATIONS - NORTHERN ACCESS ROUTE

PEBBLE PROJECT EIS

FIGURE 3.18-4

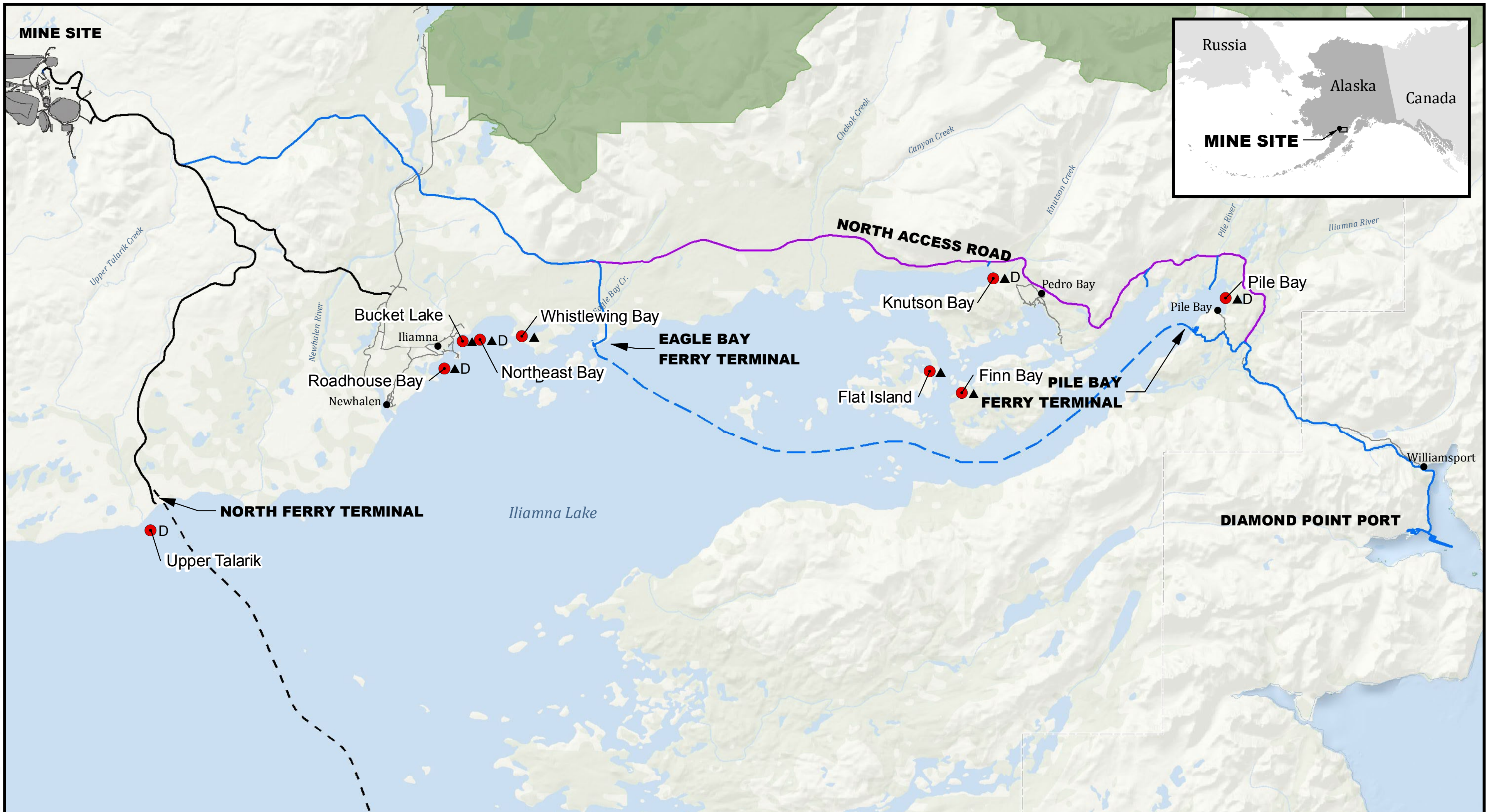
The surface water was characterized by: low levels of TDS (2 to 126 mg/L for all stations, 18 to 45 mg/L for Newhalen River); mostly near-neutral pH (4.6 to 8.8 for all stations, 6 to 7.8 for Newhalen River); and high DO concentrations (9 to 19 mg/L for all stations, 9 to 17 mg/L for Newhalen River). Additionally, TSS for all stations ranged from 0.2 to 51.6 mg/L and 0.5 to 9.1 mg/L for Newhalen River. During months when surface water samples were collected, temperatures ranged from 0.1 to 23ºC for all stations, and 1 to 16ºC at the Newhalen River station. The full annual range of water temperatures could not be characterized because samples were not collected during some winter months (November, December, or January).

The cation composition of the water samples was dominated by calcium and was consistent between sampling events. The anion composition was typically dominated by bicarbonate, but varied over time. Concentrations of nutrients were low; specifically, most ammonia and phosphorous concentrations were below detection limits. Total nitrogen (nitrate+nitrite) averaged 1 mg/L for all stations and 0.37 mg/L for the Newhalen River. Collectively for all stations, concentrations of the trace elements aluminum, copper, lead, and zinc were above the most stringent ADEC maximum criteria in a few cases. Only aluminum was above the most stringent criterion in about half of the Newhalen River samples.

Iliamna Lake. A total of 176 surface water samples were collected at nine stations in northeast Iliamna Lake (May to October) between 2005 and 2007 (HDR 2011a). Stations located near Alternative 1 include one near the mouth of UTC and four near Iliamna village; four additional sites were located at the east end of the lake. Samples were collected at multiple depths at five of the nine locations (Figure 3.18-5). Ambient water measurements included DO, temperature, specific conductance, oxidation reduction potential, pH, turbidity, and water clarity. Table K3.18-13 provides a summary of the lake water quality data. Samples were collected and analyzed at various locations in four different regions: UTC, Iliamna Village Area, Pedro Bay Area, and at Pile Bay. The UTC drainage and Iliamna Village area sample locations represent water quality information for proposed alternative, and the Pedro Bay area and Pile Bay area lend relevant water quality insight for transportation alternatives utilizing mine access along the northeast side of Iliamna Lake.

The sample data for all sites suggest that Iliamna Lake has water quality conditions similar to the natural conditions of other regional lakes. Aluminum, copper, iron, lead, manganese, and alkalinity were detected at concentrations that were outside the most stringent ADEC water quality criteria; however, mean concentrations did not exceed water quality criteria. Cation and anion dominance was generally characteristic for temperate lakes. Concentrations of major ions did not vary with depth, suggesting that the water at the sampling sites were well mixed. The concentrations of several major ions and TDS were lower earlier in the summer, peaked in September, and declined again in October. These temporary increases are likely associated with the influence of inflow from streams and precipitation.

Regional variations in constituent concentrations were observed for some trace elements including aluminum, cobalt, copper, iron, lead, and manganese. In particular, significant variation was observed in the mean concentration of aluminum. Mean concentrations of total aluminum varied greatly between locations; mean concentrations at Pile Bay were over ten times that of the UTC area. Chromium, cobalt, copper, iron, lead, and manganese also showed some notable variation (about 50 percent change) in mean concentrations. Samples collected at UTC consistently yielded lower concentrations than other locations for these trace metals.



Sources: EBD Appendix B, Figure B-1

Water Sample Locations

- ● Shallow samples collected 3' below lake surface
- D Deep samples collected at 1/2 total depth + 3' above lake bottom
- ▲ Sediment sample location

Alternative 1

- Transportation Corridor
- Natural Gas Pipeline
- Mine Site

Alternative 2

- Transportation Corridor
- Ferry Route
- Ferry/Port Sites

Alternative 3

- Transportation Corridor

Other Features

- Local Roads
- Borough Boundary
- National Park

US Army Corps of Engineers

3 0 3 6

Miles

SURFACE WATER AND SEDIMENT SAMPLE LOCATIONS - ILIAMNA LAKE

PEBBLE PROJECT EIS

FIGURE 3.18-5

HDR Investigators noted that concentrations of nutrients and major ions found during the 2005 to 2007 study were similar to concentrations from a study conducted at Iliamna Lake nearly 40 years before. The single exception was sodium, which was present at nearly twice the concentration found in the earlier study. However, only a few ions (copper, lead, aluminum, iron, manganese, and alkalinity) had concentrations outside water quality standards established by ADEC for freshwater. The investigators attributed the latter to geological influences, and noted their consistency with previous studies conducted at Iliamna Lake and other area watersheds (HDR 2011a).

Field data collected in 2017 added three additional sample locations assessing the surface water quality near the proposed ferry terminals in Iliamna Lake. Samples were taken near the surface and near the bottom of the lake. These data did not yield any exceedances of the most stringent water quality criteria (Table K3.18-1) for total or dissolved metals, or any conventional parameters tested (GeoEngineers 2018a, Table 6a).

Port Access Road. Water quality data are limited along the port access road south of Iliamna Lake. Field studies in 2018 recorded turbidity measurements at stream crossings along the port access road at levels below the instrument detection level (7-11 NTU) for all but two stream crossings, at which turbidity levels of 24 and 13 were recorded. Turbidity measurements at the Gibraltar River crossing were also below the instrument detection level (PLP 2018-RFI 036).

Drinking Water Sources. Three communities around Iliamna Lake have community surface water systems as their primary drinking water source, including Nondalton, Kokhanok, and Igiugig (Figure 3.16-1). Nondalton uses infiltration galleries from Six Mile Lake (which drains into the Newhalen River); Kokhanok draws water from Iliamna Lake; and Igiugig has one active intake in the Kvichak River, just downstream of Iliamna Lake. No State of Alaska data is available on drinking water sources for Pile Bay and Williamsport (ADEC 2018; ADNR 2018a).

Past water system violations in these communities reported by ADEC (between 1995 and 2018) are mostly monitoring violations that represent failure to collect a sample. Drinking water standard exceedances are rare, but have included coliform, iron, manganese, arsenic, lead, and copper (ADEC 2018).

3.18.2.2 Groundwater Quality

Drinking Water Wells. The village of Newhalen uses both community and private groundwater wells as drinking water sources, while Iliamna and Pedro Bay rely on private groundwater wells. Drinking water wells were sampled at four locations (Newhalen, Nondalton, Iliamna, and Pedro Bay) in 2004 and 2005 to assess regional water quality across the transportation corridor (Schlumberger et al. 2011a). These wells were similar in quality, with exceedances of drinking water quality standards for total arsenic in Newhalen, Nondalton, and Pedro Bay; and pH exceedances in Newhalen and Pedro Bay. Newhalen has had numerous monitoring violations from failure to collect a sample since 1995, but rare exceedance violations have only been registered for coliform (ADEC 2018).

Mine Access and Port Access Roads. Groundwater quality beneath the proposed 84-mile transportation corridor under Alternative 1 and the additional segments under Alternatives 2 and 3 can be characterized as similar to that of the mine site and port. Along the northern mine access road in the Nushagak and Kvichak watersheds, the groundwater quality of the transportation corridor is similar to that of the mine site. Trend analysis of the mine site groundwater system (discussed above) suggests that TDS concentrations decrease with distance from the mine site. The northern mine access road traverses a series of shallow intermittent surficial deposits, including glacial, glaciofluvial, and alluvial deposits (Detterman and Reed 1973). The port access road would traverse flat ground and low hills, much of which is bare rock covered with a thin layer of soil (AECOM 2018h). There are few known potentially groundwater-bearing surficial deposits along the port access road, with few intermittent glaciofluvial and alluvial surficial deposits (Detterman and Reed 1973). This terrain suggests that shallow groundwater occurrences along this route would be limited. Groundwater quality beneath the port access road is likely similar to that of the port site.

North Access Road. The northern access road under Alternative 3 would cross a variety surficial deposits, all of which have the potential to be groundwater bearing. These are intermittent in the eastern part of the route and thicker in the western part of the road (Detterman and Reed 1973; Schlumberger et al. 2011a). Groundwater quality and characteristics can be influenced by these surficial deposits and bedrock geology, which is complex throughout the Cook Inlet basin (Brabets et al. 1999). A single groundwater quality sample was collected in Pedro Bay near the northern access route and was similar in quality to wells sampled at Newhalen, Nondalton, and Iliamna (Schlumberger et al. 2011a).

3.18.2.3 Substrate/Sediment Quality

Physical Characteristics. Stream substrates intersected by the transportation corridor under all alternatives include a wide range of fine to coarse sediments (Grossman 1998). Stream sediments at the northern end of the road corridor are dominated by sand and silt, with some stretches high in gravel and cobbles, while other stretches are rich in organic matter (PLP 2018-RFI 036). Limited substrate data along the Iliamna spur road shows that some stream crossings are dominated by gravel and cobbles, while others are high in fine-grained sand, silt, and organic matter. Along the mine access road south of the intersection with the Iliamna spur road, substrates are dominantly silt, sand, and gravel (PLP 2018-RFI 036). No substrate data is available for streams along the southern portion of the mine access road.

A small number of nearshore and deeper water sediment samples from Iliamna Lake were collected in 2005 and 2006 (Figure 3.18-5). Substrate offshore of the north ferry terminal near the mouth of UTC was described as consisting of small gravel. Lake sediment analyzed near Iliamna village was described as fine-grained material (HDR 2011a). Sediment samples collected near the proposed ferry terminals in Iliamna Lake in 2017 consist primarily of underdeveloped sand-gravel beaches with intermittent cobble, and larger rocks, and occasional outcrops of bedrock (GeoEngineers 2018a).

Stream substrates along the port access road show similar diversity to those north of Iliamna Lake. Sand and silt are the dominant sediment size, with a high percentage of organic matter present as well. Sampled streams have a higher percentage of boulders and less gravel south of Iliamna Lake. Sediment at the proposed location of the Gibraltar River bridge is dominated by gravel and cobble substrate. Sediments in drainages with proposed crossings by the other four bridges along the port access road tend to be more coarse-grained, with a higher percentage of cobbles and boulders (PLP 2018-RFI 036). Samples of substrate from four ponds within approximately 5 miles of the southern access road were all recorded as mud/fine sediment (Grossman 1998).

Chemical Quality. Sediment in streams intersected by the transportation corridor under all alternatives show little to no known existing contamination (Grossman 1998). Of 12 pond substrate samples analyzed by NURE within approximately 20 miles of the mine access road, none showed evidence of contamination (Grossman 1998).

Table K3.18-20 provides a summary of Iliamna Lake sediment quality data collected in 2005 and 2006. Sediment quality measurements for Iliamna Lake were examined at the Iliamna village area (four sample locations), Pedro Bay area (three sample locations), and at Pile Bay (one sample location). Minor variations in sediment content occur between the three areas;

however, mean constituent concentrations only exceeded TELs for cadmium in the Iliamna village area and for copper at the Pile Bay location. In these instances, concentrations did not reach the probable effects level. Sediment samples collected from two locations near Iliamna village (Figure 3.18-5) were analyzed for trace elements and other constituents (HDR 2011a). Sediment data showed levels for copper, lead, aluminum, iron, and manganese that exceed ADEC freshwater sediment criteria (same as SQGs). This is likely due to the highly mineralized nature of the local geology, and is similar to chemistry in other area lakes.

Of four pond substrate samples analyzed by NURE within approximately 5 miles of the port access road, none showed any evidence of contamination (Grossman 1998).

3.18.3 Marine Ports

3.18.3.1 Surface Water Quality

The discussion of marine water quality below presents regional information, as well as data collected in northern Kamishak Bay (2004 to 2012) and offshore of the Amakdedori port site (2018) that are pertinent to Alternative 1. Additional details of marine water quality in the Iliamna/Iniskin estuary north of Kamishak Bay that are pertinent to the Diamond Point port (Alternatives 2 and 3) are provided in Appendix K3.18.

Suspended Particulates/Turbidity. Cook Inlet basin is an expansive watershed surrounding the 180-mile-long Cook Inlet waterbody. Covering more than 38,000 square miles of southern Alaska, it receives water from six major watersheds and many smaller ones. More than 10 percent of the basin is covered by glaciers, and suspended sediment loading in glacier-fed rivers without lakes is significant, leading to generally high suspended sediment load in some portions of Cook Inlet (PLP 2018d), particularly in the upper inlet areas.

Hart Crowser (2015a) provides physical and chemical data from the Ursus Cove area at the north end of Kamishak Bay (about 17 miles northeast of Amakdedori), which are likely similar to the Amakdedori port site because of its exposure to lower Cook Inlet oceanographic conditions. Turbidity in the sampled areas at the north end of Kamishak Bay ranged from near 0 to 13 NTU, probably reflective of varying exposures to wave activity. Turbidity was described as generally moderate, except near the shoreline during windy periods, and did not exhibit any obvious trends that would indicate point-source inputs (Hart Crowser 2015a). TSS was 5 mg/L at both surface and bottom, indicating a well-mixed and relatively clear water column.

The amount of suspended solids and accompanying turbidity in waters adjacent to the proposed Amakdedori port site would be a function of seabed composition (e.g., silt, mud, sand). Extrapolation of onshore geophysical survey data (Zonge 2017) and NOAA (2015) nautical chart information for the approach to the port site suggest that the seabed in this area consists of sand and gravel with scattered boulders. This suggests that suspended solids are of naturally low concentrations and that water is relatively clear (i.e., low turbidity). Field studies conducted in 2018 at four offshore locations near the Amakdedori port site (two near-bottom and two near-surface samples) measured no exceedances of the marine screening criteria or the most stringent water quality criteria for TSS with an average of 15.3 mg/L (GeoEngineers 2018a, Table 5). However, under energetic wave conditions, any loose sediment on the seabed would be stirred upward into the water column, thereby temporarily increasing suspended solids and turbidity.

Salinity Gradient and Temperature. The Amakdedori port site is on the open coast of Kamishak Bay. As such, water properties such as salinity and temperature can be expected to be similar to those of lower Cook Inlet (Muench and Schumacher 1980). However, some freshening of surface waters in the immediate vicinity of Amakdedori Creek might occur; while under southerly winds, greater freshening could occur as a result of flows from sources to the south, such as McNeil and Kamishak rivers. The extent of any freshening is dependent on flows from those sources and the persistence of southerly winds. The freshening of surface waters would be manifest as a thin, low-salinity lens overlying saltier water, which would be mixed quickly into the water column by any wave action produced by brisk winds.

Hart Crowser (2015a) temperature and salinity data from the Ursus Cove area are likely to be similar to the Amakdedori port site, although they may be influenced by freshening from upland sources through Ursus Lagoon. For the 2012 sampling period (August), mean water temperatures ranged from 12.9 to 14^{0}C, while mean salinities ranged from 22.8 to 25.7 parts per thousand. The small range in data for both temperature and salinity suggest a fairly homogenous water column. Temperature exhibited seasonal warming up to mid-summer and then subsequent cooling, but was also a function of water depth, indicating the role of insolation as a factor in temperature trends. Salinity decreased from spring to late summer, reflecting the influence of upland sources on coastal waters, and then increased in autumn months.

Organics and Inorganics. The area surrounding Cook Inlet north and east of the port site is a relatively populated and industrialized region of Alaska. Therefore, its waters are influenced to some degree by urban (and a small amount of agricultural) runoff, oil and gas activities (e.g., accidental spills, discharges of drilling muds and cuttings, production waters, and deck drainage), effluent from municipal wastewater treatment facilities, oil and other chemical spills, offal from seafood processing, and other regulated discharges. Waters free from contaminants, however, are considered a principal component of the Cook Inlet beluga whale critical habitat in the Amakdedori port area. Hence, the comparatively low levels of contaminants documented in Cook Inlet beluga whales, as well as in chemical analyses of water and sediment in the area, suggest that contaminant concentrations in lower Cook Inlet are low (NMFS 2016a).

Hydrocarbon concentrations sampled in 2004 at the northern end of Kamishak Bay, as well as metal and trace element concentrations collected in 2008, showed little to no effect from anthropogenic sources. The majority of organic constituents tested were not detected (Hart Crowser 2015a: Table 34-7). Inorganics analyzed in both surface water and bottom water at a depth of about 50 feet in northern Kamishak Bay (Hart Crowser 2015a: Table 34-8, Station MRC20) showed that none exceeded Alaska water quality standards or National Recommended Water Quality Criteria (EPA 2018d). In samples collected offshore of the Amakdedori port site, exceedances of marine water screening levels were measured in boron for both total and dissolved metal concentrations at all locations. Additionally, total iron concentrations exceeded the marine screening level for all sample locations (GeoEngineers 2018a: Table 5).

3.18.3.2 Groundwater Quality

Aquifer systems found in small drainages around the Cook Inlet region, such as those in the Amakdedori and Diamond Point port areas, include groundwater occurrences in saturated fractures in bedrock which provide water to streams near the port areas during winter (Glass 2001). Aquifers are primarily situated within glacial and fluvial deposits overlying sedimentary and low-grade metamorphic bedrock. Glacial deposit aquifers have been described as irregular in distribution and highly variable in composition and flow (Brabets et al.1999).

The thickness of surficial deposits in the Amakdedori port area are believed to range from about 50 to 100 feet thick in the port area based on geophysical survey results (Zonge 2017). Potential groundwater-bearing surficial deposits in the Diamond Point area would be limited to alluvium and alluvial fan deposits in the small drainage west of Diamond Point, and morainal deposits in uplands west of the proposed terminal (Detterman and Reed 1973). There are no existing drinking water wells in either port area. Potable water supplies for seasonal work at the Diamond Point quarry come from temporary mobile sources (ADNR 2014a).

3.18.3.3 Substrate/Sediment Quality

Physical Characteristics. Studies in upper and lower Cook Inlet provide a general characterization of seafloor substrate and sediment depositional processes in the region. Lower Cook Inlet is a tidal embayment with a substrate of abundant glacial sediments, predominantly cobbles, pebbles and sand, with minor amounts of silt and clay (Sharma and Burrell 1970). Large ice-rafted boulders are also present in some areas (Thurston and Choromanski 1994). Over 40 million tons of sediment is discharged per year into the inlet by surrounding major drainages (Rember and Trefry 2005). Sediment transport in some areas of upper Cook Inlet has been shown to be exceptionally high, with 10,000 to over 100,000 cubic yards of sediment moving in and out of the Port of Anchorage area in a matter of days or weeks (USACE 2013). A combination of shallow water, high tidal fluctuations, and strong currents constantly mobilize seafloor sediments in the inlet, keeping sediments in suspension, resulting in highly turbid water, and inhibiting deposition of fine-grained sediments (Rember and Trefry 2005). Fine sediments introduced by major rivers feeding into upper Cook Inlet are carried in suspension, and have been shown to be deposited as far as 150 miles south in lower Cook Inlet (ADL 2001). Analysis by Atlas et al. (1983) determined that the Kamishak Bay is a natural depositional area for fine sediments and hydrocarbons.

The shoreline at Amakdedori is a wave-dominated coastal berm largely composed of weathered cobbles, boulders, and exposed bedrock rising from the intertidal zone. Amakdedori Creek alluvial fan-delta deposits extend about 1,000 feet offshore into Kamishak Bay (PLP 2018-RFI 039). Seafloor sediment at and around the Amakdedori port location is primarily comprised of subtidal gravel and beach complex (GeoEngineers 2018a, Figure 2). Bathymetry in Kamishak Bay around the Amakdedori port location was investigated through a multi-beam survey in 2017, which indicated that the seafloor is relatively smooth with a gentle slope (60 feet over 5.6 miles). Results from three boreholes indicate that sub-bottom sediment consists primarily of fine silty sand with occasional course gravel and shell fragments, and a fines content ranging from 14 to 19 percent. Sediment samples from the estuarine environments of Iliamna and Iniskin bays, about 30 miles northeast of the port site, revealed substrates of fine sediment (SLR et al. 2011a).

Waterbody substrate data from the onshore environment at the Amakdedori port site are limited. Sediment from two ponds, one about 0.5 miles north and the other approximately 3 miles south, was described as mud/fine sediment (Grossman 1998).

Chemical Quality. Data on regional sediment chemical quality in Cook Inlet are found in PLP baseline studies and other substrate studies including the Integrated Cook Inlet Environmental Monitoring and Assessment Program. Limited data from dredging operations and sediment sampling suggest that sediments generally have low concentrations of contaminants (USACE 2013; ADL 2001). Low levels of hydrocarbons have been detected at multiple sites in the inlet, potentially connected with offshore oil development, past oil spills, or natural oil seeps within the region. Glacial sediments, which are continually transported into the inlet by the major drainages, may also bring metals and hydrocarbons from upstream sources into Cook Inlet. Municipal discharges and seafood processing also contribute potential contaminants to Cook Inlet substrate. Extreme tidal fluctuations and strong currents constantly disperse and dilute potential pollutants in the inlet (ADL 2001).

Sampling of offshore sediment has been conducted at two locations near the Amakdedori port site, and in various other locations in lower Cook Inlet. Sediment quality data from the two locations near the Amakdedori port site were analyzed for concentrations of inorganic and organic chemicals. Results indicate that concentrations of metals fell below the TEL for all measured quantities except for manganese and nickel. An exceedance of nickel in marine sediments was detected in one sample collected from subtidal sands/fines, but mean concentrations did not exceed the marine TEL. Manganese concentrations exceeded the marine TEL for both sampled locations in subtidal sands/fines, and yielded a mean concentration of 380 mg/kg, exceeding the marine TEL (GeoEngineers 2018a, Tables 7a and 7b).

Samples of fine sediment were collected from the offshore estuarine environments of Iliamna and Iniskin bays near Diamond Point. Some of the samples showed arsenic, copper, nickel and zinc levels higher than the threshold of biological effect, and measurable hydrocarbons. There is current development in the Diamond Point area, and minor marine vessel traffic at Williamsport at the head of Iliamna Bay. Estuarine sediments are generally more fine-grained than offshore of Amakdedori, which is more exposed to open water. Fine-grained sediments generally retain chemical pollutants more than coarse-grained sediments, due to higher surface area-to-volume ratios.

Chemical substrate data from the onshore environment at the Amakdedori port site are limited. Sediment from two ponds, one within 0.5 miles to the north and one about 3 miles south of the port site, were analyzed by NURE and were reported to have no contamination (Grossman 1998).

3.18.4 Natural Gas Pipeline Corridor

3.18.4.1 Surface Water Quality

Surface water quality data for the onshore part of the natural pipeline corridor are summarized above under “Transportation Corridor.” Water quality information for Cook Inlet and Kamishak Bay pertinent to the pipeline is summarized above under “Surface Water Quality,” Marine Ports. The pipeline would tie into the existing natural gas supply at a compressor station near Anchor Point. This would result in no additional stream or waterbody crossings on the Kenai Peninsula. The closest stream to the horizontal directional drilling (HDD) part of the corridor is about 200 feet to the north (PLP 2017, Figure G-012).

3.18.4.2 Groundwater Quality

Summary groundwater quality information pertinent to the natural gas pipe corridor can be found above under “Transportation Corridor.” The only additional sections of pipeline that do not match the road alternatives would be at the east end of the pipeline on Kenai Peninsula, and the short section from Ursus Cove to Diamond Point under Alternatives 2 and 3.

As described in Section 3.17, Hydrogeology, groundwater beneath Kenai Peninsula is known to occur in thick glacial and alluvial deposits (Karlstrom 1964; Nelson and Johnson 1981). Seven private groundwater wells are currently located a distance of 600 to 1,600 feet away from the HDD part of the pipeline terminus. Groundwater quality data is not publically available on private wells (ADNR 2018a).

There would be limited shallow groundwater occurrence within a narrow strip of alluvial deposits along the short pipeline corridor between Ursus Cove and Diamond Point (Detterman and Reed 1973). No groundwater quality data has been collected in this area.

3.18.4.3 Substrate/Sediment Quality

Physical Characteristics. A description of nearshore Cook Inlet physical substrate characteristics is provided above under "Marine Ports." Field studies indicate that the substrate in the western portion of Kamishak Bay is primarily comprised of subtidal gravel with intermittent reef and sand/fine substrate in the region near the port location (GeoEngineers 2018a, Figure 2). Publicly available information regarding the substrate of Cook Inlet in areas further offshore is sparse. Substrate in the vicinity of mooring facilities could include flows from Augustine Volcano, which have been documented to occur every few 100 years (Section 3.15, Geohazards).

Water depths in the center of Cook Inlet range from about 50 to over 500 feet (NOAA nautical chart #16660). Numerous oil and natural gas pipelines currently span the bottom of Cook Inlet; however, all current pipelines are located in the northern part of the Cook Inlet and there are none in the vicinity of the project (ADNR 2018d). Pipeline damage has previously been documented from boulders moved on the seafloor by strong tides and currents.

Chemical Quality. Seafloor substrate in lower Cook Inlet generally has low toxicity (ADL 2001). Chemical quality of sediment in the nearshore parts of Kamishak Bay and Iliamna/Iniskin estuary are summarized above under "Marine Ports." Sediment quality data for the offshore part of the pipeline route are limited as described previously. Sediment sampled from one stream in the Kenai Peninsula area near the east end of the pipeline did not show evidence of contamination (Grossman 1998).

3.19 NOISE

Information on applicable noise and vibration concepts and methodologies used in characterizing noise of the affected environment is provided by AECOM (2018c).

Noise is typically characterized as unwanted sound. Because the natural existing ambient sound is generally not considered a problem, it is not typically classified as noise. The ambient sound level is a composite of sound from all sources, including the natural background and anthropogenic sources—it is, by way of example, the total sound received by the microphone of a sound level meter. Existing ambient sound levels are often the starting point for analyzing project-associated noise impacts, because such environmental noise analysis typically compares project-associated noise to either existing ambient or natural background sound based on applicable adverse effect or impact assessment criteria.

The Environmental Impact Assessment (EIS) analysis area for this section includes the mine, port, transportation corridor, and natural gas pipeline corridors for each alternative and variants, and the surrounding area where project-associated noise could have a direct effect on human receptors. A radius of 10 miles from the mine site was used as a screening distance for potential noise impact in this EIS, because based on preliminary conservative calculations (assuming typical equipment to be used and acoustical propagation rates), it is considered to be a distance beyond which the noise effects are expected to be negligible. Similarly, for all other non-mine project components (transportation corridor, port, ferry terminal sites, and natural gas pipeline corridor), including all alternatives and variants, a conservative screening distance of 2 miles from the project feature or alignment was used to help locate and identify potential noise-sensitive receptor (NSR) property parcels.

Impacts to other resources from noise are addressed in other sections of the EIS: Section 4.5, Recreation; Section 3.9, Subsistence; Section 3.11, Aesthetics; Section 4.23, Wildlife Values; Section 4.24, Fish Values; and Section 4.25, Threatened and Endangered Species.

The effects of noise on people can include general annoyance, interference with speech communication, sleep disturbance, and in the extreme, hearing impairment. At any location, both the magnitude and frequency of environmental noise may vary considerably over the course of each day and throughout the week and year. This variation is caused not only by various noise source activities, but also by conditions such as changing weather conditions, seasonal vegetative ground cover, presence of ice or flowing water from nearby creeks and rivers, and wind.

Examples of outdoor and indoor noise levels that could be experienced by current residents near or in the EIS analysis area are provided in Table 3.19-1 as context for describing existing conditions. These levels are measured in terms of “A-weighted” decibels (dBA), which are used to quantify sound and its effect on people (EPA 1978), and emphasize frequencies best heard by humans. AECOM 2018c provides explanation of the principles of acoustics and weighted sound levels. Noise levels listed in Table 3.19-1 represent day-night sound levels (L_{dn}), an energy-averaged value over a 24-hour period that reflects increased sensitivity to noise when people are usually sleeping.

Table 3.19-1: Examples of Noise Levels

Outdoor	Noise Levels (dBA, L_{dn})	Indoor
Jet flying over at 1,000 feet	100	Rock band
Gas lawn mower at 3 feet	90	Blender at 3 feet
Next to busy highway	88	N/A
0.75-mile from touchdown at major airport	86	Garbage disposal at 3 feet
Noisy urban area during the day	70	Vacuum cleaner at 10 feet
Wooded suburban residential	51	Refrigerator at 3 feet
Rural residential	39	N/A
Wilderness Ambient	35	Library

dBA = A-weighted decibel
Ldn = Day-night sound level, expressed in dBA
N/A = Not Applicable
Source: EPA 1978; Caltrans 2009

Existing noise levels in the areas of each project component are discussed below, as compared to the examples of typical noise levels shown in Table 3.19-1. For this analysis, an NSR is generally defined as an area where human use likely occurs, such as human dwellings, seasonal shelters, and temporary campsites (defined in more detail in Section 4.19). The most likely types of land parcels within the 2-mile analysis distance that may have NSRs are Native allotments. These lands may be expected to include permanent or temporary structures to support a residence or hunting and fishing activities. No current definitive information regarding individual dwellings or other buildings is available for all the Native allotments; therefore, the occurrence of allotments is used as a means to conservatively estimate NSRs in the analysis area, by assuming all allotments may have at least one NSR.

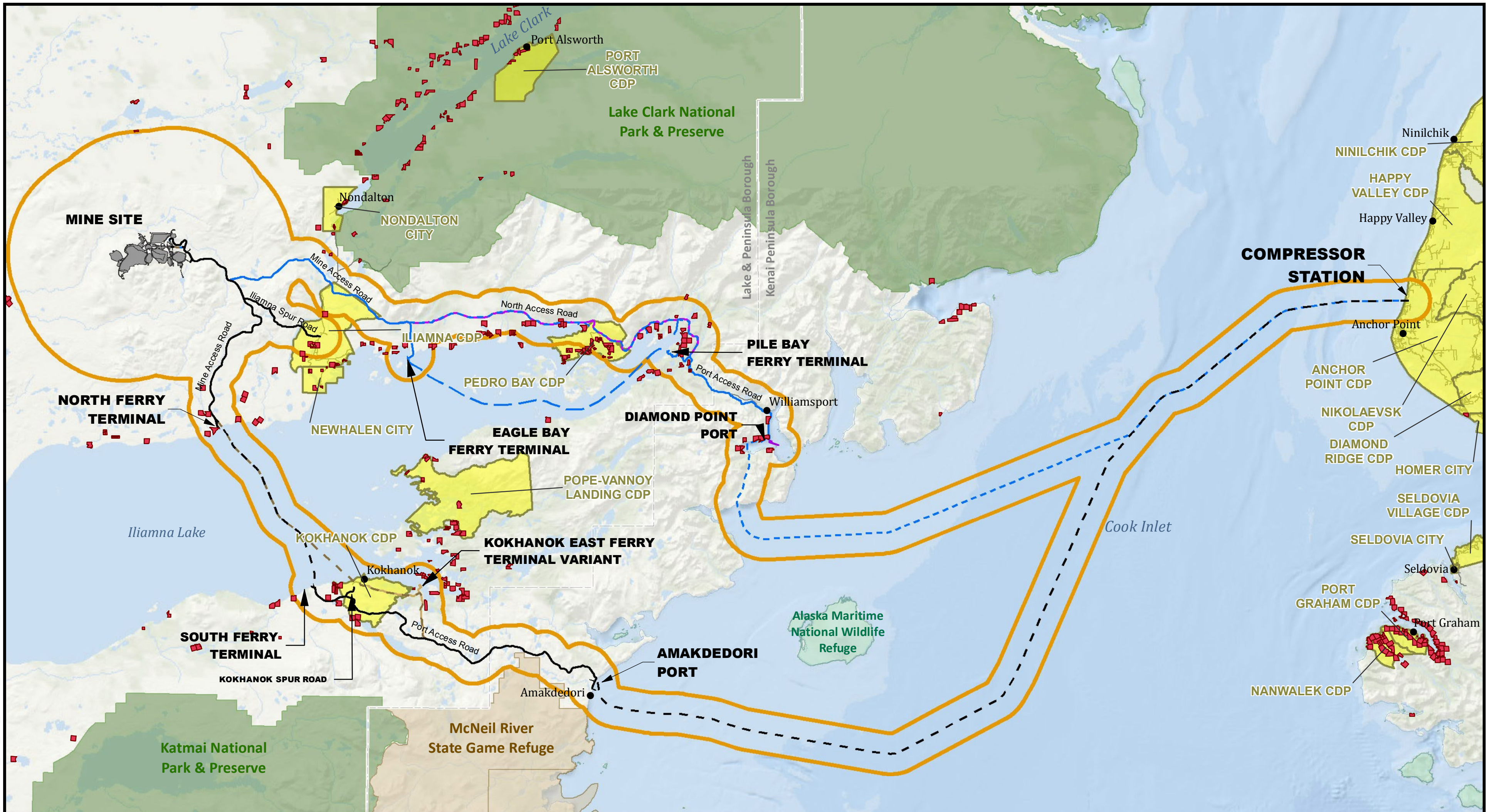
Figure 3.19-1 shows the noise analysis area using the 10-mile distance for the mine site area and 2-mile distance for all other components for all three alternatives, census-designated places (USCB 2017, 2018a, 2018c, 2018d), and Native allotments.

The following sections describe the existing sound in areas for all alternatives, and a section summarizing potential NSRs associated with each alternative (Alternatives 1, 2 and 3 and associated variants). For the alternative variants, both existing sound and potential NSRs are discussed in separate sections to enable comparison to the main alternative (i.e., no variant).

3.19.1 Alternative 1 – Applicant's Proposed Alternative

3.19.1.1 Mine Site – Existing Sound

The mine site would be in a remote region of Alaska, characterized as having no development. No existing ambient sound data were collected in the vicinity of the mine site. However, data on ambient sound levels for generic land use types are available (Table 3.19-1).The values in Table 3.19-1 can be used to estimate the existing (pre-project) ambient sound level for corresponding land use types in the EIS analysis area. Due to its remoteness and lack of development, the existing land use in the vicinity of the mine site corresponds to the "wilderness ambient" classification in Table 3.19-1. Therefore, the baseline ambient sound level for the mine site would be 35 L_{dn} (Table 3.19-2).



Sources: PLP 2018d; ADNR; BLM 2018; USCB 2017, 2018a, c, d

US Army Corps of Engineers®

5 0 5 10
Miles

Noise Analysis Areas (10-mi analysis distance for Mine Site, 2-mi analysis distance for Other Infrastructure)
Native Allotments
Census-Designated Place

Alternative 1
Mine Site
Transportation Corridor
Natural Gas Pipeline

Kokhanok East Ferry Terminal Variant
Transportation Corridor
Natural Gas Pipeline

Alternative 2
Transportation Corridor
Ferry Route

Alternative 2/3
Natural Gas Pipeline

Alternative 3
Transportation Corridor

Other Features
Local Roads
Borough Boundary
State Game Refuge/Sanctuary
Wild and Scenic River
National Wildlife Refuge
National Park

NOISE ANALYSIS AREAS

PEBBLE PROJECT EIS

FIGURE 3.19-1

Table 3.19-2: Baseline Outdoor Noise Levels at Mine Site

Pebble Project Component	Baseline Outdoor Ambient Sound Level (dBA)	Basis
Mine site includes all features in the mine site footprint: open pit, mill and ore processing, water treatment plants, water management ponds, bulk and pyritic tailings storage facilities, power plant, utilities, services and infrastructure, mine maintenance, and safety controls.	35 L_{dn}	Typical L_{dn} for Wilderness (EPA 1978), L_{dn} for Outdoor Locations

Notes:
dBA = A-weighted decibel
L_{dn} = day-night sound level, expressed as dBA
Source: EPA 1978

3.19.1.2 Transportation Corridor – Existing Sound

For the purpose of describing existing noise levels, facilities in the transportation corridor are grouped and summarized according to location and use, as follows:

- **Mine Access Road** – As with the mine site, most of the mine access road would be in a remote area with no development. No ambient sound data were collected in the vicinity of the mine access road. The existing land use in the vicinity of the mine access road (including its southern terminus on the northern shoreline of Iliamna Lake) corresponds with the "wilderness ambient" classification in Table 3.19-1, and therefore has a baseline noise level of 35 dBA L_{dn}.
- **Iliamna Spur Road** – As with the mine access road, the spur road would be in a remote area with very little development. Aside from its southern terminus near Iliamna Airport, no ambient sound data were collected in the near vicinity of the spur road; existing sound levels correspond with the "wilderness ambient" classification in Table 3.19-1, and therefore have a baseline noise level of 35 dBA L_{dn}. Within 1 mile of the vicinity of the southern terminus of Iliamna spur road, where the spur road intersects with the existing Portage Road, existing outdoor noise levels were measured at position "M2" as reported in Michael Minor & Associates (MMA 2010) (Table 3.19-3). From measured L_{eq} data collected during daytime, evening, and nighttime periods at M2, and additional baseline field survey positions representing a variety of land uses (residential areas, a school, and a medical clinic), baseline L_{dn} values were calculated for the communities of Iliamna and Newhalen.

Table 3.19-3: Calculated Baseline Day-Night Sound Levels at Representative Iliamna and Newhalen Community Land Uses

Measurement Location (and Summary Description)	Summer Season L_{dn} (dBA)	Winter Season L_{dn} (dBA)
M2 – Central Newhalen River Road (north of Iliamna Airport at the northernmost occupied residence on the Newhalen River Road)	53	47
M3 – Iliamna Airport (near Iliamna Air Taxi terminal)	54	61
M4 – Post Office and Community Medical Clinic (intersection of Iliamna Road and Newhalen Road)	51	52
M5 – North Newhalen (residential area just off Newhalen Road)	47	42
M6 – Newhalen School (in front of the school near Newhalen Road)	56	63

Table 3.19-3: Calculated Baseline Day-Night Sound Levels at Representative Iliamna and Newhalen Community Land Uses

Measurement Location (and Summary Description)	Summer Season L_{dn} (dBA)	Winter Season L_{dn} (dBA)
M7 – Roadhouse Bed and Breakfast (and single-family residence on Iliamna Road)	47	42
M8 – Iliamna General Store and Vicinity (on Iliamna Village Spur close to several residential buildings)	54	59
M9 – Iliamna Lake (near the docks at Slop Bucket Road and Iliamna Village Spur close to floatplane moorage)	59	47

Notes:
dBA = A-weighted decibel
L_{dn} = day-night sound level, expressed as dBA
Source: MMA 2010

- **Kokhanok Spur Road** – Most of this spur road route is undeveloped, and is compatible with the "wilderness" classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}. Baseline noise level measurements were not collected in this vicinity. At the northern terminus of the spur road are an airstrip and the community of Kokhanok, a census-designated place (US Census 2010) with a population of 140 residents, which could be considered "wilderness ambient," per Table 3.19-1. Not counting noise from occasional aircraft taking off and landing from the existing airstrip (an active public airport with Federal Aviation Administration [FAA] identifier "9K2"), the indicated level of 35 dBA L_{dn} would be conservative.
- **North Ferry Terminal** – The vicinity of this Iliamna Lake coastal area is undeveloped, and is compatible with the "wilderness ambient" classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}. Baseline noise level measurements were not conducted in this vicinity. The north ferry terminal and natural gas pipeline corridor would be within 1 mile of the Upper Talarik Creek outlet into Iliamna Lake. This area may be exposed to seasonal transportation noise sources such as small boat traffic for sport fishing during the summer, and possibly snowmachines during winter. No such motorized boats or vehicles would be expected during the shoulder seasons of freeze-up and break-up in the vicinity. These occasional or sporadic noise sources are conservatively ignored in assuming the "Wilderness Ambient" existing noise level.
- **South Ferry Terminal** – The vicinity of this Iliamna Lake coastal area is undeveloped, and is compatible with the "wilderness ambient" classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}. The ferry terminal and natural gas pipeline corridor would be within 2 miles of the Gibraltar River outlet into Iliamna Lake. This area may be exposed to seasonal transportation noise sources such as small boat traffic for sport fishing during the summer, and possibly snowmachines during winter. No such motorized boats or vehicles would be expected during the shoulder seasons of freeze-up and break-up in the vicinity. These occasional or sporadic noise sources are conservatively ignored in assuming the "Wilderness Ambient" existing noise level.
- **Port Access Road** – The port access road would traverse an undeveloped area between Iliamna Lake and Cook Inlet (at Amakdedori port), and is compatible with the outdoor ambient sound level for the "wilderness ambient" classification in Table 3.19-1, and baseline noise level of 35 dBA $L_{dn.}$ No ambient sound data have been collected.

3.19.1.3 Amakdedori Port – Existing Sound

Baseline noise levels have not been measured at the Amakdedori port site. The vicinity of the Amakdedori port site is undeveloped, and is compatible with outdoor ambient sound levels consistent with the “wilderness ambient” classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}.

3.19.1.4 Natural Gas Pipeline Corridor – Existing Sound

For the purpose of describing existing noise levels, features along the natural gas pipeline corridor are grouped and summarized according to location, as follows:

- **Mine Site to Amakdedori Port** – This section of the pipeline corridor parallels the mine access road, ferry terminals, port access road, and Amakdedori port site previously described. This portion of the corridor shares the same area and existing outdoor ambient sound environment with these project components, and is compatible with the “wilderness ambient” classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}.
- **Compressor Station near Anchor Point** – The compressor station site is common to all alternatives, and is about 5 miles north of the town of Anchor Point and the 2-mile analysis distance from the compressor station partially includes the Anchor Point census-designated place (USCD 2018a). The compressor station site is approximately 0.25 mile southeast of the Sterling Highway (Alaska Highway 1) near its intersection with Bourbon Avenue, where the pipeline would make landfall on the eastern side of Cook Inlet. Baseline noise levels were not measured in this vicinity. Using a Federal Transit Administration (FTA)-based estimation method that uses population density (21.2 people per square mile, based on US Census data (USCB 2018a) as input, the baseline outdoor ambient sound level could be calculated as 35 dBA L_{dn}, a value comparable to the “wilderness ambient” designation per Table 3.19-1. The Sterling Highway (Alaska Route 1) is a major two-lane road that parallels the coast with minimum posted speed limits of 50 miles per hour, and would be expected to raise outdoor ambient noise levels to a minimum of 50 dBA L_{dn} within about 1,000 feet of the road (which includes the compressor station site) per FTA guidance.

3.19.1.5 Alternative 1 – Sensitive Receptors

There are no sensitive receptors within the 10-mile distance of the mine site. The 2-mile distance used for analysis of other Alternative 1 components includes 22 Native Allotments (2,715 acres); and partially includes Kokhanok, Iliamna, and Anchor Point census-designated places (USCG 2081a) (Figure 3.19-1).

3.19.1.6 Action Alternative 1 – Summer-Only Ferry Operations Variant

Noise conditions and potential NSRs under this variant would be the same as described for Alternative 1.

3.19.1.7 Action Alternative 1 – Kokhanok East Ferry Terminal Variant

<u>Existing Sound</u>

The Kokhanok east ferry terminal site would be about 6.5 miles east of the south ferry terminal site described for Alternative 1 (see Chapter 2, Alternatives Including Applicant’s Proposed Alternative). Section 3.9, Subsistence, describes conditions and activity in the vicinity of the

Kokhanok east ferry terminal that may contribute to background noise, including seasonal use of boats, snowmachines, and all-terrain-vehicles. Except for sounds associated with these sources, the outdoor ambient sound level would be the same baseline noise level of 35 dBA L_{dn}.

Sensitive Receptors with Variant

Evaluated data sets used to identify potential NSRs are described in AECOM 2018c. The 2-mile analysis distance for this variant includes 22 Native Allotments (2,513 acres), and partially includes Kokhanok and Anchor Point census-designated places (USCB 2018a, 2018c).

3.19.1.8 Action Alternative 1 – Pile-Supported Dock Variant

Existing sound and potential NSRs would be the same as described for Alternative 1.

3.19.2 Action Alternative 2 – North Road and Ferry with Downstream Dams

3.19.2.1 Mine Site

Existing sound and potential NSRs would be the same as described for Alternative 1.

3.19.2.2 Transportation Corridor

For the purpose of describing existing noise levels, facilities in the transportation corridor are grouped and summarized according to location, as follows:

- **Mine Access Road** – No ambient sound data were collected in the vicinity of the mine access road. The majority of the mine access road (including its southern terminus on the northern shoreline of Iliamna Lake, near Eagle Bay) would be in a remote area with no development, and corresponds with the "wilderness ambient" classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}.
- **Eagle Bay Ferry and Pile Bay Ferry Terminals** – No ambient sound data were collected in these vicinities. These Iliamna Lake coastal areas are generally undeveloped, and would be considered compatible with the "wilderness ambient" classification in Table 3.19-1, with a baseline noise level of 35 dBA $L_{dn.}$
- **Port Access Road** – No ambient sound data were collected in this area, which has little development. The road would connect the Pile Bay ferry terminal to the Diamond Point port, bypassing all but 5 miles of the existing Williamsport-Pile Bay Road. The existing road is primarily used by large tractor-trailer rigs in the summer season to haul boats and other bulky freight between Iliamna Lake and Cook Inlet. Other than the existing road segment, there is little development, and the baseline outdoor ambient sound level is "wilderness ambient" classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}. Infrequent truck traffic on the existing Williamsport-Pile Bay Road would temporarily raise the outdoor ambient sound level near the route.

3.19.2.3 Diamond Point Port

Based on recent site observations (AECOM 2018h), development in the vicinity of the Diamond Point port site is associated with a gravel and rock quarry. According to Special Condition #6 on the US Army Corps of Engineers (USACE) permit (POA-2008-523) (USACE 2012), seasonal activities are permitted from May 1 to October 31 each year. Depending on the progress of tideland fill and the corresponding pace of gravel and rock material production, noise-producing activities could include dredging, pile-driving, rock blasting, distribution of materials, and the operation of equipment, consistent with the description in POA-2008-523. Material extracted from the quarry would be transported via marine route. There would be no quarry-associated vehicle traffic contributing to baseline noise conditions on the port access road (see above under port access road). One or more of these noise-producing sources would temporarily elevate outdoor ambient sound levels to a degree that would depend largely on the distance between the receptor location and the source of the noise-producing activity or event.

Outside of this permitted site development activity, little or no noise-producing activities occur at the Diamond Point port site. This suggests that outdoor ambient sound levels would reflect naturally occurring acoustical contributors and be more consistent with the "wilderness ambient" classification in Table 3.19-1, and a baseline noise level of 35 dBA L_{dn}. Depending on proximity to the Cook Inlet shoreline and the magnitude of winds and wave activity, localized sound levels may be higher. Baseline noise levels were not measured at this location.

3.19.2.4 Natural Gas Pipeline Corridor

Baseline noise levels are addressed by location along the natural gas pipeline corridor as follows:

- **Mine Site to Diamond Point Port** – This overland section of the pipeline corridor would parallel the north route mine access road (see description of transportation corridor for Alternative 2, Chapter 2). Existing outdoor baseline noise levels are compatible with the "wilderness" classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}.
- **Ursus Cove to Diamond Point Port** – This section of the pipeline would be buried between Ursus Cove to Cottonwood Cove, placed on the seafloor across the cove, and connect to the onshore portion at the Diamond Point port site. The area represented by this pipeline section is undeveloped, and is compatible with the "wilderness ambient" classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}.
- **Compressor Station near Anchor Point** – Baseline noise level in the vicinity of the compressor station would be as described for Alternative 1.

3.19.2.5 Alternative 2 – Sensitive Receptors

Evaluated data sets used to identify potential NSRs are described in AECOM 2018c. The 2-mile analysis distance includes 76 Native Allotments (6,022 acres), and passes through a portion of Iliamna, Pedro Bay, and Anchor Point census-designated places (USCB 2017, 2018a, 2018b).

3.19.2.6 Alternative 2 – Summer-Only Ferry Operations Variant

Existing noise levels and potential NSRs would be the same as described for Alternative 1.

3.19.2.7 Alternative 2 – Pile-Supported Dock Variant

Existing noise levels and potential NSRs would be the same as described for Alternative 1.

3.19.3 Action Alternative 3 – North Road Only

3.19.3.1 Mine Site

Existing sound and potential NSRs would be the same as described for Alternative 1.

3.19.3.2 Transportation Corridor

For the purpose of describing existing noise levels, facilities in the transportation corridor are grouped and summarized according to location, as follows:

- **Mine Access Road** – Most of the mine access road is remote, with no development. Along the undeveloped portion of the overland transportation route, the "wilderness ambient" classification in Table 3.19-1 would be expected, and therefore have a corresponding baseline noise level of 35 dBA L_{dn}. Pedro Bay is a village along the proposed north route, where existing outdoor noise levels were measured at positions M10, M11, and M12 (MMA 2010). From measured L_{eq} data collected during daytime, evening, and nighttime periods at these three positions, calculated baseline L_{dn} values for the Pedro Bay community are shown in Table 3.19-4.

Table 3.19-4: Calculated Baseline Day-Night Sound Levels at Representative Pedro Bay Community Land Uses

Measurement Location (and Summary Description)	Summer Season L_{dn} (dBA)	Winter Season L_{dn} (dBA)
M10 – Pedro Bay on Iliamna Lake (along the lakeshore next to several cabins used for fishing trips and where several floatplanes were moored)	48	42
M11 – Pedro Bay Tribal Center (behind Tribal Center, up the hill)	48	40
M12 – Pedro Bay School (on school grounds near the main school entrance; additional readings taken behind school at power plant)	44	44

Notes:
dBA = A-weighted decibel
L_{dn} = day-night sound level, expressed as dBA
Source: MMA 2010

3.19.3.3 Diamond Point Port

Baseline sound and potential NSRs would be the same as described for Alternative 2.

3.19.3.4 Natural Gas Pipeline Corridor

For the purpose of describing existing noise levels, features along the natural gas pipeline corridor are grouped and summarized according to location, as follows:

- **Mine Access Road** – This section of the pipeline would parallel the mine access road as described for Alternative 2; would share the same area and existing outdoor ambient sound environment with the mine access road; and is compatible with the "wilderness ambient" classification in Table 3.19-1, and baseline noise level of 35 dBA L_{dn}). There may be localized higher L_{dn} values in the vicinity of the Pedro Bay village, per Table 3.19-4.
- **Ursus Cove to Diamond Point Port** – Baseline sound would be the same as described for Alternative 2.
- **Anchor Point** – Baseline sound would be the same as described for Alternative 1.

3.19.3.5 Alternative 3 – Sensitive Receptors

Evaluated data sets used to identify potential NSRs are described in AECOM 2018c. There are no sensitive receptors within the 10-mile distance of the mine site. The 2-mile zone of all other Alternative 3 project components includes 70 Native Allotments (5,616 acres), and partially includes Iliamna, Pedro Bay, and Anchor Point census-designated places (USCB 2017, 2018a, 2018d).

3.19.3.6 Alternative 3 – Concentrate Pipeline Variant

Under this variant, existing sound and identified NSRs would be the same as described above for the natural gas pipeline corridor for Alternative 3.

3.19.4 Comparison of Sensitive Receptors by Alternative

Table 3.19-5 provides a comparative summary of the analysis area for each alternative and variant; within a 10-mile distance for the mine site, and a 2-mile distance for all other project components (Figure 3.19-1). The analysis distance would encompass the conservative area in which noise impacts could potentially occur, as defined in Section 4.19, Noise. Table 3.19-5 lists the number and acreage of Native Allotments associated with each alternative and variant, as well as proximity to census-designated places.

Table 3.19-5: Comparison of Potential Noise Sensitive Receivers by Alternative

Alternative and Variant	Analysis Area[1]	Native Allotments		Proximity to Census Designated Places[1]			
	Acres	Count	Acres	Iliamna	Kokhanok	Pedro Bay	Anchor Point
Alternative 1 (Main)	804,638.3	22	2,715	Yes	Yes	No	Yes
Alternative 1 – Kokhanok East Ferry Terminal Variant	800,199.1	22	2,513	Yes	Yes	No	Yes
Alternative 1 – Summer-Only Ferry Operations Variant	804,709.2	22	2,715	Yes	Yes	No	Yes
Alternative 1 – Pile-Supported Dock Variant	804,626.6	22	2,715	Yes	Yes	No	Yes
Alternative 2 (Main)	753,764.2	76	6,022	Yes	No	Yes	Yes
Alternative 2 Summer-Only Ferry Operations Variant	753,874.5	76	6,022	Yes	No	Yes	Yes
Alternative 2 – Pile-Supported Dock Variant	753,838.2	76	6,022	Yes	No	Yes	Yes
Alternative 3 (Main)	742,036.9	70	5,616	Yes	No	Yes	Yes
Alternative 3 – Concentrate Pipeline Variant	741,927.2	70	5,616	Yes	No	Yes	Yes

[1]10-mile analysis distance from mine site and 2-mile analysis distance for other components.
Source: PLP 2018d; BLM 2018; USCB 2017, 2018a, 2018c, 2018d