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 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 project. The discussion below addresses potentially affected waterbodies, baseline water balance model, floodplain magnitude and frequency, flood hazards, floodplain functions and values, tides, and water use (both surface and groundwater). Drainage basins (synonymous in this document with catchments, watersheds, sub-catchments), flow patterns, 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), which also considered previous studies and data collected by the US Geological Survey (USGS) and US Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 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. Details regarding meteorological inputs to the baseline watershed model (BWM), including model calibration and validation, 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 (Figure 3.16-1). The largest rivers draining into Bristol Bay are the Nushagak and Kvichak rivers. These 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 in 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.

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

Sources: PLP 2020-RFI168;
PLP-2019-RFI153; USGS 2017

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25 0 25 50
Miles

Watersheds

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

Action Alternatives

- Natural Gas Pipelines
- Alternative 1a
- Alternative 1
- Alternative 2
- Alternative 3

BRISTOL BAY WATERSHED

PEBBLE PROJECT EIS

FIGURE 3.16-1

3.16.1 Alternative 1a

This section describes the surface water hydrology of Alternative 1a.

3.16.1.1 Mine Site

The mine site is in the upper portions of the NFK, SFK, and Upper Talarik Creek (UTC) watersheds (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 (Figure 3.16-3). The open pit, as well as the overburden stockpile, open pit water management pond (WMP), water treatment plant (WTP) #1, and the SFK treated water discharge point would be in the SFK watershed. Only the UTC treated water discharge point and a short portion of the mine access road would be in the UTC watershed (Figure 3.16-3).

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 publicly 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)	Main 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 et al. 2011a

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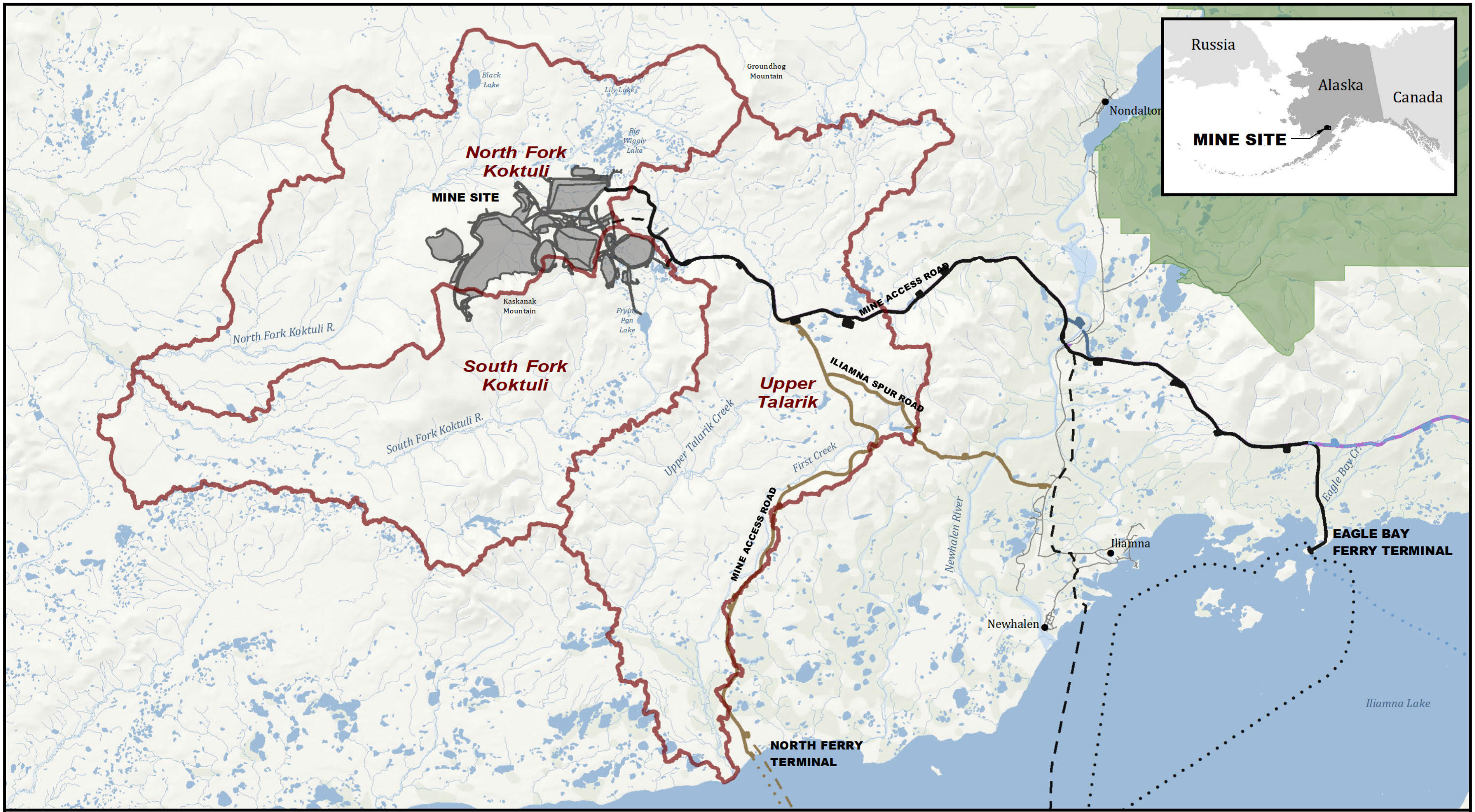
[2] The mine study area (Knight Piésold et al. 2011a) described in this section is within the EIS analysis area.



Sources: PLP 2020-RFI168; PLP 2019-RFI153

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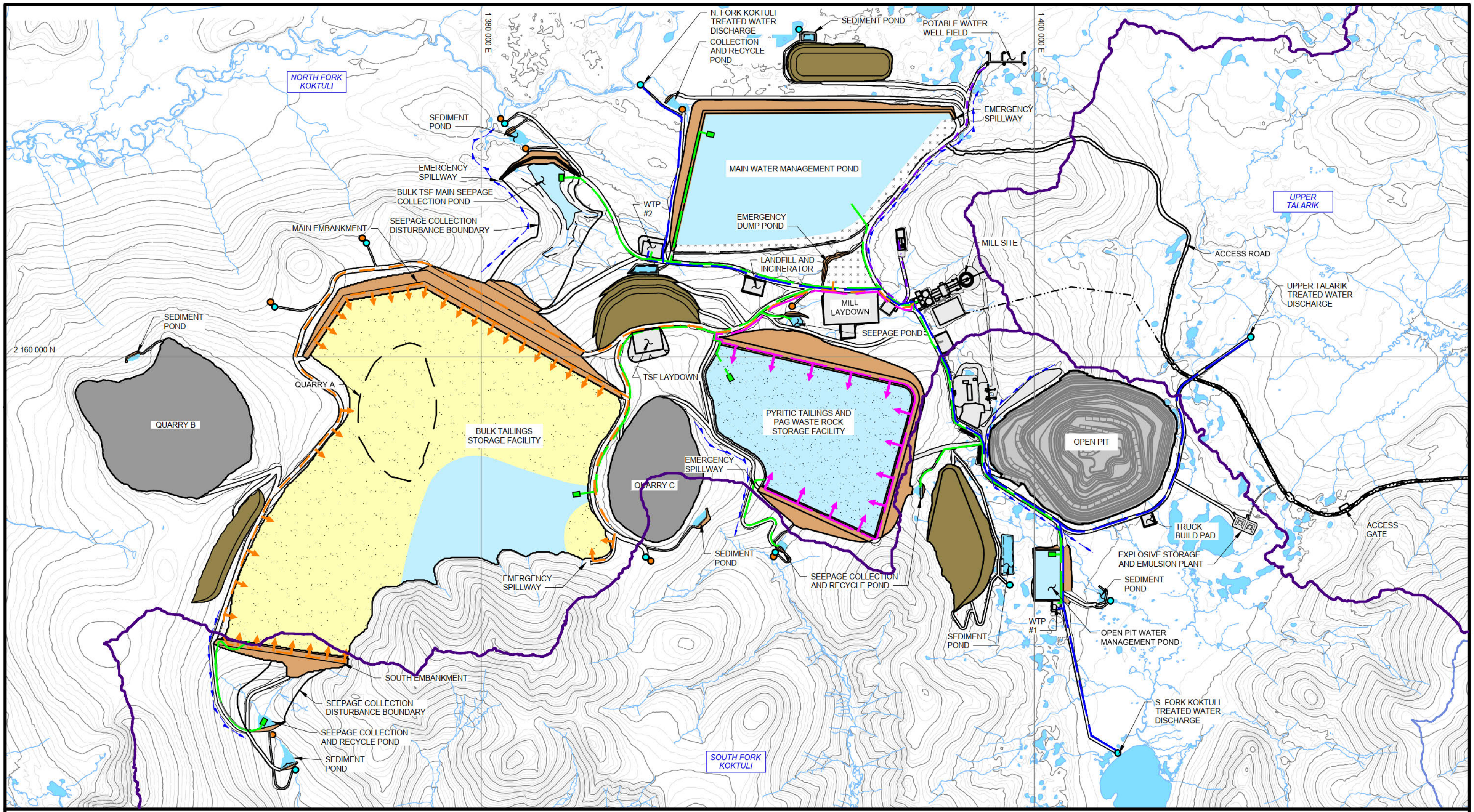
WATERSHEDS IN THE MINE STUDY AREA

PEBBLE PROJECT EIS

FIGURE 3.16-2



Source: Knight Piesold 2019s

US Army Corps of Engineers®

0.5 0 0.5 1

Miles

LEGEND

- ▢ OPEN PIT
- 🟨 BULK TAILINGS
- ▢ PYRITIC TAILINGS AND PAG WASTE ROCK
- 🟫 EMBANKMENT FILL
- ▢ POND
- ▨ LINER
- ▢ QUARRY
- 🟫 OVERBURDEN AND GROWTH MEDIUM STOCKPILE
- ═ ROAD (NOTE 2)
- — · · — NATURAL GAS PIPELINE
- — RECLAIM PIPELINE
- 🟩 RECLAIM WATER PUMPING BARGE
- — BULK TAILINGS PIPELINE
- ↓ BULK TAILINGS DISCHARGE
- — PYRITIC TAILINGS PIPELINE
- ↓ PYRITIC TAILINGS DISCHARGE
- — · · — WTP POTABLE WATER PIPELINE
- — WTP DISCHARGE PIPELINE
- ● WATER QUALITY MONITORING POINT
- ● GROUNDWATER QUALITY MONITORING AND POTENTIAL PUMP BACK AREA
- ← ← DIVERSION CHANNEL
- — MAJOR DRAINAGE DIVIDE

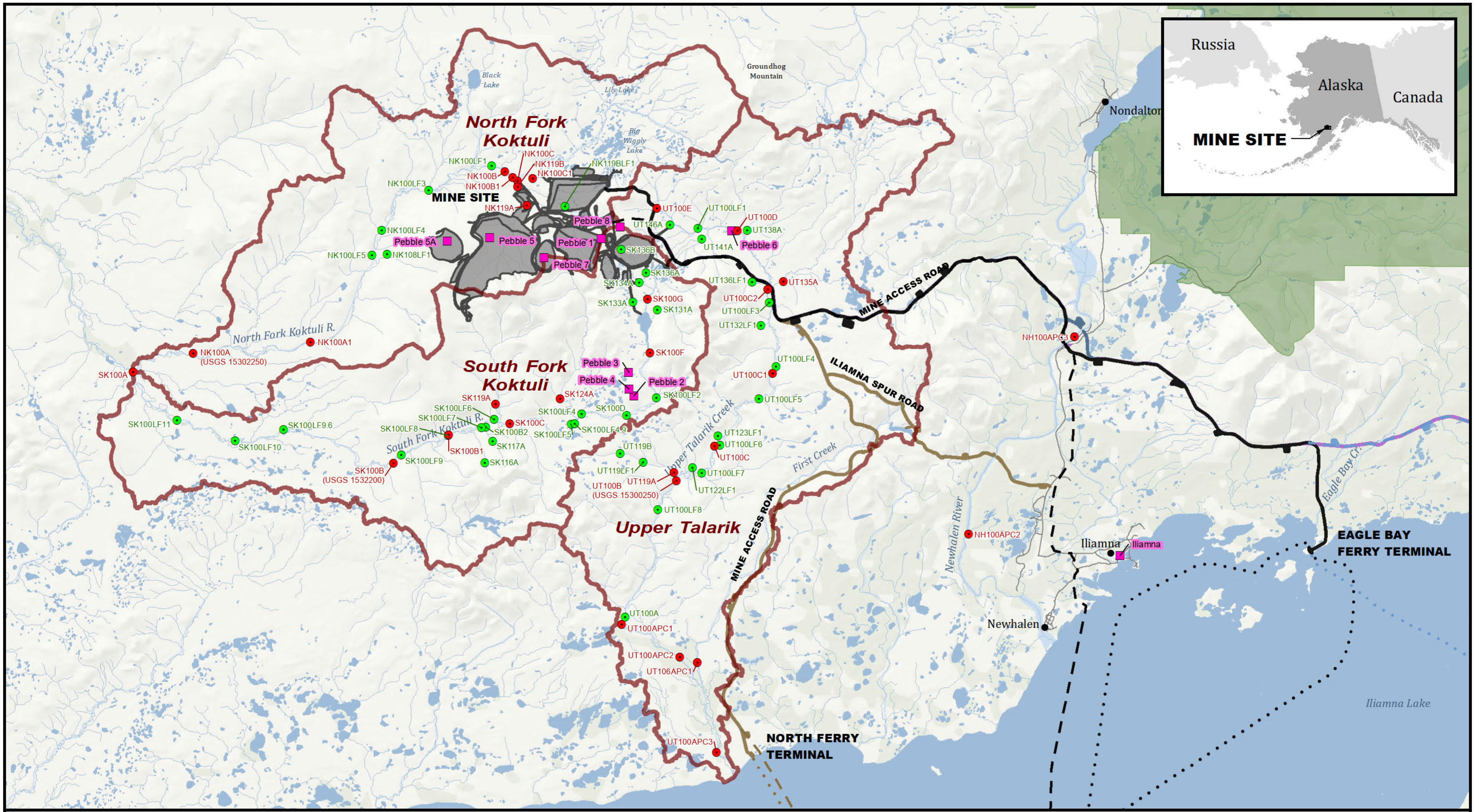
NOTES:

1. CONTOUR INTERVAL IS 25 FEET.
2. CONCEPTUAL HAUL, SERVICE, AND ACCESS ROAD CUT AND FILL EXTENTS SHOWN INCLUDE ALLOWANCE FOR BERMS, COLLECTION DITCHES, AND POWER POLES, AS REQUIRED.
3. STOCKPILE AND EMBANKMENT FOOTPRINTS INCLUDE ALLOWANCE FOR COLLECTION DITCHES.
4. GROUNDWATER QUALITY MONITORING LOCATIONS WILL BE ESTABLISHED WITHIN THE ZONE OF INTEREST ALONG THE TOE OF THE EMBANKMENTS AS REQUIRED. ALLOWANCE FOR THE INSTALLATION OF THE MONITORING AND/OR PUMPBACK WELLS INCLUDED WITHIN THE ROAD FOOTPRINTS.

WATERSHEDS AND MINE SITE FOOTPRINT

PEBBLE PROJECT EIS

FIGURE 3.16-3



Sources: PLP 2020-RFI168; PLP 2019-RFI153; Knight Piesold 2011a and 2015b

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2 0 2 4
Miles

- ● Continuous Monitoring Gage Stations
- ● Early Spring Low-Flow Measurement Sites
- ■ Meteorological Stations
- Major Drainage Boundary

Action Alternatives

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

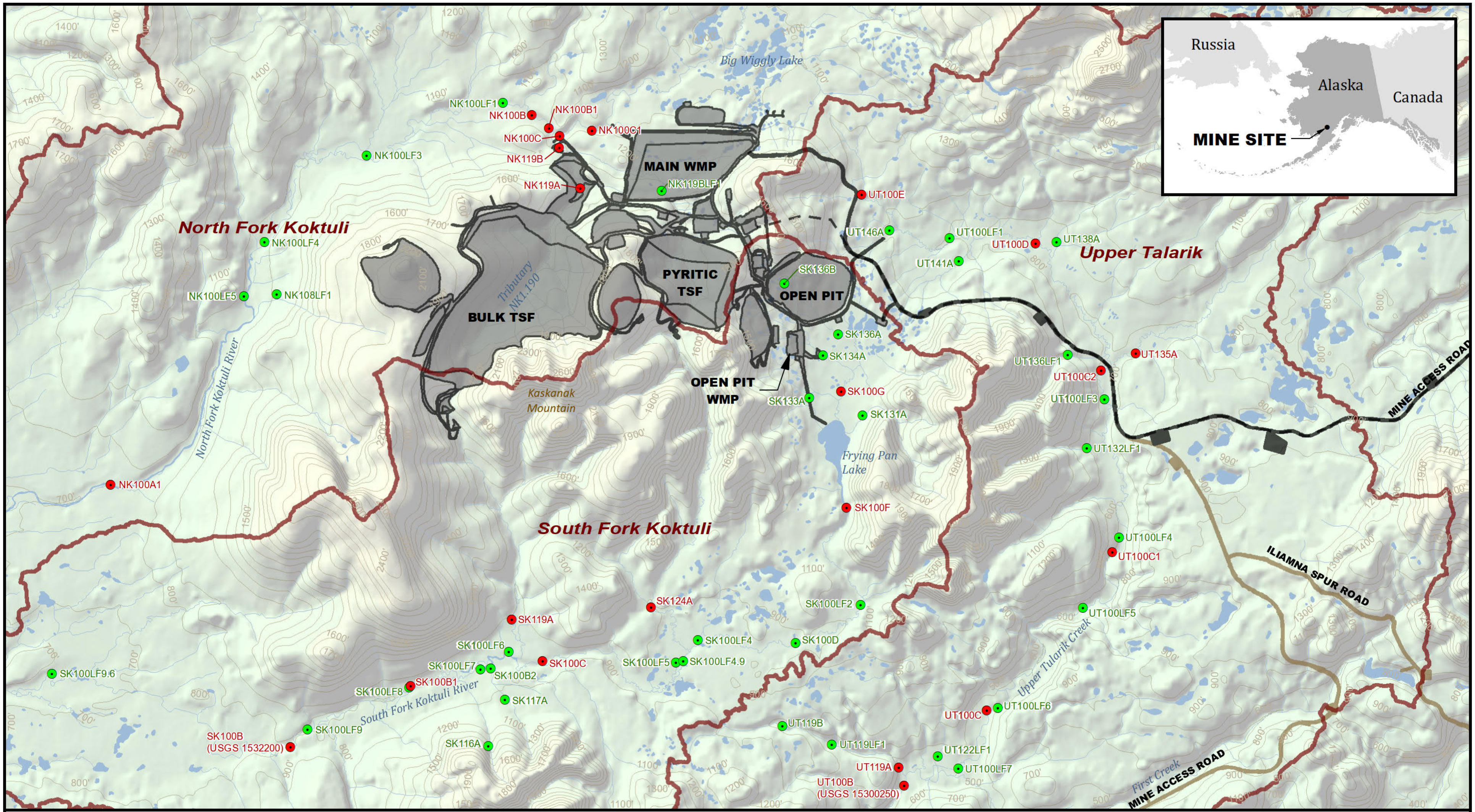
Other Features

- Local Roads
- Lake Clark National Park & Preserve

STREAM GAGING STATIONS IN MINE STUDY AREA

PEBBLE PROJECT EIS

FIGURE 3.16-4



Sources: PLP 2019-RFI153;
Knight Piesold 2011a, 2015b

US Army Corps of Engineers

1 0 1 2
Miles

● Continuous Monitoring Gage Stations

● Early Spring Low-Flow Measurement Sites

Action Alternatives

- - Natural Gas Pipeline

▨ Alternative 1a

▨ Alternative 1

Other Features

100' Contour (Existing)

River/Stream

Lake/Pond

Major Drainage Boundary

STREAM GAGING STATIONS IN THE VICINITY OF THE MINE SITE

PEBBLE PROJECT 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 (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 3,074 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 (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 (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). Groundwater stored in the overburden sustains winter base flow[3] along most of the streams and rivers (Schlumberger 2015a). Streamflow in the mine site watersheds exhibits complex interactions with groundwater, with both gaining and losing stream reaches, depending on local soil types, land surface gradients, and water table gradients. In some stream reaches, hyporheic flow[4] occurs on a very local scale in response to channel features, substrate types, and fluctuating stream water levels. Considering these variations, there is generally a net positive contribution to base flow from groundwater in most stream segments. Section 3.17, Groundwater Hydrology, further describes interaction, importance, and function of these deposits related to surface water runoff, groundwater storage, and exchange between surface water and groundwater.

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

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

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 3.16-4 depicts all gaging station locations in the three watersheds, and Figure 3.16-5 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 K3.16-1 lists stream gaging stations, organized by watershed, that continuously collect flow data during the open water season, and the number of years in which data were collected at each station. Table K3.16-2 presents a summary of the early spring low-flow discharge measurements collected at both continuous and non-continuous data collection sites in each watershed. Streamflow measurements presented in Table K3.16-2 provide the range of early spring flows recorded at each monitoring location between 2005 and 2012, and represent different conditions during the period of record. 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.

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 NK119A (Tributary NK 1.190) are discussed below.

NK100C, Main Stem (main channel of the NFK River) (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, 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[5] at NK100C is 48 cubic feet per second (cfs) (see Table K3.16-3). 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 K3.16-2). Low-flow discharge measurements ranged from 8 to 22 cfs during the 8-year period of record. Spring and fall instantaneous peak discharge measurements[6] were obtained over a 5-year period (see Table K3.16-4). 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 (Figure 3.16-5): Station NK119A is in the western tributary of the NFK River (the tributary is designated in baseline studies as NK 1.190). The bulk tailings storage facility (TSF) and bulk TSF seepage control pond (SCP) would be in the NK 1.190 catchment (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

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[5] **Average annual discharge** is the mathematical average of all discharge measurements (i.e., flow) recorded over a year.

[6] **Instantaneous peak discharge (or flow)** is the maximum instantaneous discharge occurring during the designated period.

(Knight Piésold et al. 2011a). Based on 8 years of record, the long-term average annual discharge at NK119A is 24 cfs (see Table K3.16-3). 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 (see Table K3.16-2). 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 (see Table K3.16-4). 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.

South Fork Koktuli River

There are six gaging stations along the main stem of the SFK River (Figure 3.16-4). Station data from SF100F (main stem of the river) and SK119A (Tributary SK 1.190) are discussed below.

SF100F, 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 K3.16-3). 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 (see Table K3.16-2). 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 K3.16-4). 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.

SK119A, Tributary (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 (Figure 3.16-5). Tributary SK1.190 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 K3.16-3). 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 K3.16-2). 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 K3.16-4). 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 (Figure 3.16-4). Station data from UT100D (main stem of the river) are discussed below.

UT100D, 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 in 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 K3.16-3). 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 K3.16-2). 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 K3.16-4). 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) (Figure 3.16-4) because of upstream losses of streamflow to groundwater. In the UTC watershed, streamflow at gage UT119A (Figure 3.16-4) gains substantial flow from groundwater in 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).

Baseline Watershed

Model A BWM was developed in 2011 as a tool for understanding the connection between climate, surface water, and groundwater systems under pre-mining conditions in the NFK, SFK, and UTC watersheds. Additionally, the BWM was used to estimate long-term baseline surface water and groundwater flows for assessing potential changes to flow related to project development (Schlumberger 2011a).

The BWM is a semi-distributed spreadsheet-based precipitation-runoff model (Knight Piésold 2019g) that incorporates the key components of the hydrologic cycle, including precipitation as rain and snow, evaporation, sublimation, runoff, and surface storage; and groundwater recharge, discharge, and storage (Knight Piésold 2019g; Schlumberger 2011a). The components of the BWM are presented in Figure K3.16-4. The BWM was developed by Knight Piésold from first principles (AECOM 2018o) in Microsoft Excel (Knight Piésold 2019g), and run with a monthly time step. The BWM was calibrated to 60 months of streamflow data (starting in mid-2004) at 22 nodes corresponding to established streamflow gauging stations (Knight Piésold 2019g). After BWM calibration, the BWM was used with a 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. Key findings about hydrometeorological, hydrogeologic, and hydrologic characteristics of the NFK, SFK, and UTC watersheds are described below (Knight Piésold 2019g).

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 meteorological monitoring station Pebble 1 in the mine site (Knight Piésold 2018a, 2019g) (Figure 3.16-4). Details of the procedures used to generate the long-term synthetic temperature and precipitation record are presented in Knight Piésold (2018g, 2019g). As described in Appendix K3.16, 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 2019g). In general, the magnitude of the factors was determined from hydrometeorological data collected in the analysis area, and/or calibration of the BWM (i.e., pre-mine) to available surface and groundwater data (Knight Piésold 2019g).

NFK Watershed

The NFK watershed is in an area of rain shadow or snow loss, as indicated by the model calibration need for local sub-catchment precipitation factors that are below 1.0 in most sub-catchments to achieve a balance between estimated precipitation and measured streamflows. This is consistent with the NFK headwater sub-catchment locations on the leeward side of many of the topographical high points in the watershed model area.

Stations NK119A and NK119B are on Tributary NK 1.190, upstream of their respective confluence with the NFK River. These two catchments respectively have the highest and third-highest mean elevations in the watershed model area (see Table K3.16-1). NK119A has one of the highest mean annual unit discharge (MAUD) values in the watershed model area (see Table K3.16-15), attributable to its high average elevation and subsequently high net precipitation, and its relatively low rate of groundwater flow leaving the sub-catchment. In contrast, NK119B has substantial groundwater flow losses.

Stream losses from the NK119B channel occur upstream of gage NK119B, and no flow occurs at this gage during low-flow winter months. The simulated March flow at NK119B is very near 0 cfs (see Table K3.16-15).

The drainage area above gage NK100C includes the headwaters of the NFK River. Approximately 1 cfs of groundwater flow is modeled to cross the catchment boundary from the NK100C sub-catchment to the sub-catchment of gage UT100E in the UTC watershed (see Table K3.16-15).

A large glacial outwash deposit is downstream of NK119A, NK119B, and NK100C (Schlumberger 2011a). Low-flow measurements indicate that losses to groundwater in the glacial outwash occur downstream of NK100B. Low-flow measurements along the stream channel indicate flows decrease from NK100B through NK100LF2, which suggests high groundwater flow rates in the outwash sand and gravel (flow rates in streams are typically expected to increase with distance downstream). Flows increase again near low-flow gage NK100LF3, which is near the downstream extent of mapped outwash sand and gravel. At NK100LF4, the next low-flow station downstream, the low-flow rate increases.

Consistent with the presence of outwash deposits and winter low-flow measurements, channel flows are modeled to infiltrate the stream bed and recharge the groundwater system in sub-catchments NK100C and along the upstream reach of NK100A1.

SFK Watershed

The SFK River watershed is in an area of increased precipitation or net snow accumulation, as indicated by the model calibration need for local sub-catchment precipitation factors of 1.0 or greater in most sub-catchments to achieve a balance between estimated precipitation and measured streamflows. This is consistent with the headwater SFK sub-catchment locations on the windward side of the highest topographic features in the watershed model area.

Stations SK119A and SK124A are on tributaries SK 1.190 and SK 1.124, upstream of their respective confluences with the SFK River. These two neighboring catchments have some of the highest mean elevations in the watershed model area (see Table K3.16-1). Similar to NK119A, SK119A has one of the highest MAUD values in the watershed model area (see Table K3.16-15). Station SK119A has notably more runoff than SK124A, despite having only a slightly higher average elevation, which may be attributed to it receiving substantially more windblown snow; and its gage is higher up in its watershed, and therefore above the glaciofluvial deposits that underlie SK124A. Therefore, SK119A has more precipitation input, and a substantially smaller proportion of its total flow goes to ground before the gage.

The headwater portions of sub-catchments SK119A and SK124A are in very steep valleys. These drainages flow over permeable glacial fluvial sand and gravel deposits in their lower reaches. Both reaches are modeled to lose surface flows to the subsurface as the runoff flows over the more permeable deposits (see Figure K3.16-2). The SK 1.124 sub-catchment is divided into two separate areas in the watershed model (SK124Aa and SK124A) to simulate the infiltration of surface flows along the lower portion of the stream reach. Infiltration of surface flows along tributary SK 1.124 is supported by the measured mean annual unit runoff (Knight Piésold 2018g), which is equivalent to approximately 30 inches per year (in/yr), and is much lower than the calculated average annual net precipitation for Pebble 1, suggesting there is a sizable amount of groundwater flow bypassing the gage of this headwater catchment.

Stream losses from the SK 1.190 channel occur downstream of the SK119A gage in the sub-catchment of gage SK100B1. Losses from channel SK 1.124 occur upstream of the SK124A gage, and contribute substantially to the groundwater regime in sub-catchment SK100C (see Figure K3.16-2).

The channel at SK100C goes dry during most years, during both the summer and winter low-flow periods, but most consistently during the winter. Groundwater flow out of the SK100C sub-catchment is the highest of all catchments, and averages 32 cfs (see Table K3.16-15). A portion of this groundwater continues downstream to sub-catchment SK100B, and a portion of the groundwater flows as an inter-basin transfer to tributary UT119A. The simulated stream flows at SK100C were dry during March for most years.

A large amount of water is predicted to infiltrate the channel between SK100B and SK100A. Low-flow measurements indicate that baseflow decreases downstream from SK100B to SK100LF10 (about 7.8 miles downstream), and then recovers at SK100A (about 13.9 miles downstream) (Schlumberger 2011a). The losses are likely related to the extensive sand and gravel aquifer materials downstream of UT100B, and the parallel tributary on the same alluvial plain that likely captures some of the SFK flows. The recovery of baseflow at SK100A and the low flows measured at Kaskanak Creek (gage KC100A; Knight Piésold 2018g) indicate that if there are any cross-catchment seepage losses from this section of the SFK River, they are very small.

Consistent with the presence of outwash deposits and winter low measurements, channel flows are modeled to infiltrate the stream bed and recharge the groundwater system in sub-catchments SK124A, SK100C, SK100B1, and SK100A.

UTC Watershed

Sub-catchments in the UTC watershed have the lowest mean elevations of the study area. Windblown snow patterns appear to be fairly balanced in this watershed, as indicated by the model calibration need for local sub-catchment precipitation factors ranging between 0.88 and 1.17 to achieve a balance between estimated precipitation and measured streamflows.

Headwater sub-catchment UT100E receives approximately 1 cfs of cross-boundary groundwater flow from the NK100C sub-catchment (see Table K3.16-15). Base flows dominate the hydrograph for UT100E, consistent with the many seeps mapped immediately upstream of this gage (Schlumberger 2011a).

Stream gage UT119A measures discharge from tributary UT 1.190 immediately upstream of the confluence with UTC. Sub-catchment UT119A receives approximately 21 cfs of cross-boundary groundwater flow from the SFK watershed (see Table K3.16-15). The remainder of the groundwater discharge in the sub-catchment originates as recharge in the UT119A catchment area (about 6 cfs). There is very little surface runoff feeding UT119A, and the measured flows are predominantly groundwater discharge. Unit flows at UT119A are much higher than at any other gage in the watershed model area because of the cross-boundary groundwater flow from the SFK watershed.

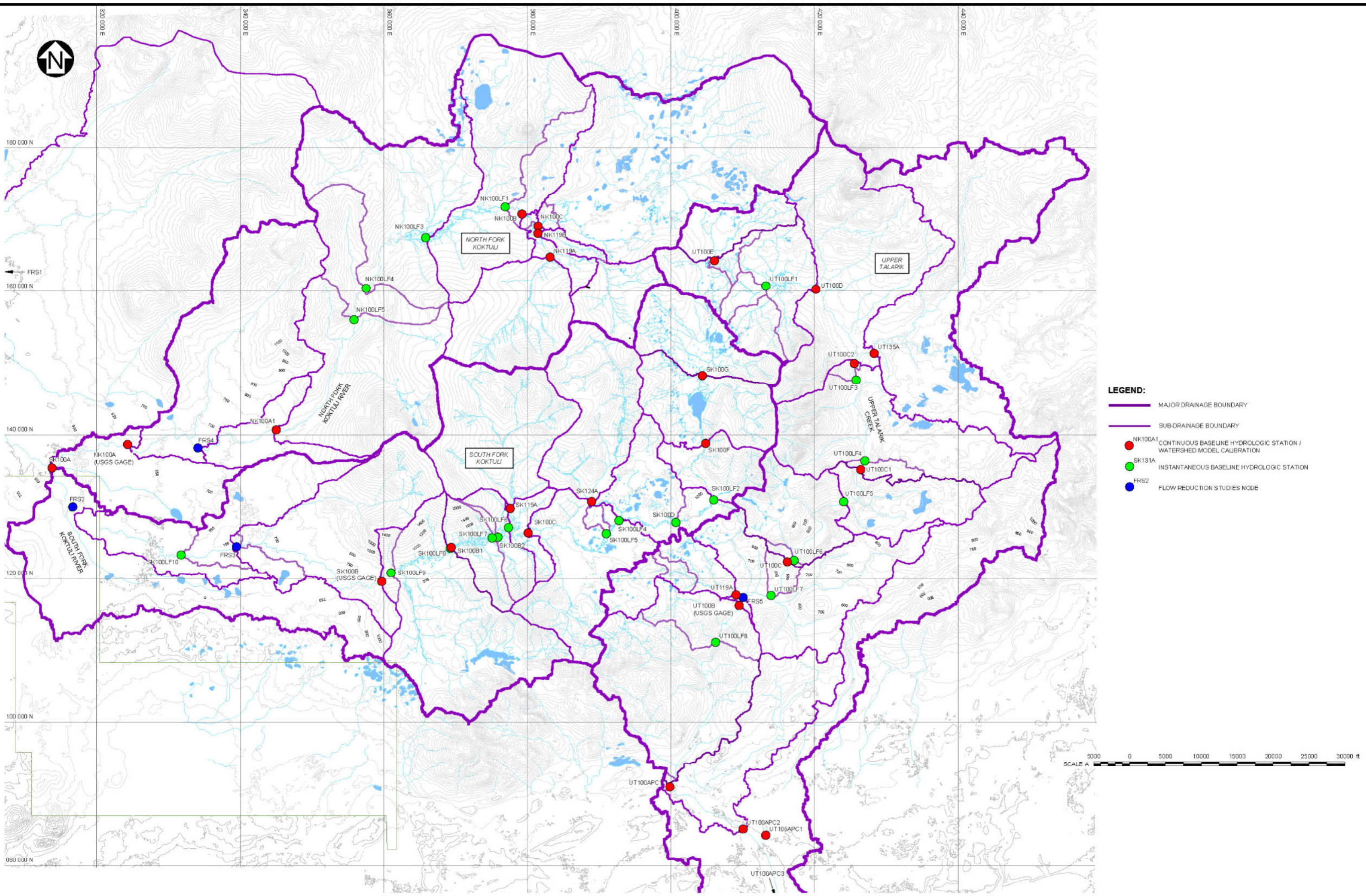
Streamflows with Distance Downstream

Long-term streamflows were estimated at several intermediary BWM nodes between the calibrated nodes (Knight Piésold 2019g). Intermediary node locations represent hydrology stations where winter low-flow measurements have been collected, and are shown on Figure 3.16-6. Intermediary nodes were assigned BWM parameter values the same as the calibrated BWM node immediately downstream, with some adjustment to the groundwater parameter values to ensure that simulated streamflows are consistent with instantaneous measurements of streamflow (low flows) and with the geologic conditions along the channel.

The patterns of how estimated winter low flows vary with distance downstream along the NFK, SFK, and UTC channels are provided on Figure 3.16-7 through Figure 3.16-9. The line representing the average simulated winter low flows on Figure 3.16-7 through Figure 3.16-9 represents the average of all minimum winter low flows over the 76-year simulated period. The lowest simulated flows during the winter of 2011 are also shown as a reference because conditions were drier during that year than many other years, and therefore winter low flows are lower than the average of the period of record (Knight Piésold 2019g).

A stream reach with low flows that increase with distance downstream is a gaining reach, and a stream reach with low flows that decrease with distance downstream is a losing reach. The patterns of gaining and losing stream reaches indicate the degree of groundwater and surface water interaction along the channel, particularly during low-flow winter months when there is no rain, and streamflows therefore represent the groundwater contribution to streamflow. Patterns of gaining and losing stream reaches included in the simulated flow record and evident on Figure 3.16-7 to Figure 3.16-9 include:

- Low flows along the NFK channel are predicted to decrease between NK100B and low-flow hydrology station NK100LF2 at mile 4.5, and then low flows subsequently increase with distance downstream. The losing section along the NFK channel corresponds to the presence of an outwash sand and gravel deposit and streamflow increases where this deposit ends near station NK100LF3 (Figure 3.16-7).
- Low flows along the SFK channel initially increase to SK100F and subsequently decrease over an approximately 7-mile section. The channel in this stream section (between SK100D and SK100C) is often dry during low-flow periods. Flows subsequently increase downstream of SK100C (mile 13.8), although additional stream losses occur at SK100B1 (mile 17.9) and along a stream section between SK100LF9 and flow reduction study (FRS) node FRS-3 (between mile 20 and mile 27). Low flows increase in SFK downstream of FRS-3 (mile 28) (Figure 3.16-8).
- Low flows along the UTC channel are predicted to increase with distance downstream. A rather sharp increase in low flow is predicted at UT100B, due in large part to the contribution of flow from Tributary UT 1.190, which is consistent with the pattern of the low-flow measurements (Figure 3.16-9).



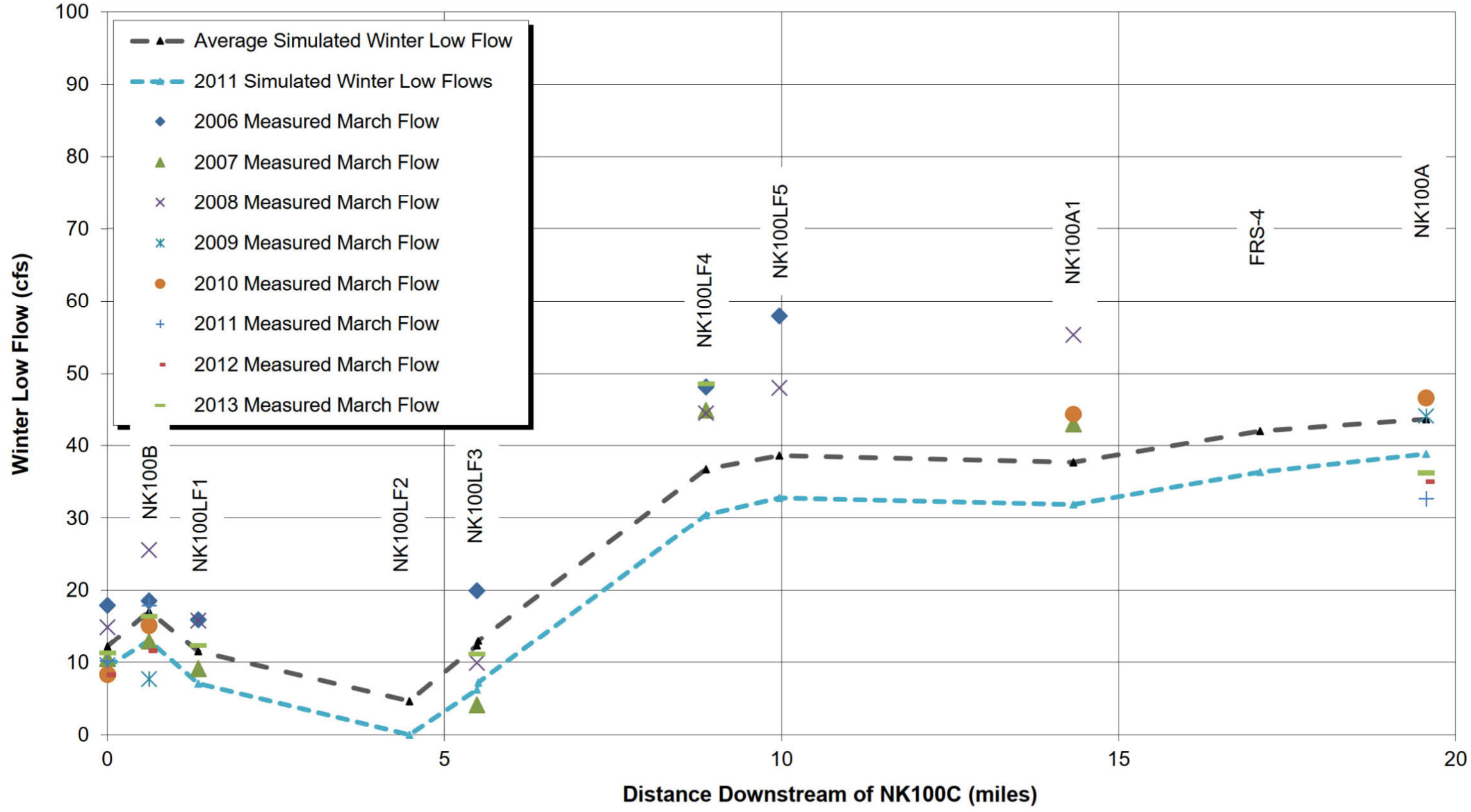
Source: Knight Piesold 2019g, Figure 4.1

US Army Corps of Engineers®

HYDROLOGIC STATIONS AND SUB-CATCHMENTS WITH SIMULATED LONG-TERM FLOW

PEBBLE PROJECT EIS

FIGURE 3.16-6



NOTES:

1. AVERAGE SIMULATED WINTER LOW FLOW IS THE AVERAGE OF ALL SIMULATED ANNUAL MINIMUM WINTER LOW FLOWS FROM 1942 TO 2017.
2. THE 2011 SIMULATED LOW FLOWS PRESENT THE LOWEST SIMULATED FLOW OF THE WINTER LOW FLOW SEASON AT EACH LOCATION FOR THAT YEAR.

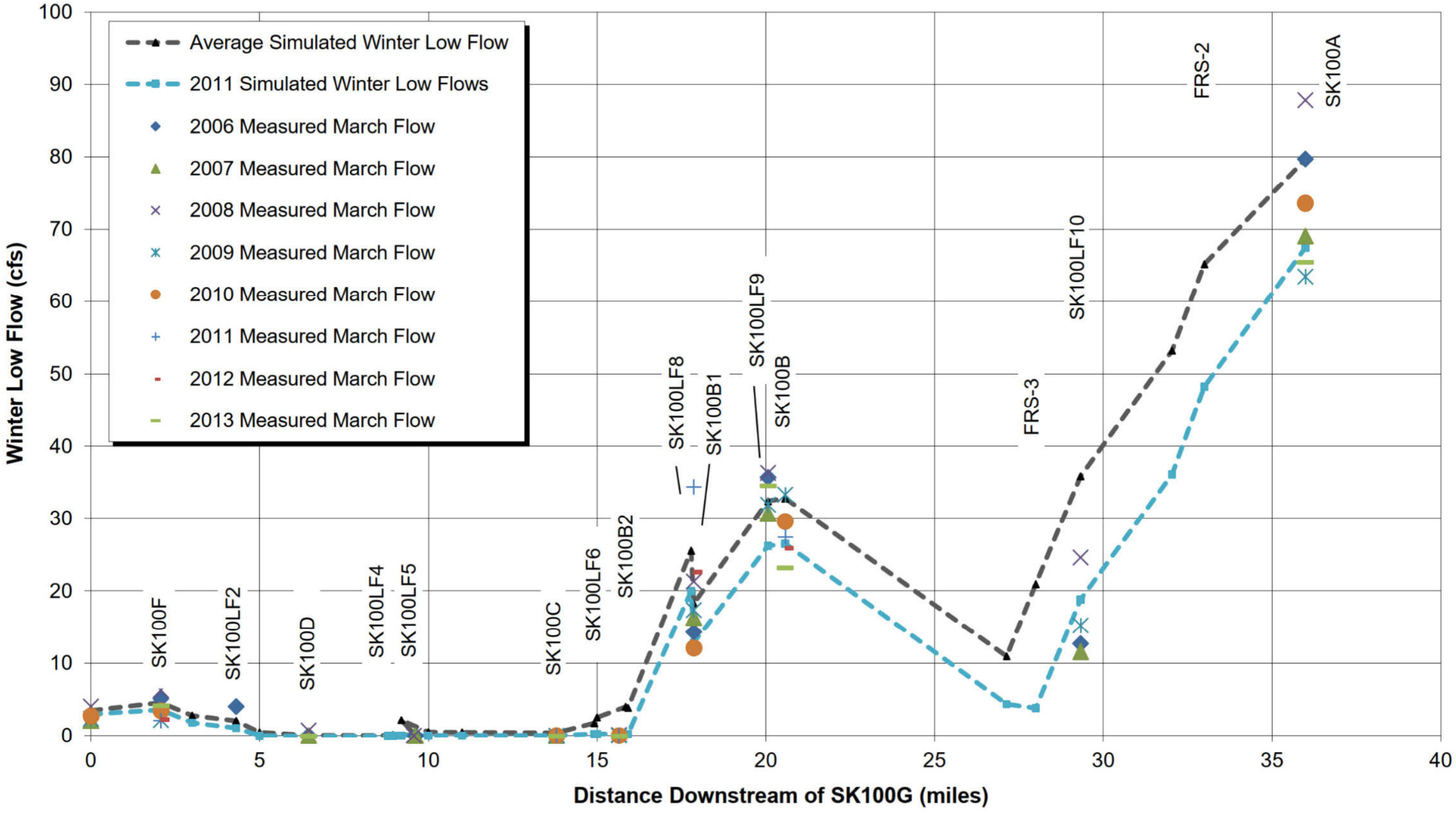
Source: Knight Piesold 2019g, Figure 4.2

US Army Corps of Engineers®

NORTH FORK KOKTULI STREAMFLOW WITH DISTANCE DOWNSTREAM

PEBBLE PROJECT EIS

FIGURE 3.16-7



NOTES:

1. AVERAGE SIMULATED WINTER LOW FLOW IS THE AVERAGE OF ALL SIMULATED ANNUAL MINIMUM WINTER LOW FLOWS FROM 1942 TO 2017.
2. THE 2011 SIMULATED LOW FLOWS PRESENT THE LOWEST SIMULATED FLOW OF THE WINTER LOW FLOW SEASON AT EACH LOCATION FOR THAT YEAR.

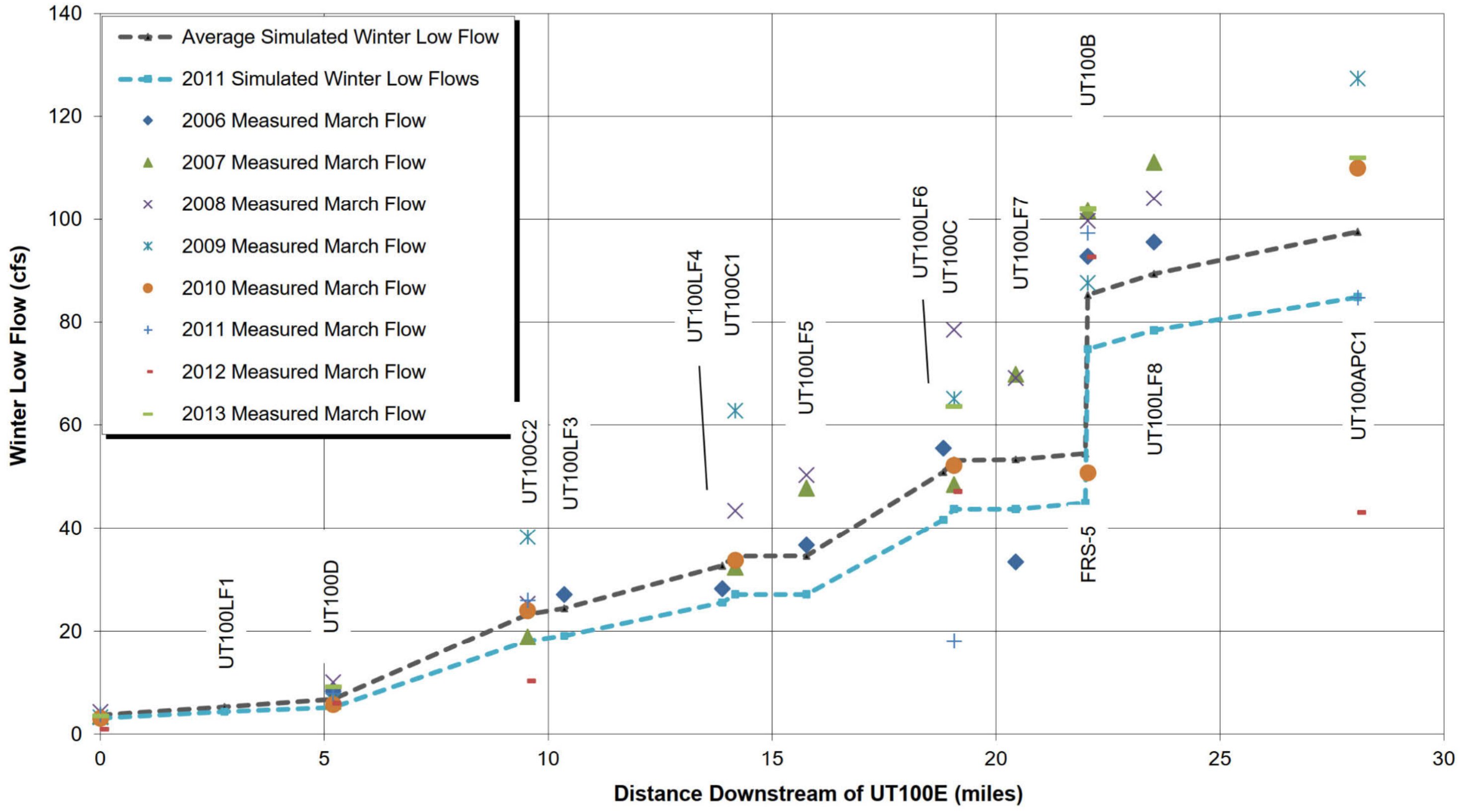
Source: Knight Piesold 2019g, Figure 4.3

US Army Corps
of Engineers®

SOUTH FORK KOKTULI STREAMFLOW WITH DISTANCE DOWNSTREAM

PEBBLE PROJECT EIS

FIGURE 3.16-8



NOTES:

1. AVERAGE SIMULATED WINTER LOW FLOW IS THE AVERAGE OF ALL SIMULATED ANNUAL MINIMUM WINTER LOW FLOWS FROM 1942 TO 2017.
2. THE 2011 SIMULATED LOW FLOWS PRESENT THE LOWEST SIMULATED FLOW OF THE WINTER LOW FLOW SEASON AT EACH LOCATION FOR THAT YEAR.

Source: Knight Piesold 2019g, Figure 4.4

US Army Corps of Engineers®

UPPER TALARIK CREEK STREAMFLOW WITH DISTANCE DOWNSTREAM

PEBBLE PROJECT EIS

FIGURE 3.16-9

The mine site water balance model was then developed to reflect end-of-mine conditions, and rerun with the 76-year synthetic temperature and precipitation record. Finally, the mine site water balance model was altered to reflect post-mine closure conditions, and run with the 76-year synthetic temperature and precipitation record.

The results from the mine site water balance 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 BWM, are presented in Appendix K3.16.

The mine site water balance model predicts the movement of water in the mine site, using inputs from the BWM and the groundwater model (Knight Piésold 2019f, g, n; PLP 2019-RFI 109g). The mine site water balance model was developed with GoldSim® software and is based on a 20-year conceptual mine life (Knight Piésold 2019f, g, n; PLP 2019-RFI 109g). The output of the mine site water balance 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 2019f, g, n; PLP 2019-RFI 109g), and resulted in seventy-six 20-year period evaluations of water flow and storage. The results from the mine site water balance model and the implications for mine operation are presented in Section 4.16, Surface Water Hydrology. The groundwater model 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 (see Table K3.16-5) in the mine study area[7] (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[8] of 2 to 10 years was estimated based on a Log-Pearson[9] 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[10] 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 then used to estimate the 25-year through 200-year flood-peak discharges at other stations in the group containing the USGS stream gage station.

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

[8] 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.

[9] Log-Pearson type III is a statistical technique for fitting frequency distribution data to predict the design flood for a river at a location.

[10] The weighted estimates were prepared according to the recommendations in Curran et al. (2003).

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.

Long-Term Climate Change

It is prudent to consider whether or not the use of historical streamflow and climate records, which are being used to evaluate surface and groundwater hydrology and the impacts to surface and ground waters, 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)—Historical trends in annual temperature, precipitation, and discharge were reviewed at locations in or close to the analysis area.
- National Weather Service (NWS) (2012)—Evaluated whether there were statistically significant trends in the annual maximum precipitation data used by the NWS 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.
- Knight Piésold (2018g)—Historical trends in annual temperature and precipitation were reviewed at locations in the area and compared to statements made in the 2017 Climate Science Special Report prepared by the US Global Change Research Program (USGCRP 2017).

The following is a brief summary of the long-term climate change analyses documents described above; additional details are provided Appendix K3.16.3. There is 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 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 NWS (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 in 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 in 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.

The 2017 Climate Science Special Report prepared by the USGCRP as part of the Fourth National Climate Assessment (CA4) (USGCRP 2017) was recently published. Key statements from the report pertain to future temperature and precipitation increases. Knight Piésold (2018g, Appendix A) compared statements made in the report to the trends and patterns present in the temperature and precipitation data sets for Iliamna Airport during the period 1943 to 2017, as published by the US National Oceanic and Atmospheric Administration (NOAA). The following is a summary of Knight Piésold (2018g, Appendix A) key conclusions.

- The 1943-2016 temperature records for Iliamna, when taken at face value, appear to indicate that temperatures in the Pebble project area are gradually increasing with time. For example, the trendline for annual mean temperatures has a slope of 0.06, indicating that those temperatures are increasing at an average rate of approximately 0.6 degrees Fahrenheit (°F) per decade. Similarly, the trendline for annual minimum daily temperatures has a slope of 0.13, indicating that those temperatures are increasing at an average rate of approximately 1.3°F per decade. Projected over the next 3 decades, these rates equate to temperature increases of 1.8°F and 3.9°F, respectively. These changes are generally consistent with climate change projections and the findings of the NCA4 report, which states: "…over the next few decades (2021-2050), annual average temperatures are expected to rise by about 2.5°F for the United States, relative to the recent past (average from 1976-2005), under all plausible future climate scenarios."
- However, when the warm and cold phases of the PDO are taken into account, in particular when the substantial step-up in temperatures that occurred coincident with the phase shift in 1976/1977 is considered, the temperatures show no significant trends. Temperatures between 1943 and 1976 were reasonably consistent, and temperatures between 1977 and 2016 were also reasonably consistent. However, average temperatures during the respective periods were substantially different. For example, the mean of the annual mean temperatures for the pre-shift period is 1.9°F lower than for the post-shift period, and the mean of the annual minimum daily temperatures is 5.6°F lower. This pattern is inconsistent with the findings of the NCA4 report, and with all climate change publications reviewed by Knight Piésold to date. Based on available information, no climate change model is able to simulate the temperature step associated with the PDO. This fact is not particularly surprising because the mechanisms behind the PDO are not well understood. The PDO has essentially been in a warm phase for the last 40 years, and based on past patterns, it would likely shift into a cold phase in the near future. This shift may or may not be accompanied by a general drop in temperatures. If a substantial drop in temperatures is anticipated, it would be prudent to continue using the full available historical temperature record to simulate probable future climate conditions (and associated flow values, etc.). However, if a downward step in temperatures is not anticipated and the

post-1976 dataset is believed to better represent future climate conditions, as much of the literature suggests, then it would be most appropriate to use only the more recent portion of the historical temperature record to simulate probable future temperature conditions.

- When comparing temperatures from the pre- and post-PDO shift periods, cold temperatures demonstrate a much more pronounced change than warm temperatures. For instance, temperatures for the winter months show a greater temperature increase than do temperatures for any other season, and annual minimum daily temperatures show a much greater temperature increase than maximum daily temperatures. However, within the warm and cold periods of the PDO none of various temperature values show any significant trends.
- The 1943-2016 precipitation records for Iliamna indicate that annual total precipitation in the Pebble project area has remained fairly consistent over time, and there is no trend evident in the annual precipitation values over the full period of record. Similarly, splitting the dataset according to the timing of the warm and cold phases of the PDO does not reveal any significant trends. The mean annual precipitation values for the cold and warm phases of the PDO are 26.3 inches and 26.2 inches, respectively.
- In contrast to the NCA4 statement that winter/spring precipitation in Alaska is projected to increase, the Iliamna precipitation record indicates that winter/spring precipitation has been essentially constant for the past 70 years. There is no statistically significant trend in the 1943-2016 precipitation record. Splitting the winter/spring precipitation dataset according to the timing of the cold and warm phases of the PDO reveals that there is no significant trend during the cold phase, but there is a significant decreasing trend during the warm phase. Based on this evaluation of the Iliamna precipitation record, there is more likely to be a decrease in winter/spring precipitation than an increase. However, the mean winter/spring precipitation values for the two periods are remarkably similar, at 10.2 inches and 10.3 inches, respectively.
- Although there is no statistically significant trend in annual snowfall during the 1943-2016 period, there is a substantial (16.5 percent) difference between the mean annual snowfall values for the periods corresponding to the cold and warm phases of the PDO. This difference reflects the effects of the generally warmer winter conditions during the warmer period that result in less snow and more rain during the winter months.
- Similar to the pattern of annual total precipitation, the annual maximum daily precipitation values show no trends during the 1943-2016 period, or during the periods corresponding to the warm and cold phases of the PDO. This result appears to contradict the strong statement of the NCA4 report: "The frequency and intensity of heavy precipitation events are projected to continue to increase over the 21st century," particularly because the mean daily value for the cold phase of the PDO (1.64 inches) is very similar to the corresponding value (1.73 inches) for the warm phase of the PDO. However, further evaluation of the data indicates that the coefficient of variation is 0.23 for the cold phase data; while the coefficient of variation is almost 50 percent greater (0.33) for the warm phase data. This difference indicates that there were much greater year-to-year differences during the more recent warm phase, which has implications for the determination of design precipitation events for the project, and most notably the probable maximum precipitation (PMP) event, which is used for the design of the TSF and water management facilities. Because the PMP value is so extreme, and its determination requires extensive extrapolation, the spread in the data used to derive the rainfall statistics has a huge influence on the results. For instance, data from the warm phase of the PDO indicate a PMP value that is approximately 40 percent greater

than a PMP calculated using data from the cold phase. Therefore, it is very important to determine if the data from the warm phase of the PDO are more representative of future conditions at the Pebble Project than the data from the cold phase, or if data from the full period of record are most representative.

- To conclude, the NCA4 report presents results that represent projected future climate conditions over large areas, which indicate expectations of increasing temperatures and precipitation in the project area. The historical climate datasets for Iliamna generally do not support these results, particularly when the PDO effect is considered. However, it must be recognized that patterns in past climate records do not necessary provide a strong indication of future climate conditions, and that there is large uncertainty inherent in climate change forecasts. Accordingly, when accounting for potential climate change, it is important to be cognizant of this uncertainty and to assess each climatic parameter of interest in the context of how it would be used, and of how sensitive a design or modeling result may be to changes in that parameter.

Climate science is a complex subject and the climate change models generate a wide range of possible future conditions, depending on the assumptions used in the model and/or the scenario being evaluated by the model. Predictions of changes in average annual temperature and precipitation are less useful for hydrologic design than predictions of changes associated with specific times of the year and/or various recurrence intervals. Similarly, trends in average annual conditions do not necessarily indicate trends in less-frequent events, as are typically used for hydrologic design. 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, would determine whether streamflow increases or decreases.

Knight Piésold (2009 and 2018g), USGS (2016b), and NWS (2012) all evaluated the stationarity[11] of the historic precipitation and/or discharge data for Alaska and for sites near the mine site, and reported no statistically significant trend in either precipitation or discharge. This is important, although not conclusive. Common engineering practice is to assess historical data, and then determine how to account for the uncertainties related to climate change. Sometimes the potential for climate change is addressed by using only the most recent portion of the record; sometimes it is addressed by adding 10 to 20 percent to the values determined by an assessment of the historical record (Knight Piésold 2018g, Appendix A). The impact of the uncertainties associated with estimates of hydrologic conditions at the mine site is discussed further in Section 4.16, Surface Water Hydrology.

3.16.1.2 Transportation Corridor

This section describes baseline surface water conditions across the transportation corridor under Alternative 1a. 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, Alternatives.

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[11] **Stationarity** implies that statistical properties of a process generating a time series do not change over time; however, it does not mean that the series does not change over time, just that the way it changes does not itself change over time.

The surface water hydrology in the watersheds surrounding the mine site is well-characterized, as described above (Knight Piésold et al. 2011a, 2015b). Hydrologic data are spatially and temporally limited along the transportation corridor. A portion of the mine access road is in the UTC watershed, for which hydrologic, meteorological, and biological data are available. The UTC watershed is well-studied compared to most remote, undeveloped watersheds in Alaska, for which data are largely lacking. Limited data are available for the port access road, and except for the Newhalen River, there are limited hydrologic data available for 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 at the mine site; 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 permafrost).

Drainage Basins

Mine Access Road

The mine access road would extend from the mine site southeast to the Eagle Bay ferry terminal, roughly 5 miles east of Iliamna (see Figure 2-18). This mine access road is the same as described for Alterative 2. The mine access road would be 6 miles shorter than the mine access road under Alternative 1. East from the mine site, the mine access road follows low-lying to moderately undulating terrain containing numerous lakes across the UTC watershed. The road crosses into the Newhalen River watershed through a low pass at roughly 800 feet amsl. After crossing the Newhalen River, the road continues along low-lying to moderately undulating terrain along the southern flank of Roadhouse Mountain to the Eagle Bay ferry terminal on Iliamna Lake. Roadhouse Creek, a small low-velocity stream fed from several runoff streams of Roadhouse Mountain, flows south into Iliamna Lake near Iliamna. The drainage area contributing to this gage station[12] is small, well-vegetated, and includes several small ponds. Bed materials in the stream are sands and medium gravels. The channel is incised in several areas, and vegetation is generally present to the low-flow water line and overhanging the bank. This stream is stable in high runoff events.

Stream crossings would require culverts and bridges. Bridges would be used to cross the main channel of UTC, Newhalen River (south crossing), and Eagle Bay Creek Bridge (see Figure 2-18). The Newhalen River south crossing would have a bridge length of 510 feet, and a footprint of 26.9 acres, and there are no wetlands or cultural artifacts identified at the crossing (PLP 219-RFI 154). The Newhalen River bridge location (south crossing) is structurally controlled with a single well-defined channel width of approximately 400 feet, with relatively stable river banks due to the channel being incised in bedrock (PLP 2019f) (see Figure 2-18).

Port Access Road

The port access road corridor starts at the south ferry terminal at Kokhanok 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 (Figure 3.16-1). The terrain along the road corridor west of the divide consists of low, rounded

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[12] Gage Station GS-20a is shown on Figure 3.16-24 in Section 3.16-3, Alternative 2 – North Road and Ferry with Downstream Dams.

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 (Figure 3.16-10). 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 small streams (Figure 3.16-10). Bridges would be used to cross two larger unnamed streams.

Streamflow

Mine Access Road and Ferry Terminals

Except for the Newhalen River, most of the streams crossed between the Eagle Bay ferry terminal and the UTC watershed are ungaged. Along the ferry route between Eagle Bay and Pile Bay, the USGS operates one crest gaging station on Chinkelyes Creek. Where sufficient streamflow data are not available for purposes of analysis, 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 2003 (Curran et al. 2003).

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 in 1951 at the Newhalen River (ID 15300000) close to the village of Iliamna, and was active through 1986. For the period of record, the average annual discharge was 9,237 cfs (see Table K3.16-6). 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) (Figure 3.16-4). Continuous streamflow measurements were collected at NH100-APC3 during the open flow season (May to October) from 2008 to 2013. For the period of record during the open flow season, the average discharge was 15,011 cfs. Streamflows at these two Newhalen River stations were found to be highly correlated, so NH100-APC2 was discontinued after 2009, and flows at the former station location have been estimated by regression analysis against station NH100-APC3 (Knight Piésold 2015b). Based on regression analysis for the same period of record, estimated average discharge at NH100-APC2 was 15,268 cfs.

Sources: PLP 2019-RFI153; USGS; ADNR

US Army Corps of Engineers

Proposed Crossings

- ● Bridge
- ○ Culvert

Action Alternatives

- ⋯ Ferry Routes
- Natural Gas Pipelines
- Alternative 1a
- Alternative 1
- Alternative 1 Kokhanok East Ferry Terminal Variant

Other Features

- Borough Boundary
- Local Roads
- National Park
- Major Drainage Boundary

STREAM CROSSINGS AT PORT ACCESS ROAD

PEBBLE PROJECT EIS

FIGURE 3.16-10

The Newhalen River 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). Based on streamflow data from USGS gaging station (ID 15300000), the Newhalen River has a mean annual unit runoff of 2.7 cubic feet per square mile (cfs/mi^2) (approximately 35 inches of annual basin runoff depth) (Knight Piésold et al. 2011a). Streamflow information collected in the UTC watershed is presented above in the description of the mine site. In 2005, the USGS established a continuous gage station on Roadhouse Creek (ID 15300200) at the site of the historical USGS crest gage, near Iliamna. Roadhouse Creek is representative of lowland watercourses lacking mountainous headwaters along the transportation corridor. The average annual streamflow for the period of record is 19 cfs, and the unit runoff rate is around 1 cfs/mi^2 (or 14 inches of annual basin runoff depth) (see Table K3.16-6).

The upper reaches of Roadhouse Creek contain many small tributaries, and PLP placed a gaging station (GS-20a) on one of the streams flowing off Old Lake. The location was chosen to be representative of smaller tributaries in the transportation corridor study area (Knight Piésold et al. 2011a). Instantaneous discharge measurements were recorded at both Roadhouse Creek gaging stations in 2004 (summer months only) and 2005 (winter and summer months); the results are presented in Table K3.16-7 through Table K3.16-9.

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 (Figure 3.16-10). 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 port access road crossing would be approximately 2.4 miles south of where it discharges into Iliamna Lake. At the bridge location, the Gibraltar River is structurally controlled with a single channel width of approximately 100 feet, and the river floodplain width is approximately 200 feet (PLP 2019e). 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 2003 (Curran et al. 2003).

Floodplain Function and Values

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

Flood magnitude and frequency have not been estimated for the streams and rivers crossed by the Alternative 1a port access road. 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 2003 (Curran et al. 2003). Flood magnitude for select frequencies was estimated using these USGS regression equations for four of the streams crossed by the Alternative 1a mine access road (PLP gaging stations GS-17a, GS-18a, GS-20, and GSs-20a), presented in Table K3.16-10.

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 Alternative 1a port access road 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.

Stream bed and bank observations were noted along the mine access road at PLP gaging stations GS-17a, GS-18a, GS-20, and GSs-20a (Table K3.16-10 and Knight Piésold et al. 2011a). Gaging station GS-17a is on the west fork of Eagle Bay Creek. Bed materials in the stream are sands and medium gravels. The channel is slightly incised in several areas, and vegetation is generally present to the low-flow water line. This stream is relatively stable in high runoff events.

Gaging station GS-18a is on an unnamed creek on the southern slope of Roadhouse Mountain. Bed materials in the stream are sands and medium gravels. The channel is incised in several areas, and vegetation is generally present to the low-flow water line and overhanging the bank. This stream is stable in high runoff events.

Gaging station GS-20 is on lower Roundhouse Creek. Bed materials in the stream are sands and medium gravels. The channel is incised in several areas, and vegetation is generally present to the low-flow water line and overhanging the bank. This stream is stable in high runoff events.

Gaging station GS-20a is on upper Roundhouse Creek. Upper Roadhouse Creek is a low-velocity stream that has a well-incised channel and vegetated banks. The bed material is mostly silty sand with some gravel. The topography surrounding the creek is low-lying; therefore, the stream banks are often overtopped.

3.16.1.3 Amakdedori Port (Uplands—Fresh Water)

Drainage Basins

Amakdedori port is 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 gage stations are present in the port area (USGS 2018c). Where sufficient streamflow data are not available, regional regression equations that might be used for this project are the USGS regression equations published in 2003 (Curran et al. 2003).

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, and along the transportation corridor.

Flood Magnitude and Frequency

Flood magnitude and frequency have not been estimated for Amakdedori Creek; however, the port would be required to be developed based on a design flood event for Amakdedori Creek. Regional regression equations that might be used for this project are the USGS regression equations published in 2003 (Curran et al. 2003).

Surface Water Use

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

3.16.1.4 Lower Cook Inlet Port and Natural Gas Pipeline Corridor (Marine Water)

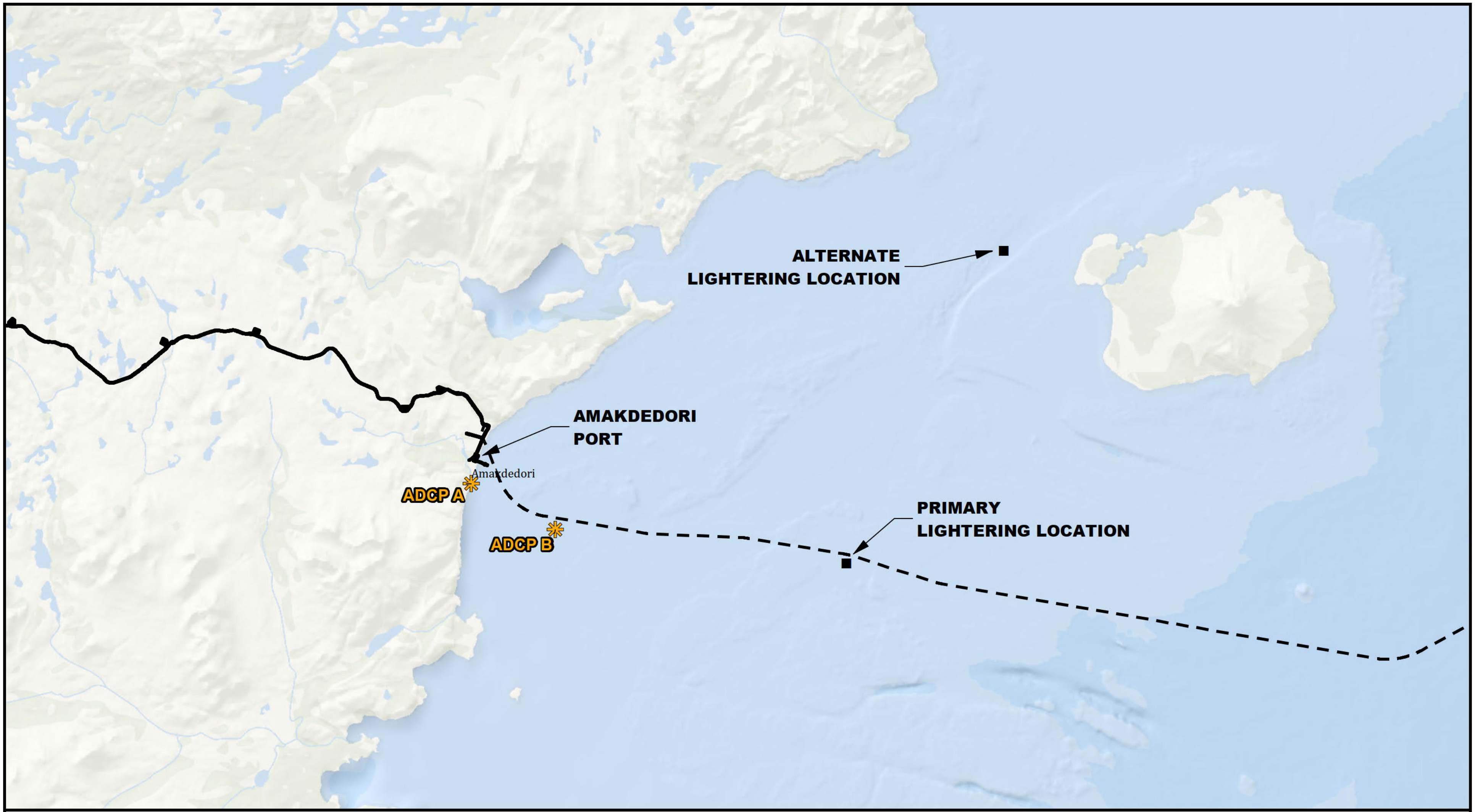
This section describes the affected environment with respect to marine waters of the port locations and pipeline corridors under all action alternatives.

Available Information

Environmental baseline data relevant to marine water conditions are available for the vicinity of the Iliamna and Iniskin bays area, 25 to 30 miles north of the Amakdedori port site (Pentec Environmental/Hart Crowser and SLR 2011). Instrumentation included an acoustic wave profiler (AWAC), deployed near the entrance to Iliamna Bay between 2010 and 2012. Although these data are useful for evaluating the Diamond Point port location under Alternative 2—North Road and Ferry with Downstream Dams and Alternative 3—North Road Only, these AWACs are not applicable to Amakdedori; which, due to its location on the western shore of Kamishak Bay, has meteorology and oceanography (metocean) conditions more like Lower Cook Inlet than the sheltered locations of Iliamna and Iniskin bays.

Publicly available metocean information for Lower Cook Inlet includes regional wave data from three NOAA buoys, two of which are in lower Cook Inlet (National Data Buoy Center [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 (Figure 3.16-11). A meteorology station, also maintained by NOAA, is on the northeastern side of Augustine Island (NDBC Station AUGA2).

To augment the publicly available metocean information, Terrasond Ltd. deployed two Teledyne RDI Sentinel-V acoustic Doppler current profilers (ADCPs) near the Amakdedori port site at locations ADCP A and ADCP B (Figure 3.16-11), where water depths are 7 meters and 14.6 meters, respectively (Ausenco 2019a). The locations of the two ADCPs were selected to correspond with berth and lightering locations under consideration at that time (March 2018). The ADCPs measured wave heights and periods, current velocity profiles, and water level data for the period from March 4 through 12, 2019. Brief interruptions occurred during this period for data download, battery changes, and general maintenance. An analysis of the data is provided in Ausenco (2019b).



Sources: PLP 2019-RFI153;
Ausenco 2019b, Figure 1-1

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✳ Acoustic Doppler Current Profilier (ADCP) Location

Alternative 1a

- ■ Lightering Location
- ▬ Transportation Corridor
- – – Natural Gas Pipeline

ADCP DEPLOYMENT LOCATIONS, AMAKDEDORI PORT AND LIGHTERING LOCATIONS

PEBBLE PROJECT EIS

FIGURE 3.16-11

In addition to measured wind and wave data, two sets of numerical wind and wave hindcasts were analyzed: the NOAA WaveWatch III (WWIII) Alaska Grid—Reanalysis data set and the WaveWatch III Alaska Grid—Multi dataset (Point 223, 311) for the periods 1979-2009 and 2005-2019, respectively. These two datasets were merged to form a longer timescale of data, and were analyzed at a representative grid point WW3 (Figure 3.16-12). Sources of wind data, used subsequently for nearshore wave hindcasts, are listed in Table 3.16-2.

A comprehensive analysis of the ADCP data established its relationship to the publicly available wind and wave data from locations shown in Figure 3.16-12, and listed in Table 3.16-2 (Ausenco 2019b).

Table 3.16-2: Sources of Wind Data

Name	Source	Type	Duration
Augustine Island (AUGA2)	National Data Buoy Center	Measured	2000-2019
East Amatuli Island (AMAA2)	National Data Buoy Center	Measured	2003-2019
McNeil River	National Resources Conservation Service	Measured	2012-2019
WaveWatch III Alaska Grid—Multi dataset (Point 223,311)	NCEP/NCAR Reanalysis 2 Dataset (NOAA's Earth Systems Research Laboratory: Physical Sciences Division)	Hindcast	2005-2019
WaveWatch III Alaska Grid—Reanalysis dataset (Point 223,311)	NCEP/NCAR Reanalysis 2 Dataset (NOAA's Earth Systems Research Laboratory: Physical Sciences Division)	Hindcast	1979-2009
Amakdedori Port Meteorological Station	Pebble Limited Partnership	Measured	Oct 2017-Oct 2019

Notes:

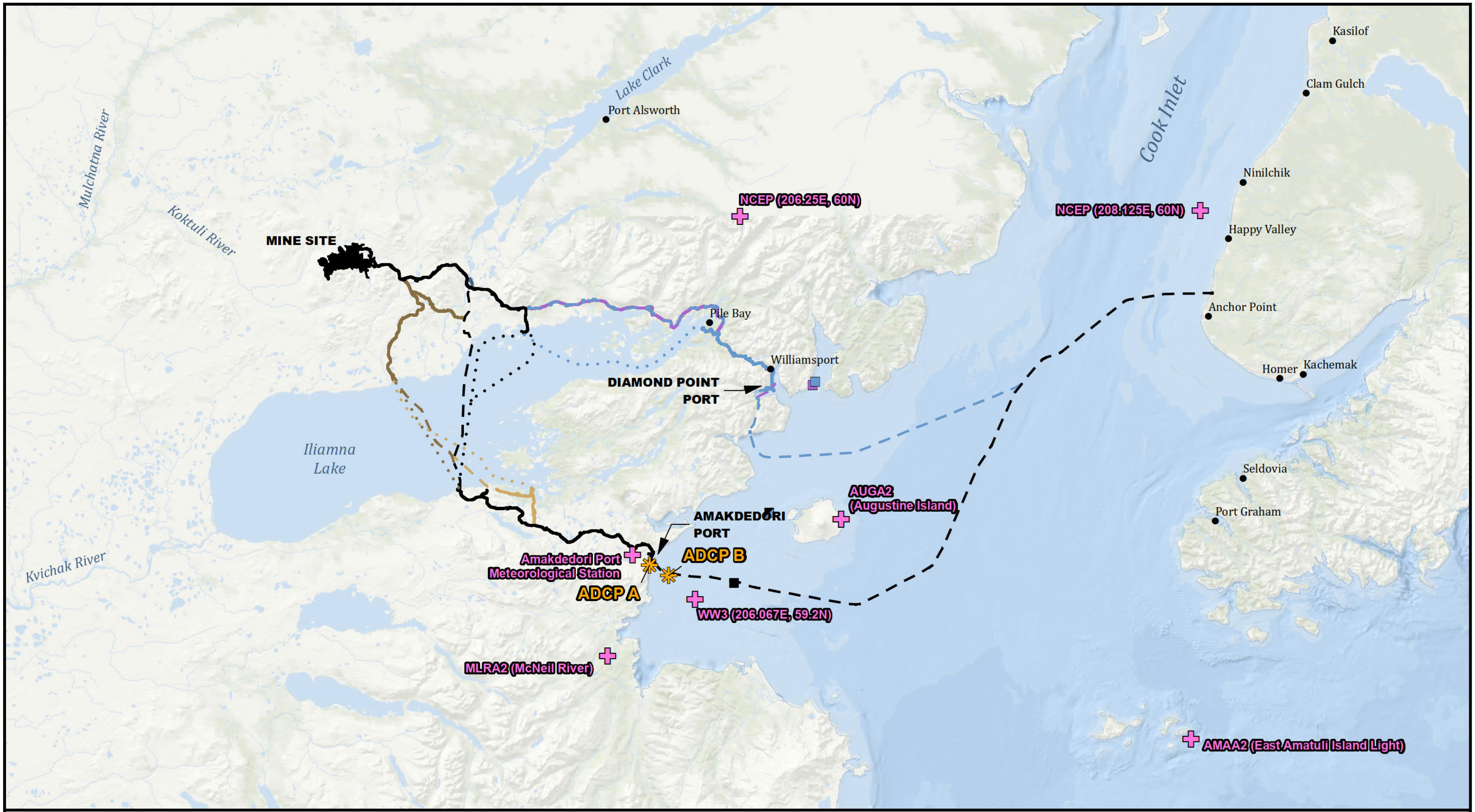
NCAR = National Center for Atmospheric Research
NCEP = National Centers for Environmental Prediction
NOAA = National Oceanic and Atmospheric Administration

Source: Ausenco 2019b, Table 2-1

Bathymetry

Regional bathymetric data are available through online data archives maintained by NOAA, primarily in the form of smooth sheet bathymetry. Additionally, PLP acquired multiple bathymetric datasets between 2017 and 2019, as described and documented in IntecSea 2019. A composite of the available bathymetric data for lower Cook Inlet in the vicinity of the proposed natural gas pipeline crossing is provided in Figure 3.16-13.

The seafloor across lower Cook Inlet reflects its glacial and tectonic history and the processes related to its dynamic metocean and surficial sediment conditions. The IntecSea (2019) survey of the proposed pipeline route reveals an array of seafloor features, from sediment ripples and waves to compound and complex bedforms, including dunes, ridges, and boulder fields. IntecSea (2019) analysis provides detailed geometry of a route through these seabed features with due consideration to pipeline engineering to avoid potential hazards and regulatory requirements to avoid sites of potential archaeological importance.



Sources: PLP 2020-RFI168; PLP 2019-RFI153; Ausenco 2019b, Figure 2-1

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Miles

- ✚ Data Sources
- ✳ Acoustic Doppler Current Profiler (ADCP) Location

Action Alternatives

- ■ Lightering Locations
- · · · · Ferry Routes
- — — Natural Gas Pipelines
- ■ Alternative 1a
- ■ Alternative 1
- ■ Alternative 1 Kokhanok East Ferry Terminal Variant
- ■ Alternative 2
- ■ Alternative 2 Newhalen River North Crossing Variant
- ■ Alternative 3

SOURCES OF ADCP DATA AND WIND AND WAVE DATA

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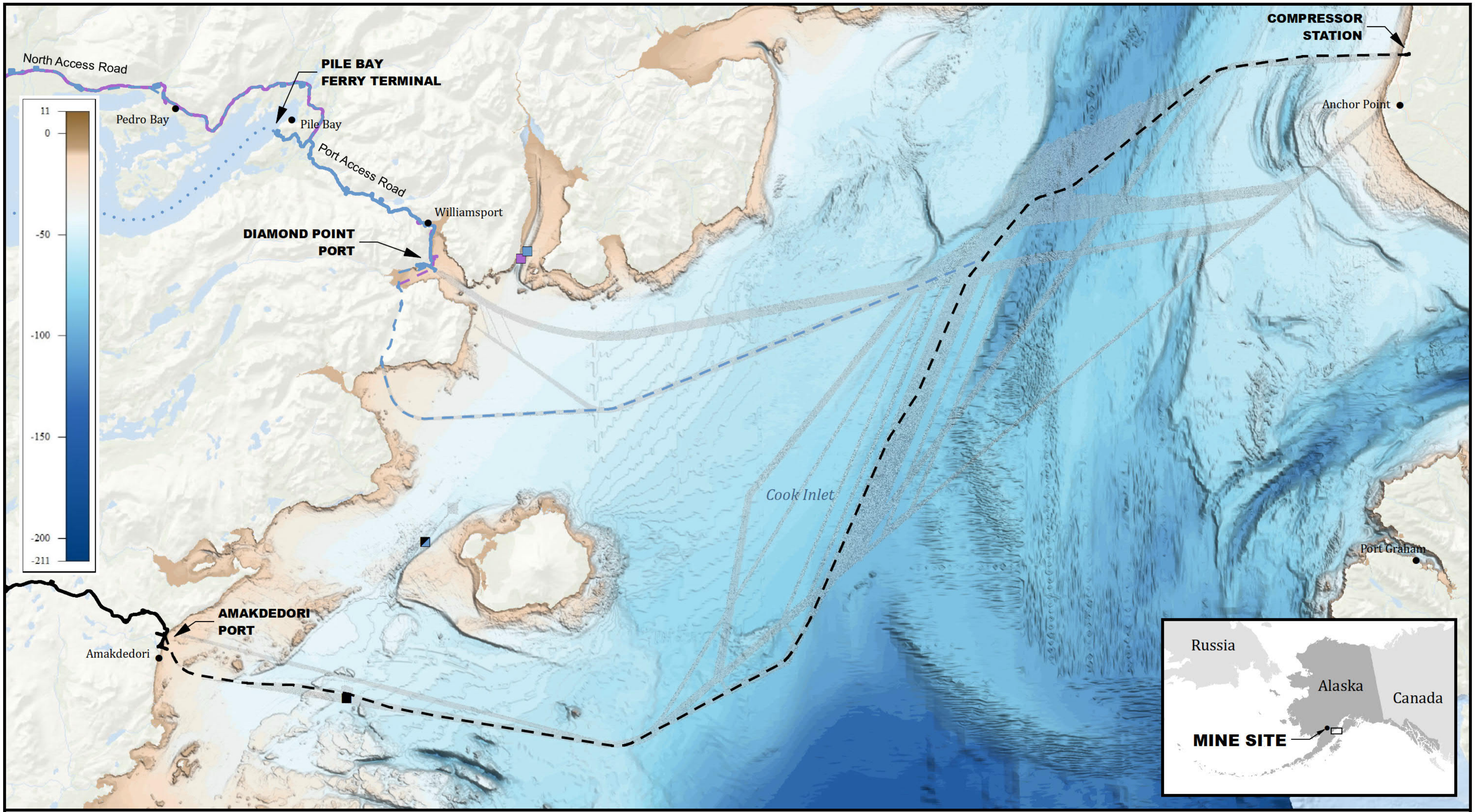
FIGURE 3.16-12



Sources: PLP 2020-RFI168; PLP 2019-RFI153; IntecSea 2019, Appendix B - Map 1; NOAA

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5 0 5 10

Miles

Action Alternatives

- ■ Lightering Locations
- ···· Ferry Routes
- – – Natural Gas Pipelines
- ■ Alternative 1a
- ■ Alternative 2
- ■ Alternative 3

Note: Gray shading along natural gas pipeline corridors indicate survey transects.

BATHYMETRY OVERVIEW OF COOK INLET PIPELINE CORRIDOR

PEBBLE PROJECT EIS

FIGURE 3.16-13

The marine (i.e., subsea) portion of the proposed natural gas pipeline corridor has a total route length of approximately 104 miles, of which approximately 80 miles are in federal outer continental shelf (OCS) waters of Cook Inlet, as detailed in IntecSea (2019, Table 4-2). The maximum depth of the pipeline route is approximately 271 feet. The majority of the seabed exhibits gradients of 2.5 or less, while most bedform fields exhibit a range of gradients up to 10°, with a few isolated slopes reaching near 20°. For the entire pipeline route, Figure 3.16-14 shows the depth profile and seabed gradient, both of which are essential information for engineering and installation of the pipeline.

Metocean Overview

Metocean conditions in Cook Inlet are known to be complex both spatially and temporally. However, those conditions having relevance to a subsea pipeline are generally limited to wave and tide-induced currents and the accompanying sediment transport. Bottom currents are influenced by the seabed topography; which, along with the surficial sediments, affect frictional response and complexity of the flow regime. It is expected that a pipeline crossing from Anchor Point to Amakdedori port would encounter variable current conditions in both direction and flow velocity, primarily due to tidal and seasonal cycles (IntecSea 2019).

Sources of suspended sediment in Cook Inlet include waterborne discharges from several glacial rivers, as well as wind-driven contributions from coastal bluffs along its periphery. Transport, deposition, and re-suspension of sediments occur mostly in response to tidal currents and storms, which give rise to formation of the complex bedforms mentioned above. Seabed sediments range in size from fine sands to boulders. The bedforms in the area of the pipeline route are indicative of a dynamic bottom current regime of varying intensity (IntecSea 2019). Additional metocean studies are in progress to define and model the anticipated bottom currents along the pipeline route, as well as plan for future site-specific current monitoring.

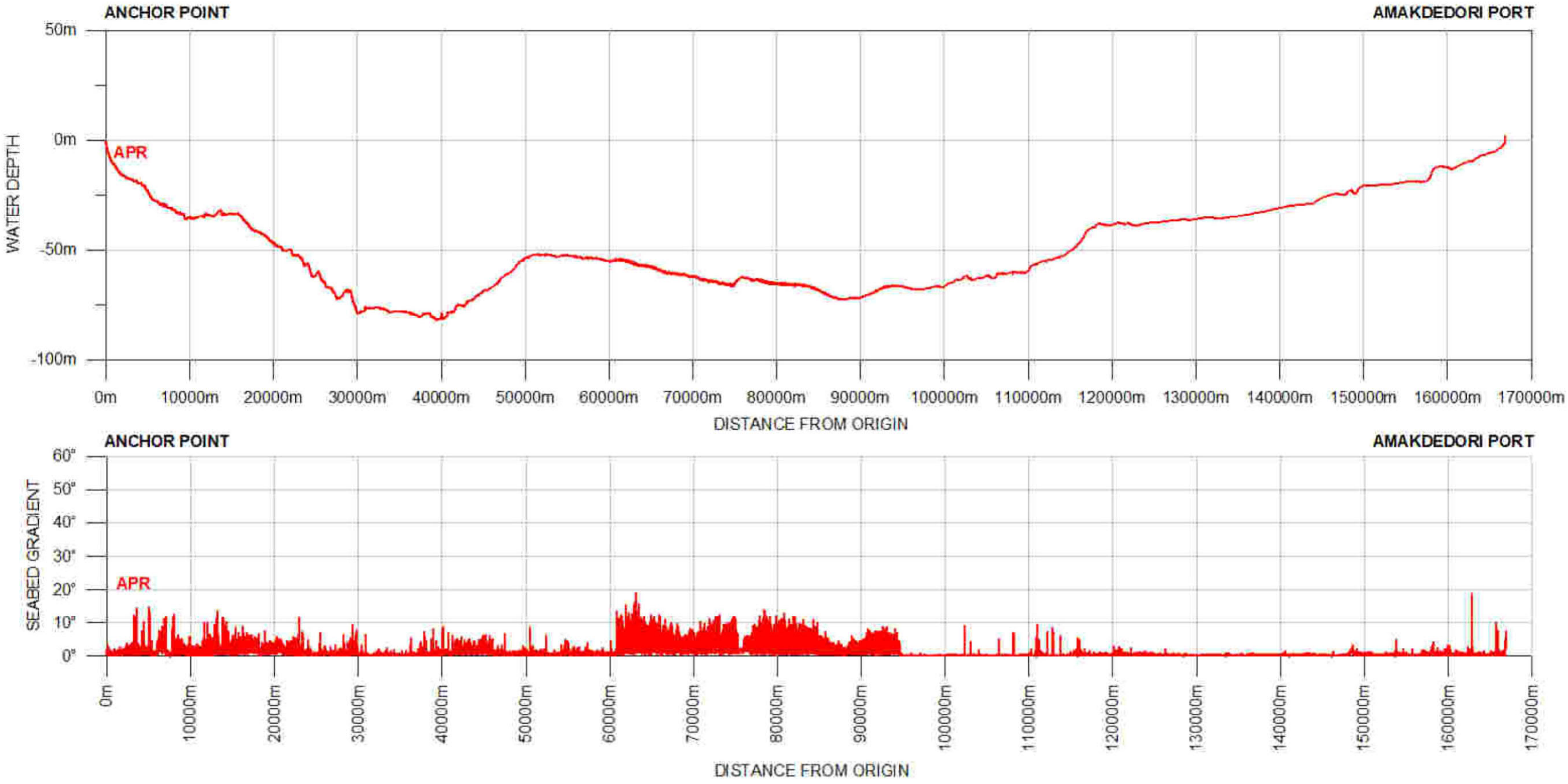
Regional Wave Climate

The suitability of any location as a port site is determined by its capability to provide shelter to vessels during nearshore operations and while docked. Therefore, the exposures of the alternative sites to wind and the resultant waves (especially from the northeast and east), are critical factors in evaluating their suitability as ports.

To evaluate exposures of the alternative port sites to waves coming from outside their immediate vicinity, wind data from several sources in lower Cook Inlet were analyzed to determine statistical characteristics of the waves measured over periods of observation (PLP 2018-RFI 039). The analysis yielded annual probabilities of occurrence for waves of various heights and periods. Results of such analyses are usually expressed as “return periods” of specific wave characteristics such as height or period. The return period is the reciprocal of the annual probability of occurrence of the specified characteristic. For example, wave heights (or periods) having annual probabilities of occurrence of 0.2, 0.1, and 0.04 are said to have return periods of 5, 10, and 25 years, respectively, and typically are called the 5-, 10- and 25-year waves. Wave heights thus defined are usually considered to be the significant wave height, which is defined statistically to be the mean height of the highest one-third of the waves.[13] Table 3.16-3 lists return periods from 2 to 25 years of significant wave heights from all three NOAA buoys.

---

[13] The term **significant wave height** is used to denote the characteristic height of the random waves in a sea state. Notwithstanding its robust statistical definition, in oceanographic tradition, significant wave height is believed to correspond to what a mariner observes when visually estimating the average wave height.



Source: Intecsea 2019, Figure 44

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BATHYMETRIC AND SEABED GRADIENT PROFILES ALONG AMAKDEDORI PORT ROUTE

PEBBLE PROJECT EIS

FIGURE 3.16-14

Table 3.16-3: Lower Cook Inlet—Available Wave Data

Source	Dates of Data Available	Significant Wave H_s (feet) and Return Period				T_p(s) for large events
		2-Year	5-Year	10-Year	25-Year	
NDBC 46080, Gulf of Alaska	2002-2012	26	32	34	36	11 to 14
NDBC 46105, Kennedy Entrance	2008, 2011-2012	23	25	27	—	9 to 12
NDBC 46108, Lower Cook Inlet	2011-2013, 2015-2018	9	10	11	12	8 to 11
Iliamna Bay AWAC	2010-2012	15	17	18	—	8 to 9

Notes:

AWAC = acoustic wave and current profiler
NDBC = National Data Buoy Center
H_s = significant wave height (in feet)
T_p(s) = period of peak wave energy
(—) = no data

Source: PLP 2018-RFI 039, Table 1

Data from the Iliamna Bay AWAC were similarly analyzed with results listed in Table 3.16-4. Also available from these analyses were directions *from* which waves were observed.

Analyses for buoys NDBC 46105 and 46108 are presented as wave roses (Figure 3.16-15 and Figure 3.16-16). Each of these figures shows the directions *from* which waves were observed as percentages of total observations for ranges of significant wave heights measured by each buoy. NDBC 46108 is just southwest of the tip of Kenai Peninsula, so it is sheltered from most waves except those from the south-southwest. NDBC 46105 is fully exposed to waves from the east and southeast, but also receives notable wave activity from the west during locally generated storms, and therefore is probably the best indicator of regional wave climate to which Amakdedori is exposed.

Table 3.16-4: Offshore Data Available from NBDC and External Sources

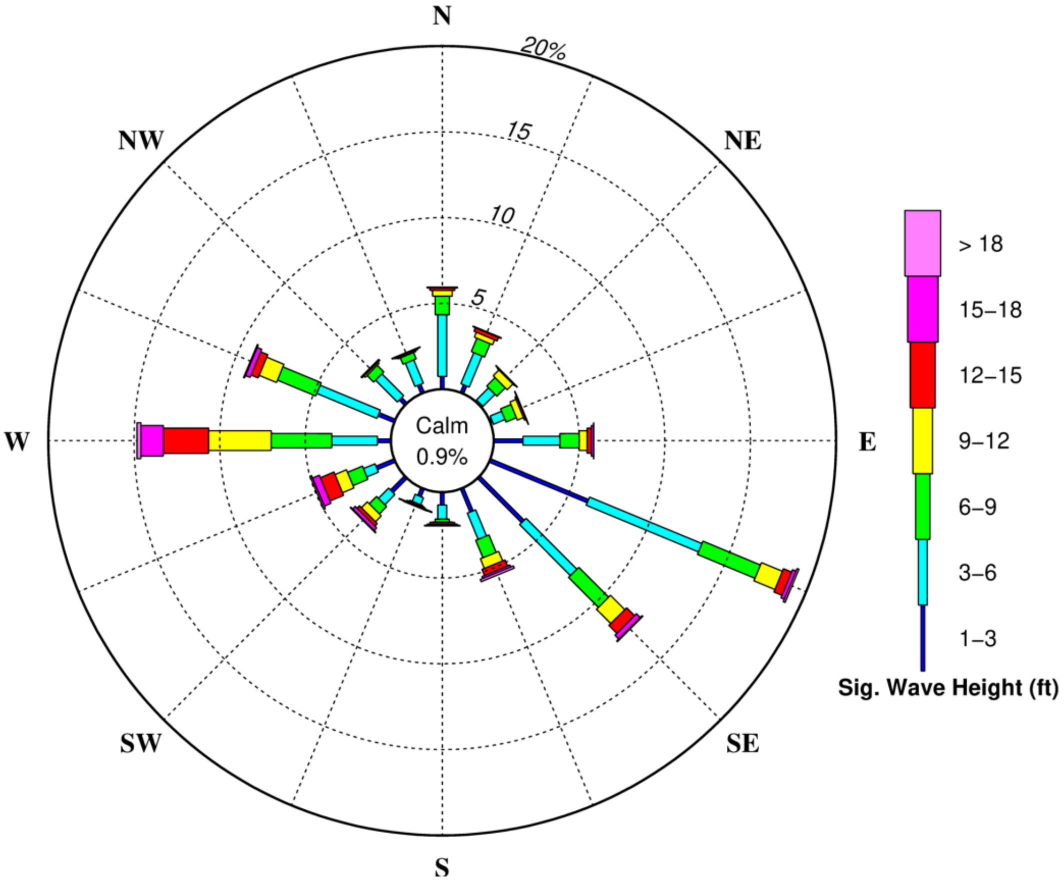
Source	Dates of Data Available	Return Period H_s (feet)				T_p(s) for large events
		2-Year	5-Year	10-Year	25-Year	
NBDC 46080	2002-2012	26	32	34	36	11 to 14
NBDC 46105	2008, 2011-2012	23	25	27	—	9 to 12
NBDC 46108	2011-2013, 2015-2018	9	10	11	12	8 to 11
Iliamna Bay AWAC	2010-2012	15	17	18	—	8 to 9

Notes:

AWAC = acoustic wave and current profiler
NBDC = National Data Buoy Center
H_s = significant wave height (in feet)
T_p(s) = peak wave period
(—) = no data

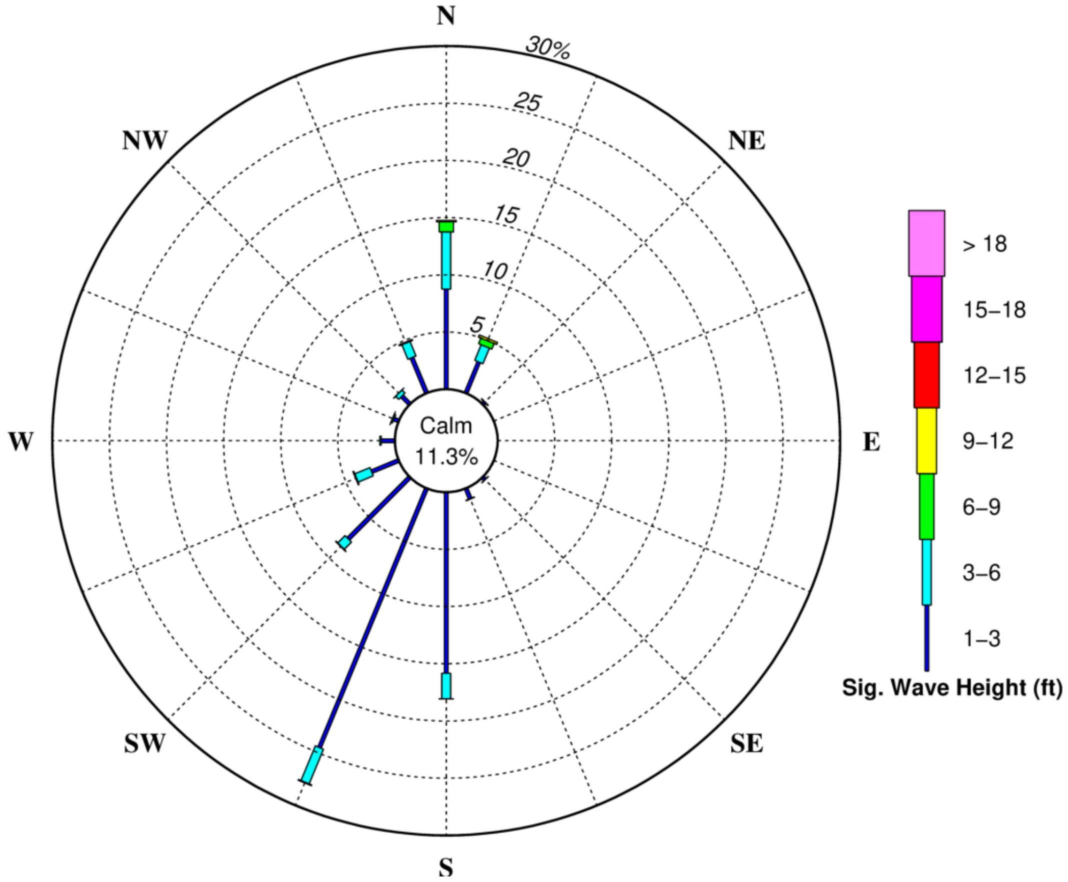
Source: PLP 2018-RFI 039, Table 1

Figure 3.16-15: Wave Rose of Wave Conditions from Buoy NBDC 46105 (Kennedy Entrance)



Source: PLP 2018-RFI 039, Figure 3

Figure 3.16-16: Wave Rose of Wave Conditions from Buoy NDBC 46108 (Lower Cook Inlet)



Source: PLP 2018-RFI 039, Figure 4

Local Wave Climate

As waves travel from offshore to shallower water at port locations, they are transformed both in height and direction by processes of "shoaling" and "refraction" due to the decreasing water depth and seabed topography. To understand the transformation of waves entering the PLP port operations area, a SWAN (Simulating WAves Nearshore) numerical model was developed for Kamishak Bay and the adjacent Lower Cook Inlet area. SWAN is a third-generation wave model, developed at Delft University of Technology (Netherlands) that is widely used by coastal engineers and port designers for analysis of waves in coastal regions and inland waters. SWAN can simulate the processes of shoaling and refraction, wave generation by wind, as well as wave energy dissipation by white-capping, bottom friction and depth-induced breaking. SWAN presents results of its computations in terms of wave propagation in time and space. See Holthuijsen (2007) for a complete description of SWAN wave model (physics) and numerical techniques.

SWAN's nested grid feature was used to increase detail and quality of simulation in areas of significant importance. An outer grid (250 cells by 175 cells) with 500-meter resolution was used to model the broader wave generation area in Lower Cook Inlet. Nested within the outer grid was a 62.5-meter resolution grid (96 cells by 64 cells) to model effects of shoaling, refraction, and wave breaking in the nearshore/shallow areas near the Amakdedori port site in Kamishak Bay. All SWAN computations were conducted at mean sea level and in stationary mode; that is, with wind speed and direction constant in time, which effectively amounts to a conservative assumption for the computations; that is, results are an exaggeration of actual conditions.

After calibration to available local wind measurements, Augustine Island wind data were adapted for wind input to the SWAN model. Several of the larger storms recorded during the ADCP measurement program were identified, and selected for analysis during the numerical modeling efforts. Corresponding wind measurements from Augustine Island during the selected storms were used as input to the SWAN wave simulations. Inputs and outputs for the modeled storms are provided in Ausenco (2019b, Appendix 2). Results from three SWAN simulations are plotted in Figure 3.16-17, Figure 3.16-18, and Figure 3.16-19, following figures from Ausenco (2019b) for a southeasterly wind event, a northwesterly wind event, and a northeasterly wind event, respectively.

To verify the validity of the computational procedure and the calibration of the wave model to local wind measurements, time series of hindcast wave conditions from SWAN simulations were compared to measured wave data from the ADCP deployments. Although there was some scatter in the data, the correlation between measured and predicted conditions at the ADCP deployment locations was good, especially in a statistical sense by which the probability of exceedance of a predicted significant wave height agrees well with that derived from measurements. It was noted that the SWAN model predictions tended to be marginally conservative for significant wave heights exceeding 1.5 meters. This is likely due to the assumption of *stationary* wind conditions in the SWAN model, and the Augustine Island winds being applied as a *spatially uniform* wind field over the computational area, neither of which is a reasonable expectation for natural conditions, and consequently injects a measure of conservatism in the results. See Ausenco (2019b) for details of calibration and verification procedures.

Extreme Wind and Wave Conditions

Three distinct wind sectors were identified in the analysis of the 20-year Augustine Island record of wind measurements, as adjusted and augmented by other wind data: Northeast (20 to 70 degrees), southeast (90 to 150 degrees), and northwest (225 to 330 degrees). The maximum wind speeds from each sector were subjected to an extreme value[14] analysis by fitting the data to a Gumbel distribution,[15] which enabled estimation of wind speeds for storm events having return periods from 1 to 200 years (Figure 3.16-20).

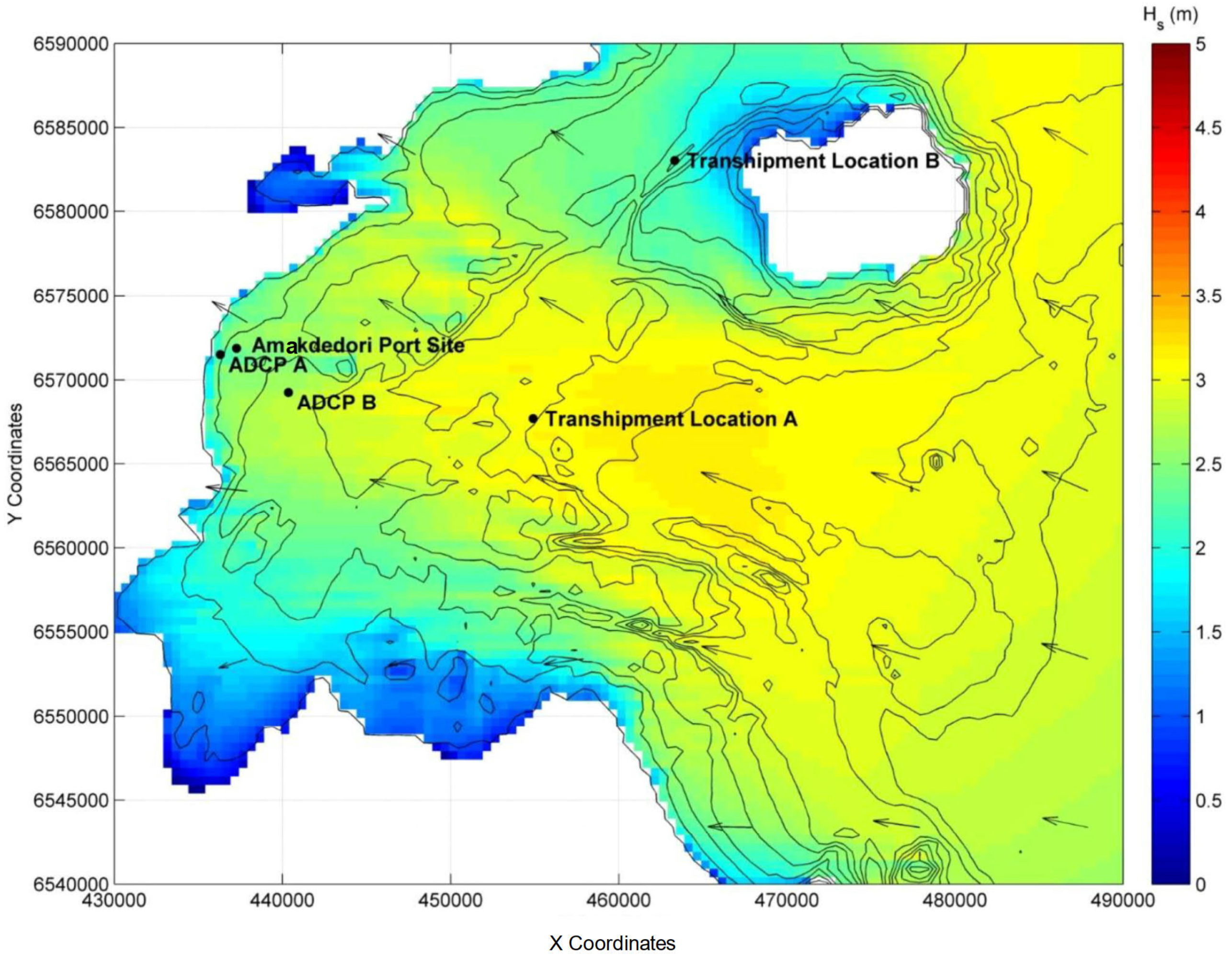
Table 3.16-5 lists extreme wind speeds from northeast, southeast, and northwest sectors for return periods from 1 to 200 years. These extreme wind conditions correspond to the 95 percent upper confidence limit of the Gumbel distribution fit. The annual probability of exceedance of an N-year return period event is 1/N. Also, because the extreme value analysis is based on a 20-year dataset, the uncertainty associated with wind speed predictions increases for return periods exceeding 50 years.

Based on the wind speeds derived in the extreme value analysis, the SWAN model was used to estimate corresponding wave conditions at the locations of interest in Kamishak Bay. The SWAN runs were made for water depths at mean sea level, and do not account for tidal variation, which can be more pronounced at the shallower port location. The calculated extreme significant wave heights for the lightering locations A and B, and for Amakdedori port, respectively, are listed in Table 3.16-6 and Table 3.16-7.

---

[14] The purpose of an extreme value analysis is to analyze observed extreme values of a phenomenon (e.g., winds, waves, floods) over a given period with the goal of forecasting further extremes beyond that period.

[15] Gumbel Distribution—The purpose of an extreme value analysis is to analyze observed extreme values of a phenomenon (e.g., winds, waves, floods) over a given period with the goal of forecasting further extremes beyond that period. Typically, the extreme values beyond those observed are represented by a Gumbel probability distribution or a variation of it.



Note: Colors indicate significant wave height (m) and arrows indicate peak wave direction.

Source: Ausenco 2019b, Figure 3-8

NOTE: Transhipment location is the same as lightering location. Location A is primary; Location B is the alternate lightering location under Alternatives 1a and 1.

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SWAN MODEL RESULTS FOR THE SOUTHEASTERLY WIND EVENT ON MAY 4, 2018

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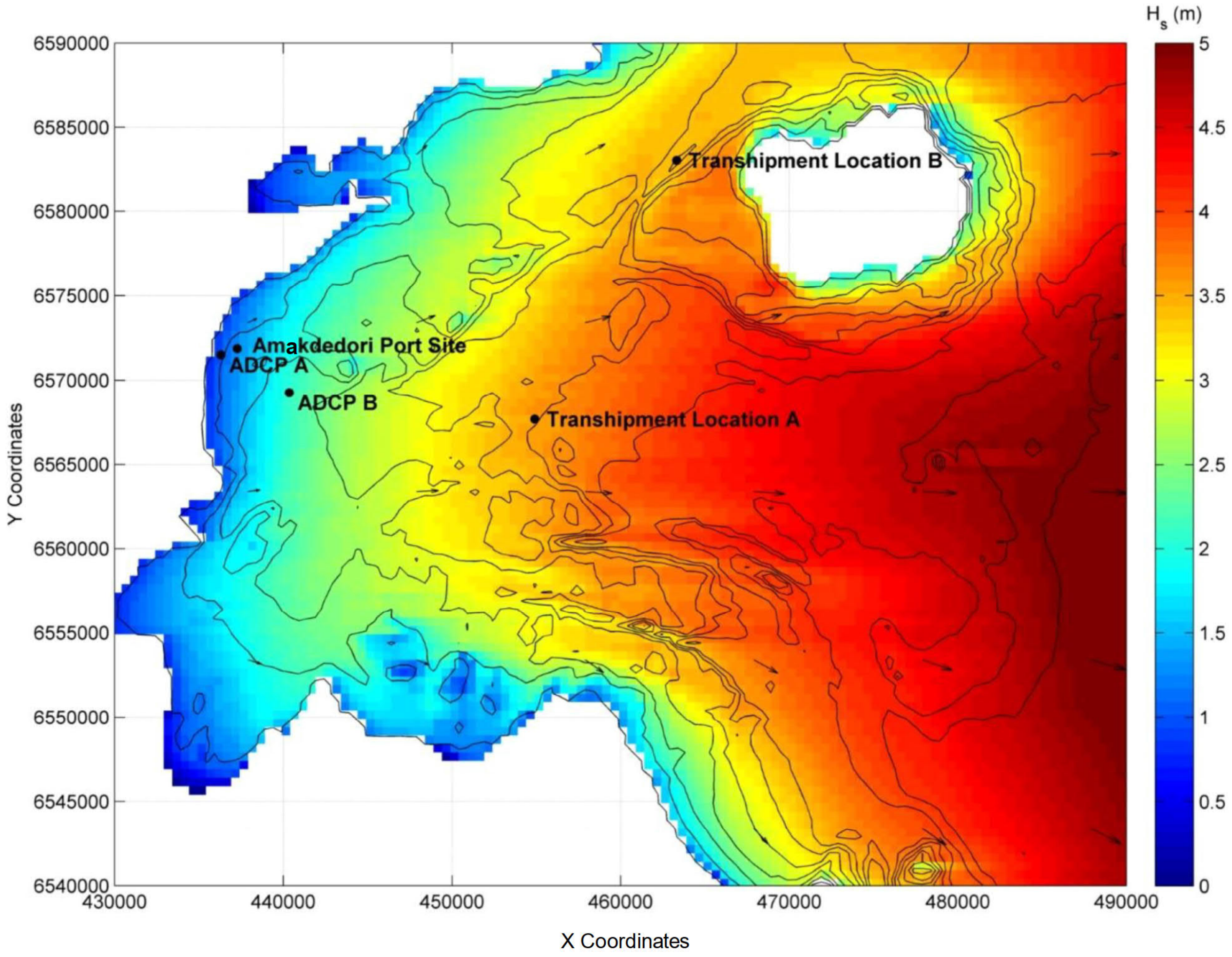
FIGURE 3.16-17



Note: Colors indicate significant wave height (m) and arrows indicate peak wave direction.

Source: Ausenco 2019b, Figure 3-9

NOTE: Transhipment location is the same as lightering location. Location A is primary; Location B is the alternate lightering location under Alternatives 1a and 1.

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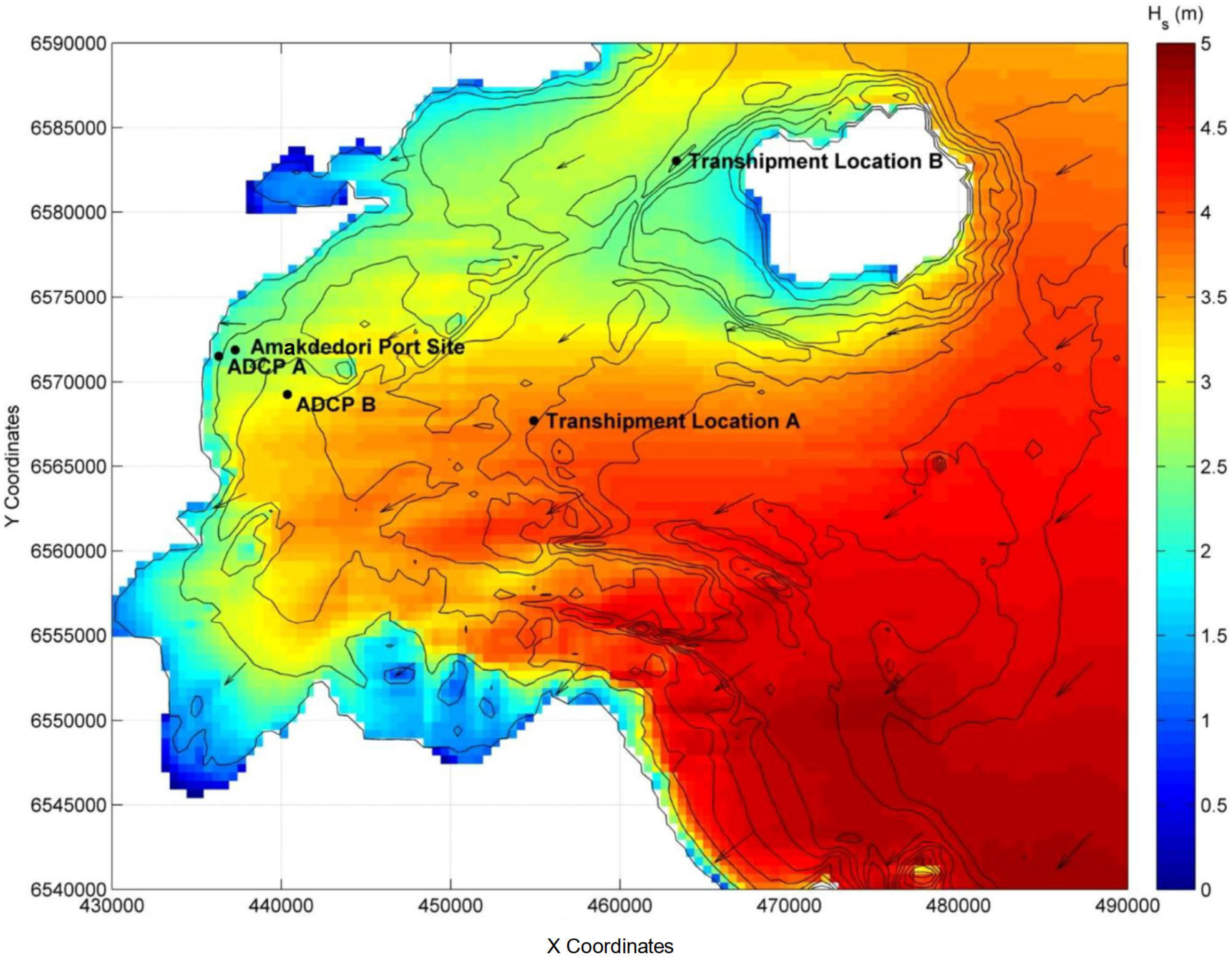
SWAN MODEL RESULTS FOR THE NORTHEASTERLY WIND EVENT ON DECEMBER 18, 2018

FIGURE 3.16-18



Note: Colors indicate significant wave height (m) and arrows indicate peak wave direction.

Source: Ausenco 2019b, Figure 3-10

NOTE: Transhipment location is the same as lightering location. Location A is primary; Location B is the alternate lightering location under Alternatives 1a and 1.

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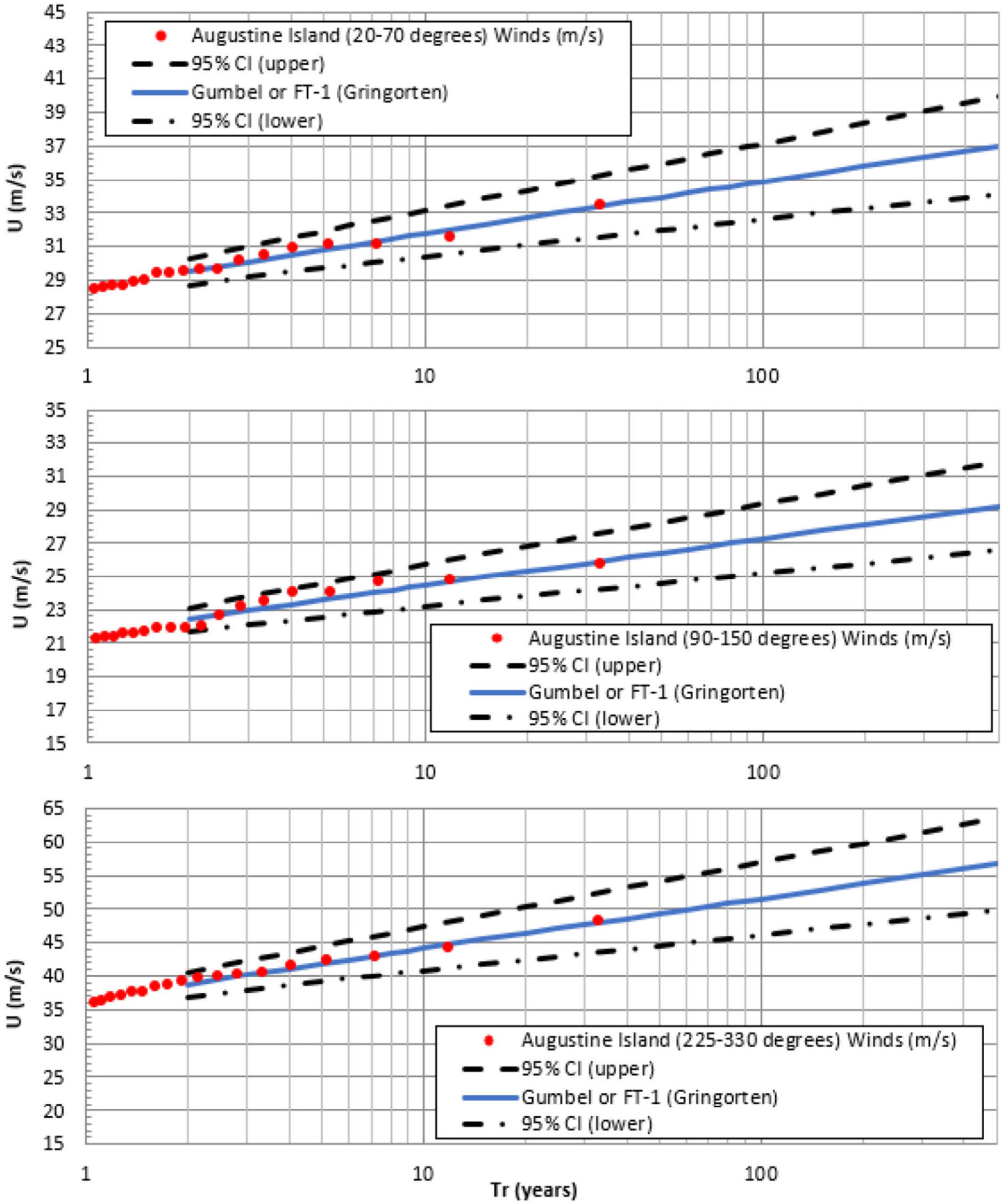
SWAN MODEL RESULTS FOR THE NORTHEASTERLY WIND EVENT ON NOVEMBER 25, 2018



Source: Ausenco 2019b, Figure 3-14

US Army Corps of Engineers

EXTREME VALUE ANALYSIS USING GUMBEL DISTRIBUTION FIT TO STORM WIND SPEEDS FROM THE AUGUSTINE ISLAND WIND STATION FOR NORTHEAST (20-70 DEG), SOUTHEAST (90-150 DEG), AND NORTHWEST WIND DIRECTIONS (225-330 DEG)

FIGURE 3.16-20

Table 3.16-5: Extreme Wind Speeds from Adjusted Augustine Island Dataset

Return Period (years)	Northeast Windspeed (m/s)	Southeast Wind Speed (m/s)	Northwest Wind Speed (m/s)	Omni-Directional (m/s)
Associated Primary Wind Direction (degrees)	38	110	290	290
Annual event	29.8	22.7	39.5	39.5
5	31.9	24.6	44.5	44.5
10	33.1	25.7	47.7	47.4
20	34.7	27.2	51.2	51.2
50	35.9	28.2	54.1	54.1
100	37.1	29.3	56.9	56.9
200	38.3	30.4	59.8	59.8

Notes:

m/s = meters per second

Source: Ausenco 2019b, Table 3-1

Table 3.16-6: Extreme Significant Wave Heights at Lightering Locations A and B

Return Period (years)	Lightering Location A Significant Wave Height (meters)			Lightering Location B Significant Wave Height (meters)		
	Northeast	Southeast	Northeast	Northeast	Southeast	Northwest
Annual event	4.8	4.5	4.1	3.2	3.1	3.7
5	5.4	4.9	4.4	3.5	3.4	3.9
10	5.9	5.1	4.6	3.6	3.5	4.1
20	6.0	5.3	4.8	3.7	3.6	4.5
50	6.2	5.5	4.8	3.9	3.7	4.5
100	6.3	5.7	4.8	3.9	3.8	4.5
200	6.5	5.8	4.8	4.0	3.9	4.5

Source: Ausenco 2019b, Table 3-3

Table 3.16-7: Extreme Significant Wave Heights at Amakdedori Port

Return Period (years)	Amakdedori Port Site Significant Wave Height (meters)		
	Northeast	Southeast	Northwest
Annual Event	2.9	3.3	1.5
5	3.1	3.4	1.7
10	3.3	3.5	1.8
20	3.3	3.5	1.8
50	3.3	3.5	1.8
100	3.3	3.6	1.8
200	3.4	3.6	1.8

Source: Ausenco 2019b, Table 3-4

Although the extreme northwesterly "Kamishak gap" winds (Fett 1993) are seen to be dominant among the three sectors, they are the least effective in creating waves at the port site than either northeast or southeast, due to the much shorter fetch for northwest winds (Table 3.16-7). At Lightering Location A, both northeast and southeast winds create larger waves than northwest winds, but at Lightering Location B, the maximum waves created by winds from all three sectors are similar (Table 3.16-6).

Marine Water Dynamics—Tides, Currents, and Storm Surge

The information recorded by ADCPs deployed by Ausenco (2019) showed that the mean tide range at Amakdedori is approximately 7.5 meters, which corresponds closely to that observed at Nordyke Island (about 6 miles south-southeast of Amakdedori (NOAA 2019b).

Prevailing currents are those associated with the tide and are generally aligned with depth contours of the seabed. Observed current speeds at both ADCP locations were relatively low and almost always below 0.4 meter per second (m/s) (0.8 knot) during the yearlong observation period. Currents at ADCP Site A were essentially parallel to shore, as would be expected in shallow water. At ADCP Site B, the currents were mainly oriented towards the west-northwest during flood tide and towards east-northeast during ebb tide.

Storm surge occurs when strong winds cause a change in local mean sea level, by transport of water toward or away from the shore. A wind-induced rise of sea level is called a positive surge, while a lowering of sea level is a negative surge. Strong winds from the northeast or east could produce a positive storm surge in Kamishak Bay, while strong southwest winds could produce a negative storm surge. The probable magnitudes of either positive or negative storm surges have not been calculated, but would be considered as facility design is further advanced (see Section 4.16, Surface Water Hydrology; and Appendix M1.0, Mitigation Assessment, for suggested mitigation regarding coastal engineering analysis). However, the absence of any visible signs of positive storm surge (e.g., debris line on or above the beach) suggests this would be a minor concern.

Coastal Geomorphology

In their comprehensive study of marine habitats from Diamond Point south to Ursus Cove and Amakdedori, Geoengineers (2018) reported that rocky substrates occur along much of the Kamishak Bay shoreline. Rock is the dominant substrate throughout most of the tidal zone, while mud or other unconsolidated sediments compose beaches that extend from the rocky habitat down into the subtidal zone. Therefore, the shoreline is durable and contains little if any sediment that is available to transport along the coast. Although the shoreline appears to be dynamic, with vertical rock faces and large cobbles, it is not expected that significant shoreline erosion would occur over the lifetime of the facility (PLP 2019-RFI 039).

Sea Ice

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: 1) dates of first and last observed ice of any severity; 2) the number of weeks of "significant" ice; and 3) 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 from 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 significant ice cover 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 the 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[16] (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.

Because marine sea ice is a seasonal occurrence in the lower Cook Inlet, seabed ice gouging is a potential concern for engineering of the proposed natural gas pipeline from Anchor Point to Amakdedori. Ice gouging is a phenomenon that can occur in association with large accumulations of ice, such as floating “pans” of sea ice, that may have developed a keel that extends below the water surface deep enough to contact, impact, and thus “gouge” the seabed. Areas that are potentially susceptible to ice gouge are defined by water depths equal to or shallower than potential keel depths. Accordingly, a sea ice keel could impact an exposed or insufficiently protected pipeline by striking it, and thereby imparting a force on the pipeline, either directly or through ice-soil-pipeline interaction. The force delivered by such impact could deform or move a buried pipe, potentially causing severe damage or even failure of the pipeline.

IntecSea (2019) referenced a study (ASL 2019) of ice gouging in Cook Inlet, in which it was concluded that areas having water depths less than 11 meters (36 feet) should be considered susceptible to ice gouging. The proposed pipeline route crosses two areas that meet this criterion: one segment along Anchor Point, 1 kilometer (0.6 mile) in length, and the other on its approach to Amakdedori, 5.3 kilometers (3.2 miles) in length. According to IntecSea (2019), no definitive evidence of ice gouging is identified in the seabed at either of these areas. However, given the dynamic current and tidal conditions, and generally coarse nature of surficial seabed soils, preservation of ice gouges in the seabed seems unlikely.

The usual mitigation for addressing risk of ice keels impacting a pipeline is to bury the pipeline at sufficient depth to avoid impact entirely; or alternatively, ensure that the pipe has sufficient strength to withstand such impact imparted to it by the disturbance zone of a gouging ice keel. Ongoing geotechnical studies will provide guidance for engineering solutions to mitigate the ice gouging risk potential.

3.16.1.5 Iliamna Lake (Ferry Terminals, Ferry Crossing, and Pipeline Crossing)

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).

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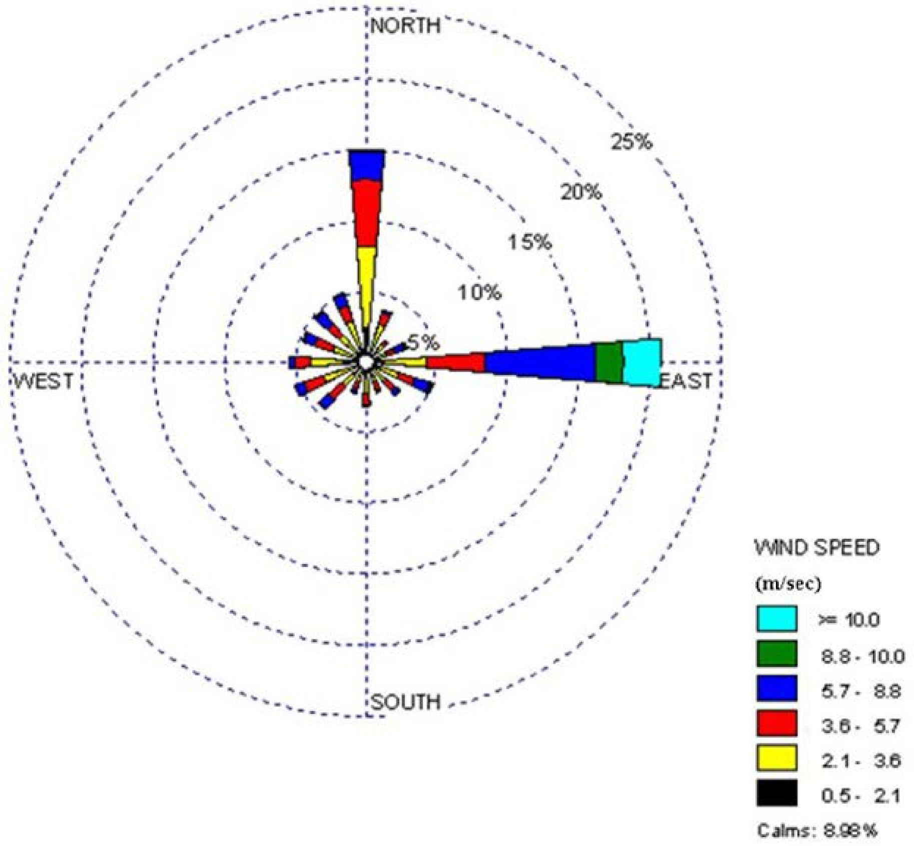
[16] **Ice concentration** is the amount of ice covering an area, written as either a fraction or percentage of ice coverage. In general 3/10 (30 percent) is navigable by ship; 9/10 (90 percent) is considered solid ice (http://seaiceatlas.snap.uaf.edu/glossary).

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 the 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 (Figure 3.16-21). A limited amount of data are available from Igiugig Airport at the western end of Iliamna Lake.

Figure 3.16-21: 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 3.16-21 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 from 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 windy year of 2008.

For the purpose of estimating Iliamna Lake wave conditions for each of the alternatives, it was determined that the maximum daily average wind speeds observed at Iliamna Airport provided the best available measure of sustained winds. Rather than depend solely on the 4 years of meteorological data collected during the environmental baseline study program to estimate wave conditions on Iliamna Lake, wind data from the National Climate Data Center (NCDC) were reviewed for both Iliamna Airport and Igiugig (NOAA 2019c).

The first objective of the historical data review was to determine at least qualitatively whether wind observations at Iliamna Airport were sufficiently similar to those at Igiugig Airport to be considered representative of winds over the entire lake. This is a reasonable concern, because Iliamna Airport lies at the northwesterly corner of the lake, and Igiugig Airport is at the extreme western end of the lake, and is likely more representative of winds over the longest fetch afforded by the lake. Assuming that the winds at the two airports were sufficiently similar, the second objective was to obtain sufficient wind information to estimate wave conditions to which project alternatives would be exposed, with reliance primarily on data from Iliamna Airport.

Although the NCDC database for Iliamna extends from the 1940s, it was determined that examination of the past 21 years, 1999-2019, would be sufficient for the present purpose. For Igiugig, the NCDC database extends only from 2006, so the period examined was limited to 2006-2019 for comparison to Iliamna.

Table 3.16-8 lists maximum daily average wind speed and direction for each of the 21 years at Iliamna, and for all years since 2006 at Igiugig for which data are available, as compiled from the NCDC data review. Although short-term “gusts” significantly greater (30 to 50 percent) than the average daily wind speeds are listed in the NCDC database, those gusts were generally not of sufficient duration to produce fully developed wave conditions.[17] Furthermore, there was no evidence found to support anecdotal reports of extreme winds during scoping meetings (Midnight Sun Court Reporters 2018): “I spent many years in Igiugig in the fall, and it probably blows 100 miles an hour at Iliamna Lake three to five times a year. 100 miles an hour. They want to cross it all the time.”

The maximum daily average wind speeds at Iliamna Airport for the 21 years ranged from 24.6 mph (2012) to 35.6 mph (2009). Wind directions for the maximum daily average wind speeds for 20 of 21 years were within the sector 70° to 120° (ENE-ESW), with the single exception of 300° (WNW) in 2012. The suitability of Iliamna wind measurements to represent conditions over the entire lake was judged (but not rigorously tested) to be satisfactory, according to their similarity to simultaneous wind conditions observed at Igiugig (Table 3.16-8).

The estimates of wave conditions listed in Table 3.16-9 were calculated using wave forecasting equations from the US Army Corps of Engineers Coastal Engineering Manual (USACE 2002). The range of wind speeds for which wave conditions were calculated was selected to span the observed maximum daily averages, as listed in Table 3.16-8; and to accommodate anecdotal reports of substantially higher wind speeds.

Significant wave heights and peak energy wave periods were calculated for sustained wind speeds from 20 to 80 mph for fetch lengths corresponding to maximum exposures of Alternative 1a (Eagle Bay ferry terminal to south ferry terminal); Alternative 1 (north ferry terminal to south ferry terminal); and Alternative 2 (Eagle Bay ferry terminal to Pile Bay ferry terminal).

The usefulness of the estimates of Table 3.16-9 for project engineering would be improved by relating wave conditions to wind speeds from Table 3.16-8 via an extreme value analysis (per Gumbel 2004 or Palutikoff et al. 1999) to obtain realistic estimates of wave conditions with return periods of 2 or more decades. Presumably, this analysis would occur as the plan for ferry

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[17] Fully developed wave conditions occur when energy input to the waves is equal to energy dissipated by internal turbulence and wave breaking. The dynamic equilibrium thus established between energy input and dissipation occurs under sustained winds for a given fetch and/or duration.

operations is further developed (see Appendix M1.0, Mitigation Assessment, regarding recommended comprehensive coastal engineering analysis).

Table 3.16-8. Annual Maximum of Average Daily Wind Speed and Direction at Iliamna and Igiugig Airports

Date	Iliamna		Igiugig	
	Speed	Direction	Speed	Direction
	miles per hour	True	miles per hour	True
12/21/2009	35.6	100	9	100
2/16/2001	32.9	100	*	*
12/19/2000	31.1	80	*	*
12/28/2003	30.4	90	*	*
12/29/2014	30.4	90	37	80
12/22/2017	30.4	100	26	70
2/22/2002	30.2	90	*	*
3/7/2013	29.8	100	34	90
2/9/2010	28.4	80	n/a	n/a
10/26/2019	28.0	100	n/a	n/a
12/3/2011	27.7	110	23	100
12/30/2018	27.7	90	n/a	n/a
2/4/2006	27.5	70	30	100
12/29/2015	27.5	100	38	350
2/14/1999	27.3	80	*	*
4/9/2004	26.6	100	*	*
1/30/2007	26.6	120	22	80
5/5/2005	26.0	80	*	*
12/24/2016	25.7	90	30	60
5/23/2008	25.1	110	30	80
1/12/2012	24.6	300	14	310

*No records in NCDC database

Table 3.16-9: Estimated Wave Conditions for Alternative 1a, Alternative 1, and Alternative 2

Wind Speed (miles per hour)	Alternative 1a: Eagle Bay Ferry Terminal/South Ferry Termial Fetch ≈ 20 miles		Alternative 1: North Terminal/ South Ferry Terminal Fetch ≈ 30 miles		Alternative 2: Ferry—Eagle Bay Ferry Terminal/Pile Bay Ferry Terminal Fetch ≈ 15 miles	
	Fully Developed, Fetch-Limited Wave Conditions					
	H_s (feet)	T_s (second)	H_s (feet)	T_s (second)	H_s (feet)	T_s (second)
20	3.0	3.8	3.7	4.3	2.6	3.4
40	5.7	4.7	6.9	5.3	4.9	4.2
60	8.3	5.3	10.1	6.0	7.1	4.8
80	10.9	5.8	13.3	6.6	9.4	5.3

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; however, anecdotal reports indicate that it can be as much as 4 feet thick in late spring (Billmeier 2015), but can vary from a few inches to a few feet over a short distance. Such variations in lake ice thickness are likely partially attributable to stacking of ice floes by wind. Lake ice hazards, such as pressure ridges driven by wind, are known to occur in Iliamna Lake (Billmeier 2015; Andrew 2017). No information was found to assess whether such pressure ridges are capable of gouging (i.e., scouring) the lake bed.

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.

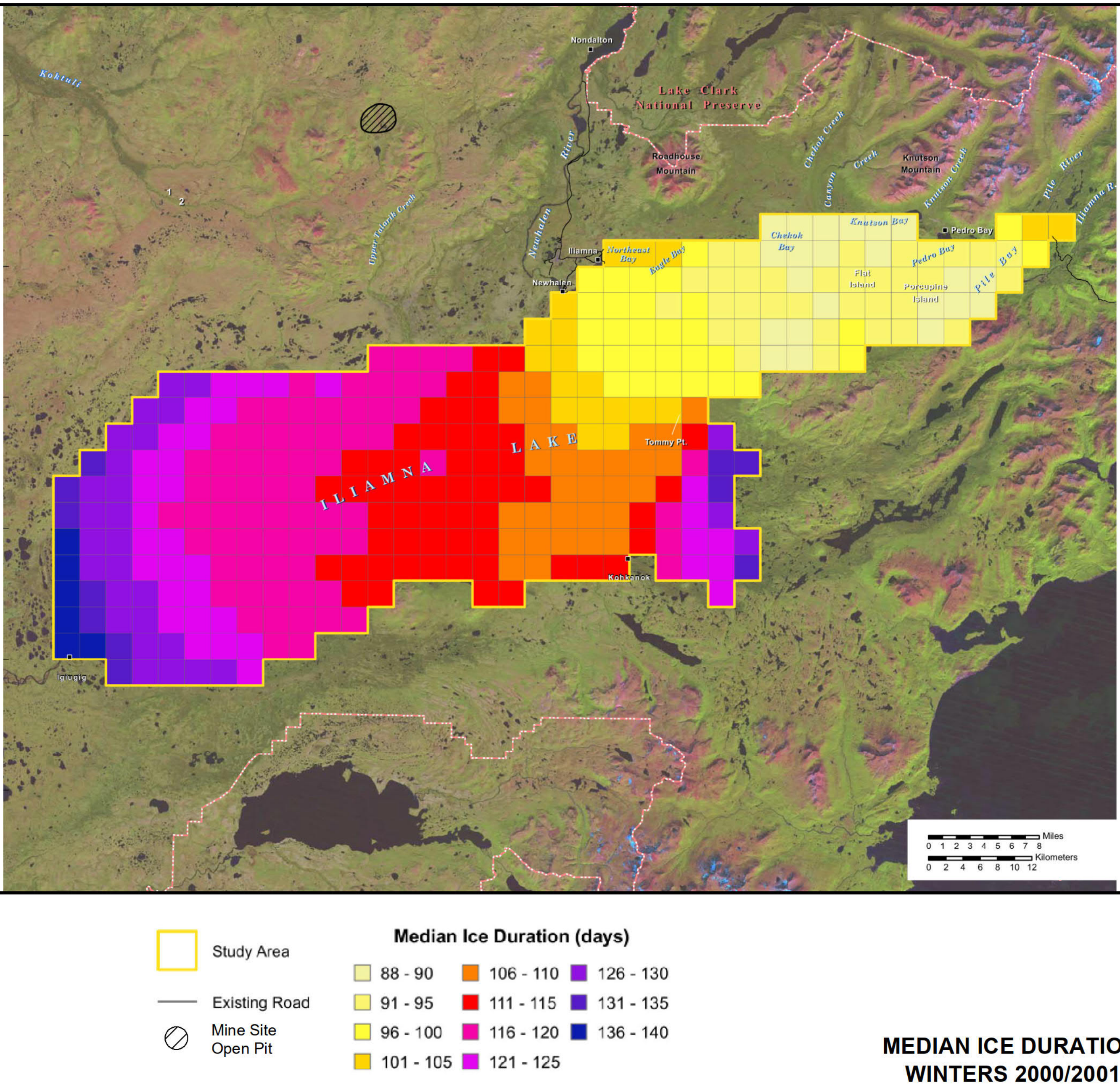
The analysis spanned 19 winters, with 15 that had prolonged periods of complete or nearly complete ice cover. Four of the 19 winters had minimal or no periods of complete ice cover. During the winter of 2015/2016, only trace ice cover was observed during the entire winter. Often, there were weeks of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

Figure 3.16-22 (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.

3.16.1.6 Natural Gas Pipeline Corridor (Uplands—Fresh Water)

PLP would construct a port on lower Cook Inlet for import of supplies and building materials, and for export of ore concentrate. For Alternative 1a and all other alternatives, the compressor station would be on the eastern side of Cook Inlet (see Figure 2-37). The compressor station would be constructed in the Granoos Creek watershed, a small coastal stream that drains into the Anchor River just upstream of where Anchor River drains into Cook Inlet. Horizontal directional drilling would be used to install pipe segments from the compressor station out into waters that are deep enough to avoid navigation hazards. The marine portion of the pipeline corridor is addressed above under “Lower Cook Inlet Port and Natural Gas Pipeline Corridor (Marine Water).”

The pipeline would cross Iliamna Lake from Kokhanok to the north shore of Iliamna Lake, near the community of Newhalen, and continue overland as a pipeline-only segment to where it would connect with the mine access road, east of the Newhalen River crossing.



Source: ABR 2018a, Figure 3

US Army Corps of Engineers

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

Drainage Basins

Granoos Creek is a coastal watershed on the Kenai Peninsula near Anchor Point. The Granoos Creek watershed is low-lying, containing small lakes and wetlands that make up its headwaters east of the coast. The drainage basin descriptions for the natural gas pipeline corridor are the same as those provided for the transportation corridor between Amakdedori port and Iliamna Lake. Based on the National Hydrography Dataset, there are 10 stream crossings along the portion of the pipeline corridor north of Iliamna lake. Most of these are unnamed streams with no known published information, except for Bear Creek. Bear Creek is small tributary of the Newhalen River, originating from small lakes along the western base of Roadhouse Mountain. The Bear Creek watershed area is 2.6 square miles, and contains low-lying undulating topography with several small lakes and wetlands.

Streamflow

Granoos Creek is an ungaged stream; no streamflow data are available. Available surface water data in the natural gas pipeline corridor between Amakdedori port and Iliamna Lake are the same as those described for the transportation corridor. North of Iliamna Lake, Bear Creek is the only gaged stream with published streamflow data. USGS established a gaging station on Bear Creek in 2005 (ID 15300100). Based on streamflow data collected between 2005 and 2012, the mean annual discharge is 8.8 cfs, and the mean annual peak discharge is 39 cfs.

Floodplain Function and Values

Floodplain function and values along the pipeline corridor are anticipated to be similar to those discussed above for the streams in the immediate vicinity of the mine and along the transportation corridor between Amakdedori Port and Iliamna Lake, because this segment is not populated, and there is currently no infrastructure in the area that would be in the floodplain. The pipeline segment north of Iliamna Lake would parallel the western side of the existing Newhalen/Iliamna Road; however, floodplain function and values are anticipated to be similar because the area west of the road is not populated, and there is currently no infrastructure in the area that would be in the floodplain.

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 watersheds along the pipeline corridor are essentially undeveloped, a pre-mine flood hazard does not exist.

Flood Magnitude and Frequency

Flood magnitude and frequency for Bear Creek is presented in Table K3.16-10. Regional regression equations that might be used for ungaged streams along the pipeline corridor include the USGS regression equations published in 2003 (Curran et al. 2003).

3.16.2 Alternative 1

3.16.2.1 Mine Site

The affected environment would be the same as Alternative 1a.

3.16.2.2 Transportation Corridor

Drainage Basins

Mine Access Road

The Alternative 1 mine access road extends from the mine site to the north ferry terminal on Iliamna Lake (Figure 3.16-23), traversing the UTC watershed for the entire length. The road would cross streams with culverts or bridges. Bridges would be used to cross the main channel of UTC and First Creek (Figure 3.16-23).

Iliamna Spur Road

The Iliamna spur road would connect the mine access road to the existing road that extends north from Iliamna (see Figure 2-51). The 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. The Newhalen River is described under Alternative 1a.

Port Access Road

The port access road for Alternative 1 is the same as for Alternative 1a.

Floodplain Function and Values

Floodplain function and values under Alternative 1 are anticipated to be similar to those discussed for Alternative 1a.

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 watersheds along the Alternative 1 transportation corridor are essentially undeveloped, a pre-mine flood hazard does not exist.

Alternative 1—Kokhanok East Ferry Terminal Variant

The Kokhanok east ferry terminal variant would result in changes to port access road route, including a Kokhanok east spur road that would extend from the port access road to community of Kokhanok (Figure 3.16-10). The port access road to the Kokhanok east ferry terminal site would not require crossing the Gibraltar River, and would also have fewer overall stream crossings. This variant would cross total of five streams requiring culverts between the Kokhanok east ferry terminal south to the port access road; west of the Kokhanok east ferry terminal, there would be two streams crossed requiring culverts, and one requiring a bridge crossing (Figure 3.16-10).

Streamflow

Mine Access Road

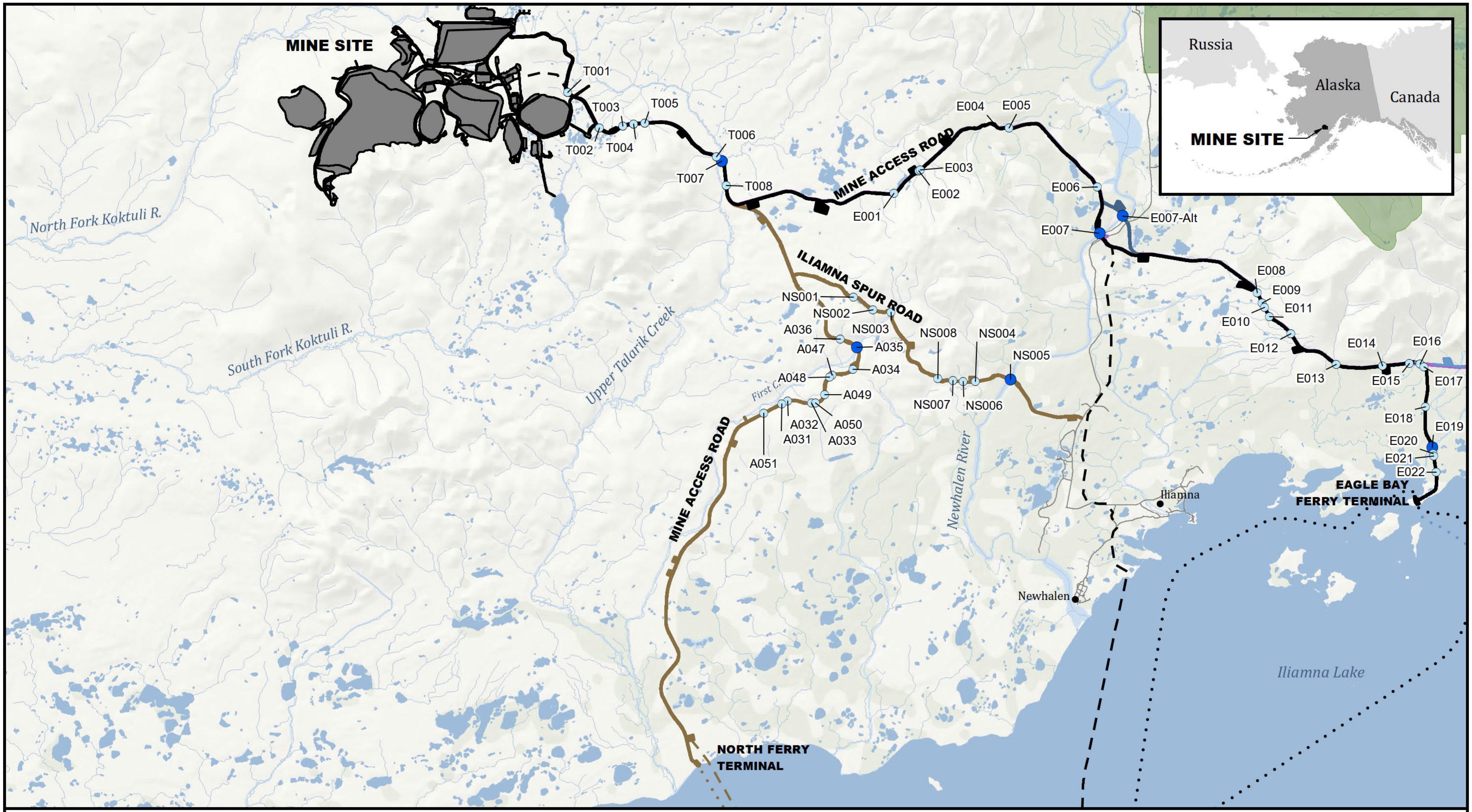
The mine access road at the mine site is at an elevation of approximately 1,700 feet amsl. The area between the mine site and Iliamna Lake is characterized by gently rounded hills and wide valleys. The mine access road would be relatively close to and roughly parallel the UTC watershed boundary for the majority of its length. Culverts would be used for the road to cross approximately 20 small tributaries (Figure 3.16-23). 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. Streamflow information collected in the UTC watershed is presented above under the description of the mine site.

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, crossing the Newhalen River south of the Alternative 1a crossing (Figure 3.16-23 and see Figure 2-51). Streamflow for the Newhalen River is discussed under Alternative 1a, and streamflow information for the other streams crossed by the Iliamna spur road was not available at the time of this writing.

Alternative 1—Kokhanok East Ferry Terminal Variant

Under this variant, the port road would cross 55 rivers and streams. Culverts would be used to cross 50 small streams, and bridges would be used to cross five larger rivers and streams (Figure 3.16-10). The Gibraltar River would not be crossed under this variant. Streamflow information for the other streams crossed by this variant was not available at the time of this writing.



Sources: PLP 2020-RFI168;
PLP 2019-RFI153; ADNR

US Army Corps of Engineers

2 0 2 4
Miles

Proposed Crossings

- ● Bridge
- ○ Culvert

Action Alternatives

- ····· Ferry Routes
- — — Natural Gas Pipelines

- ■ Alternative 1a
- ■ Alternative 1
- ■ Alternative 2
- ■ Alternative 2 Newhalen River North Crossing Variant
- ■ Alternative 3

Other Features

- —— Local Roads
- 🟩 Lake Clark National Park & Preserve

STREAM CROSSINGS AT
MINE ACCESS AND ILIAMNA SPUR ROADS

PEBBLE PROJECT EIS

FIGURE 3.16-23

3.16.3 Alternative 2—North Road and Ferry with Downstream Dams

This section describes the surface water hydrology of Alternative 2 and associated variants for the transportation corridor and pipeline corridor. Chapter 2, Alternatives, describes the corridors in greater detail.

3.16.3.1 Mine Site

The surface water hydrology would be the same as described for Alternative 1a.

3.16.3.2 Transportation Corridor and Pipeline Corridor

Drainage Basins

The mine access road drainage basin description is the same as for Alternative 1a mine access road.

On the western side of Cook Inlet, the principal (named) streams along the transportation corridor and pipeline corridor under Alternative 2 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; and at Eagle Bay Creek (to the Eagle Bay ferry terminal). 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. Elevation along this portion of the corridor ranges from sea level at Diamond Point to 900 feet amsl. Further west, along the northeastern side of Iliamna Lake, the pipeline corridor follows topography that is less steep (40 to 700 feet amsl), 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 1a 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 principal (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 are facilitated by the steep terrain, and thin surficial sediments on mountain slopes. Closer to the mine site, peak flow attenuation and base flow augmentation are facilitated by gentler terrain, increased thickness of surficial sediments, and increased number of surface waterbodies (Knight Piésold et al. 2011a).

Culverts and bridges would be for stream crossings. Along the mine access road, bridges would be constructed at Upper Talarik Creek, Newhalen River, and Eagle Bay Creek (see Figure 2-68). Bridge crossings along the port access road are Iliamna River, Timberline Creek, Chinkelyes Creek, and Williams Creek. Figure 3.16-24 depicts waterbody crossings for Alternative 2 and Alternative 3.

Streamflow

Figure 3.16-25 depicts gaging stations (USGS and PLP) along the transportation corridor for Alternative 2 (and Alternative 3). Along the Alternative 2 port access route between the Pile Bay ferry terminal and Diamond Point port, the USGS operates a crest gaging station (ID 15300350) on Chinkelyes Creek, and a continuous gaging station (ID 15300300) on the Iliamna River (Figure 3.16-65 and Table K3.16-6).

Along the Alternative 2 pipeline route between Pile Bay and the mine site, the USGS operates a crest gage on Chekok Creek (ID 15300270), a continuous streamflow gaging station on Roadhouse Creek, and one on the Newhalen River. Roadhouse Creek and Newhalen River streamflow is described under Alternative 1. Eighteen manual discharge measurements have been recorded at the gaging station on Chekok Creek between 2011 and 2013; 12 of the measurements were recorded during the open flow season, and six were recorded during the low-flow winter months. During the open flow season, streamflow ranged from 97.4 cfs to 276 cfs; and during the winter months, streamflow ranged from 29 cfs to 58.7 cfs.

In addition to the hydrographs from USGS gaging stations shown on Figure 3.16-26, 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 (see Table K3.16-7), winter 2005 (see Table K3.16-8), and summer 2005 (see Table K3.16-9).

Alternative 2—Newhalen River North Crossing Variant

The Newhalen River North Crossing Variant would have a bridge length of 510 feet, and a footprint of 46.6 acres, and there are known wetlands and cultural artifacts identified at the crossing (PLP 219-RFI 154). Surface water hydrology would be similar to the crossing under Alternative 2.

Floodplain Function and Values

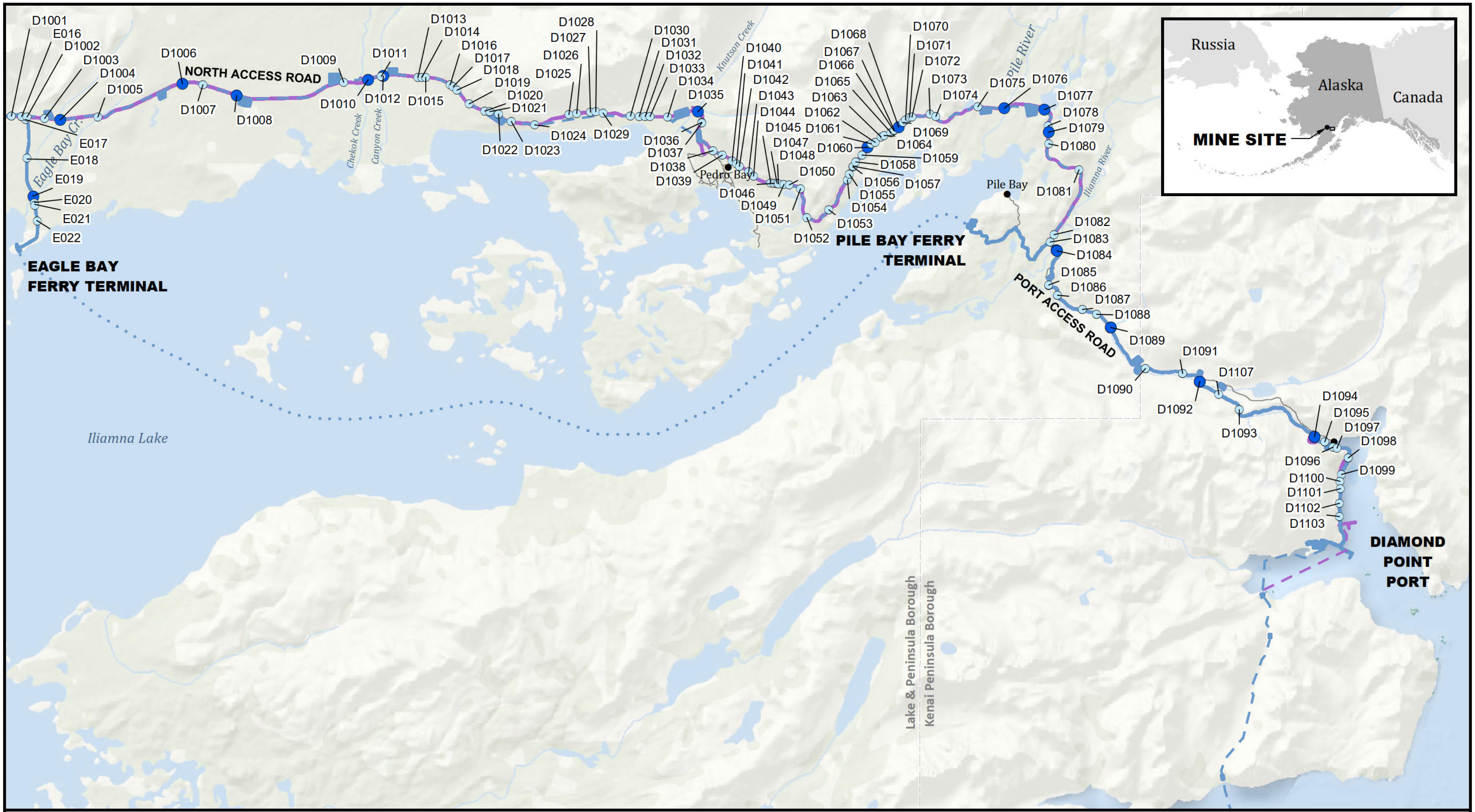
Floodplain function and values between Diamond Point port and Iliamna Lake would differ from those described for the mine site due to the steep mountainous terrain of the Aleutian Range, and fewer existing floodplains and wetlands This would result in fewer floodplains to provide floodplain functions and values. Further west, along the northeastern side of Iliamna Lake, the pipeline corridor follows topography that is less steep, with watersheds containing wider valleys, numerous lakes, and wetlands. Therefore, along this segment, floodplain function and values are anticipated to be similar to those discussed under Alternative 1a.

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 watersheds along the Alternative 2 transportation corridor are essentially undeveloped, a pre-mine flood hazard does not exist. However, there are a few locations along the corridor that have infrastructure such as the Newhalen River bridge and the Iliamna River, Timberline Creek, Chinkelyes Creek and Williams Creek bridges along the existing portion of the Williamsport-Pile Bay Road. Also, there could be some infrastructure (e.g., structures) on Native Allotments within the transportation corridor.

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 K3.16-10.



Sources: PLP 2020-RFI168;
PLP 2019-RFI153; ADNR

US Army Corps of Engineers

2 0 2 4

Miles

Proposed Crossings
- ● Bridge
- ○ Culvert

Action Alternatives
- ⋯ Ferry Routes
- ‒ ‒ Natural Gas Pipelines
- ▨ Alternative 2
- ▨ Alternative 3

Other Features
- — Local Roads
- - - Borough Boundary
- 🟩 National Park

TRANSPORTATION AND PIPELINE CORRIDOR STREAM CROSSINGS - ALTERNATIVE 2 AND ALTERNATIVE 3

PEBBLE PROJECT EIS

FIGURE 3.16-24

Sources: PLP 2019-RFI153;
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)

Action Alternatives

···· Ferry Routes

– – Natural Gas Pipelines

▨ Alternative 2

▨ Alternative 2 Newhalen River North Crossing Variant

▨ Alternative 3

Other Features

—— Local Roads

– – Borough Boundary

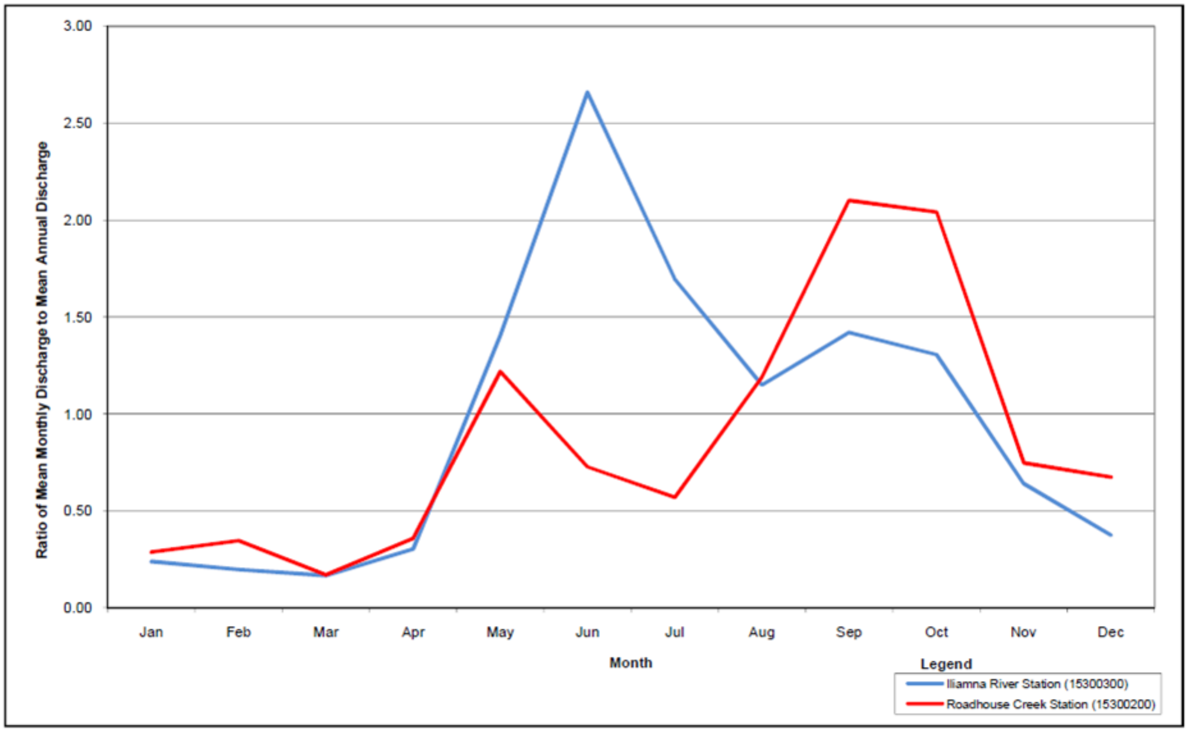
🟩 National Park

STREAM GAGING STATIONS - TRANSPORTATION CORRIDOR, ALTERNATIVE 2 AND ALTERNATIVE 3

PEBBLE PROJECT EIS

FIGURE 3.16-25

Figure 3.16-26: Mean Annual Hydrograph Comparison—Iliamna River and Roadhouse Creek USGS Gaging Stations



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

3.16.4 Alternative 3—North Road Only

The affected environment for surface water for Alternative 3 and associated variant is similar to that described under Alternative 2, with the exception of the port location, which is north of Diamond Point (PLP 2020d, Figure 1-5) (see Figure 2-80). Streams would be crossed with culverts and bridges. Planned bridged crossings along the north access road are depicted in Figure 2-79. Figure 3.16-24 depicts stream crossings for the north access road and port access road.

Floodplain Function and Values

Floodplain function and values under Alternative 3 are anticipated to be similar to those described for Alternative 2.

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 watersheds along the Alternative 3 transportation corridor are essentially undeveloped, a pre-mine flood hazard does not exist.

3.16.5 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.

3.16.5.1 Domestic Surface Water Use

Three community water systems in the Iliamna Lake area extract surface water for domestic use: Nondalton, Kokhanok, and Igiugig (Figure 3.16-27). The Nondalton system uses infiltration galleries[18] 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 in 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 Alternative 2 and Alternative 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 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 in the DWPAs reflect buffers around surface drinking water sources and watershed boundaries (Figure 3.16-27).

3.16.5.2 Mine Site Water Use

Surface water in 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 in 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 in 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 (ADNR 2018c).

3.16.5.3 Port Water Use

There is no known or documented surface water use at either Amakdedori or Diamond Point port sites (under either Alternative 2 or Alternative 3) (ADEC 2018f).

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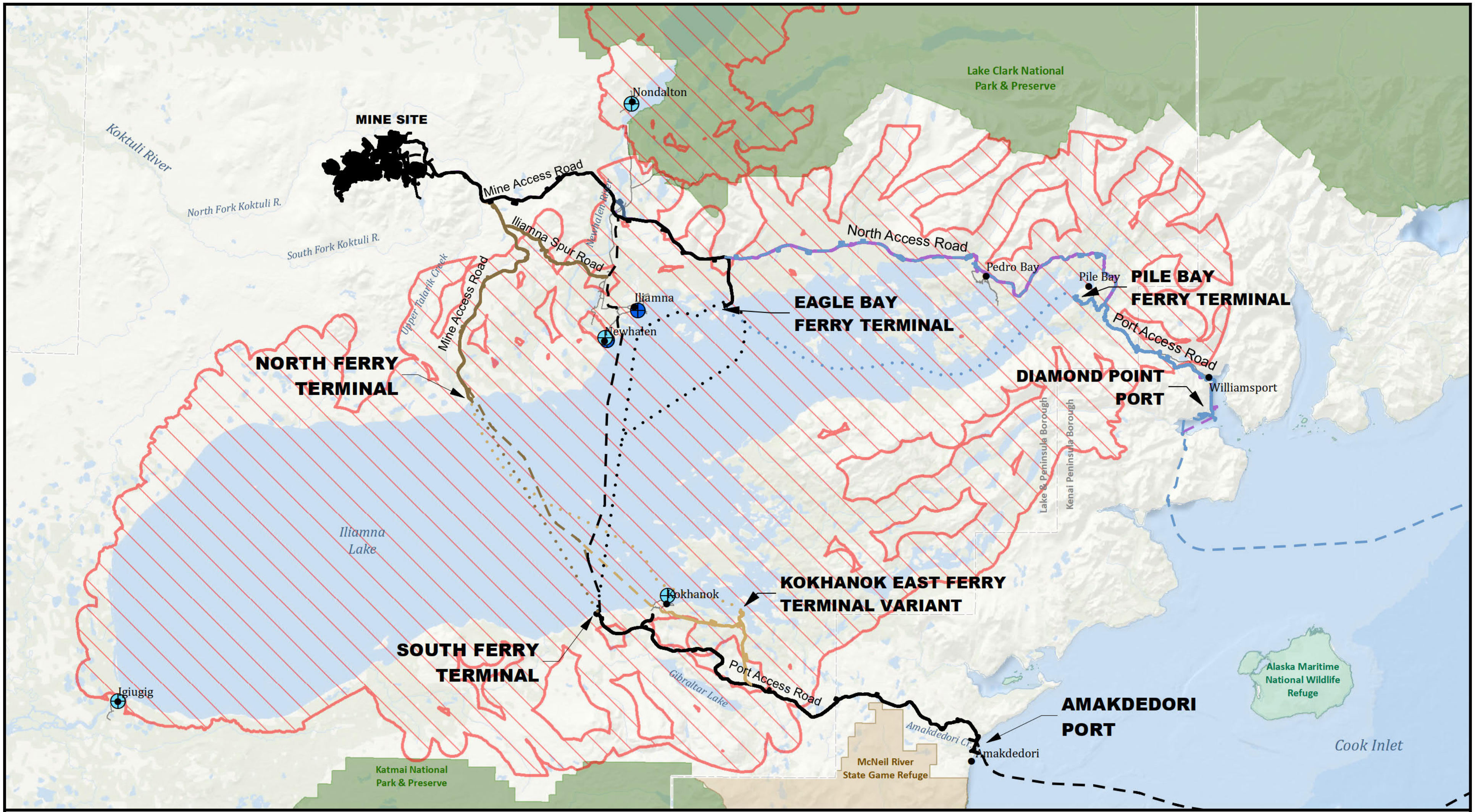
[18] **Infiltration gallery**—a horizontal perforated pipe structure installed to facilitate transfer of water from a shallow aquifer, such as may occur near a lake or river shoreline.



Sources: PLP 2020-RFI168;
PLP 2019-RFI153; ADEC

- ⊕ Community Water System
- ⊕ Non-Community Water System
- ▨ Drinking Water Protection Area

Action Alternatives

- ⋯ Ferry Routes
- – – Natural Gas Pipelines
- ■ Alternative 1a
- ■ Alternative 1
- ■ Alternative 1 Kokhanok East Ferry Terminal Variant
- ■ Alternative 2
- ■ Alternative 2 Newhalen River North Crossing Variant
- ■ Alternative 3

Other Features

- — Local Roads
- - - Borough Boundary
- 🟩 National Park
- 🟩 National Wildlife Refuge
- ■ State Game Refuge/Sanctuary

DOMESTIC WATER SOURCES IN ILIAMNA LAKE AREA

PEBBLE PROJECT EIS

FIGURE 3.16-27

3.16.5.4 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 (Alternative 2 and Alternative 3). By 2012, the run-of-the-river-type hydropower plant supplied more than 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.