K3.10 HEALTH AND SAFETY

The evaluation of impacts on human health is a required component of the National Environmental Policy Act (NEPA) as it pertains to negative and beneficial consequences of the project on potentially affected communities. This appendix contains information on health effects categories (HECs) 1 through 8 supplemental to Section 3.10, Health and Safety. HECs 1 through 4 are the focus of and are detailed in Section 3.10, Health and Safety, because they are the most relevant to the project or are a concern to stakeholders and affected communities; therefore, this appendix presents a brief summary of HECs 1 through 4 and provides their baseline data tables, if generated. HECs 5 through 8 are expected to have lower relevance to the project, and are also presented in this appendix, including baseline data tables, if generated.

K3.10.1 HEC 1: Social Determinants of Health

Factors such as income, education, isolation, and early access to healthcare are termed social determinants of health (SDH) because any changes in these factors, positive or negative, can lead to corresponding changes in the physical, mental, and social health of the population. For those SDH not covered in Section 3.3, Needs and Welfare of the People—Socioeconomics, Table K3.10-1 summarizes the additional SDH that are relevant and important indicators for this HEC because they may potentially be impacted by the project. Overall, the affected communities whose health may be most impacted by the project in the Environmental Impact Statement (EIS) analysis area (or communities that may use the area for residence, subsistence, or recreation) are the remote, rural communities in the Bristol Bay Region (includes the Lake and Peninsula Borough [LPB], Bristol Bay Borough, and Dillingham Census Area) and Kenai Peninsula Region. The remote communities generally have lower levels of employment, income, formal educational attainment, and access to amenities than more urbanized communities. Although they are comparable to the larger urban areas in some areas of health, there are other areas such as alcohol consumption and violent crime, including aggravated assault and rape, where the rural areas may have higher health needs.

Table K3.10-1: Social Determinants of Health (HEC 1)

Determinant	Data Period	Iliamna Lake/Lake Clark Communities	Nushagak/Bristol Bay Communities	Lake and Peninsula Borough	Dillingham Census Area	Bristol Bay Borough	Bristol Bay Region	Kenai Peninsula Region	Anchorage/ Mat-Su Region	Alaska	National
Life Expectancy in Years	2009-2013	--	--	--	--	--	71.4 (AN)	71.6 (AN)	71.6 (AN)	70.7 (AN) 78.0 (White)	79.1 (White)
Adequate Prenatal Care in Percent (%)	2009-2013 (unless noted)	63.3 (all races; 2014-2016)	36.1 (all races; 2014-2016)	55.3[a] (all races; 2014-2016)	47.4[b] (all races; 2014-2016)	51.8 (all races; 2014-2016)	35.4 (AN)	64.2 (AN)	63.9 (AN)	50.0 (AN) 54.5 (AN 2013) 68.8 (White 2013) 62 (all races; 2014-2016)	--
Infant Mortality (rate per 1,000 live births)	2009-2013 (unless noted)	--	--	--	--	--	5.9[c] (AN)	--	5.6 (AN)	6.7 (AN) 8.9 (AN 2013) 3.5 (White 2013)	5.1 (White 2013)
Teen Pregnancy (rate per 1,000 births)	2009-2013 (unless noted)	--	70[c] (all races; 2014-2016)	--	44.4[b] (all races; 2014-2016)	--	65.8 (AN)	45.2 (AN)	52.9 (AN)	69.2 (AN) 47.3 (AN 2013) 20.5 (White 2013) 27.5 (all races; 2014-2016)	18.6 (White 2013)
Adult Dental Care (percent with dental visit in past year)	2006-2014 (unless noted)	--	--	--	--	--	66.4 (AN)	56.3 (AN)	63.7 (AN)	58.7 (AN) 56.5 (AN 2014) 65.5 (White 2014)	65.3 (White 2014)
Adult Tooth Loss (percent with 1 or more teeth removed due to tooth decay or gum disease)	2006-2014 (unless noted)	--	--	--	--	--	58.6 (AN)	59.1 (AN)	51.9 (AN)	59.5 (AN) 60.5 (AN 2014) 37.7 (White 2014)	43.4 (all races; 2014)
Adult Mental Health (average days poor mental health per 30 days)	2010-2014 (unless noted)	--	--	2.2 (all races; 2011-2015)	2.8 (all races; 2011-2015)	2.6 (all races; 2011-2015)	3.2 (AN)	4.7 (AN)	4.6 (AN)	3.6 (AN) 3.0 (White) 3.2 (all races; 2011-2015)	3.4 (all races; 2005-2009)
Adult Binge Drinking (percent in past 30 days)	2010-2014 (unless noted)	--	--	16.6 (all races; 2011-2015)	14.1 (all races; 2011-2015)	24.5 (all races; 2011-2015)	14.8 (AN)	27.4 (AN)	19.7 (AN)	19.8 (AN) 19.8 (White) 18.8 (all races; 2011-2015)	17.7 (White)
Adult Alcohol Mortality (rate per 100,000 population)	2012-2015	--	--	--	--	--	49.3[c] (AN)	--	43.0 (AN)	29.8 (AN) 3.9 (non-AN)	3.0 (White)
All Violent Crime (rate per 100,000 population)	2017, all races	N/A	N/A	N/A	1,646	0[c]	N/A	421 (KPB)	733 (MSB) 1,203 (AM)	829	394
Aggravated Assault (rate per 100,000 population)	2017, all races	--	--	--	1,098	0[c]	--	211 (KPB)	624 (MSB) 799 (AM)	575.4	248.9
Robbery (rate per 100,000 population)	2017, all races	--	--	--	127[c]	0[c]	--	37 [c] (KPB)	89[c] (MSB) 263 (AM)	128.5	98
Rape (rate per 100,000 population)	2017, all races	--	--	--	422[c]	0[c]	--	173 (KPB)	9.9[c] (MSB) 132 (AM)	116.7	41.7

Notes:

-- = Not Available	AM = Anchorage Municipality	AN = Alaska Native	KPB = Kenai Peninsula Borough	Mat-Su = Matanuska-Susitna	MSB = Matanuska-Susitna Borough

[a] LPB, excluding the eight Iliamna Lake/Lake Clarke Communities
[b] Dillingham Census Area, excluding the three Nushagak/Bristol Bay communities
[c] Rate based on fewer than 20 cases/counts (may not be statistically reliable)

Iliamna Lake/Lake Clark communities include Port Alsworth, Newhalen, Kokhanok, Nondalton, Iliamna, Levelock, Iguigig, and Pedro Bay.
Nushagak/Bristol Bay communities include New Stuyahok, Koliganek, and Ekwok.
Other surrounding potentially affected communities, such as Dillingham, are represented in the information provided for the larger areas in which they reside (Dillingham Census Area, Bristol Bay Borough, and Kenai Peninsula Borough [KPB]).
The Bristol Bay Region includes the LPB, Dillingham Census Area, Bristol Bay Borough, and surrounding area. Kenai Region includes KPB and the surrounding area.
Sources: ANTHC 2016a, b, c, 2017b, c, d, e, f, g, h; FBI 2017; McDowell Group 2018b

K3.10.2 HEC 2: Accidents and Injuries

Accidents and injuries include both fatal and non-fatal incidents that are primarily unintentional and affect the mortality and morbidity rates of a community. Intentional incidents include homicide and suicide (note: overlaps with suicide HEC 1, psychosocial stress). Non-fatal and fatal intentional and unintentional injuries can place a substantial burden on available healthcare resources (such as hospitals, clinics, and ambulances). Table K3.10-2 presents the baseline accident and injury rates for the affected communities. Overall, in comparison to national and state rates, the levels of unintentional deaths and injuries in the potentially affected communities were higher. Suicide mortality rates for the Dillingham Census Area were similar to Anchorage and state rates, while Bristol Bay region rates were higher, and the Kenai Peninsula rates were lower in comparison to the Dillingham Census Area, state, and national rates.

K3.10.3 HEC 3: Exposure to Potentially Hazardous Materials

Environmental exposure to chemicals through the air, land, or water is also considered a health determinant. Baseline data may be qualitative in terms of proximity to known contamination sources, or quantitative through analytical data collection (e.g., water quality data, soil analytical data). Overall, baseline conditions of exposure to potentially hazardous chemicals may include the occurrence of localized poor air quality in some areas from outdoor dust or indoor air pollution, as well as elevated levels of a few naturally occurring metals in soils, surface waters, groundwater, and some food sources. Dust from unpaved roads may circulate contaminants that can be deposited onto surface water and further redistributed to sediments. Exposure to these trace elements through direct and dietary exposure pathways represents baseline hazardous exposure potential for the potentially affected communities in the EIS analysis area. Although there are numerous known contaminated sites in the EIS analysis area, these sites are under active oversight by government agencies, and agency directives are expected to control or prevent exposure to the general public. Additionally, no contaminated site records coincided with or were in proximity to the project footprint. Therefore, the proximity of these sites is not expected to contribute to the baseline exposure to hazardous materials. In the EIS analysis area, background data were obtained for air and are presented and discussed in Section 3.20, Air Quality. Baseline data were collected for soil, surface water, sediment, groundwater, vegetation, and fish tissue, and are provided and discussed in their respective sections: Section 3.14, Soils; Section 3.18, Water and Sediment Quality; Section 3.26, Vegetation; and Section 3.24, Fish Values. In addition, Section 3.23, Wildlife Values, provides a description of the birds, terrestrial mammals, and marine mammals that are known and have a potential to occur in the project area; while Section 3.9, Subsistence, provides information on traditional ecological knowledge, seasonal rounds, and subsistence harvest patterns for each of the potentially affected communities evaluated for subsistence.

Table K3.10-2: Accidents and Injuries (HEC 2)

Determinant	Data Period	Iliamna Lake/Lake Clark Communities	Nushagak/Bristol Bay Communities	Lake and Peninsula Borough	Dilingham Census Area	Bristol Bay Borough	Bristol Bay Region	Kenai Peninsula Region	Anchorage/Mat-Su Region	Alaska	National
Unintentional Injury Deaths (rate per 100,000 population)	2012-2015 (unless noted)	160[c] (all races; 2012-2016)	--	--[a]	180[b] (all races; 2012-2016)	140[c] (all races; 2012-2016)	151.8 (AN)	65.0[c] (AN)	101.7 (AN)	99.4 (AN) 38.9 (non-AN)	42.4 (White)
Unintentional Injury (percent of injuries)	2009-2016	--	--	92.4 (all races)	84 (all races)	--	85.5 (all races)	--	--	83.3 (all races)	--
Unintentional Injury Hospitalization (rate per 100,000 population)	2002-2011	--	--	--	--	--	134.4 (AN)	94.9 (AN)	102.4 (AN)	109.2 (AN)	--
Hospitalizations due to Falls, ranking of cause of hospitalization	2009-2016 (unless noted)	--	--	#1 Leading Cause	#1 Leading Cause	#2 Leading Cause	--	--	--	43.9 (AN; 2002-2011) #1 Leading Cause	--
Hospitalizations due to Vehicles, ranking of cause of hospitalization	2009-2016 (unless noted)	--	--	#2 Leading cause is other land transport	#2 & #3 Leading causes are other land transport and motor vehicle traffic	#1 Leading cause is other land transport	--	--	--	31.5 (AN; 2002-2011 #2 & #4 Leading causes are other land transport and motor vehicle traffic	--
Suicide Mortality (age-adjusted rate per 100,000 population)	2012-2015 (unless noted)	--	--	--	40[b,c] (all races; 2012-2016)	--	58.1[c] (AN)	30.1[c] (AN)	37.0 (AN)	40.9 (AN) 17.9 (non-AN)	14.3 (White)

Notes:
-- = Not Available
AN = Alaska Native
Mat-Su = Matanuska-Susitna
[a] LPB, excluding the eight Iliamna Lake/Lake Clark communities
[b] Dillingham Census Area, excluding the three Nushagak/Bristol Bay communities
[c] Rate based on fewer than 20 cases/counts (may not be statistically reliable)
Iliamna Lake/Lake Clark communities include Port Alsworth, Newhalen, Kokhanok, Nondalton, Iliamna, Levelock, Iguigig, and Pedro Bay
Nushagak/Bristol Bay communities include New Stuyahok, Koliganek, and Ekwok
Other surrounding potentially affected communities, such as Dillingham, are represented in the information provided for the larger areas in which they reside (Dillingham Census Area, Bristol Bay Borough, and KPB)
The Bristol Bay Region includes the LPB, Dillingham Census Area, Bristol Bay Borough, and surrounding area. Kenai Region includes the KPB and surrounding area
Sources: ANTHC 2015, 2017f, i, j; McDowell et al. 2011a; McDowell Group 2018b

K3.10.4 HEC 4: Food, Nutrition, and Subsistence Activity

The role of adequate and high-quality food and nutrition is of paramount importance to health. The cost of living is higher in Alaska than the national average, and the cost of living/food in the EIS analysis area is typically more than two times that of Anchorage (see Section 3.3, Needs and Welfare of the People—Socioeconomics). Table K3.10-3 presents the baseline nutrition, lifestyle, and poverty levels for the affected communities. In Alaska, subsistence activities greatly contribute to community nutrition and food security because they provide dietary items such as fish, game, and berries that are highly nutritious, relatively low in cost, and also support cultural and social cohesion. A large proportion of households in the EIS analysis area participates in subsistence activities and depends on procured wild food resources (see Section 3.9, Subsistence). Percentages of nutritional intake are typically fairly similar between LPB, Dillingham Census Area, Bristol Bay Borough, and Alaska. Overall, LPB, Dillingham Census Area, and Bristol Bay Borough families have lower rates of those living below the poverty level threshold for Alaska Natives state-wide, and fairly similar to national whites (see Section 3.10, Health and Safety, HEC 4). Subsistence activities are the basis of many local economies and are important for nutrition and food security in the communities in the EIS analysis area as compared to the state.

K3.10.5 HEC 5: Infectious Diseases

The role of infectious diseases in the mortality and morbidity rates of a population is well known. Planned project activities include the creation of worker housing and camps during construction and operations, and may bring together various populations of workers under communal conditions that would be managed in accordance with the project's programs for maintenance of clean, hygienic, and sanitary operations. Reportable infectious diseases (influenza and pneumonia) were the tenth leading cause of death to all races in Alaska (ADHSS 2017a). Conditions that may promote the spread of infectious disease include unsafe water, poor personal hygiene, and unsanitary conditions. As discussed under HEC 6, the potentially affected communities in the EIS analysis area have a high rate of water and sanitation service; therefore, baseline sanitary conditions in these communities do not promote the spread of infectious disease. Other infectious diseases impact human health quality and mortality, including sexually transmitted infections, HIV, tuberculosis, septicemia, and viral hepatitis. Immunizations play an important role in decreasing the rates of some infectious diseases.

Table K3.10-4 presents the leading infectious disease rates for Alaska and regions, when available, as well as childhood immunization rates. Regional Alaska Native rates of sexually transmitted infections (as represented by chlamydia and gonorrhea) are comparable to or lower than state Alaska Native rates, while the more urban Anchorage region has rates higher than the state average (ANTHC 2017k, l). However, state and regional Alaska Native sexually transmitted infections rates are two or more times the rates of non-Alaska Native state rates, and three or more times the national rates for whites. Childhood immunization rates in Bristol Bay Borough are lower than state and national rates.

Table K3.10-3: Food, Nutrition, and Subsistence (HEC 4)

Determinant	Data Period	Lake and Peninsula Borough	Dilingham Census Area	Bristol Bay Borough	Alaska	National
Adults Who Have a Subsistence Lifestyle (percent)	2009-2015	78.5 (all races)	79.5 (all races)	74.1 (all races)	30.5 (all races)	--
Adults Who Eat Less Than Five Daily Servings of Fruit and Vegetables (percent)	2007-2015	81.2 (all races)	81.0 (all races)	90.8 (all races)	78.6 (all races)	--
Adults Who Consume One or More Sugar-Sweetened Beverages or Soda (percent)[a]	2011-2015	37.7 (all races)	48.6 (all races)	25.3 (all races)	30.5 (all races)	--
Families Below the Federal Poverty Level Threshold (percent)	2012-2016 (unless otherwise noted)	15.2 (all races)	14.8 (all races)	4.3 (all races)	23.2 (2011-2015; AN)	12.1 (2011-2015; whites)
By Individual Potentially Affected Communities (percent; all races)		Kokhanok—28.6 Nondalton—25.0 Newhalen—23.5 Levelock—14.3 Iliamna—9.1 Port Alsworth—5.6 Igiugig—0 Pedro Bay—0	New Stuyahok—28.1 Ekwok—16.7 Koliganek—5.7			

Notes:
-- = Not Available
AN = Alaska Native
Subsistence lifestyle and nutrition determinants are self-reported, and subsistence lifestyle was defined by the respondents
[a] Sugar-sweetened beverages or sodas do not include 100% fruit juice, diet drinks, or artificially sweetened drinks
The federal poverty threshold is updated for inflation, but does not vary geographically, and is based on pre-tax income (ANTHC 2017a)
Sources: McDowell 2018a, b; ANTHC 2017a

Table K3.10-4: Infectious Diseases (HEC 5)

Infectious Disease Indicators (Period)	Bristol Bay Region	Kenai Region	Anchorage/ Mat-Su Region	Alaska	National
Influenza and Pneumonia (mortality age-adjusted rate per 100,000 population) (2012-2015)	--	--	--	21.3 (AN) 9.9 (non-AN)	15 (White)
Tuberculosis (rate per 100,000 population) (2016)	--	--	--	37 (AN) 7.7 (all races)	2.9 (all races)
Chlamydia Cases (age-adjusted rate per 100,000 population) (2015)	1,728.3 (AN)	873.8 (AN)	2,504.4 (AN)	1,653.8 (AN) 452.3 (non-AN)	187.2 (White)
Gonorrhea Cases (age-adjusted rate per 100,000 population) (2015)	169.4* (AN)	184.5* (AN)	792.2 (AN)	436.7 (AN) 70.6 (non-AN)	44.2 (White)
Immunization Rate for Alaskan Children (percent) (2015, unless noted)	40.0 Bristol Bay Borough (all races; 2016)	--	--	75.1 (AN) 66.3 (all races)	72.7 (White)

Notes:
-- = Not Available
* = rate based on less than 20 cases/counts (may not be statistically reliable)
AN = Alaska Native
Mat-Su = Matanuska-Susitna
The Bristol Bay Region includes the LPB, the Dillingham Census Area, Bristol Bay Borough, and surrounding area. Kenai Region includes KPB and surrounding area
Sources: ANTHC 2017a, k, l, m; ADHSS 2017b, 2018; McDowell 2018b

Some regional rates (mortality from influenza and pneumonia, and tuberculosis rates, as well as immunization rates in the Kenai and Anchorage regions) are not readily available. However, deaths from infectious disease were not rated among the top three leading causes of deaths reported for the Bristol Bay, Kenai, or Anchorage regions (ADHSS 2017a; McDowell 2018b). Therefore, the lack of regional infectious disease rates might be due to the low state rates (ADHSS 2017a; ANTHC 2017i), privacy concerns, and/or tracking or reporting methodology.

K3.10.6 HEC 6: Water and Sanitation

The lack of safe water supply (i.e., running water) and suitable sewage disposal can represent a major public health and community development problem. The project would develop, operate, and maintain its own water supply and water treatment facilities. Lack of in-home water and sewer service may cause severe skin infections and respiratory illnesses. Prior to 2004, a large portion of rural Alaska communities were classified as "unserved Rural Alaska Communities," which is defined as a community having 45 percent or more homes that are not served by central wells, and have a mix of central sewage plumbing, septic systems, honey buckets, and outhouses.

In 2016, 83.5 percent of rural Alaska Native communities were served by water and sewer services (a significant increase since 2004). In the Bristol Bay Region (which includes Bristol Bay Borough, Dillingham Census Area, and LPB), 99 percent of households had water and sewer services. In the Kenai Peninsula, service was 100 percent (ANTHC 2017n). However, as discussed in Section 3.3, Needs and Welfare of the People—Socioeconomics, for rural communities that have water and sanitary service systems, operating and maintaining the systems are challenged by the high cost of energy, lower populations to support higher-than-average maintenance costs, and a shortage of experienced maintenance operators (ASCE 2018). See Section 3.3, Needs and Welfare of the People—Socioeconomics, for further details on water, sewer, and solid waste.

K3.10.7 HEC 7: Non-Communicable and Chronic Diseases

Non-communicable and chronic diseases consume a large part of healthcare resources and affect the overall health status of a population. The incidence of such disease is typically associated with multiple contributing factors, including genetics, lifestyle and socioeconomic status, and trends, which may be relatively slow to show increases or decreases. In the context of evaluating an individual project, it may be difficult to attribute a single project-related cause to changes in disease incidence. However, community-wide changes, such as increases in employment rates and economic security or access to healthcare, may result in improved health outcomes related to chronic diseases. Therefore, understanding baseline rates of non-communicable and chronic diseases helps to inform a better understanding of overall community health status, although the impacts related to a single project may not be easily defined.

Similar to state-wide trends, the three recent leading causes of death due to non-communicable and chronic diseases for the potentially affected communities were cancer and heart disease (at community, borough/census area, and regional levels), as well as chronic obstructive pulmonary disease, including chronic lower respiratory disease, at regional level (ADHSS 2017a; ANTHC 2017a, i; McDowell 2018a, b). Table K3.10-5 presents the recent average age-adjusted non-communicable and chronic disease mortality (death) rates for the three leading regional causes, as well as percentage of Medicare recipients with Alzheimer's disease/dementia, and several chronic disease contributing factors.

Heart disease rates (per 100,000 individuals) in the Iliamna Lake/Lake Clark communities, Nushagak/Bristol Bay communities, and LPB are higher than Anchorage and state rates (McDowell 2018b; ADHSS 2017a; ANTHC 2017a, i, p). Overall cancer death rates (per 100,000 individuals) in the Iliamna Lake/Lake Clark communities and LPB are higher than Nushagak/Bristol Bay communities, as well as Anchorage and state rates, which were all fairly similar (McDowell 2018b; ADHSS 2017a; ANTHC 2017a, i, o). Looking at specific cancers, colorectal cancer is higher in the LPB than Dillingham Census area and state rates; while lung and bronchus cancer deaths are lower in the LPB and Dillingham Census area when compared to state rates (McDowell 2018b). Cancer incidence is variable, but generally similar between the regions, state, and national rates; with the exception of lower incidence in the Dillingham Census Area (colorectal as the leading type) and higher in the Kenai Peninsula Region (McDowell 2018b). Although Kenai Peninsula and Anchorage regions have chronic obstructive pulmonary disease rates lower than state levels, the Bristol Bay region has much higher rates than the state (ANTHC 2017a, q).

Table K3.10-5: Non-Communicable and Chronic Diseases (HEC 7)

Disease Type and Metric	Date Period	Iliamna Lake/ Lake Clark Communities	Nushagak/Bristol Bay Communities	Lake and Peninsula Borough	Dilingham Census Area	Bristol Bay Borough	Bristol Bay Region	Kenai Peninsula Region	Anchorage/ Mat-Su Region	Alaska	National
Cancer Deaths (age-adjusted rate per 100,000 population)	2012-2015 (unless noted)	320[c,e] (all races; 2012-2016)	230[c,e] (all races; 2012-2016)	340[a,e] (all races; 2012-2016) 229.3[a] (all races; 2005-2014)	160[b,e] (all races; 2012-2016) 196.4[a] (all races; 2005-2014)	140[c,e] (all races; 2012-2016) 273.7[a] (all races; 2005-2014)	232.4 (AN)	203.1 (AN)	259.2 (AN)	242.7 (AN) 154.5 (non-AN) 175.7 (all races; 2005-2014)	164 (White)
Colorectal	2005-2014	--	--	107.7	73.9	--**	--	--	--	43.1	--
Lung and bronchus	2005-2014	--**	--**	48.5	38.2	--**	--	--	--	59.9	--
Cancer Incidence (age-adjusted rate per 100,000 population)	2010-2014 (unless noted)	--	--	511.9 (all races)	359.9 (all races)	442.7 (all races)	443.4 (AN; 2012-2015)	586.0 (AN; 2012-2015	526.5 (AN; 2012-2015)	427.0 (all races) 498.9 (AN)	450.3 (White)
Female breast	2010-2014	--	--	--**	--**	213.7	--	--	--	125.6	--
Colorectal	2010-2014	--	--	107.7	107.7	--**	--	--	--	43.1	--
Heart Disease Deaths (age-adjusted rate per 100,000 population)	2012-2015 (unless noted)	280[c] (all races; 2012-2016)	330[c] (all races; 2012-2016)	410[a] (all races; 2012-2016)	190[b] (all races; 2012-2016)	140[c] (all races; 2012-2016)	262.6 (AN)	264.3 (AN)	226.1 (AN)	208.2 (AN) 133.3 (non-AN)	167.7 (White)
Chronic Obstructive Pulmonary Disease Deaths (age-adjusted rate per 100,000 population)	2012-2015	--	--	--	--	--	91.3[c] (AN)	56.3[c] (AN)	61.2 (AN)	68.0 (AN) 35.2 (non-AN)	44.0 (White)
Alzheimer's Disease/ Dementia (percent of Medicare Beneficiaries)	2015	--	--	--	8.2	5.6	--	--	--	7.1	--
Chronic Disease Contributing Factors											
Adult Overweight (percent with a BMI of 25 to 29.9)	2010-2014 (unless noted)	--	--	70.0 (all races; 2011-2015)	71.3 (all races; 2011-2015)	84.7 (all races; 2011-2015)	38.6 (AN)	37.8 (AN)	35.0 (AN)	34.9 (AN)[d] 38.2 (White)[d]	35.9 (White)
Adult Obesity (percent with a BMI of 30 or more)	2010-2014 (unless noted)	--	--				35.1 (AN)	36.3 (AN)	37.4 (AN)	35.2 (AN)[d] 26.9 (White)[d]	26.4 (White)
Adult Physical Activity (percent who meet recommended weekly activity)	2011-2013	--	--	--	--	--	36.9 (AN)	11.3 (AN)	17.5 (AN)	18.5-18.7 (AN) 24.6-26.4 (White)	20.4-20.9 (all races)
Adults Who Believe Get Enough Physical Activity (percent)	2011-2015	--	--	74.3 (all races)	57.2 (all races)	73.2 (all races)	--	--	--	52.0 (all races)	--
Adult Current Smoking (percent who have had 100+ cigarettes and currently smoke)	2010-2014 (unless noted)	--	--	29.1 (all races; 2011-2015)	34.8 (all races; 2011-2015)	27.8 (all races; 2011-2015)	45.3 (AN)	33.9 (AN)	31.1 (AN)	36.4 (AN) 18.3 (White) 20.5 (all races; 2011-2016)	19.0 (White)
Adult Formerly Smoked (percent who had 100+ cigarettes)	2011-2015	--	--	28.3 (all races)	25.9 (all races)	30.1 (all races)	--	--	--	27.5 (all races)	
Adult Current Smokeless Tobacco Use (percent currently use smokeless tobacco product)	2010-2014	--	--	--	--	--	15.0 (AN)	14.8 (AN)	6.7 (AN)	12.8 (AN) 3.8 (White)	3.4 (2014, all races)
Adult Ever Used Chewing Tobacco (percent)	2011-2015	--	--	29.5 (all races)	30.5 (all races)	35.5 (all races)	--	--	--	21.0 (all races)	--

Notes:
-- = Not Available ** = Data suppressed due to fewer than six cases AN = Alaska Native BMI = Body Mass Index Mat-Su = Matanuska-Susitna
[a] LPB, excluding the eight Iliamna Lake/Lake Clark communities
[b] Dillingham Census Area, excluding the three Nushagak/Bristol Bay communities
[c] Rate based on fewer than 20 cases/counts (may not be statistically reliable)
[d] Alaska-wide and all races, 66.1 percent of adults are overweight/obese (2011-2015)
[e] Malignant neoplasms (cancerous tumors)
Iliamna Lake/Lake Clark communities include Port Alsworth, Newhalen, Kokhanok, Nondalton, Iliamna, Levelock, Iguigig, and Pedro Bay
Nushagak/Bristol Bay communities include New Stuyahok, Koliganek, and Ekwok
Other surrounding potentially affected communities, such as Dillingham, are represented in the information provided for the larger area in which they reside (Dillingham Census Area, Bristol Bay Borough, and KPB)
The Bristol Bay Region includes the LPB, the Dillingham Census Area, Bristol Bay Borough, and surrounding area. Kenai Region includes Kenai Borough and surrounding area
Recommended physical activity defined as 150 minutes of moderate-intensity activity or 75 minutes vigorous-intensity activity, or an equivalent combination, each week per Center for Disease Control's 2008 Physical Activity Guidelines for Americans
Sources: ANTHC 2017a, o, p, q, r, s, t, u, v; CDC 2016; McDowell 2018a, b

Cancer was one of the top two causes of death in the LPB, while cancer and heart disease were the top two causes of death in the Dillingham Census Area. The three types of cancer with the highest incidence were colon/rectum (17.9 percent), lung (17.2 percent), and breast (15.1 percent) (ANTHC 2017a, o). The highest rate (per 100,000 individuals) of cancer incidence is colorectal cancer in the LPB (107.7 percent) and Dillingham Census Area (107.7 percent), while the highest rate of cancer incidence is breast cancer in Bristol Bay Borough (213.7 percent) (McDowell 2018b). Colorectal cancer and lung and bronchus cancer had the highest cancer mortality rates per 100,000 individuals in the LPB (107.7 and 48.5 percent, respectively), and the Dillingham Census Area (73.9 and 38.2 percent, respectively). Most of these cancer incidence and mortality rates appear higher than those reported for Alaska overall, with a colorectal cancer incidence rate of 43.1 percent, female breast cancer incidence rate of 125.6 percent, and colorectal cancer mortality rate of 43.1 percent; but Alaska's lung and bronchus cancer mortality rate (59.9 percent) is higher (McDowell 2018b; ADHSS 2017a; ANTHC 2017a, i, o).

Chronic disease contributing factors include, but are not limited to weight, physical activity, smoking, and tobacco use. In general, the LPB and Dillingham Census Area have fairly similar rates of adults who are overweight and obese (i.e., a Body Mass Index above 25) compared to the state, while Bristol Bay rates were higher in comparison. The LPB and Bristol Bay Borough self-report much higher percentages of believing they get enough physical activity compared to Alaska overall, while the Dillingham Census Area self-reports rates only slightly above Alaska overall (McDowell 2018b). In general, smoking and tobacco use rates of current smokers, and adults who have used chewing tobacco, are higher in the LPB, the Dillingham Census Area, and Bristol Bay Borough in comparison to state levels.

K3.10.8 HEC 8: Health and Safety Services Infrastructure and Capacity

An important measure of the health-related resilience and support structure of a community is the quality and quantity of healthcare and safety services that are available to the residents. In the context of evaluating project impacts to health, the capacity of existing healthcare and safety services to accommodate baseline health care and safety needs, as well as the healthcare and safety needs of populations that may migrate in or emergency incidents that may occur during project activities may be of concern. For example, if a project is in an area that is already underserved with regard to healthcare services, the addition of more workers who may need to use the services may further strain an already overloaded system. In many cases, project proponents may commit to operating their own healthcare facilities to serve their employees, thereby avoiding any demands on the local systems.

Health Services—The LPB and Bristol Bay Borough report lower or similar access to health plans, medical care, and a personal doctor compared to Alaska overall, but higher medical costs. The Dillingham Census Area reports lower or similar access to medical care, access to a doctor, and medical cost, but reports higher access to health plans than seen in Alaska overall (McDowell et al. 2011a).

These health services findings are summarized on a more regional basis in Section 3.3, Needs and Welfare of the People—Socioeconomics. Healthcare services generally include small local clinics operated by regional providers. Access to the region and most of its communities is limited to small aircraft and boat.

Relatively up-to-date and complete information on baseline health services infrastructure and capacity is available for the eight Iliamna Lake/Lake Clark communities in the LPB, and the three Nushagak/Bristol Bay communities in the Dillingham Census Area, for the LPB, Dillingham Census Area, and Bristol Bay Borough (McDowell Group 2018b). All these communities, with the exception of Port Alsworth, have a health clinic served by 1 to 5 health aides.

Hospitalizations—Hospitals in the area serve a variety of adult and pediatric needs for the surrounding communities. In 2015, the statewide leading causes of diagnosed hospitalizations were pregnancy/childbirth, respiratory diseases, and digestive system diseases (ANTHC 2016d). The following summarizes the leading causes of hospitalizations in 2016 (ADHSS 2017c) and 2017 (McDowell Group 2018b):

- Statewide: Pregnancy/childbirth, newborn/neonate conditions, and musculoskeletal/ connective tissue diseases in 2016. Childbirth, septicemia (except in labor), and osteoarthritis in 2017.
- Southwest Region (includes the LPB, the Dillingham Census Area, and Bristol Bay Borough): Pregnancy/childbirth, newborn/neonate conditions, and respiratory diseases in 2016.
  - LPB: Childbirth and other complications of birth, including postpartum care of mother in 2017.
  - Dillingham Census Area: Childbirth, septicemia (except in labor), pneumonia (except that caused by tuberculosis or sexually transmitted diseases), and alcohol-related disorders in 2017.
  - Bristol Bay Borough: Childbirth and alcohol-related disorders in 2017.
- Gulf Coast Region (includes Kenai Peninsula): Musculoskeletal/connective tissue diseases/disorders, pregnancy/childbirth, and newborn/neonate conditions in 2016.
- Anchorage: Pregnancy/childbirth, newborn/neonate conditions, and musculoskeletal/ connective tissue diseases/disorders in 2016.

Although there are some variations in the top three leading causes of hospitalizations by year and region, pregnancy/childbirth and newborn/neonate and/or complications of pregnancy and childbirth or newborn/neonate conditions are consistently the leading causes.

Adequacy of Health Services—Areas may be designated as having health impact issues for the adequacy of health services, designated as a Health Professional Shortage Area (HPSA) and/or a Medically Underserved Area/Population (MUA/P). HPSA designation may be due to a shortage of primary medical care, dental, or mental health providers; while MUA/P designation may include groups of persons who face economic, cultural, or linguistic barriers to healthcare (HRSA 2018). The LPB (with the eight communities closest to the project), the Dillingham Census Area (with the three other communities geographically close to the project), Bristol Bay Borough, Kenai Peninsula, and Anchorage are all designated as MUA/P (Dillingham Census Area and Kenai Peninsula Borough are designated MUA/P—governor's exception). Table K3.10-6 presents the HPSA ratings (out of 26) for these regions. The rating is used to establish the communities with the greater needs per shortage area, indicated by those communities with higher HPSA ratings.

It should be noted that these designations are most directly comparable when the populations are similar; otherwise, a relatively low population area such as the LPB may appear to have less "need" than a densely populated area, when the difference may be more due to the population disparity than the actual "need." Furthermore, comparing a community to a larger region or state would not be meaningful because the region or state value represents a sum total that includes the communities.

Table K3.10-6: Health Professional Shortage Area Ratings

Shortage Area	Lake and Peninsula Borough	Bristol Bay Borough	Dillingham Cenus Area	Kenai Peninsula Borough	Anchorage Borough
Primary Care	--	15 to 17	13 to 17	8 to 18	3 to 21
Dental Care	16	0 to 16	16 to 20	6 to 23	6 to 20
Mental Health	14	14 to 16	14 to 20	15 to 21	6 to 20

Note:
-- = Not listed.
Source: HRSA 2018

Public Safety Services—Up-to-date information on baseline public safety services infrastructure is available for the eight Iliamna Lake/Lake Clark communities in the LPB and the three Nushagak/Bristol Bay communities in the Dillingham Census Area (McDowell 2018a). Table K3.10-7 summarizes the number of village public safety officers (VPSOs), village police officers (VPO), ambulances, and fire trucks, as well as the number of emergency medical technicians (EMTs) and emergency trauma technicians (ETTs) serving these communities in 2018. Overall, these communities have lower access to safety services than larger nearby communities, such as the city of Dillingham, which has a police department and a hospital (McDowell 2018a, b), and Anchorage. Communities without a VPSO or VPO rely on Alaska State Trooper coverage.

Table K3.10-7: Safety Services

Public Safety Infra-structure	Port Alsworth	Newhalen	Kokhanok	Nondalton	Iliamna	Levelock	Igiugig	Pedro Bay	New Stuyahok	Koliganek	Ekwok
VPSO	0	0	0	0	0	0	0	0	1	1	0
VPO	--	--	--	--	--	--	--	--	1	--	--
Ambulances	0	1	0	1	1	0	1	1	1	0	0
Fire Trucks	0	1	0	1	1	1	1	0	0	0	0
EMT	0	3	--	5	3	0	0	1	1	4	0
ETT	--	--	10	--	--	--	--	--	--	--	--

Notes:
-- = Not Available
VPSO = Village public safety officer
VPO = Village police officer
EMT = Emergency medical technician
ETT = Emergency trauma technician
Communities without a VPSO or VPO rely on Alaska State Trooper coverage
Larger nearby communities have a more robust safety infrastructures, such as Dillingham City, which has a police department
Source: McDowell 2018a

K3.12 TRANSPORTATION AND NAVIGATION

K3.12.1 Existing Flight Paths and Shipping Routes

General flight paths from Anchorage to Bristol Bay and Alaska Peninsula communities are over Iliamna, or the project area if there is inclement weather over Iliamna Lake (FAA 2018; Ravn 2018). Table K3.12-1 lists the existing flightpaths of low altitude flights (up to, but not including, 18,000 feet above mean sea level) in the Environmental Impact Statement (EIS) analysis area. Figure K3.12-1 shows flight paths in the vicinity of Iliamna Lake.

The project would use existing shipping routes to transport supplies to and concentrate from the project area. Figure K3.12-2 shows the project barging routes, which are based on existing routes used for transpacific commercial shipping and traffic to Alaska. An alternative inland barge route that is used under adverse conditions is also included (PLP 2020-RFI-163).

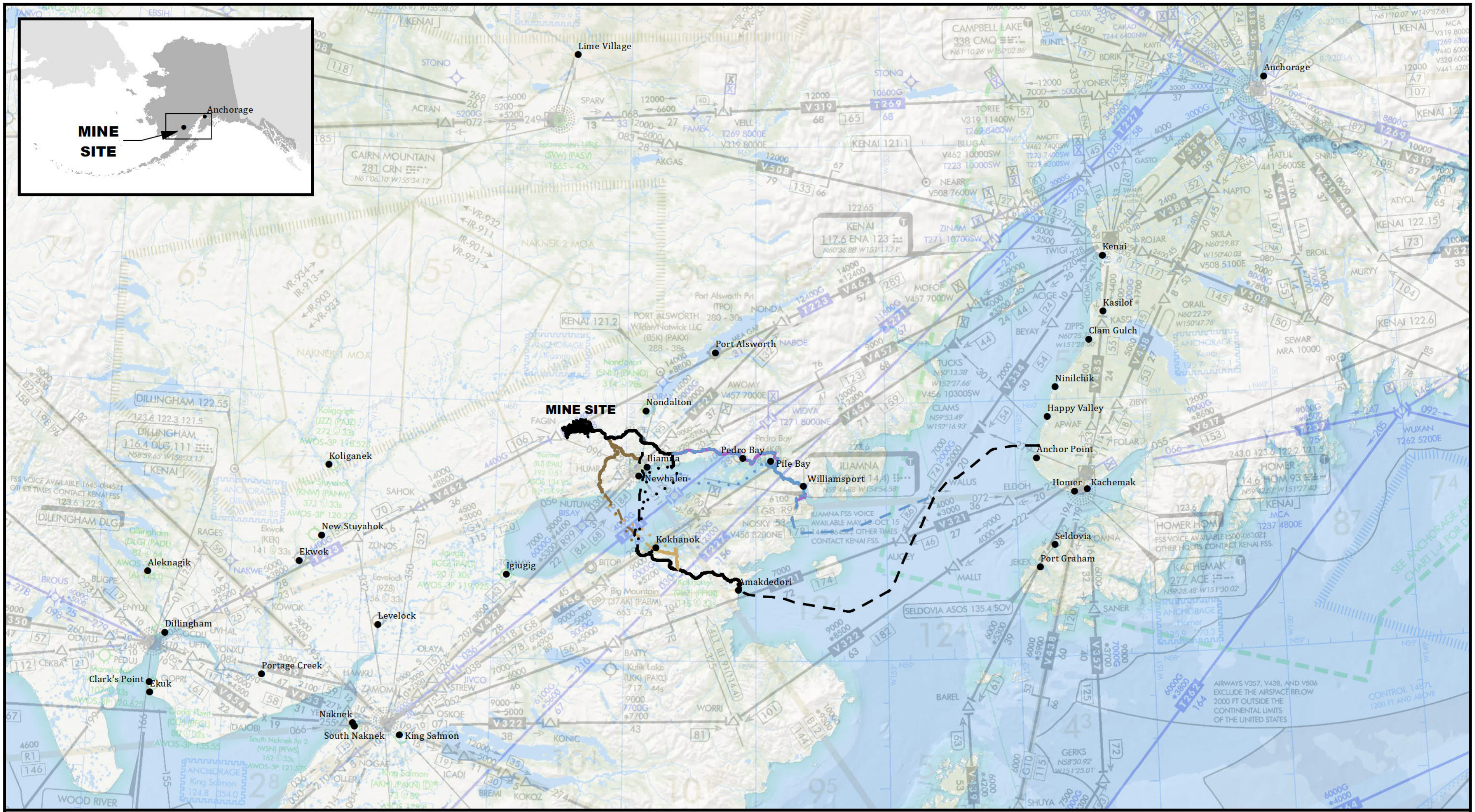
Table K3.12-1: Flight Paths near Iliamna Lake

Flightpath ID	Type	Elevation[1]	Endpoint 1	Endpoint 2	Endpoint 3	Path Over	Route Notes
V462	Victor Airways	14,000	Anchorage	Dillingham	--	Mine site, Port Alsworth, Lake Clark, potentially Lake Clark Pass, Cook Inlet	Route matches path of T223
T223	Low-Altitude RNAV only route	4,400G - 12,400G	Anchorage	Dillingham	--	Mine site, Port Alsworth, Lake Clark, potentially Lake Clark Pass, Cook Inlet	Route matches path of V462
V427	Victor Airways	3,000 – 14,000	Anchorage	Iliamna	King Salmon	Iliamna Lake, near the north ferry terminal, Iliamna, Newhalen, Lake Clark National Park, connects to V462 just south of Lake Clark	Connects with V462/T223 route east of Lake Clark to Anchorage
	Victor Airways	6,000G - 9,000G	Anchorage	Iliamna	King Salmon	Iliamna Lake, near north ferry terminal, Iliamna, Newhalen, Lake Clark National Park, Connects to V462 just south of Lake Clark	Connects with V462/T223 route east of Lake Clark to Anchorage—appears to be the low-version of the same route—no name found
V456	Victor Airways	13,000	Anchorage	Kenai	King Salmon	Kokhanok, south ferry terminal, Iliamna Lake, Pile Bay, north access road, Lake Clark National Park (SE), Cook Inlet	South side of Iliamna Lake
V457	Victor Airways	9,000	Kenai	Iliamna	--	Iliamna, North Road, Lake Clark National Park (SE), Cook Inlet	--
V321	Victor Airways	4,000 – 7,000	Homer	King Salmon	--	Just south of Amakdedori port, Cook Inlet	South of Iliamna Lake, over Amakdedori port
T271	Low-Altitude RNAV only route	4,000G – 11,800G	Anchorage	King Salmon	--	Iliamna Lake, north access road, between ferry terminals for Alt 1 and Alt 2, Lake Clark National Park (SE), Cook Inlet	--
T227	Low-Altitude RNAV only route	3,400G – 13,000G	Big Lake	Port Heiden	--	Alt 2 port access road, north access road, Lake Clark National Park (SE), Cook Inlet	South and east of Iliamna Lake, west of Amakdedori
G4	LF/MF Airway	4,500	Dillingham	Iliamna	--	North access road, Iliamna	--

Table K3.12-1: Flight Paths near Iliamna Lake

Flightpath ID	Type	Elevation[1]	Endpoint 1	Endpoint 2	Endpoint 3	Path Over	Route Notes
R99	LF/MF Airway	5,000	King Salmon	Iliamna	--	Iliamna Lake, north ferry terminal, Iliamna	Along V427 Route
G8	LF/MF Airway	6,000	King Salmon	Homer	--	South ferry terminal, Kokhanok, Iliamna Lake (SE small section)	--
G8 R99	LF/MF Airway	6,100	Iliamna	Homer	--	Alt 2 and Alt 3 natural gas pipeline, Iliamna Bay, Cook Inlet (over pipeline routes)	--
B12	LF/MF Airway	10,000	Iliamna	Kodiak	--	Iliamna, Iliamna Lake, Kokhanok east ferry terminal, south access road, South Kamishak Bay on Cook Inlet	--

Notes:
[1] Elevation is given in feet above mean sea level
Alt = alternative
LF/MF = Airways based on Low-Frequency / Medium-Frequency radio frequencies
RNAV = Area Navigation—a type of route and navigation method
SE = Southeast
Source: FAA 2018



Sources: PLP 2020-RFI168; PLP 2019-RFI153;
FAA IFR Low Altitude Chart Dec 2019

US Army Corps of Engineers®

20 0 20 40

Miles

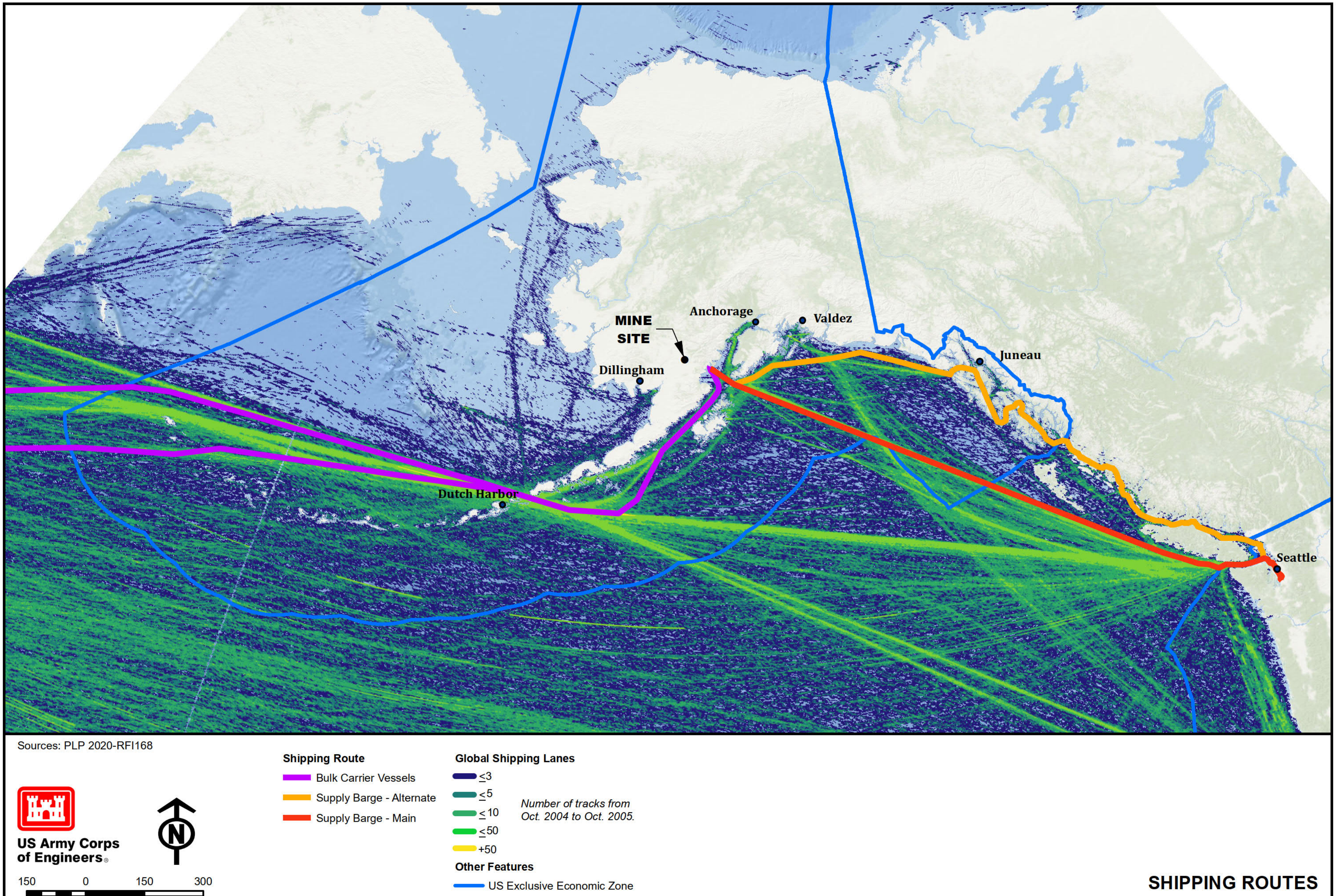
Action Alternatives

- ···· 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

FLIGHT PATHS

PEBBLE PROJECT EIS

FIGURE K3.12-1



Sources: PLP 2020-RFI168

SHIPPING ROUTES

PEBBLE PROJECT EIS

FIGURE K3.12-2

K3.13 GEOLOGY

This appendix contains supplemental information on the affected environment for the following topic(s) related to:

- Geology-related field and desktop studies
- Paleontological resources.

K3.13.1 Geology-Related Field and Desktop Studies

The geology-related findings presented in Section 3.13 and Section 4.13, Geology, were based on the review of field and desktop studies completed for the project area, including the following:

- Relevant existing literature and studies completed by the Applicant and others, including published geological reports and maps prepared by the US Geological Survey (USGS), Alaska Division of Geological and Geophysical Surveys and others (Knight Piésold 2011a, d; Detterman and Reed 1973, 1980; Hamilton and Klieforth 2010; Nokleberg et al. 1994; Plafker et al. 1994; Wilson et al. 2012)
- Evaluation and interpretation of aerial photographs taken from aircraft, which can provide a good understanding of the surficial geological conditions (Knight Piésold 2011a, d)
- Field reconnaissance studies, including helicopter and on-the-ground geologic mapping to verify the aerial photograph-related findings (Knight Piésold 2011a, d)
- Offshore drill holes and bathymetry (i.e., depth of water) surveys to support the ferry transportation corridors and natural gas pipeline alternative-related studies (Knight Piésold 2011a, d; GeoEngineers 2018a)
- In the mine site vicinity:
    - More than 700 drill holes were completed in the mine study area using helicopter-portable drilling equipment (see Section 3.15, Geohazards and Seismic Conditions, Figure 3.15-4). About 500 of the drill holes were completed to understand the mineralogy, and the remaining drill holes supported civil engineering-related studies. Rock and soil samples were collected for detailed evaluation during and after the field work (Knight Piésold 2011a, d; PLP 2019-RFI 014b).
    - Excavation of more than 300 test pits in the mine study area, ranging in depth from about 1.5 to 3 meters, was completed by a helicopter-portable excavation apparatus (Knight Piésold 2011a, d).
    - Ground-based (versus aircraft) geophysical surveys were completed with helicopter- and boat-portable instruments in the mine study and project area to understand the physical characteristics of the mineralized bedrock and near-shore sediments. These studies were non-invasive (i.e., did not include drilling or excavations), and relied on electronic sensors to map the geology. The geophysical studies included seismic reflection, infrared imagery, and induced polarization (Knight Piésold 2011a, d).

K3.13.2 Paleontological Resources

K3.13.2.1 Alternative 1a

Mine Site

Cretaceous Kahiltna flysch sedimentary units are largely derived from eroded volcanic rocks and are not likely to contain fossils. Other volcanic and intrusive igneous rocks in the mine site area are not suitable lithologies for fossil formation and preservation. Quaternary glacial sediments at the mine site are unlikely to host fossils; without measurable permafrost, significant findings of frozen Pleistocene megafauna are not likely (Blodgett and Zhang 2018; Arctos 2018).

Transportation Corridor

As with the mine site, the intrusive igneous and volcanic bedrock that spans most of the transportation corridor is not an amenable lithology for fossil formation and preservation. Pleistocene glacial sediments along the transportation corridor are unlikely to host fossils; without the preserving effects of measurable permafrost, significant findings of Pleistocene megafauna are not likely (Blodgett and Zhang 2018; Arctos 2018).

There are known paleontological resource sites at the southern terminus of the transportation corridor where the road meets the port. Quaternary beach deposits present in the area are locally fossiliferous, originating from erosion of nearby Jurassic marine sedimentary rock (see Amakdedori port section below); therefore, fossils are likely present in that area (Detterman and Reed 1973). About 20 acres of the transportation corridor footprint is on Quaternary beach deposits that could contain significant fossil resources. Additionally, the transportation corridor comes within 800 feet of the Talkeetna and Naknek Formations, which have produced significant vertebrate paleontological resources (Wilson et al. 2012).

Amakdedori Port

Jurassic marine sedimentary rocks around the port site are host to numerous diverse marine invertebrate fossils. Fossil ammonites, brachiopods, cephalopods, and pelecypods are abundant in the Naknek and Talkeetna formations' members exposed in the bluff directly northeast of the port facility (Blodgett and Zhang 2018; Detterman and Reed 1973, 1980; Wilson et al. 2012). Cephalopod fossils eroded from nearby Jurassic sedimentary rock have been found in the same beach deposits in the port facility footprint (Arctos 2018). Although these are common fossils, they are considered significant as sources of new data concerning Jurassic evolutionary trends, species survival beyond Triassic extinctions, and the global and regional development of Jurassic marine biological communities (Sandy and Blodgett 2000). The Naknek Formation at other sites in the region contains vertebrate fossils from the Jurassic marine reptile *Megalneusaurus*, which represents the only find of this species in Alaska, and one of only two occurrences of this genus in North America (Blodgett et al. 1995; Weems and Blodgett 1996). Terrestrial vertebrate trackways have also been discovered in the Naknek Formation at other locales in the region (Blodgett et al. 1995). These findings demonstrate a potential for paleontological resources in the Amakdedori port footprint.

Natural Gas Pipeline Corridor

The paleontological environment of the natural gas pipeline corridor is the same as that discussed above for the transportation corridor. The pipeline-only segment just east of Newhalen on the northern side of Iliamna Lake, then north to the southern crossing of the Newhalen River, would be on Tertiary volcanic and intrusive igneous rocks with interspersed segments, including Quaternary glacial sediments (Wilson et al. 2015). Quaternary sediments along both sides of Cook Inlet are unlikely to contain fossils; without the preserving effect of measurable permafrost, significant findings of Pleistocene megafauna are not likely (Blodgett and Zhang 2018; Arctos 2018). In the offshore section of corridor, the shallow floor of Cook Inlet is filled with abundant sand, pebbles, cobbles, and boulders flushed into the inlet from young glacial deposits across the region; no fossil resources would be expected.

K3.13.2.2 Alternative 1

Mine Site

Paleontological resources at the mine site would be the same as described for Alternative 1a.

Transportation Corridor

Paleontological resources along the transportation corridor would be the same as described for Alternative 1a.

Amakdedori Port

Paleontological resources for the port site under Alternative 1 are the same as described for Alternative 1a.

Natural Gas Pipeline Corridor

Paleontological resources for the pipeline corridor would be the same as described for Alternative 1a.

Alternative 1—Summer-Only Ferry Operations Variant

The Summer-Only Ferry Operations Variant does not affect paleontological resources; therefore, paleontological resources for this variant are not described.

Alternative 1—Kokhanok East Ferry Terminal Variant

The paleontological environment for this variant is considered to be comparable to Alternative 1a based on the presence of similar substrate conditions; however, Jurassic, Triassic, and possibly older complex assemblages of metamorphosed volcanic and sedimentary rock associated with the Kokhanok Complex coincide with the Kokhanok East Ferry Terminal Variant footprint. Based on the reported mix of lithologies of variable metamorphic grade, the presence or preservation of fossils in this discrete lithologic occurrence at the Kokhanok port site are considered low to unlikely.

Alternative 1—Pile-Supported Dock Variant

The paleontological environment for this variant would be the same as described for Alternative 1a.

K3.13.2.3 Alternative 2—North Road and Ferry with Downstream Dam and Alternative 3—North Road Only

The Diamond Point port footprint, under either alternative port location, would be on volcanic and intrusive igneous bedrock. The north access road and/or pipeline segments of Alternative 2 (including the access road to the Eagle Bay ferry terminal and the Newhalen River North Crossing Variant) and Alternative 3 (including the Concentrate Pipeline Variant) are contiguously mapped as volcanic and intrusive igneous bedrock with interspersed segments, including Quaternary glacial sediments (Wilson et al. 2015). Igneous substrates are not considered amenable for fossil formation and preservation; the interspersed Quaternary glacial sediments are not considered likely to host fossils.

K3.14 SOILS

This appendix contains additional technical information on the following topics related to baseline soil conditions provided in Section 3.14, Soils:

- Technical classification of soils in the project footprint
- Permafrost occurrence in the project footprint
- Baseline soil chemistry

K3.14.1 Project Footprint Soil Classification

Available literature directly associated with the mine site and transportation corridor components is limited to the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) (formerly known as the Soil Conservation Service) 2016 Soil Survey Geographic Database (SSURGO) for the Bristol Bay-Northern Alaska Peninsula, North and Bordering Areas (NRCS 2019), and the Exploratory Soil Survey of Alaska (ESS) (Rieger et al. 1979).

Some soils information provided in the ESS does not translate directly to current 2006 classification system standards, *Keys to Soil Taxonomy, 10th edition* (USDA 2006), but comparative equivalent soil-type estimates can be made. Two additional soil orders that occur in the project area (i.e., Andisols and Gelisols) have been added to the ESS since 1979. Where applicable, soil descriptions from the ESS have been translated to current 2006 classification system equivalents (Three Parameters Plus 2011a). Corresponding equivalents are based on available ESS descriptions and extrapolations from other nearby studies for the village of Nondalton and Chisik Island (Table K3.14-1).

Table K3.14-1: Corresponding ESS and 2006 Classifications for Applicable Soils

ESS Map Units	1979 Classification	2006 Classification
HY4, SO11, IA7	Pergelic cryofibrists	Typic fibristels
SO11	Humic cryothods	Typic humicryods
IA7, IA9	Typic cryandepts	Typic haplocryands Typic vitricryands

Notes:
ESS = Exploratory Soil Survey of Alaska
Source: Three Parameters Plus 2011a, Table 5-2

K3.14.1.1 Mine Site Soil Types

Soil descriptions obtained from SSURGO include the entire mine site footprint, and to a lesser extent, portions of the transportation corridor and pipeline in proximity to the mine site. Soil descriptions for all other portions of the project footprint are limited to the ESS. All the soil types in the project footprint are not likely addressed in the ESS, because the ESS is limited to a general soils map and does not provide site-specific interpretations. Although not a direct comparison to NRCS soil descriptions, available project soil classification information acquired from shallow sampling activities (18-inch depth) have been incorporated (where available). Soil map units and acreages associated with the mine site based on information obtained using SSURGO are listed below. Additional soil characteristics for each soil map unit and major components are provided in Table K3.14-2.

Table K3.14-2: Mine Site Soil Types and Characteristics

Soil Map Unit and Major Components	Parent Material Description	Taxonomy	Landscape Position	Slope Range (%)	Natural Drainage Class	Runoff Class	Erosion Water (Kw Factor)	Erosion Wind (WEG)	Flooding	Ponding	Frost Action
D36MTG—Western Maritime Mountains											
Dwarf scrub residual slopes and similar soils	Herbaceous organic material over gravelly cryoturbate, over weathered igneous and sedimentary rock	Loamy-skeletal, isotic Typic Dystrocryepts	Mountains, hills (upper third)	1 to 50	Well Drained	High	0.37 to 0.10	5	None	None	Moderate
Scrub gravelly colluvial slopes and similar soils	Herbaceous organic material over gravelly slope alluvium, over gravelly colluvium and/or gravelly till	Loamy-skeletal, isotic Typic Humicryepts	Hills, plains	0 to 38	Well Drained	High	0.20 to 0.05	3	None	None	Moderate
Sedge organic mountains and similar soils	Mossy organic material over gravelly slope alluvium	Loamy, isotic, euic Terric Cryosaprists	Depressions on mountains	4 to 7	Very Poorly Drained	Very High	0.02 to 0.37	8	None	Occasional	High
D36HIL—Western Maritime Glaciated Hills and Plains											
Dwarf scrub loamy eolian slopes	Organic material over coarse-loamy eolian deposits	Coarse-loamy, isotic Typic Haplocryods	Plains, hills	1 to 5	Well Drained	High	0.43 to 0.64	5	None	None	Moderate
Low scrub loamy eolian slopes	Mossy organic material over coarse-loamy cryoturbate, over coarse-loamy eolian deposits	Coarse-loamy, isotic Typic Dystrocryepts	Hills, plains	0 to 13	Moderately Well Drained	Medium	0.43 to 0.64	7	None	None	Moderate
Scrub loamy eolian slopes	Herbaceous organic material over coarse-loamy eolian deposits	Coarse-silty, isotic Typic Haplocryods	Hills, plains	0 to 42	Well Drained	High	0.49 to 0.64	7	None	None	High
D36HIJ—Western Maritime Eolian Plains Sloping											
Dwarf scrub loamy eolian slopes	Organic material over coarse-loamy eolian material	Coarse-loamy, isotic Typic Dystrocryepts	Hills, plains	1 to 10	Well Drained	High	0.43 to 0.64	5	None	None	Moderate
Sedge organic depressions	Mossy organic material over organic material, over coarse-loamy eolian deposits	Loamy, isotic, euic Terric Cryosaprists	Plains	0 to 7	Very Poorly Drained	Negligible	0.02 to 0.64	8	None	Frequent	High

Notes:

Drainage Class: Classes of natural soil drainage that range from excessively drained, somewhat excessive drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained.

Runoff Class: The loss of water from an area by flow over the land surface assuming soil surfaces are bare. Classes range from negligible, very low, low, medium, high, and very high.

Frost Action: The likelihood of upward or lateral expansion of the soil caused by frost heave processes. Clayey soils with a high water table are most susceptible, whereas well-drained coarse soil textures are least susceptible.

Kw Factor: Erosion factor of the whole soil for the surface mineral horizon that indicates the susceptibility of the soil to sheet and rill erosion by water. Values range from 0.02 to 0.69. Higher values correspond to soils more susceptible to sheet and rill erosion by water.

WEG (Wind Erodibility Group): Susceptibility of soil to wind erosion. Values range from 1 (most susceptible) to 8 (least susceptible).

Source: NRCS 2019

- D36MTG Western Maritime Mountains—5,796 acres (approximately 69 percent): Typical soil profile characteristics for soils at greater elevations (upper third of elevation range) on mountains and hills (slopes 0 to 50 percent) consist of 0 to 2 inches of decomposed plant material and organic silt loam over gravelly silt loam mixtures that are underlain by extremely stony loam mixtures and lithic bedrock (25 to 67 inches). Typical soil profile characteristics for soils associated with hill/plains (slopes 0 to 38 percent) consist of 0 to 2 inches of decomposed plant material over gravelly silt loam of gravelly and very gravelly silt loam mixtures. Typical soil profile characteristics for soils associated with depressions on mountains (slopes 4 to 7 percent) consist of 0 to 10 inches of mucky peat over muck and gravelly silt loam.
- D36HIL Western Maritime Glaciated Hills and Plains—2,092 acres (approximately 25 percent): Typical soil profile characteristics for soils associated with hills/plains (slopes 0 to 13 percent) consist of 0 to 4 inches of moderately decomposed plant material and highly organic silt over medial highly organic silt loam, over silt loam and sandy silt loam mixtures. Typical soil profile characteristics for soils associated with plains/hills (slopes 1 to 5 percent) consist of 0 to 5 inches of moderately decomposed plant matter and highly organic silt loam over very fine sandy loam and stratified silt loam mixtures. Typical soil profile characteristics for soils associated with hills/plains (slopes 0 to 42 percent) consist of 0 to 6 inches of slightly decomposed plant material and highly organic silt loam over medial highly organic silt loam and very fine sandy loam, over very fine sandy loam mixtures.
- D36HIJ Western Maritime Eolian Plains, Sloping—503 acres (approximately 6 percent): Typical soil profile characteristics for soils associated with hills/plains (slopes 1 to 10 percent) consist of 0 to 5 inches of moderately decomposed plant material and highly organic silt loam and very fine sandy loam mixtures. Typical soil profile characteristics for soils associated with plains (slopes 0 to 7 percent) consist of peat and mucky peat to 28 inches, underlain by very fine sandy loam.

K3.14.1.2 Transportation Corridor Soil Types

Available SSURGO soil descriptions for the transportation corridor are limited to those in proximity to the mine site area. Soil map units for these portions of the transportation corridor are the same as those described above for the mine site. Soil map units and corresponding acreages associated with these portions of transportation corridor for all alternatives are as follows:

- D36MTG Western Maritime Mountains—approximately 87 acres
- D36HIL Western Maritime Glaciated Hills and Plains—approximately 82 acres
- D36HIJ Western Maritime Eolian Plains, Sloping—approximately 9 acres

Soil descriptions for the remaining portions of the transportation corridor are limited to the ESS. The ESS recognizes four soil map units in the transportation corridor study area, which are described below with corresponding acreages.

- IA7 Typic Cryandept—344 acres (approximately 39 percent): Very gravelly, nearly level to rolling Peregelic Cryofibrists, nearly level association. Soils are also associated with rolling plains bordering Iliamna Lake and rolling ground moraines, terminal moraines, outwash plains, and paleo-beach ridges, small lakes, and muskegs. Typic Cryandepts are well-drained, acidic, and formed in shallow volcanic material over gravelly glacial material dominated by low-tundra vegetative species. Shallow permafrost can reportedly be associated with a Pergelic Cryofibrists component (where present) consisting of sedge peat muskegs and coarse acid moss.

- IA9 Typic Cryandepts—203 acres (approximately 23 percent): Very gravelly, hilly to steep association, and likely to exhibit variable characteristics similar to soil map unit D36MTG. Soils are well-drained, strongly acidic, and formed in volcanic material with a thin surface cover of decomposed plant matter mixed with volcanic ash. Common vegetation includes alder, grasses, or low shrubs.
- IA17 Dystric Lithic Cryandepts—328 acres (approximately 37 percent): Hilly to steep association. Soils are associated with low hills and ridges bordering mountainous areas. Well-drained loamy soils are formed in volcanic ash over shallow (20-inch) metamorphic bedrock or gravelly till and overlain with a thin layer of organic material.
- HY4 Pergelic Cryofibrists—13.5 acres (approximately 1 percent): Nearly level association. Soils are associated with nearly level, broad, wet lowlands near lakes and coastal margins. Organic-rich sedge and moss (e.g., muskeg) soils underlain by silt and sand mixtures are poorly drained, and can reportedly be associated with the presence of shallow permafrost. Vegetation includes water-tolerant sedges, low shrubs, and black spruce.

K3.14.1.3 Pipeline Corridor Soil Types

Soil types along the shared route for the transportation corridor are the same as those described above. This also includes the pipeline-only segment of Alternative 1a from Iliamna Lake near Newhalen to the mine access road. Two detailed soil map units are associated with the approximately 6 acres of pipeline infrastructure ground disturbance on the eastern side of Cook Inlet:

- Unit 640—Qutal silt loam, 0 to 4 percent slopes, 5.5 acres: Medial over loamy, amorphic over mixed, superactive Aquandic Haplocryods. Soils are associated with moraines on till plains and depressions on till plains dominated by a spruce-birch forest spruce-willow community. Soils consist of very gravelly sand overlain with silt loam and a thin interval of decomposed plant material. Soils are somewhat poorly drained with no flooding or ponding, with a slight hazard of erosion for water, but severe hazard of erosion by wind.
- Unit 568—Island silt loam, 0 to 4 percent slopes, 0.25 acre: Medial over loamy, amorphic over mixed, superactive Pachic Fulvicryands. Soils are associated with till plains dominated by shallow kettles. Soils consist of gravelly sandy loam overlain with silt loam and a thin interval of decomposed plant material. Soils are well drained with no flooding or ponding, with a slight hazard of erosion by water, but severe hazard of erosion by wind.

K3.14.1.4 Soil Types Unique to Alternatives

ESS soil types (i.e., principal component) that coincide with footprints associated with alternatives are described below.

- RM1 Rough Mountainous Land: Steep rocky slopes.
- SO1 Typic Cryorthods: Nearly level association. Soils are associated with low-rolling glacial moraines, broad terraces, and lake- and muskeg-filled depressions. Well-drained to very poorly drained soils formed in silty loess (20 to 40 inches) over gravelly glacial till to fibrous organic soils in depressions between moraines.
- SO11 Humic Cryorthods: Hilly to steep association. Soils are associated with foot slopes and moraines. Well-drained soils formed in silty volcanic ash (10 to 24 inches) over very gravelly glacial till, and overlain by partially decomposed organic matter.

K3.14.2 Permafrost Occurrence

Recent permafrost distribution estimates that coincide with project components on the western side of Cook Inlet are considered to be isolated occurrences (Jorgenson et al. 2008). Isolated permafrost varies from 0 to 10 percent of the landscape subsurface. No permafrost occurrence is anticipated to coincide with project infrastructure on the eastern side of Cook Inlet. Thermokarst landform features, which are the result of permafrost freeze and thaw processes, can be indicative of permafrost, or residual expressions of where permafrost no longer exists. Existing thermokarst landscape features and future areas susceptible to thermokarst processes in the project footprint are generally not present (Olefeldt et al. 2016). Frozen ground conditions have been observed in near-surface soils in a few test pits and soil borings, but conditions were indiscernible from active layer processes that annually freeze and thaw at depths of up to 10 feet. Ground temperature measurements at depth in the mine site study area (SLR et al. 2011a) reported a mean temperature of 39.1 degrees Fahrenheit. Groundwater temperature measurements from the deposit area were also above freezing throughout the year. Although such conditions do not preclude the occasional occurrences of permafrost, current conditions do not support increased permafrost development, and any remaining permafrost is considered to be a relic from past conditions. Where present, relic permafrost is likely limited to shaded areas and north-facing slopes; poorly drained shallow surface soils overlain with insulative organics; and deep, coarse-grained soils (Three Parameters Plus 2011a). Based on information provided in the ESS, principal components associated with Pergelic Cryofibrists (HY4) and Typic Cryandepts (IA7) soil types in the project footprint may coincide with relic permafrost occurrence in areas of very poorly drained organic soils (e.g., fibrous sedge and muskeg) of nearly level association that include depressions and valley bottoms.

K3.14.3 Baseline Soil Chemistry

Baseline shallow surface soil samples (less than 0.5 foot deep) were collected to determine the variability in naturally occurring constituents at the mine site and along limited segments of transportation corridor alternatives. Lists of naturally occurring compounds (i.e., analytes) evaluated as part of the mine site surface soil studies are presented in Table K3.14-3 and Table K3.14-4, and transportation corridor surface soil studies are presented in Table K3.14-5 and Table K3.14-6. Results associated with each are discussed separately below.

K3.14.3.1 Mine Site

A total of 237 surface soil samples were collected from 117 locations in the mine site study area (SLR et al. 2011a). These samples were analyzed for trace elements, cyanide, and sodium at 237 surface soil locations; anions and cations at 235 surface sample locations; petroleum hydrocarbons as diesel-range organics (DRO) and residual range organics (RRO), respectively, at 23 surface soil locations; and total organic carbon (TOC) at 53 surface sample locations. The sample locations were considered representative of undisturbed baseline conditions.

Table K3.14-3: Mine Site Study Area Surface Soil Trace Elements and Cations

Analyte	Frequency of Detection[a]	Percent Detected	Range of Detects (mg/kg) (Min-Max)	Range of Method Detection Limits (mg/kg) (Min-Max)	Range of Method Reporting Limits (mg/kg) (Min-Max)	Mean[b] (mg/kg)	Median[b] (mg/kg)	Standard Deviation[b]	Coefficient of Variation	Comparative Action Levels[c] (mg/kg)
Trace Elements										
Aluminum	237/237	100%	932 – 109,000	0.67 – 100	2.14 – 500	17,644	16,400	12,175	0.69	N/A
Antimony	211/237	89%	0.040 – 2.14	0.033 – 2.13	0.11 – 6.86	0.24	0.20	0.22	0.93	33
Arsenic	227/237	96%	1.03 – 73.8	0.30 – 21.3	0.50 – 68.6	10.2	8.07	10.1	0.99	7.2 (inorganic)
Barium	237/237	100%	14.8 – 576	0.050 – 10.0	0.30 – 50.0	84.9	65.5	67.1	0.79	17,000
Beryllium	224/237	95%	0.051 – 5.89	0.033 – 2.13	0.11 – 6.86	0.41	0.34	0.45	1.09	170
Bismuth	105/237	44%	0.073 – 1.05	0.066 – 20.0	0.21 – 100	1.30	0.13	4.26	3.27	N/A
Boron	65/237	27%	0.54 – 9.34	0.36 – 50.0	1.16 – 117	4.82	3.45	4.62	0.96	N/A
Cadmium	146/237	62%	0.072 – 3.06	0.050 – 4.26	0.21 – 13.7	0.24	0.16	0.32	1.33	76 (Diet)
Calcium	237/237	100%	222 – 31,100	10.0 – 645	31.9 – 2,060	2,577	1,700	2,993	1.16	N/A
Chromium	233/237	98%	1.15 – 113	0.050 – 8.24	0.30 – 27.5	17.7	14.7	14.5	0.82	1.0 x 10^5 (Cr^3) 3.9 (Cr^6)
Cobalt	232/237	98%	0.45 – 24.2	0.030 – 10.3	0.10 – 34.3	6.55	5.63	4.60	0.70	N/A
Copper	236/237	100%	2.65 – 197	0.19 – 12.4	0.64 – 41.2	27.4	16.3	35.2	1.28	3,300
Iron	237/237	100%	588 – 103,000	2.00 – 452	4.00 – 1,460	20,694	19,300	13,532	0.65	N/A
Lead	236/237	100%	0.66 – 78.4	0.050 – 4.26	0.21 – 13.7	8.74	7.54	8.85	1.01	400
Magnesium	237/237	100%	74.1 – 9,930	10.0 – 795	31.9 – 2,540	3,076	2,930	2,022	0.66	N/A
Manganese	237/237	100%	5.43 – 6,560	0.066 – 50.0	0.21 – 300	388	279	559	1.44	N/A
Mercury	224/237	95%	0.014 – 0.72	0.013 – 0.30	0.042 – 2.00	0.12	0.072	0.12	0.98	3.1 (elemental)
Molybdenum	179/237	76%	0.40 – 68.1	0.30 – 21.3	1.00 – 68.6	1.82	0.92	4.71	2.59	N/A
Nickel	235/237	99%	0.59 – 53.8	0.066 – 4.26	0.21 – 13.7	9.16	7.42	7.10	0.77	1,700 (soluble salts)
Potassium	224/237	95%	100 – 5,510	30.0 – 2,130	106 – 6,860	621	511	523	0.84	N/A

Table K3.14-3: Mine Site Study Area Surface Soil Trace Elements and Cations

Analyte	Frequency of Detection[a]	Percent Detected	Range of Detects (mg/kg) (Min-Max)	Range of Method Detection Limits (mg/kg) (Min-Max)	Range of Method Reporting Limits (mg/kg) (Min-Max)	Mean[b] (mg/kg)	Median[b] (mg/kg)	Standard Deviation[b]	Coefficient of Variation	Comparative Action Levels[c] (mg/kg)
Selenium	219/237	92%	0.18 – 79.3	0.050 – 10.3	0.30 – 34.3	2.76	1.10	7.34	2.66	410
Silver	117/237	49%	0.030 – 1.45	0.030 – 2.13	0.10 – 6.86	0.11	0.059	0.20	1.80	410
Thallium	179/237	76%	0.0099 – 5.00	0.0066 – 5.00	0.021 – 30.0	0.24	0.088	0.61	2.53	0.83 (soluble salts)
Tin	27/237	11%	1.06 – 2.90	0.33 – 21.3	1.06 – 100	1.94	0.96	2.99	1.54	N/A
Vanadium	210/237	89%	4.67 – 227	0.10 – 64.5	0.50 – 206	46.4	47.0	31.1	0.67	420
Zinc	235/237	99%	2.77 – 228	0.33 – 21.3	1.06 – 68.6	43.9	40.0	33.2	0.76	25,000
Anions and Cations[d]										
Ammonia (as nitrogen)	214/235	91%	0.50 – 2,200	0.50 – 120	3.00 – 382	363	179	440	1.21	N/A
Chloride	158/237	67%	0.40 – 28.3	0.30 – 30.0	0.98 – 100	2.74	1.50	3.73	1.36	N/A
Cyanide	199/237	84%	0.028 – 0.75	0.024 – 4.00	0.049 – 20.0	0.19	0.15	0.18	0.92	26 (CN^-)
Fluoride	54/235	23%	0.33 – 39.3	0.30 – 18.4	0.98 – 59.5	0.88	0.36	2.67	3.04	N/A
Sodium	215/237	91%	56.2 – 1,860	30.0 – 2,130	106 – 6,860	208	153	181	0.87	N/A
Sulfate	211/237	90%	0.41 – 1,820	0.30 – 30.0	0.98 – 100	19.8	4.26	122	6.19	N/A

Notes:

[a] Number of samples with detectable concentrations/total number of samples analyzed.
[b] When calculating the mean, median, and standard deviation, non-detect results were included as one-half the method detection limit. Non-detect results assigned a "U" or "UJ" qualifier were included as one-half the reporting limit.
[c] Where provided, comparative action level is based on Alaska Department of Environmental Conservation (ADEC) 18 Alaska Administrative Code (AAC) 75, Oil and Other Hazardous Substances Pollution Control, September 29, 2018, Table B1. Method Two – Soil Cleanup Levels, Human Health, Over 40 Inch Zone (ADEC 2017a).
[d] All data presented on a dry-weight basis.

mg/kg = milligram per kilogram
Max = maximum
Min = minimum
N/A = none available

Source: SLR et al. 2011a, Table 10.1-3

Table K3.14-4: Mine Site Study Area Surface Soil Diesel Range Organics and Residual Range Organics, and Total Organic Carbon

Analyte	Frequency of Detection[a]	Percent Detected	Range of Detects (mg/kg) (Min-Max)	Range of Method Detection Limits (mg/kg) (Min-Max)	Range of Method Reporting Limits (mg/kg) (Min-Max)	Mean[b] (mg/kg)	Median[b] (mg/kg)	Standard Deviation[b]	Coefficient of Variation	Comparative Action Levels[c]
DRO[d]	13/23	57%	11.7 – 1300	2.01 – 127	20.1 – 1,270	209	72.5	299	1.43	8,250
RRO[d]	23/23	100%	32.7 – 12,300	2.01 – 127	20.1 – 1,270	2,028	1,150	2,895	1.43	8,300
TOC[d,e]	53/53	100%	0.3% – 65.1%	0.00026% – 2.08%	0.0061% – 4.16%	6.51%	2.20%	12.6%	1.93	N/A

Notes:

[a] Number of samples with detectable concentrations/total number of samples analyzed.
[b] When calculating the mean, median, and standard deviation, non-detect results were included as one-half the method detection limit. Non-detect results assigned a “U” or “UJ” qualifier were included as one-half the method reporting limit.
[c] Where provided, comparative action level is based on ADEC 18 AAC 75, Oil and Other Hazardous Substances Pollution Control, September 29, 2018, Table B2. Method Two – Petroleum Hydrocarbon Soil Cleanup Levels, Ingestion, Over 40 Inch Zone (ADEC 2017a).
[d] All data presented on a dry-weight basis.
[e] For TOC, unit of measure is percentage rather than milligrams per kilogram (mg/kg).

DRO = diesel range organics
mg/kg = milligram per kilogram
Max = maximum
Min = minimum
N/A = none available
RRO = residual range organics
TOC = total organic carbon

Source: SLR et al. 2011a, Table 10.1-5.

Table K3.14-5: Transportation Corridor Surface Soil Trace Elements and Cations

Analyte	Frequency of Detection[a]	Percent Detected	Range of Detects (mg/kg) (Min-Max)	Range of Method Detection Limits (mg/kg) (Min-Max)	Range of Method Reporting Limits (mg/kg) (Min-Max)	Mean[b] (mg/kg)	Median[b] (mg/kg)	Standard Deviation[b]	Coefficient of Variation	Comparative Action Levels[c] (mg/kg)
Trace Elements										
Aluminum	17/17	100%	1,350 – 24,300	0.62 – 56.4	1.99 – 182	8281	6,840	6,360	0.77	N/A
Antimony	6/17	35%	0.055 – 1.29	0.031 – 0.28	0.10 – 0.91	0.14	0.055	0.30	2.17	33
Arsenic	8/17	47%	1.47 – 50.1	0.57 – 3.72	1.79 – 11.8	4.40	1.47	11.8	2.69	7.2 (inorganic)
Barium	17/17	100%	8.36 – 53.7	0.094 – 0.61	0.30 – 1.96	29.2	24.7	14.8	0.51	17,000
Beryllium	10/17	59%	0.070 – 0.26	0.031 – 0.20	0.10 – 0.65	0.11	0.10	0.073	0.66	170
Bismuth	0/17	0%	N/A – N/A	0.062 – 0.41	0.20 – 1.31	N/A	N/A	N/A	N/A	N/A
Boron	1/17	6%	7.95 – 7.95	3.09 – 20.3	9.97 – 65.3	4.13	3.82	2.22	0.54	N/A
Cadmium	7/17	41%	0.076 – 0.59	0.062 – 0.41	0.20 – 1.31	0.14	0.10	0.13	0.95	76 (Diet)
Calcium	7/17	100%	469 – 8130	9.37 – 123	29.9 – 394	2,491	1,860	1,983	0.80	N/A
Chromium	17/17	100%	0.93 – 21.4	0.12 – 0.78	0.40 – 2.61	5.25	3.84	4.84	0.92	1.0 x 10^5 (Cr^3) 3.9 (Cr^6)
Cobalt	16/17	94%	0.63 – 6.56	0.15 – 0.98	0.50 – 3.27	1.92	1.41	1.54	0.80	N/A
Copper	17/17	100%	2.06 – 18.2	0.18 – 1.18	0.60 – 3.92	7.84	7.37	3.80	0.48	3,300
Iron	17/17	100%	1,830 – 23,200	4.41 – 282	14.2 – 909	8,986	6,370	6,947	0.77	N/A
Lead	17/17	100%	0.72 – 6.30	0.062 – 0.41	0.20 – 1.31	2.15	1.62	1.39	0.65	400
Magnesium	17/17	100%	117 – 3,960	9.37 – 123	29.9 – 394	977	497	1,114	1.14	N/A
Manganese	17/17	100%	13.8 – 382	0.062 – 0.81	0.20 – 2.63	88.7	52.8	98.1	1.11	N/A
Mercury	15/17	88%	0.034 – 0.19	0.012 – 0.081	0.041 – 0.27	0.081	0.087	0.047	0.57	3.1 (elemental)
Molybdenum	4/17	24%	0.58 – 2.03	0.31 – 2.03	1.00 – 6.53	0.58	0.40	0.50	0.86	N/A
Nickel	16/17	94%	0.46 – 9.79	0.062 – 0.41	0.20 – 1.31	2.44	1.86	2.28	0.93	1,700 (soluble salts)
Potassium	14/17	82%	114 – 734	30.9 – 407	99.7 – 1310	238	204	156	0.66	N/A
Selenium	15/17	88%	0.19 – 2.06	0.15 – 0.98	0.50 – 3.27	0.63	0.54	0.47	0.75	410
Silver	1/17	6%	0.14 – 0.14	0.031 – 0.20	0.10 – 0.65	0.060	0.050	0.038	0.64	410

Table K3.14-5: Transportation Corridor Surface Soil Trace Elements and Cations

Analyte	Frequency of Detection[a]	Percent Detected	Range of Detects (mg/kg) (Min-Max)	Range of Method Detection Limits (mg/kg) (Min-Max)	Range of Method Reporting Limits (mg/kg) (Min-Max)	Mean[b] (mg/kg)	Median[b] (mg/kg)	Standard Deviation[b]	Coefficient of Variation	Comparative Action Levels[c] (mg/kg)
Thallium	1/17	6%	0.081 – 0.081	0.0062 – 0.041	0.020 – 0.13	0.012	0.0077	0.018	1.50	0.83 (soluble salts)
Tin	1/17	6%	2.83 – 2.83	0.31 – 2.03	1.00 – 6.53	1.32	1.04	0.75	0.57	N/A
Vanadium	17/17	100%	7.05 – 60.7	0.94 – 8.54	2.99 – 27.3	28.0	24.1	17.2	0.61	420
Zinc	17/17	100%	5.85 – 39.9	0.31 – 2.03	1.00 – 6.53	18.3	15.0	10.9	0.59	25,000
Anions and Cations[d]										
Ammonia (as nitrogen)	17/17	100%	5.62 – 1,030	2.30 – 40.1	7.30 – 127	411	349	261	0.63	N/A
Chloride	13/17	76%	0.44 – 9.69	0.31 – 1.96	1.00 – 6.33	2.20	1.63	2.48	1.13	N/A
Cyanide	14/17	82%	0.049 – 0.21	0.024 – 0.13	0.049 – 0.27	0.11	0.11	0.064	0.58	26 (CN^-)
Fluoride	4/17	24%	0.31 – 1.37	0.31 – 1.96	1.00 – 6.33	0.52	0.38	0.35	0.68	N/A
Sodium	16/17	94%	124 – 508	30.9 – 407	99.7 – 1310	297	304	105	0.35	N/A
Sulfate	16/17	94%	1.08 – 341	0.31 – 1.96	1.00 – 6.33	26.0	4.10	81.7	3.14	N/A

Notes:

[a] Number of samples with detectable concentrations/total number of samples analyzed.
[b] When calculating the mean, median, and standard deviation, non-detect results were included as one-half the method detection limit. Non-detect results assigned a “U” or “UJ” qualifier were included as one-half the reporting limit.
[c] Where provided, comparative action level is based on ADEC 18 AAC 75, Oil and Other Hazardous Substances Pollution Control, September 29, 2018, Table B1. Method Two – Soil Cleanup Levels, Human Health, Over 40 Inch Zone (ADEC 2017a).
[d] All data presented on a dry-weight basis.

mg/kg = milligram per kilogram
Max = maximum
Min = minimum
N/A = none available

Source: SLR et al. 2011a, Table 10.4-2

Table K3.14-6: Transportation Corridor Surface Soil Diesel Range Organics and Residual Range Organics, and Total Organic Carbon

Analyte	Frequency of Detection[a]	Percent Detected	Range of Detects (mg/kg) (Min-Max)	Range of Method Detection Limits (mg/kg) (Min-Max)	Range of Method Reporting Limits (mg/kg) (Min-Max)	Mean[b] (mg/kg)	Median[b] (mg/kg)	Standard Deviation[b]	Coefficient of Variation	Comparative Action Levels[c]
DRO[d]	1/1	100%	1,520	58.6	586	1,520	1,520	N/A	N/A	8,250
RRO[d]	1/1	100%	9,220	58.6	586	9,220	9,220	N/A	N/A	8,300
TOC[d,e]	17/17	100%	0.13% – 45.7%	0.026% – 1.74%	0.052% – 3.48%	18.2%	15.1%	12.4%	0.68	N/A

Notes:

[a] Number of samples with detectable concentrations/total number of samples analyzed.
[b] When calculating the mean, median, and standard deviation, non-detect results were included as one-half the method detection limit. Non-detect results assigned a "U" or "UJ" qualifier were included as one-half the method reporting limit.
[c] Where provided, comparative action level is based on ADEC 18 AAC 75, Oil and Other Hazardous Substances Pollution Control, September 29, 2018, Table B2. Method Two – Petroleum Hydrocarbon Soil Cleanup Levels, Ingestion, Over 40 Inch Zone (ADEC 2017a).
[d] All data presented on a dry-weight basis.
[e] For TOC, unit of measure is percentage rather than milligrams per kilogram (mg/kg).

DRO = diesel range organics
mg/kg = milligram per kilogram
Max = maximum
Min = minimum
N/A = none available
RRO = residual range organics
TOC = total organic carbon

Source: SLR et al. 2011a, Table 10.4-2

Anions and cations evaluated in surface soil samples included chloride, cyanide, fluoride, sulfate, ammonia (as nitrogen), and sodium. The highest mean concentration among evaluated ions was ammonia, followed by sodium. The lowest mean concentration among evaluated ions was cyanide. Depth-based variations in ion concentrations were apparent, based on comparison to co-located shallow subsurface soil sample results. Mean concentrations of cyanide and ammonia were greater in surface samples; while mean sulfate concentrations were greater in shallow subsurface samples (SLR et al. 2011a).

RRO hydrocarbons were detected at all 23 surface sample locations, and DRO was detected at 13 surface sample locations. Mean concentrations of 209 milligrams per kilogram (mg/kg) and 2,028 mg/kg were reported for DRO and RRO, respectively (Table K3.14-4). The elevated presence and wide range of reported hydrocarbon concentrations are attributed to naturally occurring biogenic sources, based on absence of prior disturbances, analytical fingerprint methods, and presence of TOC (SLR et al. 2011a).

Similar to hydrocarbons, reported TOC concentrations varied significantly. TOC concentrations varied from 0.36 to 65.1 percent among surface soil locations. The wide range is attributed to variable quantities of organic material retained in sampled matrices during collection.

K3.14.3.2 Transportation Corridor

A total of 17 baseline surface soil samples was collected and evaluated using the same analyses as for the mine site study area. The surface samples were collected from Bristol Bay drainage uplands along the transportation corridor following the north access road associated with Alternative 3—North Road Only. Six of the 17 sample locations coincide with the transportation corridor associated with Alternative 1a from the mine site to the Eagle Bay ferry terminal, and are also representative of the pipeline-only segment from Iliamna Lake near Newhalen to the mine access road.

The hierarchy of trace element mean concentration trends were similar to those at the mine site; however, in all circumstances, trace element mean concentrations were lower in the transportation corridor (Table K3.14-5). Comparison of trace element values to those documented at the mine site indicate less mineral-rich soil conditions in the transportation corridor. Mean concentrations of iron (8,986 mg/kg) and aluminum (8,281 mg/kg) were the highest, followed by calcium (2,491 mg/kg), magnesium (977 mg/kg), and potassium (238 mg/kg). The hierarchy is reportedly consistent with a variety of soil types (SLR et al. 2011a). Although Coefficient of Variation (CV) ranges of trace elements in the transportation corridor were greater than the mine site, the average CV for all trace elements was substantially less (SLR et al. 2011a).

Because only one sample was collected and analyzed for DRO, RRO, and TOC, no comparison of mean values to the mine site study area was conducted. Reported concentrations of DRO, RRO, and TOC were 1,520 mg/kg, 9,220 mg/kg, and 18.20 percent, respectively. The elevated concentrations are representative of naturally occurring organic presence in a moist tundra/shrub habitat type.

K3.15 GEOHAZARDS AND SEISMIC CONDITIONS

This appendix contains additional technical information on the following topics related to the affected environment for geohazards described in Section 3.15, Geohazards and Seismic Conditions:

- Liquefaction processes and depth
- Baseline geotechnical data coverage at the mine site

K3.15.1 Liquefaction

Liquefaction occurs when a saturated or partially saturated soil loses strength and stiffness in response to an applied stress, such as shaking from an earthquake. When soil is saturated by water, the water fills the gaps between the soil grains (i.e., pore spaces). In response to stress, this water increases in pressure and is forced to flow out of the soil toward zones of lower pressure, usually up to the ground surface. However, if the loading is rapidly applied and large enough, or is repeated many times (e.g., earthquake shaking), the water cannot flow out in time before the next cycle of load is applied and water pressure could build up and exceed the forces (contact stresses) between the grains of soil that keep them in contact with one another. These contacts between grains are the means by which weight from structures and overlying soil layers are transferred from the ground to deeper soil or rock. This loss of soil structure causes the soil to lose its strength, which triggers liquefaction where the soil behaves like a liquid.

The depth to which liquefaction can occur has implications for the behavior of saturated tailings in an earthquake (see Section 4.15, Geohazards and Seismic Conditions). Knowledge on the maximum depth of liquefaction has evolved in recent years because of large global earthquakes and resultant liquefaction (Bray 2013; Stewart and Knox 1995; Tchakalova 2018; WSDOT 2013). The Washington State Department of Transportation Geotechnical Design Manual M 46-03.09 limits the depth for considering liquefaction to 80 feet, but suggests that analyses be performed if loose materials are below 80 feet. Stewart and Knox (1995) conclude that it is possible for excessive porewater pressures to occur below 100 feet; these pressures are sufficient to overcome the stiffness created by overburden pressures and exceed the limit for liquefaction, and great earthquakes can generate stresses of sufficient intensity and duration to produce liquefaction conditions in unconsolidated sediments, even below 1,000 feet. Tchakalova (2018) adds that the maximum depth at which liquefaction can occur is probably the same as the maximum depth at which sands and silts can remain unconsolidated and maintain sufficient porosity and hydraulic conductivity, and that whatever those depths, earthquakes of M8.0 or greater can produce stresses in the hypocenter and epicenter zones sufficient to overcome overburden pressures below 1,000 feet.

K3.15.2 Baseline Geotechnical Data Coverage

Table K3.15-1 lists the approximate number of geotechnical drillholes, test pits, and seismic lines collected in and near the footprint of different facilities at the mine site. A summary of overburden deposits and bedrock encountered in each area is provided in Section 3.15, Geohazards and Seismic Conditions. Additional details regarding geotechnical conditions beneath the footprints of major embankments are provided in Appendix K4.15, Geohazards and Seismic Conditions.

Table K3.15-1: Baseline Geotechnical Data Coverage at Mine Site

Area	Facilities	Number of Drill Holes[1]	Number of Test Pits[1]	Number of Seismic Lines
NFK-West	Bulk TSF main embankment, impoundment, and quarries	39	37	9
NFK-East	Pyritic TSF and associated SCPs	14	38	9
NFK-North	Main WMP, bulk TSF main embankment SCP, emergency dump pond	29	13	0
Pit Area	Open pit and rim	31	30	6
Bulk TSF South	Bulk TSF South embankment, and associated SCP and sediment pond	11	10	2
South of Pit Area	Open pit WMP, pit overburden stockpile, and associated sediment ponds	7	20	3

Notes:

[1] Numbers are approximate as there may be overlap between adjacent areas.

NFK = North Fork Koktuli

SCP = seepage collection pond

TSF = tailings storage facility

WMP = water management pond

Source: Knight Piésold 2011c; PLP 2013a; PLP 2018-RFI 014; PLP 2019-RFI 014b

K3.16 SURFACE WATER HYDROLOGY

This appendix contains supplemental technical information on the following topics related to baseline surface water hydrology discussed in Section 3.16, Surface Water Hydrology:

- Streamflow measurements in the mine study area
- Flood peak flows in the mine study area
- Meteorological inputs to the watershed model
- Watershed model calibration and validation
- Long-term climate change

K3.16.1 Streamflow Measurements in Mine Study Area (All Alternatives)

This section provides summary tables of streamflow measurement data collected at gaging stations in the North Fork Koktuli (NFK), South Fork Koktuli (SFK), and Upper Talarik Creek (UTC) watersheds. The tables provide a list of the gaging stations with continuous flow records, a summary of early spring low-flow measurements, a summary of average annual streamflow, and a summary of seasonal maximum and annual instantaneous discharge. The information in the tables is discussed in Section 3.16, Surface Water Hydrology.

Table K3.16-1: Streamflow Gaging Stations (Continuous Flow Data)

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

Table K3.16-1: Streamflow Gaging Stations (Continuous Flow Data)

Drainage[1]	Gaging Station		Drainage Area (mi^2)	Period of Measurement Record[2]	Record Length[3] (Years)
	Pebble ID	USGS ID			
	UT100-APC1	N/A	101.51	2007-2012	5
	UT100B	15300250	86.24	2004-2016	12
	UT100C	N/A	69.47	2007-2012	6
	UT100C1	N/A	60.37	2007-2010	4
	UT100C2	N/A	48.26	2007-2012	6
	UT100D	N/A	11.96	2004-2013	9
	UT100E	N/A	3.10	2004-2012	8
	UT106-APC1	N/A	14.14	2008-2013	3
	UT119A	N/A	4.05	2004-2013	9
	UT135A	N/A	20.42	2007-2010	0

Notes:

[1] Gaging stations listed include main stem and tributaries

[2] Calendar years that stream stage data were collected

[3] Complete water years of record (measured)—Refers to the number of years that stream stage data were collected for at least 3 months and used to compute discharge

[4] Station NK100A1 reported drainage area: Drainage area on Knight Piésold (2013a) Table 7-2 is 85 mi^2; on Table 7-4, drainage area is 81.97 mi^2

[5] Station NK100B1 and NK100C1 were installed in 2011 for the purpose of verifying measured flows at NK100B and NK100C

ID = Identification
mi^2 = square miles
N/A = Not Applicable
NFK = North Fork Koktuli
SFK = South Fork Koktuli
USGS = US Geological Survey
UTC = Upper Talarik Creek

Shaded rows are stations that represent streamflow in the upper portion, or at the mouth, of each watershed near the mine site and subject of more detailed discussion in the narrative

Source: Knight Piésold 2015b, Table 7-2, and Knight Piésold 2018g, Table 2.4

Table K3.16-2: Early Spring Low-Flow Measurements Summary 2005 to 2012[1]

Stream	Station or LF Measurement	Drainage Area (mi²)	Record Length (years)	Lowest Measured Flow (cfs)	Median Measured Flow (cfs)	Highest Measured Flow (cfs)
NFK River	***Main Stem***					
	NK100A (USGS gage)	105.86	8	11.9	47.6	84.5
	NK100A1	85.34	3	43.0	44.3	45.3
	NK100LF5	71.91	2	43.7	45.9	48.0
	NK100LF4	67.28	4	38.7	44.7	53.1
	NK100LF3	53.49	4	4.1	14.9	22.0
	NK100LF1	40.17	3	9.1	15.8	15.9
	NK100B	37.32	8	7.7	14.7	65.0
	NK100B1[3]	37.18	1	9.4	9.4	9.4
	NK100C	24.35	8	8.3	12.9	21.5
	NK100C1[3]	24.05	1	3.8	3.8	3.8
	Tributaries					
	NK108LF1	1.33	1	0.1	0.1	0.1
	NK119A	7.76	8	2.3	2.7	3.7
	NK119B	3.97	5	0.0	0.0	4.3
	NK119BLF1	3.37	1	1.4	1.4	1.4
SFK River	***Main Stem***					
	SK100A	106.92	6	63.5	76.6	125.0
	SK100LF11	90.00	1	13.9	13.9	13.9
	SK100LF10	87.17	4	11.6	13.9	24.6
	SK100LF9.6	80.68	1	0.2	0.2	0.2
	SK100B (USGS gage)	69.33	8	14.7	28.6	45.7
	SK100LF9	68.56	4	30.7	33.8	36.3
	SK100LF8	54.41	1	26.8	26.8	26.8
	SK100B1	54.41	7	12.1	17.3	34.4
	SK100LF7	51.76	1	9.6	9.6	9.6
	SK100B2	51.57	6	0.0	0.0	0.1
	SK100LF6	49.70	1	0.3	0.3	0.3
	SK100C	37.50	7	0.0	0.0	0.0
	SK100LF5	0.29	2	0.0	0.0	0.0
	SK100LF4.9	28.34	1	0.0	0.0	0.0
	SK100LF4	28.91	1	4.9	4.9	4.9
	SK100D	16.22	4	0.0	0.4	6.1

Table K3.16-2: Early Spring Low-Flow Measurements Summary 2005 to 2012[1]

Stream	Station or LF Measurement	Drainage Area (mi^2)	Record Length (years)	Lowest Measured Flow (cfs)	Median Measured Flow (cfs)	Highest Measured Flow (cfs)
	SK100LF2	15.14	1	4.1	4.1	4.1
	SK100F	11.91	7	1.2	3.5	8.3
	SK100G	5.49	5	2.1	3.6	6.0
	Tributaries					
	SK116A	0.34	2	0.0	0.1	0.1
	SK117A	0.71	3	0.0	0.0	0.0
	SK119A	10.73	6	1.8	2.7	7.6
	SK124A	8.52	6	0.0	0.0	3.0
	SK131A	2.37	4	0.0	0.8	1.1
	SK133A	0.74	3	0.2	0.2	0.3
	SK134A	1.14	4	0.2	0.7	2.4
	SK136A	1.15	4	0.9	1.0	1.2
	SK136B	0.19	3	0.0	0.3	0.4
UTC	***Main Stem***					
	UT100APC3	134.16	3	85.3	135.3	166.4
	UT100APC2	110.16	4	86.1	95.8	114.0
	UT100APC1	101.51	5	43.1	93.9	127.4
	UT100A	101.45	3	89.3	94.7	175.0
	UT100LF8	89.60	4	84.4	105.9	137.8
	UT100B (USGS gage)	86.23	7	87.7	97.5	132.7
	UT100LF7	71.72	4	34.8	69.5	97.5
	UT100C	69.46	6	18.1	50.4	136.5
	UT100LF6	70.72	2	46.1	62.1	78.1
	UT100LF5	65.35	3	47.8	49.1	50.2
	UT100C1	60.37	3	32.4	33.7	43.2
	UT100LF4	59.57	1	28.2	28.2	28.2
	UT100LF3	48.55	1	27.1	27.1	27.1
	UT100C2	48.26	5	10.3	24.0	26.0
	UT100D	11.96	8	5.7	8.1	10.5
	UT100LF1	6.36	1	6.8	6.8	6.8
	UT100E	3.10	8	3.3	3.9	4.6
	Tributaries					
	UT119A	4.05	8	21.5	23.8	28.0

Table K3.16-2: Early Spring Low-Flow Measurements Summary 2005 to 2012[1]

Stream	Station or LF Measurement	Drainage Area (mi^2)	Record Length (years)	Lowest Measured Flow (cfs)	Median Measured Flow (cfs)	Highest Measured Flow (cfs)
	UT119B	1.72	4	0.1	0.4	1.2
	UT119LF1[1]	2.32	1	15.7	15.7	15.7
	UT122LF[1]	0.06	1	1.1	1.1	1.1
	UT123LF1[1]	1.49	1	1.1	1.1	1.1
	UT132LF1	1.24	1	0.5	0.5	0.5
	UT135A	20.42	3	7.6	13.7	22.3
	UT136LF1	1.57	1	0.6	0.6	0.6
	UT138A	2.75	3	0.6	1.0	1.1
	UT141A	1.66	4	1.0	1.1	1.4
	UT146A	1.86	3	0.0	0.6	2.7

Notes:
cfs = cubic feet per second
LF = Low Flow
mi^2 = square miles
NFK = North Fork Koktuli
SFK = South Fork Koktuli
USGS = US Geological Survey
UTC = Upper Talarik Creek
yrs = years
[1] The data used to prepare this table are sourced from Knight Piésold (2015a, Table 7-4). The original table presents the individual flow measurements made in each year

One low flow measurement was made between March 7 and April 2 in each year in which measurements were made. All sites were not measured every year.

Station NK100B1 and NK100C1 were installed in 2011 for the purpose of verifying measured flows at NK100B and NK100C

Shaded rows are stations that represent streamflow in the upper portion or at the mouth of each watershed near the mine site and are the subject of more detailed discussion in the narrative

Source: Knight Piésold 2015b, Table 7-4, Figure 7.2-2, and Figure 7.2-5

Table K3.16-3: Average Annual Streamflow at Gaging Stations, 2004 to 2012

Drainage	Station	Drainage Area (mi²)	Record Length (years)	Average Annual Discharge (cfs)			
				Lowest Year	Median Year	Average Year	Highest Year
North Fork Koktuli River	NK100A	105.86	8	198.2	239.1	247.2	316.5
	NK100A1	85.34	8	169.0	198.3	205.0	260.9
	NK100B	37.32	8	64.2	81.6	84.3	112.8
	NK100B1[1]	37.18	0	-	-	-	-
	NK100C	24.35	8	36.7	47.2	47.5	63.2
	NK100C1[1]	24.05	0	-	-	-	-
	NK119A	7.76	8	14.8	22.0	23.8	35.5
	NK119B	3.97	8	2.5	4.1	4.3	6.5
South Fork Koktuli River	SK100A	106.92	8	215.1	267.4	259.3	303.9
	SK100B	69.33	8	145.4	188.5	183.7	229.0
	SK100B1	54.41	8	98.8	135.6	130.3	166.3
	SK100C	37.5	8	32.8	50.7	47.7	65.7
	SK100F	11.91	8	24.1	30.3	30.1	37.4
	SK100G	5.49	8	10.3	13.0	13.2	16.3
	SK119A	10.73	8	26.9	34.1	35.2	50.9
	SK124A	8.52	8	14.0	19.3	19.4	26.2
Upper Talarik Creek	UT100-APC3	134.16	8	286.0	326.2	324.1	351.1
	UT100-APC2	110.16	8	253.6	293.3	293.6	333.0
	UT100-APC1	101.51	8	230.0	264.5	261.8	288.5
	UT100B	86.24	8	190.0	223.0	221.4	251.0
	UT100C	69.47	8	134.2	155.0	157.5	185.7
	UT100C1	60.37	8	103.2	121.2	121.3	144.2
	UT100C2	48.26	8	87.6	105.5	104.7	125.1
	UT100D	11.96	8	23.8	28.4	27.8	31.9
	UT100E	3.1	8	7.5	9.1	9.0	10.5
	UT106-APC1	14.14	8	39.5	43.8	43.8	48.5
	UT119A	4.05	8	26.5	29.0	29.2	31.6
	UT135A	20.42	8	32.6	38.7	39.9	47.8

Notes:

[1] Station NK100B1 and NK100C1 were installed in 2011 for the purpose of verifying measured flows at NK100B and NK100C

cfs = cubic feet per second
mi² = square miles

Shaded rows are stations that represent streamflow in the upper portion or at the mouth of each watershed near the mine site and are the subject of more detailed discussion in the narrative

Source: Knight Piésold 2015b, Table 7-3. The original table presents discharge and unit runoff values for each year of record

Table K3.16-4: Seasonal Maximum and Annual Instantaneous Peak Discharge at Select Gaging Stations—Mine Site, 2004 to 2012[1]

Parameter	North Fork Koktuli River				South Fork Koktuli River					Upper Talarik Creek			
	NK100A	NK100B	NK100C	NK119A	SK100A	SK100B	SK100C	SK100F	SK119A	UT100-APC2	UT100B	UT100 C2	UT100D
April to July Maximum Instantaneous Discharge (Spring)													
Record Length (yrs)	8	2	5	8	3	8	1	3	6	N/A	8	1	1
Lowest Recorded Peak (cfs)	687	230	132	110	489	380	116	54	158	N/A	404	598	156
Median Recorded Peak (cfs)	1,525	443	284	271	1,199	1,140	116	172	335	N/A	1,011	598	156
Highest Recorded Peak (cfs)	2,310	655	586	404	1,781	1,710	116	249	484	N/A	1,340	598	156
August to November Maximum Instantaneous Discharge (Fall)													
Record Length (yrs)	9	6	6	8	4	9	8	4	9	4	9	6	8
Lowest Recorded Peak (cfs)	793	403	117	241	1,100	496	156	151	196	650	475	282	103
Median Recorded Peak (cfs)	1,560	470	202	349	1,208	1,090	289	168	475	1,005	926	483	185
Highest Recorded Peak (cfs)	2,240	760	404	690	1,484	1,510	331	233	606	1,404	1,620	825	272
Calendar Year Maximum Instantaneous Discharge													
Record Length (yrs)	9	2	4	8	4	9	2	3	7	N/A	9	1	2
Lowest Recorded Peak (cfs)	1,430	438	163	306	1,197	782	293	161	278	N/A	796	598	157
Median Recorded Peak (cfs)	1,920	547	294	384	1,209	1,440	304	172	484	N/A	1,230	598	212
Highest Recorded Peak (cfs)	2,310	655	376	690	1,781	1,710	315	249	606	N/A	1,620	598	267

Notes:

[1] Initial gaging station installation occurred July 2004. Discharge data from a September 2004 event resulted in the largest daily and instantaneous discharges on record at some of the stations, including USGS station UT100B. For frequency analysis purposes, the September 2004 event was taken to represent the maximum discharge for the 2004 calendar year at all stations, with the assumption that an even larger peak flow was unlikely to have occurred in the spring of 2004 prior to the start of the gaging program (Appendix 7C, Knight Piésold 2015b)

cfs = cubic feet per second

yrs = years

N/A = Not Available

Shaded columns indicate stations that represent streamflow in the upper portion or at the mouth of each watershed near the mine site and are the subject of more detailed discussion in the narrative

Source: Knight Piésold 2015b, Table 2, Appendix 7B. The original table presents the values for each year in which measurements were made

K3.16.2 Flood Peak Flows in Mine Study Area (All Alternatives)

Table K3.16-5 provides estimates of flood peak streamflow at selected gaging stations, and is discussed under Flood Magnitude and Frequency in Section 3.16, Surface Water Hydrology.

Table K3.16-5: Return Period Peak Flows in Mine Study Area

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

Notes:
[1] QT refers to peak streamflow with average recurrence interval of T (a number of) years
cfs = cubic feet per second
NFK = North Fork Koktuli
SFK = South Fork Koktuli
UTC = Upper Talarik Creek

Source: Knight Piésold 2018g, Table 6.14

K3.16.3 Alternative 2—Streamflow Measurements and Peak Flow Estimates

Table K3.16-6: USGS and PLP Gaging Stations in Transportation and Natural Gas Pipeline Corridors—Alternative 2

Station			Location		Period of Record				Drainage Area (m^2)	Mean Annual Discharge		Mean Annual Peak Disharge	
USGS or PLP ID	USGS or PLP Name	Type	Lat (N)	Long (W)	Start Year	End Year	No. Complete Water Years	No. Annual Peaks		Absolute Discharge (cfs)	Unit Discharge (cfs/mi^2)	Absolute Discharge (cfs)	Unit Discharge (cfs/mi^2)
15300000	Newhalen River Near Iliamna[1,2]	Continuous	59°51'34"	154°52'24"	1951	1986	35	31	3,410	9,237	2.7	26,229	7.7
NH100-APC3	Newhalen River[3]	Continuous	59°51'34"	154°52'24"	2008	2013	N/A	N/A	3,412	N/A	N/A	N/A	N/A
NH100-APC2	Newhalen River[4]	Discontinued	N/A	N/A	2008	2013	N/A	N/A	3,451	N/A	N/A	N/A	N/A
15300100	Bear Creek[5]	Crest	59°49'28"	154°52'56"	2005	2012	8	N/A	2.6	8.9	3.4	39	15.2
15300200	Roadhouse Creek Near Iliamna AK[1]	Crest	59°45'26"	154°50'49"	1973	1983	N/A	10	20.8	N/A	N/A	128	6.2
15300200	Roadhouse Creek Near Iliamna, AK[1]	Continuous	59°45'26"	154°50'49"	2005	2008	3	4	19.2	29.1	1.4	198	9.5
15300270	Chekok Creek[2]	Manual Measurements	59°50'32"	154°22'39"	2011	2013	N/A	2	60.3	N/A	N/A	N/A	N/A
15300300	Iliamna River Near Pedro Bay, AK	Continuous	59°45'31"	153°50'41"	1996	2008	12	13	129	914	7.1	15,900	124.2
15300350	Chinkelyes Creek Tributary Near Pedro Bay. AK	Crest	59°44'02"	153°48'40"	1997	2008	N/A	12	0.6	N/A	N/A	84.4	211.0

Notes:
[1] Gaging stations also representative of area included in Alternative 1a (mine access road to Eagle Bay)
[2] Source: USGS 2020b
[3] At the same location as USGS gaging station 15300000
[4] 8 river miles downstream of NH100-APC3, discontinued in 2009. Streamflow estimated by regression analysis of NH100-ACP3 data.
[5] Source: Knight Piésold 2015b
AK = Alaska
cfs = cubic feet per second
Lat (N) = Latitude (North)
Long (W) = Longitude (West)
m^2 = square mile(s)
N/A = Not Available
PLP = Pebble Limited Partnership
USGS = US Geological Survey
Source: Knight Piésold et al. 2011a, Table 7.3-1

Table K3.16-7: Summer 2004 Instantaneous Discharge Measurements in Transportation and Natural Gas Pipeline Corridors—Alternative 2[1]

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

Notes:

[1] Gaging station also representative of area included in Alternative 1a (mine access road to Eagle Bay)

cfs = cubic feet per second

N/A = Not Available

Source: Knight Piésold et al. 2011a, Table 7.3-8

Table K3.16-8: Winter 2005 Instantaneous Discharge Measurements in the Transportation and Natural Gas Pipeline Corridor—Alternative 2[1]

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

Notes:
[1] Gaging station also representative of area included in Alternative 1a (mine access road to Eagle Bay)
cfs = cubic feet per second
N/A = Not Available
Source: Knight Piésold et al. 2011a, Table 7.3-8

Table K3.16-9: Summer 2005 Instantaneous Discharge Measurements in Transportation and Natural Gas Pipeline Corridors—Alternative 2[1]

Summer 2005 Instantaneous Discharge Measurements Sample Location (West to East)		May 2005		June 2005		July 2005	
		Date	Discharge (cfs)	Date	Discharge (cfs)	Date	Discharge (cfs)
GS-23	Chinkelyes Creek	N/A	N/A	N/A	N/A	14-Jul	295.3
GS-3a	Iliamna River	N/A	N/A	14-Jun	2070.0	15-Jul	1160.0
GS-4a	Pile River	4-May	786.1	14-Jun	1641.1	15-Jul	1522.6
GS-4b	Unnamed Outlet Creek from Long Lake	N/A	N/A	N/A	N/A	N/A	N/A
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	N/A	N/A	N/A	N/A	N/A	N/A
GS-7a	Unnamed Creek near Pedro Bay Townsite	N/A	N/A	N/A	N/A	N/A	N/A
GS-8a	Knutson Creek	4-May	247.7	14-Jun	316.9	15-Jul	167.3
GS-11a	Canyon Creek	3-May	246.7	15-Jun	526.6	16-Jul	196.3
GS-12a	Chekok Creek	N/A	N/A	N/A	N/A	N/A	N/A
GS-14a	Unnamed Creek East of Eagle Bay Creek	N/A	N/A	N/A	N/A	N/A	N/A
GS-14b	Unnamed Creek West of Chekok Creek	3-May	45.3	15-Jun	13.8	15-Jul	3.1
GS-17a	West Fork Eagle Bay Creek	5-May	46.5	15-Jun	14.2	16-Jul	8.4
GS-18a[1]	Upper Creek on South Slope of Roadhouse Mountain	N/A	N/A	N/A	N/A	N/A	N/A
GS-20[1]	Roadhouse Creek	24-May	26.0	18-Jun	45.0	2-Jul	33.0
GS-20a[1]	Upper Roadhouse Creek	N/A	N/A	N/A	N/A	N/A	N/A

Table 3.16-9: Summer 2005 Instantaneous Discharge Measurements in Transportation and Natural Gas Pipeline Corridors—Alternative 2 (continued)

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

Notes:
[1] Gaging station also representative of area included in Alternative 1a (mine access road to Eagle Bay)
cfs = cubic feet per second
N/A = Not Available
Source: Knight Piésold et al 2011a, Table 7.3-8

Table K3.16-10: Estimated Peak Streamflows in the Transportation and Natural Gas Pipeline Corridors—Alternative 2[1]

Station	Stream	Peak Flows Estimated from Regression Equations for Region 3 (cfs)						
		Q_2[2]	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}
GS-23	Chinkelyes Creek	826	1,190	1,452	1,797	2,070	2,345	2,646
GS-3a	Iliamna River	3,618	5,276	6,472	8,054	9,311	10,580	11,971
GS-4a	Pile River	4,419	6,447	7,909	9,840	11,373	12,921	14,614
GS-4b	Unnamed Outlet Creek from Long Lake	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	63	94	117	148	173	198	226
GS-7a	Unnamed Creek near Pedro Bay Townsite	143	221	278	355	416	479	549
GS-8a	Knutson Creek	995	1,531	1,925	2,455	2,881	3,319	3,801
GS-11a	Canyon Creek	707	1,112	1,413	1,825	2,159	2,507	2,893
Station	**Stream**	**Peak Flows Estimated from Regression Equations for Region 4 (cfs)**						
		Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}
GS-23	Chinkelyes Creek	645	976	1,230	1,571	1,837	2,106	2,388
GS-3a	Iliamna River	3,038	4,359	5,340	6,621	7,607	8,588	9,609
GS-4a	Pile River	3,697	5,280	6,453	7,981	9,154	10,321	11,532
GS-4b	Unnamed Outlet Creek from Long Lake	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GS-6a	Unnamed Outlet Creek from Dumbbell Lake	40	66	87	116	140	165	191
GS-7a	Unnamed Creek near Pedro Bay Townsite	66	111	148	199	240	284	330
GS-8a	Knutson Creek	583	901	1,144	1,472	1,730	1,993	2,271
GS-11a	Canyon Creek	421	654	832	1,072	1,261	1,456	1,661
GS-12a	Chekok Creek	556	850	1,072	1,371	1,605	1,845	2,097
GS-14a	Unnamed Creek East of Eagle Bay Creek	202	323	417	545	647	752	865
GS-14b	Unnamed Creek West of Chekok Creek	155	246	316	413	490	569	654
GS-17a[1]	West Fork Eagle Bay Creek	129	210	274	362	433	506	585
GS-18a[1]	Unnamed Creek on South Slope of Roadhouse Mountain	86	141	184	244	292	342	396
GS-20[1]	Roadhouse Creek	176	273	346	445	524	604	689
GS-20a[1]	Upper Roadhouse Creek	81	130	169	223	266	311	358
N/A	Bear Creek[3]	35	47	57	69	87	104	124
N/A	Newhalen River Near Iliamna[4]	25,400	30,800	34,400	39,000	42,400	45,800	49,200

Notes:

[1] Gaging station also representative of area included in Alternative 1a (mine access road to Eagle Bay)

[2] Q_T refers to peak streamflow with average recurrence interval of T years

[3] Source: Knight Piésold 2015b

[4] Source: Curran et al., 2003

cfs = cubic feet per second N/A = Not Available

Source (all other stations): Knight Piésold et al. 2011a, Table 7.3-12

K3.16.4 Baseline Watershed Model

A baseline watershed model (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 was updated in 2019 to improve model calibration and validation to measured streamflows (Knight Piésold 2019g). The revised BWM used the same modeling framework and methods as the 2011 model, including the following updates:

- BWM calibration was conducted at three regional USGS gaging stations and 19 project gaging stations.
- The BWM was calibrated to measured streamflows between October 2005 and March 2010, encompassing the open flow period (October to September) with concurrent climate and streamflow data collected, except for 2010, when no precipitation data were collected at the Pebble 1 meteorological station (Knight Piésold 2018g).
- BWM validation of modeled baseline flows was conducted on measured streamflows between October 2010 and September 2013. The validation period includes the open flow period (October to September) with concurrent climate and streamflow data collected after the period when no precipitation data were collected at the Pebble 1 meteorological station in 2010. Validation was conducted at the same 22 gaging stations used for calibration.
- Eight additional stream gaging stations were added as calibration and validation nodes in the BWM.

K3.16.4.1 Meteorological Data Inputs

A meteorological data collection program was designed and implemented to provide data representative of the mine site analysis area. Meteorological data have been collected from eight monitoring stations (Figure K3.16-1) (SLR 2015a). Stations are in the general mine site analysis area, and the Iliamna Air Quality station in Iliamna, Alaska (Iliamna Airport). The closest long-term meteorological records are from Iliamna Airport.

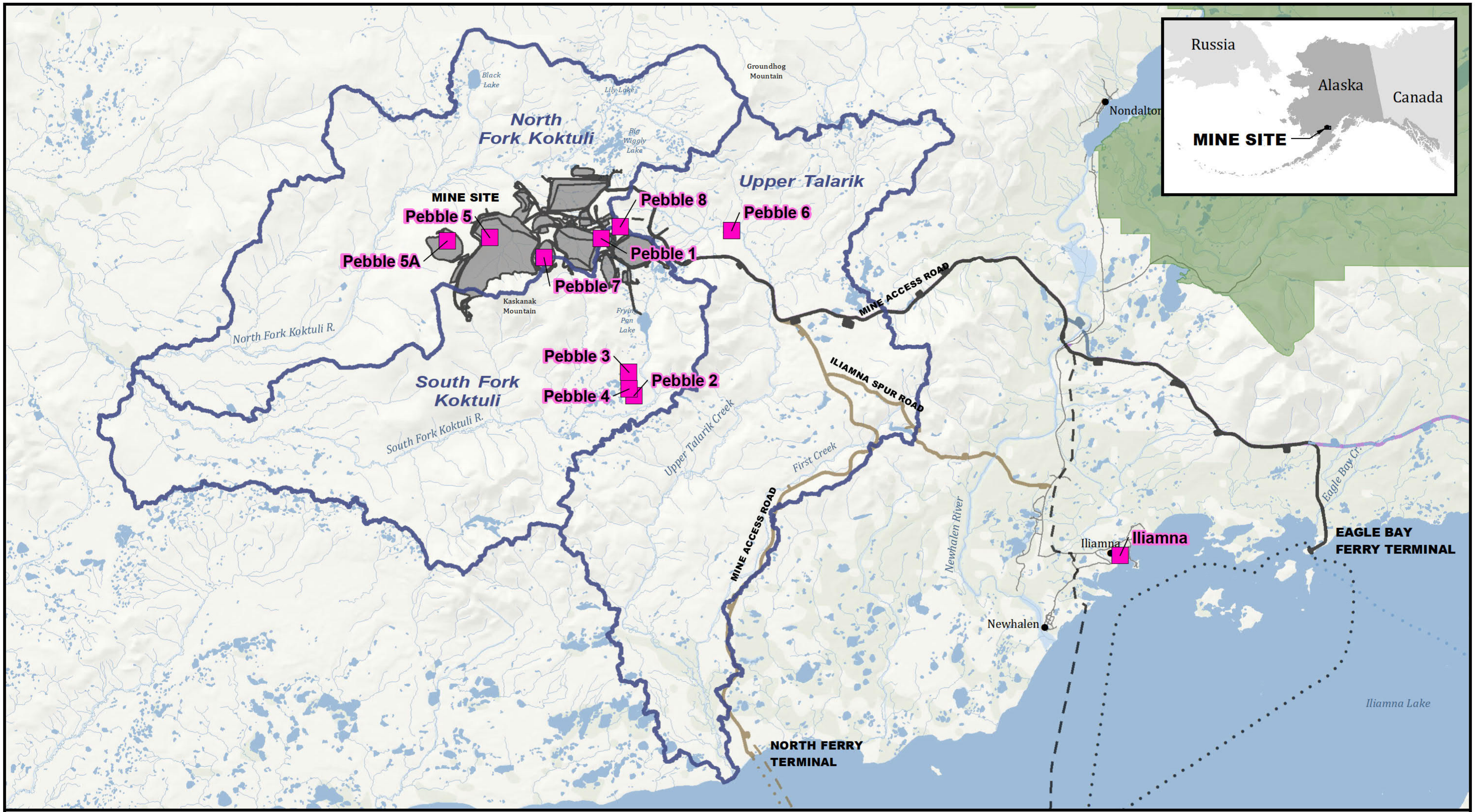
To evaluate surface water and groundwater interaction, a month-to-month water balance approach was selected, which included a semi-distributed spreadsheet method (Schlumberger 2011a; Knight Piésold 2019g). The semi-distributed model was selected due to the relatively large study area (approximately 300 square miles) and availability of streamflow data collected at locations that reflect the variability of hydrologic conditions in the study area. Additionally, the selected method allowed for adjacent sub-catchments (smaller watersheds or basins) to be chained together, including the interaction of surface water and groundwater components.

The development of the BWM included the following components (Schlumberger 2011a; Knight Piésold 2019g:

- The NFK, SFK, and UTC watersheds were divided into 22 sub-catchments; each is associated with a gaging station (Figure K3.16-2).
- Each sub-catchment was discretized by elevation into 500-foot elevation bands to further define climate, with elevation bands ranging from 300 to 2,800 feet (Figure K3.16-3).
- Representative climate conditions for temperature and precipitation were calculated for the center elevation of each elevation band. The areas in each modeled sub-catchment and each elevation band are listed in Table K3.16-11.

- Inputs to each sub-catchment included precipitation and inflow from up-gradient catchments.
- Precipitation distribution was accounted for in runoff, recharge, evapotranspiration, and sublimation.
- Groundwater recharge (combination of precipitation recharge and stream leakage) was accumulated in groundwater storage.
- Groundwater was discharged in and from each sub-catchment in proportion to the amount of groundwater in storage. A portion of this groundwater was transmitted downgradient to the next sub-catchment according to Darcy’s Law. The remainder of the groundwater was discharged in the sub-catchment as surface water.
- Surface water detention in lakes, small ponds, and wetlands is modeled using a linear reservoir assumption.
- Snowmelt was accounted for when temperatures rose enough to melt accumulated snow and generate runoff.

The input parameters to the water balance model were adjusted until modeled streamflows closely resembled measured streamflows. The following inputs were used to develop the water balance model (Schlumberger 2011a; Knight Piésold 2019g).

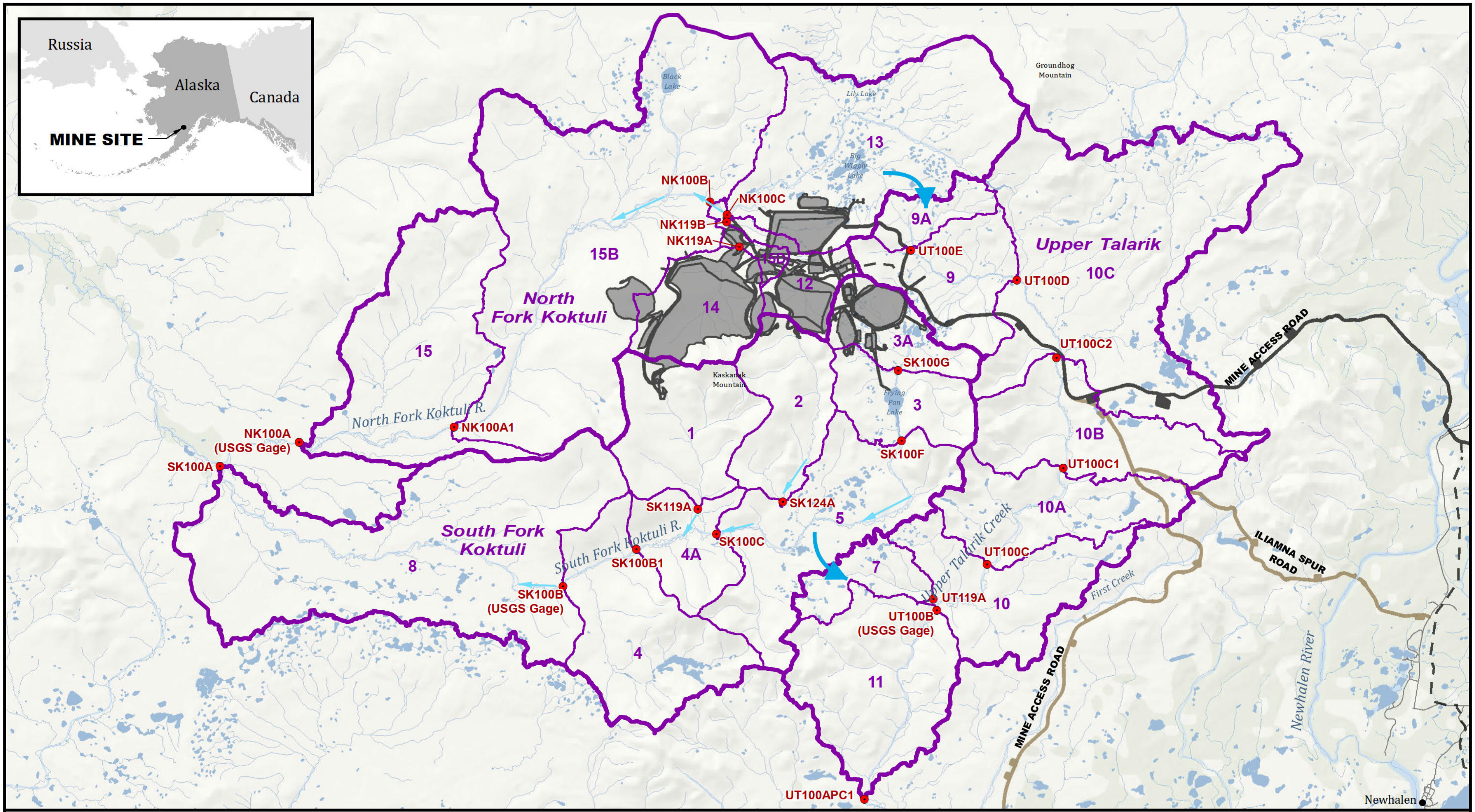


Sources: PLP 2020-RFI168; PLP 2019-RFI153; SLR 2015a; ADNR

METEOROLOGICAL MONITORING STATIONS IN THE MINE STUDY AREA

PEBBLE PROJECT EIS

FIGURE K3.16-1



Sources: PLP 2019-RFI153
Knight Piesold 2019g

US Army Corps of Engineers

2 0 2 4
Miles

- ● Continuous Hydrology Station/ Model Calibration Node
- ▬ Major Drainage Boundary
- ─ Sub-drainage Boundary/ Watershed Model Area
- → Losing Stream Reach (Surface Water Loss to Groundwater)
- ⬅ Inter-basin Groundwater Flow

Action Alternatives

- – – Natural Gas Pipelines
- ■ Alternative 1a
- ■ Alternative 1

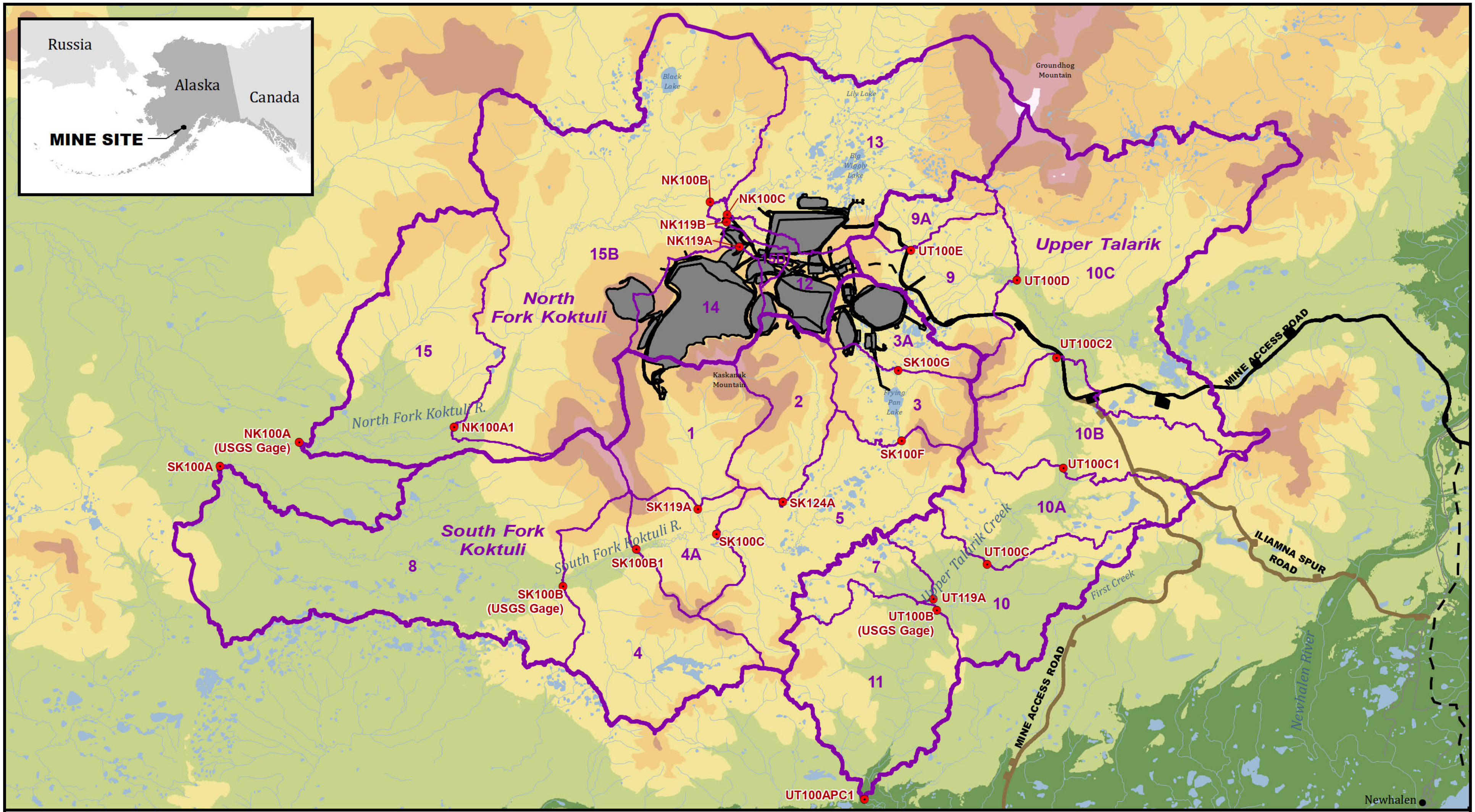
Other Features

- ─ Local Roads

BASELINE WATERSHED MODEL SUB-CATCHMENT BOUNDARIES AND SIMULATED FLOW REGIME

PEBBLE PROJECT EIS

FIGURE K3.16-2



Sources: PLP 2019-RFI153
Knight Piesold 2019g

US Army Corps of Engineers®

2 0 2 4
Miles

Topography (ft)
- 🟩 <300
- 🟩 300-800
- 🟨 800-1300
- 🟧 1300-1800
- 🟫 1800-2300
- 🟥 2300-2800
- ⬜ >2800

- ● Continuous Hydrology Station/ Model Calibration Node
- ▬ Major Drainage Boundary
- ▬ Sub-drainage Boundary/ Watershed Model Area

Action Alternatives
- ╌ Natural Gas Pipeline
- ■ Alternative 1a
- ■ Alternative 1

BASELINE WATERSHED MODEL ELEVATION BANDS

PEBBLE PROJECT EIS

FIGURE K3.16-3

Table K3.16-11: Baseline Watershed Model Sub-Catchment Areas by Elevation Band

Catchment	Area Number	Sub-Catchment	Catchment Area in Elevantion Band (mi^2)					Total Sub-Catchment Area (mi^2)	Total Contribution Area (mi^2)	Mean Sub-Catchment Elevation (feet)
			158-800	800-1300	1300-1800	1800-2300	2300-2925			
North Fork Koktuli	Area 13	NK100C	—	12.28	5.71	2.64	0.77	24	24	1,323
			—	2.94	—	—	—			
	Area 14	NK119A	—	0.53	5.31	1.70	0.22	7.8	7.8	1,654
	Area 12	NK119B	—	0.73	3.05	0.19	—	4.0	4.0	1,482
	Area 15d	NK100B	—	0.77	0.47	0.00	—	1.2	37	1,241
	Area 15b	NK100A1	1.09	27.75	15.29	3.62	0.26	48	85	1,281
	Area 15	NK100A	7.23	9.97	3.30	0.01	—	21	106	955
South Fork Koktuli	Area 3a	SK100G	—	3.41	1.76	0.32	—	5	5	1,269
	Area 3	SK100F	—	2.57	2.19	0.49	—	6.4	11.9	1,297
			—	1.16	—	—	—			
	Area 2a2	SK124Aa	—	—	3.82	1.48	0.08	5.4	5.4	—3
	Area 22	SK124A	—	3.14	—	——	—	3.1	8.5	14623
	Area 5	SK100C	—	8.17	2.56	0.37	0.01	17	37	1,147
			—	5.96	—	—	—			
	Area 1	SK119A	—	3.47	4.28	2.59	0.39	11	11	1,545
	Area 4a	SK100B1	0.45	4.14	1.12	0.47	0.01	6.2	54	1,182
	Area 4	SK100B	1.24	10.62	2.55	0.49	0.00	15	69	1,127
	Area 8	SK100A	26.50	7.75	1.86	1.01	0.47	38	107	768
Upper Talarik Creek	Area 9a	UT100E	—	2.11	0.99	—	—	3.1	3.1	1,209
	Area 9	UT100D	0.34	6.91	1.43	0.17	—	8.9	12.0	1,131
	Area 10c	UT100C2	5.66	15.43	10.96	3.37	0.88	36.3	48.3	1,252
	Area 10b	UT100C1	2.42	7.81	1.44	0.44	—	12.1	60.4	1,046
	Area 10a	UT100C	1.72	7.17	0.37	0.07	—	10.6	71.0	934

Table K3.16-11: Baseline Watershed Model Sub-Catchment Areas by Elevation Band

Catchment	Area Number	Sub-Catchment	Catchment Area in Elevantion Band (mi²)					Total Sub-Catchment Area (mi²)	Total Contribution Area (mi²)	Mean Sub-Catchment Elevation (feet)
			158-800	800-1300	1300-1800	1800-2300	2300-2925			
			1.25	—	—	—	—			
	Area 7	UT119A	1.10	2.94	0.01	—	—	4.0	4.0	915
	Area 10	UT100B	5.81	3.27	0.02	—	—	11.2	86.2	698
			2.12	—	—	—	——			
	Area 11	UT100APC1	8.85	5.75	0.68	—	—	15.3	101.5	783
									Average	1,154

Notes:
mi² = square miles
Gray shading indicated areas where additional evapotranspiration is allowed to account for wet conditions.

Area 2 sub-catchment (SK124A) separated into upland area (Area 2a) and lowland area (Area 2) to simulate infiltration of streamflow into channel in upper portion of reach.

Elevation provided for SK124A includes the entire SK124A sub-catchment (upland and lowland portions), SKA124Aa has a mean elevation of 1,703 feet.

Source: Knight Piésold 2019g, Table 2.1

K3.16.4.2 Temperature

Mean monthly temperature data collected at the Pebble 1 meteorological station were input into the BWM for the model calibration and validation periods, described previously. Temperature in each elevation band in the BWM was calculated based on an assumed temperature gradient of 3.6 degrees Fahrenheit (°F) per 1,000 feet of elevation, using the following formula (Knight Piésold 2019g):

$T = T_s – (E – E_s) (3.6/1{,}000)$, where:

T = monthly temperature in the middle of the elevation band (°F)

T_s = monthly temperature at Pebble 1 (°F)

E = elevation at middle of elevation band (feet)

E_s = elevation of Pebble 1 (1,560 feet)

For long-term flow modeling, temperature data from the Iliamna airport were used for developing a long-term dataset for the mine plan water balance model. Temperature data selected for this purpose were from the period of record from 1942 to 2017. Data gaps in the temperature data were addressed using regional regression analysis to estimate missing data from the long-term dataset (Knight Piésold 2018m).

Scaling factors were then applied to transform the temperature record from Iliamna airport into synthetic (estimated) series at the Pebble 1 station location. Scaling factors represent fundamental physical relationships and processes, which have been quantified by empirical calibration methods (Knight Piésold 2018a). The adiabatic[1] relationship between topographic elevation and air temperature is an example of a scaling factor considered for temperature. The standard adiabatic lapse rate relationship between elevation and temperature is -3.6°F per 1,000 feet of elevation. The observed temperature difference between the Iliamna Airport and Pebble 1 station is -4.7°F, which equates to a lapse rate of -3.4°F per 1,000 feet of elevation. Therefore, the observed temperature difference of -4.7°F was adopted and applied to each month of the Iliamna Airport data to create the synthetic temperature dataset for the mine site at Pebble 1 station.

K3.16.4.3 Precipitation

Pebble 1 precipitation data were used in the updated BWM for calibration and validation periods (Knight Piésold 2019g). Precipitation data from Pebble 1 are measured values and are considered to underestimate actual precipitation at the station due to gage undercatch. Data gaps in the Pebble 1 precipitation data set were addressed using precipitation values from the Iliamna airport record. Representative precipitation values at the center of each elevation band in the BWM were calculated by applying correlation factors to the Pebble 1 precipitation data. These factors were required to achieve a balance between concurrent recorded precipitation and runoff (Knight Piésold 2019g).

One correlation factor was a multiplier that accounted for the precipitation undercatch at Pebble 1. An undercatch correlation factor of 1.6 was assigned to winter months (November to March) to account for greater undercatch resulting from snow and windier conditions. For non-winter months, a correlation factor of 1.25 was applied to the Pebble 1 precipitation data (Knight Piésold 2019g).

---

[1] The **adiabatic** relationship is the process of heat being reduced in the air with change in air pressure that occurs at increased elevations. Air expands and cools as it rises, resulting in cooler air at higher elevation.

The second correlation factor was an orographic factor, which differed for winter and non-winter months to account for variable weather systems throughout the year, as well as precipitation variability affected by elevation. A correlation factor of 1.1 was applied to winter months (November to March), which is based on a 10 percent increase in precipitation per 328.1 feet gain in elevation. A correlation factor of 1.058 was applied to the non-winter months (Knight Piésold 2019g).

The orographic factors were applied using the following non-linear relationship:

$$P = P_s\, a^{(E-E_s)/328.1}$$

Where:

P = monthly precipitation at the selected elevation (inches)

P_s = monthly precipitation at Iliamna (inches)

a = orographic factor

E = elevation at middle of elevation band (feet)

E_s = elevation of Iliamna (190 feet)

The climate correlation factors incorporated in the calculation of precipitation in the BWM are listed in Table K3.16-12. In addition to the factors presented in Table K3.16-12, rain shadow effect and wind transfer of snow in each sub-catchment were accounted for by assigning a local sub-catchment specific precipitation multiplier between 0.85 and 1.15 to achieve a balance between precipitation and corresponding measured flows (Knight Piésold 2019g).

For long-term flow modeling, precipitation data from the Iliamna airport were used for developing a long-term dataset for the mine plan water balance model. Precipitation data selected for this purpose were from the period of record from 1942 to 2017. Winter precipitation at Iliamna was multiplied by 1.477 to account for expected undercatch of snow by the Iliamna gage. This was determined by correlating concurrent precipitation at Iliamna and Pebble 1, after correcting for orographic differences. Additionally, winter and summer orographic correlation factors were also assigned to the Iliamna precipitation data to account for the elevation difference of the two sites (Knight Piésold 2019g).

Table K3.16-12 Baseline Watershed Model Climate Correlation Factors

Climate Parameter	Symbol	Units	Value
Pebble 1 Winter Undercatch Factor[1]	U_1	—	1.6
Pebble 1 Non-winter Undercatch Factor	U_2	—	1.25
Winter Orographic Factor	a (winter)	per 328.1 feet	1.1
Non-winter Orographic Factor	a (non-winter)	per 328.1 feet	1.058
Iliamna Undercatch Factor	U_i	—	1.477
Lapse Rate	L	°F /1,000 feet	3.6
Maximum Temperature for Snow	T_{snow}	°F	30.2
Minimum Temperature for Rain	T_{rain}	°F	28.4
Potential Sublimation	S_{psub}	inch/day	0.02
Snowmelt Factor	M	inch/month/ °F	3.06
Base Temperature for Snowmelt	t_{min}	°F	33.8

Table K3.16-12 Baseline Watershed Model Climate Correlation Factors

Climate Parameter	Symbol	Units	Value
Surplus ET Factor[2]	f	—	0.5 or 0.9
Soil Moisture Capacity[2]	S_m	inch	4 or 14

Notes:

[1] Winter months for climate calculations are November to March and non-winter months are April to October

[2] The lower value is assigned to most sub-catchment areas. The higher value is assigned to areas that are allowed to have higher evaporation rates

Elevations: Iliamna Airport elevation 190 feet amsl

Pebble 1 elevation: 1,560 feet above mean sea level

Source: Knight Piésold 2019g, Table 2.4

K3.16.4.4 Climate Water Balance

The following sections provide a general description of climate water balance components presented in Table K3.16-11 that were used to determine how precipitation becomes water-available for surface water runoff or groundwater recharge. Climate parameter values assigned in the calibrated BWM are specified where applicable, and the parameters are assigned the same value in each sub-catchment in the BWM (Knight Piésold 2019g).

K3.16.4.5 Snow and Rain

Distribution of precipitation as either snowfall or rainfall is based on the assumption that precipitation falls as rain if the average temperature is greater than 30.2°F, and falls as snow if the average monthly temperature is below 28.4°F. For average monthly temperatures between 30.2°F and 28.4°F, it is assumed that the proportion of precipitation falling as rain or snow varies linearly (Knight Piésold 2019g).

Snowpack Sublimation

For the BWM climate water balance analysis, snowpack is assumed to sublimate at a constant rate until no snow remains on the ground, at a rate of 0.02 inch per day (Knight Piésold 2019g).

Snowpack and Snowmelt

A temperature index method based on degree-month melt factor was used to estimate snowmelt for the BWM (Knight Piésold 2019g). Potential snowmelt is calculated using the following equation:

$$\text{Monthly Snowmelt (inches)} = M\,(T - t_{min})$$

Where:

M = degree-month melt factor (3.06 inches/month/°F)

T = monthly temperature at the middle of elevation band (°F)

t_{min} = minimum temperature for snowmelt to occur (33.8°F)

For each month of the climate water balance, actual monthly snowmelt is calculated as the lesser of potential snowmelt and available snow after accounting for losses to sublimation. Snowpack is calculated by adding the current month’s snowfall to the previous month’s snowpack, and then subtracting sublimation and snowmelt estimates. Sublimation and snowmelt are accounted for until no snowpack remains.

K3.16.4.6 Potential Evapotranspiration

Monthly pan evaporation measurements were recorded at the project meteorological stations, and these values were adjusted to represent lake evaporation rates using a Class A pan coefficient of 0.7 (Knight Piésold 2018g). The mean annual evaporation for the months of May through September at Pebble 1 was estimated to be 12.5 inches, which was based on a relatively limited dataset between 2005 and 2009.

For estimating long-term monthly potential evapotranspiration (PET) in the project area, the Thornthwaite equation was adopted as the basis for PET, and is generally considered to be reasonably representative of lake evaporation. The Thornthwaite equation is shown below:

$\text{PET (inches)} = 0.63(10T/I)^{a}$

Where:

T = monthly average temperature (degrees Celsius [°C])

I = the sum of the i values for the year, where $i = (T/5)1.514$

$a = 6.751\text{x}10\text{-}^{7}(I^{3}) – 7.71\text{x}10\text{-}^{5}(I^{2}) + 1.792\text{x}10\text{-}^{2}(I) + 0.49239$

temperature conversion: °F = (°C x 9/5) + 32

Using the Thornthwaite equation, the mean annual PET estimated for Pebble 1 for the period of 2005-2009 is estimated to be 15.7 inches. This value is reasonably similar to the 12.5 inches estimated from the evaporation data for the months of May through September (Knight Piésold 2018g).

For the updated BWM, unadjusted PET estimated using the Thornthwaite equation was then adjusted to account for the number of days in the month, and the number hours in a day between sunrise and sunset, which varies by latitude. The number of days correction was calculated by multiplying by the number of days in the month and then dividing by 30 (Knight Piésold 2019g).

The equation used to calculate length of day based on latitude:

$\text{Length of day} = (24\cos^{-1}(\tan(L)\tan(0.4093\ \sin(2\pi\ \text{int}(30.4m\text{-}15)/365\text{-}1.39))))/12\pi$

Where:

L = latitude

m = month number

The BWM produced evaporation estimates consistent with measured precipitation are described in the Pebble Hydrometeorology Report (Knight Piésold 2018g).

K3.16.4.7 Actual Evapotranspiration

Potential evapotranspiration represents the evapotranspiration for a fully vegetated cover on relatively flat tilled ground with no shortage of water, whereas actual evapotranspiration (AET) is limited by the water available each month. If the PET in a given month is greater than the sum of rainfall, snowmelt, and stored soil moisture, then the AET will be less than the PET (Knight Piésold 2018g). Soil moisture capacity was estimated to be 4 inches for most sub-catchments, and 14 inches for sub-catchments with high evaporation potential (wetlands).

The 4 inches value for most sites was estimated using the following information:

$S_m = S_{max} * R_d * A$

Where:

S_m = soil moisture capacity

S_{max} = maximum soil moisture, conservatively estimated to be 2.4 inches for a 6.5-foot soil depth

R_d = the available water adjustment for rooting depth, estimated to be 1/3

A = the availability coefficient, estimated to be 50%.

The R_d value of 1/3 is based on an estimated vegetation rooting depth in the project area of 20 inches, and the recognition that soil compaction increases with depth, and therefore soil moisture decreases with depth. It is assumed that the 20-inch rooting depth, which equates to 1/4 of the 6.5-foot soil depth, contains 1/3 of the available moisture. The 14-inch value for high evaporation areas was somewhat arbitrarily selected to ensure that soil moisture would not limit evapotranspiration losses in wetland areas (Knight Piésold 2018g).

When soil moisture was less than soil moisture capacity, PET was reduced linearly with soil moisture as follows (Knight Piésold 2019g):

Adjusted (actual) evapotranspiration = $(S_2 + S_1)\ f\ (PET)/(2S_m)$

Where:

S_m = soil moisture capacity

S_1 = soil moisture at the beginning of the month

S_2 = soil moisture at the end of the month

PET = the calculated full PET after allowance for latitude and land cover type and condition

f = the reduction factor for non-ideal conditions for evapotranspiration (0.5 for most sites and 0.9 for high-evaporation sites)

As noted in Table K3.16-11, areas in sub-catchments are specified to have a higher modeled evapotranspiration to account for higher soil moisture conditions (wetlands).

K3.16.4.8 Soil Water

A monthly soil water balance is calculated based on the assumption that the soil profile could retain moisture from month-to-month. A maximum soil moisture retention of 4 inches is assumed to represent average site conditions (Knight Piésold 2019g). Accounting for sublimation, snowmelt, rainfall, and AET allows for estimation of water available for infiltration and runoff. The soil moisture is calculated for the end of each month (S_2) based on the following formula:

$S_2 = W + S_1 – (S_2 + S_1)\ f\ (PET)/(2S_m)$, where, W is the sum of rainfall and snowmelt for the month

(other terms defined above under Actual Evapotranspiration)

Solving for S_2:

$S_2 = (W + S_1(1 – f\ (PET)/(2S_m))/(1 + f\ (PET)/(2S_m))$

Calculating the soil moisture at the beginning and the end of the month provides an estimate of the soil moisture change.

K3.16.4.9 Water Available for Groundwater Recharge and Surface Water Runoff

Water available for groundwater recharge and surface water runoff (V) is calculated by subtracting monthly evapotranspiration and soil moisture change from the sum of rainfall and snowmelt (W) (Knight Piésold 2019g):

$$V = W – f(PET)(S_2 + S_1)/ (2S_m) – (S_2 – S_1)$$

This unit value of available water is multiplied by the area of each elevation band in each sub-catchment to provide input to the water balance calculation.

K3.16.4.10 Sub-Catchment Flow Distribution

Water available to groundwater and surface water systems based on the BWM, and how water moves through each system, are described in the following sections.

K3.16.4.11 Groundwater Recharge

To account for the effects of variable surface conditions, soil permeability, and available storage capacity on recharge rates, groundwater recharge of water available for runoff and recharge is estimated for the BWM (Knight Piésold 2019g). Groundwater recharge is only allowed when evaporation and soil moisture requirements are met; therefore, recharge does not occur during the summer when the soil is not fully saturated, or in the winter when the ground is covered by snow. Infiltration rate (I) in a given sub-catchment is a specified parameter that varies during calibration of the model and is set equal to the available water up to a volume equal to the product of an infiltration rate and the sub-catchment area (k_1A). For wetter months, a fraction (k_2) of the remaining available water also infiltrates ($k_2(V – k_1A)$). Therefore:

For precipitation less than or equal to k_1A

$$I\ (ft^3/month) = V$$

For precipitation greater than k_1A

$$I\ (ft^3/month) = k_1A + k_2(V – k_1A)$$

$$= k_2V + k_1A(1 – k_2)$$

This estimate of groundwater recharge is relevant at the time scale of the monthly water balance. Interflow and groundwater flow along very short paths are considered part of the surface water component with this monthly time increment. Available water not recharged remains as surface water, and the fractions k1 and k2 are selected during calibration. Additionally, the resulting recharge may include losses from stream channels (Knight Piésold 2019g).

K3.16.4.12 Groundwater Storage and Discharge

Groundwater storage and discharge in each sub-catchment are represented using a linear reservoir model (Knight Piésold 2019g). Water releases from groundwater storage at a rate determined by the product of the average volume of water in storage ($Z_1/2 + Z_2/2$) and a discharge factor (j). Monthly discharge (D) was set equal to:

$$D = j(Z_1/2 + Z_2/2)$$

Month-to-month storage is accounted in each sub-catchment, and groundwater discharge increases with increasing storage. The volume of water in storage is the sum of the storage in the preceding month (Z_1) plus the volume of water entering the system (I) minus the quantity discharged:

$$Z_2 = Z_1 + I - D$$

$$= Z_1 + I - j(Z_1/2 + Z_2/2)$$

Solving for Z_2:

$$Z_2 = (I + Z_1(1-jZ_1/2))/(1 + jZ_1/2)$$

Water entering the system includes groundwater recharge (meteoric recharge), stream losses originating in the sub-catchment, and groundwater flow contributed from the upstream sub-catchment (Figure K3.16-4). Water released from groundwater storage in the sub-catchment is either routed to the next sub-catchment downstream as groundwater, or discharged in the sub-catchment and routed downstream as surface water flow.

The maximum allowable groundwater flow leaving the sub-catchment as subsurface flow is estimated using Darcy's Law, which calculates groundwater flow as the product of transmissivity, width, and hydraulic gradient values estimated at a location beneath the hydrology station. These values may be adjusted during calibration.

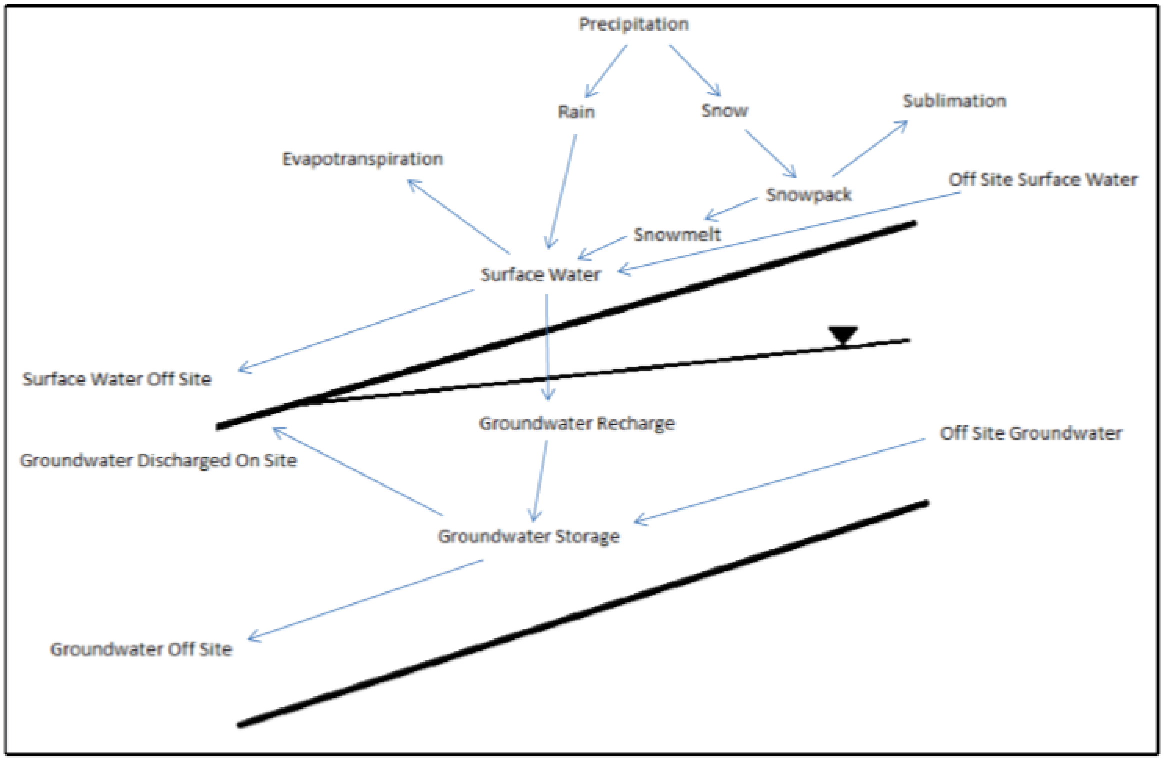
The volume of groundwater released from storage in excess of the groundwater flow off site is added to the surface water leaving the catchment. Groundwater storage and flow rates are calibrated primarily using streamflows measured at the site during the low-flow season. For a given volume of recharge, a discharge factor lower in value results in larger accumulated storage and a more uniform groundwater discharge rate (Knight Piésold 2019g).

K3.16.5 Baseline Watershed Model Description

The water balance model was refined through calibration and validation to be considered to "adequately" model the natural system. Model calibration is the process of adjusting model parameters within margins of reasonable uncertainties to achieve model representation of processes that generate results of interest. The purpose of model calibration is to ensure that the model produces flows that accurately simulates actual flows of the system being modeled. Model validation is the comparison of predictions from a mathematical model of a system to the measured behavior of the system. The purpose of model validation is to ensure that the model is able to produce outputs that mimic actual measured conditions using data inputs that were not part of the dataset that was used for the model calibration (Knight Piésold 2019g).

The difference in location between the project climate station and project hydrology stations and the short-term variability of conditions between the locations inherently limits the ability to obtain a perfect match between the modeled and measured streamflows on a month-to-month basis. However, the objective of the modeling is not to exactly replicate long-term historical flows, because the modeling pertains to the future and it is not possible to know exactly what climate and flow conditions will occur. Therefore, the objective of modeling is to reproduce wet and dry climate and associated hydrologic cycles characteristic of the project region, and generate a representative distribution of high and low flows, so that the timing and extent of wet and dry periods are correctly modeled, and the magnitudes of wet and dry flows are properly quantified calibration (Knight Piésold 2019g).

Figure K3.16-4: Water Balance Components



Source: Knight Piésold 2019g, Figure 2.1

K3.16.6 Watershed Model Calibration and Validation

The fit between modeled and measured streamflows was optimized to provide a good match to the following criteria based on visual inspection:

- Cumulative mass balance: ensure that the measured and simulated total mass of water at a gaging site are similar, and that the total volume of water leaving the modeled system is appropriate.
- Measured hydrograph: ensure that the measured time series of flows at project gaging stations generally match the simulated flows, including monthly mean flows and instantaneous winter flows.
- Flow distribution: ensure that the simulated flow record has a similar distribution of high and low flows to the measured record.

The fit to data was also assessed using the statistical Nash-Sutcliffe efficiency coefficient (NSE). The NSE provides a more objective approach that complements the visual inspection. The NSE is a commonly adopted statistical measure used in hydrology, and is calculated by comparing monthly values of measured and modeled streamflows in each sub-catchment. An efficiency of NSE = 1 corresponds to a perfect match of modeled discharge to the observed data.

The performance rating for NSE values is defined as:

- Very good: $0.75 < NSE < 1.00$
- Good: $0.65 < NSE < 0.75$
- Satisfactory: $0.50 < NSE < 0.65$
- Unsatisfactory: $NSE < 0.50$

A negative value indicates that the observed mean is a better predictor than the model (Knight Piésold 2019g).

Development of the watershed model was a multi-step process that proceeded as follows:

- Calibrate climate, groundwater, and surface water parameters to produce modeled flows that are similar to the measured streamflow at the project gaging stations (October 2005 to March 2010).
- Compare the measured and simulated streamflows over a validation period (October 2011 to September 2013).

Details of each step in the process are outlined in the following sections.

K3.16.6.1 Calibration

The BWM was calibrated to measured flows from October 2005 to March 2010 at three regional USGS hydrology stations and 19 project hydrology stations. This calibration period encompasses 4 hydrologic years with concurrent climate and streamflow data measured at the project prior to a gap in precipitation data in 2010. The calibration period extends beyond the end of the 2009 hydrologic year to include an additional winter low-flow season.

Measured streamflows used in the calibration procedure include varying and intermittent periods of synthetic monthly mean flows generated for the project station by regressing the measured streamflow data from the project stations with concurrent data from the USGS stations, and then applying the resulting regression relationships to the respective USGS station data for periods of missing data for the project stations. Streamflow data used to develop the correlation at each project station consisted of continuous flow measurement data and instantaneous flow measurements recorded during winter months. Winter flows are almost always sustained by groundwater discharge, and therefore typically do not change rapidly (Knight Piésold 2019g).

Calibrated groundwater and surface water parameters and estimated aquifer properties beneath gaging stations are summarized in Table K3.16-13. The simulated hydrologic regime showing locations of losing stream reaches and inter-basin groundwater flow is shown on Figure K3.16-2.

Comparisons between modeled and measured streamflow at the project gaging stations for the calibration period are provided on calibration plots in Knight Piésold 2019g (Appendix A, calibration plots A.1 through A.22). On each of these plots, the following are provided:

- Simulated and measured monthly streamflows in cubic feet per second (cfs): this plot provides a visual indication of the seasonal variation of the timing and magnitude of streamflow.
- Simulated and measured cumulative streamflow mass balance: this plot provides a measure of total water passing the gage over time.
- Semi-log plot of the distribution of simulated and measured flows: this plot provides a visual indication of the ability of the water balance to simulate the full range of measured flows.

A plot of measured monthly flows versus calculated monthly flows. This provides a direct indication of the model fit. Based on this fit, NSE factors were calculated (Table K3.16-14).

Table K3.16-13: Baseline Watershed Model Calibrated Model Parameters

Catchment	Area #	Sub-Catchment	Groundwater Parameters						Surface Water Parameters		
			K1 Factor[1]	K2 Factor[2]	Unit Discharge	Aquifer Transmissivity[3]	Aquifer Width[3]	Hydraulic Gradient at Discharge Point[3]	K1 Factor[1]	K2 Factor[2]	Unit Discharge
			(feet)	(%)	cfs/mi^2)	(ft^2/day)	(feet)	(ft/ft)	(feet)	(%)	(cfs/mi^2)
North Fork Koktuli	Area 13	NK100C	0.18	0.18	0.13	13,950	4,000	0.010	0.4	0.4	1.2
	Area 14	NK119A	0.09	0.09	0.160	2,790	250	0.100	0.25	0.25	1.5
	Area 12	NK119B	0.27	0.27	0.08	4,929	5,000	0.020	0.6	0.6	1.6
	Area 15d	NK100B	0.10	0.10	0.600	260,401	400	0.009	0.4	0.4	1.2
	Area 15b	NK100A1	0.10	0.10	0.580	46,500	3,000	0.004	0.27	0.27	1.9
	Area 15	NK100A	0.11	0.11	0.600	27,900	4,000	0.003	0.27	0.27	1.9
South Fork Koktuli	Area 3a	SK100G	0.17	0.17	0.200	186	1,500	0.001	0.4	0.4	1.2
	Area 3	SK100F	0.14	0.14	0.290	651	1,500	0.150	0.34	0.34	1.3
	Area 2a[4]	SK124Aa	0.06	0.06	0.450	23,250	100	0.020	0.1	0.1	1.9
	Area 2[4]	SK124A	0.17	0.17	0.280	35,340	3,300	0.004	0.15	0.15	1.9
	Area 5	SK100C	0.22	0.22	0.250	195,300	5,000	0.003	0.35	0.35	1.3
	Area 1	SK119A	0.13	0.13	0.250	32,550	600	0.010	0.25	0.25	1.5
	Area 4a	SK100B1	0.13	0.13	0.700	148,800	2,300	0.003	0.1	0.1	1.3
	Area 4	SK100B	0.13	0.13	0.330	46,500	2,000	0.003	0.6	0.6	1.2
	Area 8	SK100A	0.09	0.09	0.230	83,700	2,500	0.005	0.5	0.5	1.4
Upper Talarik Creek	Area 9a	UT100E	0.24	0.24	0.125	837	3,000	0.025	0.37	0.37	1.4
	Area 9	UT100D	0.18	0.18	0.205	24,645	1,500	0.006	0.4	0.4	1.4
	Area 10c	UT100C2	0.24	0.24	0.350	46,500	1,200	0.005	0.3	0.3	1.5
	Area 10b	UT100C1	0.25	0.25	0.040	93,000	1,200	0.005	0.2	0.2	1.4
	Area 10a	UT100C	0.25	0.25	0.040	14,880	1,200	0.005	0.25	0.25	1.5
	Area 7	UT119A	0.35	0.35	0.009	2,790	3,000	0.030	0.5	0.5	0.7
	Area 10	UT100B	0.15	0.15	0.500	18,600	1,200	0.005	0.34	0.34	1.5
	Area 11	UT100APC1	0.18	0.18	0.160	18,600	1,500	0.006	0.2	0.2	1.4

Notes:
[1] K1 factor represents the first quantity of available water to recharge groundwater/surface water (see Groundwater Recharge above for more detailed explanation of this term).
[2] K2 factor represents the proportion of remaining available water to recharge groundwater/surface water (see Groundwater Recharge above for more detailed explanation of this term).
[3] Aquifer transmissivity, width, and hydraulic gradient are estimates of the aquifer properties at the surface water discharge location.
[4] Area 2 sub-catchment (SK124A) is separated into upland area (Area 2a) and lowland area (Area 2) to simulate infiltration of streamflow into channel in upper portion of reach.
% = percent
cfs/mi^2 = cubic feet per second square miles
ft^2/day = square feet per day
ft/ft = feet per foot
Source: Knight Piésold 2019g, Table 3.1

Table K3.16-14: Nash Sutcliff Efficiency (NSE) Results for Gaging Stations

Catchment	Area #	Sub-Catchment	Nash-Sutcliffe Model Efficiency Coefficient	
			Calibration Period (Oct 2005 to March 2010)	Validation Period (Oct 2011 to Sept 2013)
North Fork Koktuli	Area 13	NK100C	0.78	0.82
	Area 14	NK119A	0.78	0.70
	Area 12	NK119B	0.60	0.63
	Area 15d	NK100B	0.81	0.81
	Area 15b	NK100A1	0.84	0.88
	Area 15	NK100A	0.84	0.89
South Fork Koktuli	Area 3a	SK100G	0.63	0.82
	Area 3	SK100F	0.83	0.86
	Area 2	SK124A	0.88	0.87
	Area 5	SK100C	0.83	0.91
	Area 1	SK119A	0.89	0.72
	Area 4a	SK100B1	0.87	0.85
	Area 4	SK100B	0.86	0.90
	Area 8	SK100A	0.87	0.90
Upper Talarik Creek	Area 9a	UT100E	0.81	0.74
	Area 9	UT100D	0.85	0.84
	Area 10c	UT100C2	0.82	0.80
	Area 10b	UT100C1	0.70	0.83
	Area 10a	UT100C	0.73	0.85
	Area 7	UT119A	0.11	0.22
	Area 10	UT100B	0.84	0.87
	Area 11	UT100APC1	0.78	0.86

Source: Knight Piésold 2019g

The calibration plots in Knight Piésold 2019g (Appendix A, calibration plots A.1 through A.22) show that measured flows are generally well matched by the flows generated by the BWM for the calibration period; this conclusion is supported by NSE values shown in Table K3.16-14, which are consistently quite high. The only station where the NSE value is notably low is station UT119A; flows at this gage are relatively constant year-round due to groundwater discharge that includes inter-basin groundwater flow from the SFK watershed. The error in the simulated flows is quite small on a percentage basis, and because the variation in the flows does not differ much from the average, the resulting NSE value is low. At all other stations, the minimum NSE is 0.60, and the average is 0.77 (Knight Piésold 2019g).

The difference between measured and predicted flows for each month of the calibration period is provided in PLP 2020-RFI 161 (Tables 1 and 2). In general, calibration results indicate that 42 percent of the time, the predicted average monthly discharge was greater than the measured monthly discharge (PLP 2020-RFI 161). The positive and negative deviations between measured and predicted flows from PLP 2020-RFI 161 are summarized in Table K3.16-18.

The greatest difference between modeled and measured flows in the calibration plots shown in Knight Piésold 2019g (Appendix A, calibration plots A.1 through A.22) is at the low end of the flow distribution curve, although these differences are quite small and are emphasized by the log scale. The winter flows during 2009 were among the lowest flows simulated by the model; on closer examination of the hydrographs for this year, it was evident that streamflows in January 2009 spiked at the USGS gaging stations due to a warm-period rain event. Temperature inputs to the watershed model are mean monthly values and do not fully capture the effects of this short time scale increase in temperature, and the BWM does not adequately simulate the corresponding short-term rise in winter flows. Therefore, the BWM predicts January 2009 streamflows lower than the measured flows at the USGS gages. However, for the purpose of engineering and aquatic habitat study purposes, the underestimation of low flows is conservative, and therefore the calibration of the BWM targeted the low end of the range of low flows (Knight Piésold 2019g).

K3.16.6.2 Validation

Results of the model validation are shown in Knight Piésold 2019g (Appendix B, validation plots B.1 through B.22), using similar plots to those developed for the calibration period. As with the calibration, measured flows are generally well matched by the flows generated by the BWM for the validation period. The cumulative flow plots, which show the total modeled and measured flows leaving a catchment, show a comparable match during the validation period to the calibration period. The streamflow distribution plots indicate that the model represents the occurrence of higher flows in the simulated records well; however, despite the lower-frequency flows being very well simulated at the USGS gages, they are overpredicted by the model at several project stations. This difference is pronounced by the log scale, and also may be influenced by the fact that most of the “measured” low flows during the validation period were based on regression models developed with the USGS station data, and were not validated with instantaneous winter flow measurements; nonetheless, the validation results suggest that winter low flows may be slightly overestimated by the model. The validation plots in Knight Piésold 2019g (Appendix B, validation plots B.1 through B.22) show that measured flows are generally well matched by flows generated by the BWM for the validation period. This is supported by validation NSE values shown in Table K3.16-13. As with the calibration NSE results, the validation NSE at UT119A was notably low. At all other stations, the minimum validation NSE is 0.63, and the average is 0.83.

The difference between measured and predicted flows for each month of the validation period is provided in PLP 2020-RFI 161 (Tables 1 and 2). In general, validation results indicate that 67 percent of the time, the predicted average monthly discharge was greater than the measured monthly discharge (PLP 2020-RFI 161). The positive and negative deviations between measured and predicted flows from PLP 2020-RFI 161 are summarized in Table K3.16-19.

Flow distribution curves that include all simulated and measured flows over the calibration and validation period (October 2005 to March 2010, and October 2011 to September 2013) are presented in Knight Piésold 2019g (Appendix C, flow distribution plots C.1 through C.3). The plots demonstrate that the model is able to simulate the full range of observed streamflows over the combined calibration and validation periods, and is considered a suitable tool for generating long-term streamflows and assessing potential affects to streamflow attributed to project development. Calibration and validation periods consider the streamflow response over a full range of high to low flows, and the match between measured and modeled flows provides confidence that the model is suitable for simulating a full range of surface and groundwater flows for streams in the watershed model area (Knight Piésold 2019g).

K3.16.6.3 Long-Term Streamflows

Long-term estimates of streamflow and groundwater flows for the period from January 1942 to December 2017 were simulated at model calibration nodes by using the long-term record of temperature and precipitation from Iliamna airport into the BWM. Mean monthly and average annual streamflow estimates for the 76-year period are presented in Table K3.16-15. A summary of the simulated mean annual surface water and groundwater flows for each sub-catchment in the calibration and validation exercise is provided in Table K3.16-16, and corresponding precipitation and groundwater recharge and discharge estimates are provided in Table K3.16-16. Groundwater recharge values in Table K3.16-17 include recharge from precipitation, as well as recharge from stream infiltration where a stream is modeled to infiltrate the channel bed in a sub-catchment (Knight Piésold 2019g).

Table K3.16-15: Baseline Watershed Model—Monthly Mean Streamflow Estimates (cfs)

Month	South Fork Koktuli								Upper Talarik Creek								North Fork Koktuli					
	Area 1	Area 2	Area 3a	Area 3	Area 4a	Area 4	Area 5	Area 8	Area 7	Area 9a	Area 9	Area 10c	Area 10b	Area 10a	Area 10	Area 11	Area 12	Area 13	Area 14	Area 15d	Area 15b	Area 15
	SK119A	SK124A	SK100G	SK100F	SK100B1	SK100B	SK100C	SK100A	UT119A	UT100E	UT100D	UT100C2	UT100C1	UT100C	UT100B	UT100APC	NK119B	NK100C	NK119A	NK100B	NK100A1	NK100A
Jan	8	3	6	11	45	68	9	135	27	5	13	50	64	84	123	144	1	22	6	31	73	86
Feb	7	2	5	9	35	55	5	113	26	5	11	39	52	72	108	126	0	19	5	26	61	72
Mar	5	1	4	7	28	46	3	99	26	4	9	31	43	63	98	113	0	16	4	22	50	60
Apr	5	2	4	7	27	47	5	112	26	4	9	31	44	64	102	120	0	15	5	22	55	71
May	71	54	27	63	266	371	125	500	32	18	59	209	261	315	424	525	10	96	52	166	449	576
Jun	101	59	30	72	297	402	137	464	34	20	62	237	273	318	412	474	16	114	75	214	483	577
Jul	48	21	18	40	151	216	63	288	31	11	33	138	157	184	245	279	7	65	32	111	249	291
Aug	51	30	16	37	168	237	64	339	29	10	31	129	150	178	244	291	4	54	34	99	261	318
Sept	57	35	20	46	198	277	84	394	29	13	41	163	189	222	301	360	6	68	39	120	322	400
Oct	41	23	18	41	162	230	73	342	29	12	38	151	174	204	279	328	6	63	28	103	269	334
Nov	24	12	14	28	107	153	46	250	28	9	28	111	131	157	220	260	3	46	15	69	175	219
Dec	12	5	9	16	63	93	21	172	27	6	18	72	87	110	156	182	1	30	7	42	100	121
Avg. Annual	36	21	14	31	129	183	53	267	29	10	29	113	135	164	226	267	4.7	51	25	85	212	260

Notes:
Flows are averaged over the period from 1942 to 2017
cfs = cubic feet per second
Source: Knight Piésold 2019g, Table 4.1

Table K3.16-16: Baseline Watershed Model—Average Annual Simulated Surface Water and Groundwater Flows (1942-2017)

Catchment	Area Number	Sub-Catchment	Contributing Area	Mean Annual Runoff		Mean Annual Unit Discharge	Underflow (Groundwater Beneath Gage)[2]	Inter-Basin Groundwater Flow[2]	Average March Streamflow
			(mi^2)	(cfs)	(in/yr)	(cfs/mi^2)	(cfs)	(cfs)	(cfs)
North Fork Koktuli	Area 13	NK100C	24.3	51	28	2.1	6.4	0.9 to UT100E	16
	Area 14	NK119A	7.8	25	44	3.2	0.8		4
	Area 12	NK119B	4.0	4.7	16	1.2	5.4		0.3
	Area 15d	NK100B	37.3	86	31	2.3	11		23
	Area 15b	NK100A1	85.3	213	34	2.5	6.4		51
	Area 15	NK100A	105.8	260	33	2.5	3.9		61
South Fork Koktuli	Area 3a	SK100G	5.5	14	35	2.6	0.003		5
	Area 3	SK100F	11.9	31	36	2.6	1.7		7
	Area 2a	SK124Aa	5.4	18	45	3.3	0.5		1
	Area 2	SK124A	8.5	21	33	2.4	5.1		1
	Area 5	SK100C	37.5	53	19	1.4	29	21 to UT119A	3
	Area 1	SK119A	10.7	36	45	3.3	2.3		5
	Area 4a	SK100B1	54.4	129	32	2.4	12		28
	Area 4	SK100B	69.3	183	36	2.6	3.2		46
	Area 8	SK100A	106.9	267	34	2.5	12		101
Upper Talarik Creek	Area 9a	UT100E	3.1	10	43	3.2	0.7	0.9 from NK100C	4
	Area 9	UT100D	12.0	29	33	2.5	3.4		9
	Area 10c	UT100C2	48.3	114	32	2.4	3.2		32
	Area 10b	UT100C1	60.4	136	31	2.2	6.5		44
	Area 10a	UT100C	71.0	164	31	2.3	1.0		64
	Area 7	UT119A	4.0	29	96	7.1	2.9	21 from SK100C	27
	Area 10	UT100B	86.2	227	36	2.6	1.3		99
	Area 11	UT100APC1	101.5	267	36	2.6	1.9		115

Notes:
[1] Values are presented as mean annual, and calculated over the period from 1942 to 2017
[2] Underflow represents the groundwater flow to the next downstream catchment. Inter-basin groundwater represents groundwater flow to a sub-catchment other than the downstream sub-catchment
% = percent
cfs/mi^2 = cubic feet per second per square mile
in/yr = inches per year

Source: Knight Piésold 2019g, Table 4.2

Table K3.16-17: Baseline Watershed Model—Summary of Precipitation, Runoff, and Groundwater Water Balance Components

Catchment	Area Number	Sub-Catchment	Sub-Catchment Precipitation Factor	Precipitation	Net Precipitation[2]	Surface Runoff from Precipitation[3]	Grounwater Recharge[3,4]	Groundwater Discharge[3,4]
			(-)	(in/yr)	(in/yr)	(in/yr)	(in/yr)	(in/yr)
North Fork Koktuli	Area 13	NK100C	0.89	48	33	17	16	12
	Area 14	NK119A	1.05	58	45	35	10	9
	Area 12	NK119B	0.89	49	35	13	21	3
	Area 15d	NK100B	0.95	49	35	25	10	30
	Area 15b	NK100A1	0.93	49	35	25	25[4]	26
	Area 15	NK100A	0.90	44	30	20	10	12
South Fork Koktuli	Area 3a	SK100G	0.95	49	36	20	15	15
	Area 3	SK100F	1.05	53	40	20	14	11
	Area 2	SK124A	1.00	54	42	32	19[4]	10
	Area 5	SK100C	1.03	51	36	17	45[4]	10
	Area 1	SK119A	1.13	60	48	34	15	12
	Area 4a	SK100B1	1.15	56	45	31	22[4]	65
	Area 4	SK100B	1.10	53	41	28	14	22
	Area 8	SK100A	1.02	47	34	24	45[4]	42
Upper Talarik Creek	Area 9a	UT100E	1.10	54	42	20	22	23
	Area 9	UT100D	0.95	48	34	18	16	12
	Area 10c	UT100C2	0.87	47	32	13	19	19
	Area 10b	UT100C1	0.85	44	29	10	18	14
	Area 10a	UT100C	0.98	47	30	11	19	26
	Area 7	UT119A	1.00	47	34	9	25	87
	Area 10	UT100B	1.15	50	37	22	15	18
	Area 11	UT100APC1	1.09	49	37	20	17	17

Notes:

[1] Values are presented as mean annual and calculated over the period from 1942 to 2017

[2] Net precipitation = rainfall = snowmelt – evaporation – change in soil moisture

[3] Surface water runoff and groundwater recharge and discharge values represent values generated in the sub-catchment only, and not contributions from upstream sub-catchments.

[4] Recharge includes recharge from stream channel infiltration in addition to meteoric water where indicated

in/yr = inches per year

Source: Knight Piésold 2019g, Table 4.3

Table K3.16-18: Summary of the Deviations between the Measured and Predicted Values during Calibration

Site	Total Number of Months	Positive Deviations				Negative Deviations			
		Number of Months	10th Percentile	50th Percentile	90th Percentile	Number of Months	10th Percentile	50th Percentile	90th Percentile
NFK100A	54	22	5	20	44	32	-49	-24	-6
NFK100A1	54	24	4	23	51	30	-48	-24	-3
NFK100B	54	23	6	25	57	31	-51	-20	-9
NFK119A	54	24	11	28	76	30	-55	-25	-5
NFK100C	54	25	2	24	66	29	-44	-23	-4
NFK119B	46	16	14	291	1175	30	-100	-70	-9
SK100A	54	22	1	19	56	32	-28	-14	-3
SK100C	44	19	16	40	300	25	-86	-32	-6
SK100B	54	17	12	35	70	37	-42	-21	-2
SK100B1	54	24	6	22	77	30	-50	-24	-2
SK100F	54	24	4	23	57	30	-48	-21	-7
SK100G	54	24	9	27	73	30	-41	-19	-5
SK124A	50	23	9	60	188	27	-100	-51	-13
SK119A	54	22	5	31	59	32	-59	-31	-5
UT100APC1	54	16	6	19	44	38	-27	-15	-5
UT100B	54	20	1	12	30	34	-30	-15	-6
UT100C	54	19	4	22	54	35	-34	-18	-5
UT100C1	54	19	7	27	59	35	-40	-17	-4
UT100C2	54	22	2	17	52	32	-43	-23	-5
UT100D	54	25	3	14	43	29	-44	-24	-2
UT100D	54	25	3	14	43	29	-44	-24	-2
UT100E	54	22	6	18	48	32	-36	-15	-3
UT119A	54	40	8	384	732	14	-56	-35	-14
Median	**54**	**22**	**6**	**23**	**57**	**30**	**-44**	**-23**	**-5**

Notes:
1. The Baseline Watershed Model was calibrated using data from October 2005 to March 2010: 54 months
2. Computations were preformed using data in Tables 1 and 2 – Measured and Predicted Streamflows.xlsm" from PLP 2020-RFI 161

Table K3.16-19: Summary of the Deviations between the Measured and Predicted Values during Validation

Site	**Total Number of Months**	**Positive Deviations**				**Negative Deviations**			
		Number of Months	**10th Percentile (%)**	**50th Percentile (%)**	**90th Percentile (%)**	**Number of Months**	**10th Percentile (%)**	**50th Percentile (%)**	**90th Percentile (%)**
NFK100A	24	17	3	18	82	7	-24	-18	-5
NFK100A1	24	17	5	20	79	7	-23	-13	-6
NFK100B	24	15	10	37	95	9	-26	-10	-5
NFK119A	24	15	6	20	78	9	-36	-18	-1
NFK100C	24	15	9	21	75	9	-33	-8	-5
NFK119B	16	6	86	140	367	10	-54	-39	-28
SK100A	24	18	6	23	61	6	-21	-13	-8
SK100C	15	9	8	38	186	6	-28	-23	-9
SK100B	24	17	2	35	77	7	-20	-17	-5
SK100B1	24	16	20	68	225	8	-23	-15	-8
SK100F	24	15	7	40	98	9	-32	-14	-4
SK100G	24	17	11	31	65	7	-21	-13	-1
SK124A	23	10	22	50	1340	13	-100	-22	-5
SK119A	24	14	9	22	118	10	-25	-17	-1
UT100APC1	24	13	2	23	42	11	-23	-17	-1
UT100B	24	14	7	17	46	10	-22	-14	-6
UT100C	24	16	6	23	48	8	-37	-17	-3
UT100C1	24	18	2	23	72	6	-48	-19	-12
UT100C2	24	17	5	39	109	7	-51	-18	0
UT100D	24	16	17	39	100	8	-44	-14	-8
UT100D	24	16	17	39	100	8	-44	-14	-8
UT100E	24	19	4	18	56	5	-37	-9	-3
UT119A	24	5	1	1	5	19	-21	-12	-1
Median	**24**	**16**	**7**	**23**	**79**	**8**	**-28**	**-15**	**-5**

Notes:
1. The Baseline Watershed Model was validated using data from October 2011 to September 2013: 24 months
2. Computations were preformed using data in Tables 1 and 2 – Measured and Predicted Streamflows.xlsm" from PLP 2020-RFI 161

K3.16.7 Long-Term Climate Change

K3.16.7.1 Temperature

The Knight Piésold studies (2009, 2018g) noted that the 1943 through 2016 temperature records for Iliamna airport appear to indicate that temperatures near the mine site are increasing over time. Mean temperatures appear to be increasing an average of 0.06°F per year, and annual minimum daily temperatures appear to be increasing an average of 0.13°F per year. Assuming this trend would continue, over the next 3 decades, this equates to an increase of 1.8°F in the mean annual temperature and an increase of 3.9°F in the average annual minimum daily temperature. These changes are generally consistent with the climate change projections of the US Global Change Research Program (USGCRP 2017), 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, Knight Piésold studies (2009, 2018g) went on to evaluate the possible impact of the Pacific Decadal Oscillation (PDO). Based on long-term temperature data for Port Alsworth, Intricate Bay, Iliamna, and Nome, it appears that there was a marked change in the mean annual temperature starting in 1977; the year a shift occurred in the PDO (Knight Piésold 2009, Figures 9, 10, and 11). When the cold and warm phases of the PDO are considered, the temperatures show no significant trend (Knight Piésold 2018g). Temperatures in each period appear reasonably consistent (1943 to 1976 versus 1977 to 2016), but the mean annual temperature for the pre-shift period is 1.9°F lower than for the post-shift period, and the mean annual minimum daily temperature is 5.6°F lower (Knight Piésold 2018g). The PDO has been in a warm phase for the last 40 years, and based on past patterns, can be expected to shift into a cold phase in the future. This shift may or may not be accompanied by a general drop in temperatures.

When comparing temperatures from the pre- and post-PDO, cold temperatures appear to have increased more than warm temperatures (Knight Piésold 2018g). Temperatures for winter months have increased more than temperatures for any other season. Annual minimum daily temperatures have increased more than maximum daily temperatures. However, during the cold and warm periods of the PDO, none of the temperature series show any significant trends (Knight Piésold 2018g).

Average monthly temperature predictions were obtained from Scenarios Network for Alaska and Arctic Planning (SNAP 2018) based on Scenario A1B[2] (see also Section 3.20, Air Quality). The predictions suggest that the average monthly Iliamna Airport temperature in 2040 through 2049 will be 1.6 to 7.0ºF higher than the average monthly temperatures between 1981 and 2010 (see Section 3.20, Air Quality, Table 3.20-6 and Table 3.20-7). The annual average temperature is estimated to increase by about 3.8ºF. The SNAP predictions are about twice the Knight Piésold (2009 and 2018g) predicted increase, and about 50 percent more than the USGCRP (2017) estimated increase "under all plausible future climate scenarios."

---

[2] The predictions are the average of five models; represent the mid-range emissions; and have a resolution of 771 meters.

K3.16.7.2 Precipitation

The Knight Piésold (2009) study also evaluated historical precipitation data looking for possible trends in precipitation magnitude and frequency. Plots of historical annual precipitation at Iliamna, Port Alsworth, and Intricate Bay show no common trend, suggesting that the precipitation regime near the mine site is not undergoing a consistent change (Knight Piésold 2009, Figure 14). A statistical analysis of trends indicated that, where trends are statistically significant, they vary in trend direction from location to location. For instance, Port Alsworth recorded statistically significant negative changes in precipitation volume in the spring, summer, and on an annual basis, with no statistically significant change in winter or fall. Records for Intricate Bay and Iliamna show statistically significantly positive volume increases during the fall, but no statistically significant changes at other times of the year, or on an annual basis (Knight Piésold 2009, Table 1). Similarly, evaluating the Iliamna data according to the timing of the cold and warm phases of the PDO did not reveal any significant trends (Knight Piésold 2018g). The mean annual precipitation values for the cold and warm phases of the PDO are 26.3 and 26.2 inches, respectively.

Although the USGCRP report (2017) indicates 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 (Knight Piésold 2018g). Knight Piésold (2018g) found no statistically significant trend in the 1943 to 2016 Iliamna winter/spring precipitation record. Furthermore, splitting the winter/spring precipitation record according to the timing of the cold and warm phases of the PDO revealed that there was no significant trend during the cold phase, but that there is a significant decreasing trend during the warm phase (Knight Piésold 2018g). The mean winter/spring precipitation for the two periods is 10.2 and 10.3 inches, respectively.

Average monthly precipitation predictions from SNAP (2018) based on Scenario A1B indicate that the average monthly Iliamna airport precipitation in 2040 through 2049 will be 0 to 0.7 inch higher than the average monthly precipitation between 1981 and 2010 (Section 3.20, Air Quality, Table 3.20-6 and Table 3.20-7). The annual average precipitation is estimated to increase by about 1.7 inches.

With regard to the possibility that climate change will lead to an increase in extreme precipitation events, Knight Piésold (2018g) evaluated the 1943 to 2016 annual maximum daily precipitation record for Iliamna. Based on their analysis, there are no trends in the record as a whole.

The National Weather Service (NWS) also evaluated whether there is a trend in the extreme precipitation dataset for Alaska. During the process of developing new precipitation-duration-frequency statistics for the State of Alaska, the NWS tested the assumption that there was no statistically significant trend in the 1-day and 1-hour annual maximum daily precipitation record. The NWS precipitation-duration-frequency statistics are prepared with the understanding that they would be used to predict the magnitude and frequency of future rainfall-runoff flood events, in addition to other uses. Statistical tests were conducted to determine the likelihood of trends (both a parametric t-test and a non-parametric Mann-Kendal test) in the data at the 5 percent significant level. Only stations with 40 or more years of record were used.

With regard to the 1-hour annual maximum precipitation data, there were only 12 stations with a 40-plus-year record length. Neither of the statistical tests detected a trend in the data for a single station.

With regard to the 1-day annual maximum precipitation data, there were 154 stations with 40 or more years of record. At 85 percent of the stations, no statistically significant trends were detected. At 8 percent of the stations, a positive trend was detected, and at 7 percent of the stations, a negative trend was detected. Spatial maps did not reveal any spatial cohesiveness in positive and negative trends. Based on review of Figure A.2.1 (NWS 2012), the three closest stations to the mine site indicated no significant trend at the 5 percent significance level.

Knight Piésold (2018g) also evaluated the possibility of trends in extreme precipitation corresponding to the cold and warm phases of the PDO, and concluded that there were no trends. The mean precipitation value for the cold phase of the PDO is 1.64 inches, and the mean precipitation value of the warm phase of the PDO is 1.73 inches (Knight Piésold 2018g). However, the coefficient of variation (i.e., standard deviation divided by the mean) is 0.23 for the cold phase, and 0.33 for the warm phase (Knight Piésold 2018g). The difference indicates that there is greater year-to-year variation during the recent warm phase than there was during the past cold phase. This has significant implications for design. For instance, using data from the warm phase of the PDO to calculate the Probable Maximum Precipitation results in a value that is approximately 40 percent greater than would be computed based on the cold-phase data (Knight Piésold 2018g).

K3.16.7.3 Streamflow

With regard to streamflow, Knight Piésold (2009) evaluated the discharge records for three regional USGS streamflow gaging stations in an attempt to detect changes attributable to climate change. The three stations were: Nuyakuk River Station (15302000), Little Susitna River Station (15290000), and Kuskokwim River Station (15304000). These three stations were selected because of their length and completeness of record, proximity to the mine site, circumferential spacing around the mine site, varied range in watershed size, and varied exposure to coastal and continental climate regimes.

Annual mean discharge-time plots (Knight Piésold 2009, Figures 18, 19, and 20) for the three stations indicate a statistically significant trend of increasing streamflow for the Nuyakuk River, but no significant trend for either the Little Susitna River or Kuskokwim River. Because the Kuskokwim River basin has a very small percentage of glacier cover and the other two basins contain no glaciers, substantial glacier melt is not likely confounding the results. The increase in the Nuyakuk River discharge occurs in every month (Knight Piésold 2009, Figure 21). This is unexpected because increasing temperatures and associated increases in evapotranspiration would be expected to result in a lowering of flows during the warmest period of the year (Knight Piésold 2009). In this instance, it appears that the possible increase in precipitation exceeds any increase in evapotranspiration (Knight Piésold 2009). The Little Susitna and Kuskokwim rivers generally exhibit increases in streamflow during the coolest months of the year, and decreases in streamflow in the warmest months of the year (Knight Piésold 2009, Figures 22 and 23). These changes are generally consistent with those expected for watersheds that are warming, but have little or no increase in precipitation.

Knight Piésold (2009) also evaluated annual instantaneous peak discharge trends. The apparent trends are not particularly strong (Knight Piésold 2009, Figures 24, 25, and 26), and only the trend for the Kuskokwim River data is statistically significant, which indicated a decreasing trend in the magnitude of the annual instantaneous peak discharge.

Knight Piésold (2009) concludes that overall, both the mean annual discharge and the annual peak instantaneous discharge appear to be relatively stable. However, the annual hydrograph shape appears to be getting “flatter,” with greater winter flows and lower summer flows.

The USGS evaluated and used the flood-peak data set to develop regression equations to predict flood-peak discharge for use in designing infrastructure throughout Alaska (Curran et al. 2016). Statistically significant trends were detected at 43 of the 387 stream gages evaluated. Of the 43 stream gages with significant trends, 22 stream gages show increasing trends, and 21 stream gages showed decreasing trends. The report (Curran et al. 2016) goes on to state that:

> No underlying cause of any trend was obvious when considering spatial distribution, regulation, land-use changes, and urbanization. Although a cursory consideration of climate as a variable in peak-flow trends suggested no obvious patterns, a thorough assessment of any correlation of significant peak-flow trends at individual sites to temporal changes in climate was beyond the scope of this report.

In an effort to further assess the potential effects that higher temperatures might have on streamflow patterns at the mine site, Knight Piésold (2009) ran a water balance model that assumed that the increasing temperature trend experienced over the past 66 years in the mine site area would continue at the same rate over the next 66 years. Based on this assumption, the model generally predicted higher base flows in the winter, lower flows in the spring, lower summer baseflows, and similar but slightly lower fall rainfall flows (Knight Piésold 2009). Knight Piésold (2009) also concluded that the model predicted lower mean annual discharge values (which is consistent with higher evapotranspiration losses), but that these changes may be exaggerated due to the influence of the PDO, which was not considered in this analysis.