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 (mi²)	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 (mi^2)	Record Length (years)	Average Annual Discharge (cfs)			
				Lowest Year	Median Year	Average Year	Highest Year
North Fork Koktuli River	NK100A	105.86	8	198.2	239.1	247.2	316.5
	NK100A1	85.34	8	169.0	198.3	205.0	260.9
	NK100B	37.32	8	64.2	81.6	84.3	112.8
	NK100B1[1]	37.18	0	-	-	-	-
	NK100C	24.35	8	36.7	47.2	47.5	63.2
	NK100C1[1]	24.05	0	-	-	-	-
	NK119A	7.76	8	14.8	22.0	23.8	35.5
	NK119B	3.97	8	2.5	4.1	4.3	6.5
South Fork Koktuli River	SK100A	106.92	8	215.1	267.4	259.3	303.9
	SK100B	69.33	8	145.4	188.5	183.7	229.0
	SK100B1	54.41	8	98.8	135.6	130.3	166.3
	SK100C	37.5	8	32.8	50.7	47.7	65.7
	SK100F	11.91	8	24.1	30.3	30.1	37.4
	SK100G	5.49	8	10.3	13.0	13.2	16.3
	SK119A	10.73	8	26.9	34.1	35.2	50.9
	SK124A	8.52	8	14.0	19.3	19.4	26.2
Upper Talarik Creek	UT100-APC3	134.16	8	286.0	326.2	324.1	351.1
	UT100-APC2	110.16	8	253.6	293.3	293.6	333.0
	UT100-APC1	101.51	8	230.0	264.5	261.8	288.5
	UT100B	86.24	8	190.0	223.0	221.4	251.0
	UT100C	69.47	8	134.2	155.0	157.5	185.7
	UT100C1	60.37	8	103.2	121.2	121.3	144.2
	UT100C2	48.26	8	87.6	105.5	104.7	125.1
	UT100D	11.96	8	23.8	28.4	27.8	31.9
	UT100E	3.1	8	7.5	9.1	9.0	10.5
	UT106-APC1	14.14	8	39.5	43.8	43.8	48.5
	UT119A	4.05	8	26.5	29.0	29.2	31.6
	UT135A	20.42	8	32.6	38.7	39.9	47.8

Notes:

[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
mi^2 = 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.

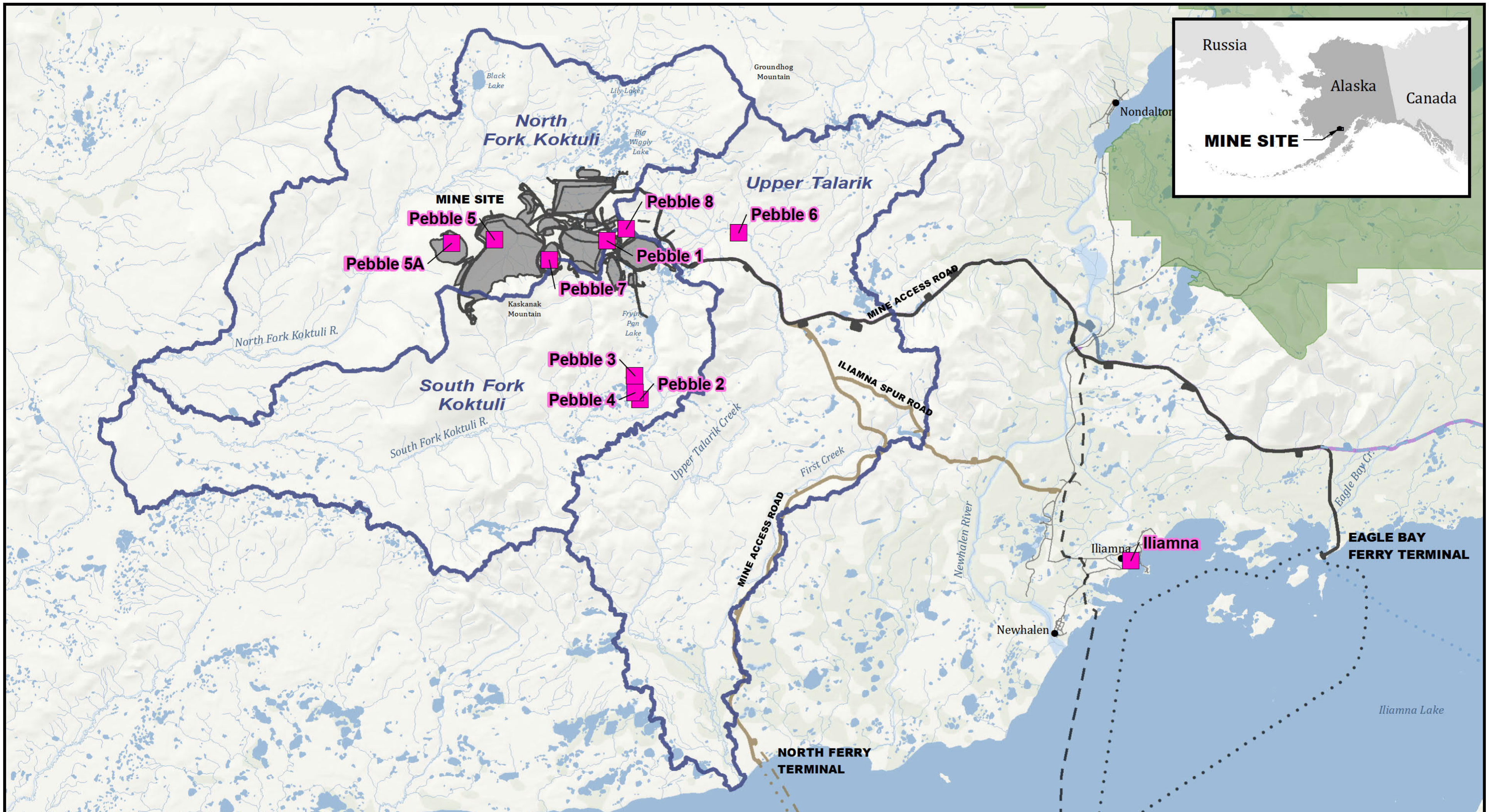
To evaluate surface water and groundwater interaction, a month-to-month water balance approach was selected, which included a semi-distributed spreadsheet method (Schlumberger 2011a; Knight Piésold 2019g). The semi-distributed model was selected due to the relatively large study area (approximately 300 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

US Army Corps of Engineers

2 0 2 4

Miles

Meteorological Stations

Major Drainage Boundary

Action Alternatives

Ferry Routes

Natural Gas Pipelines

Alternative 1a

Alternative 1

Alternative 2

Alternative 2 Newhalen River North Crossing Variant

Alternative 3

Other Features

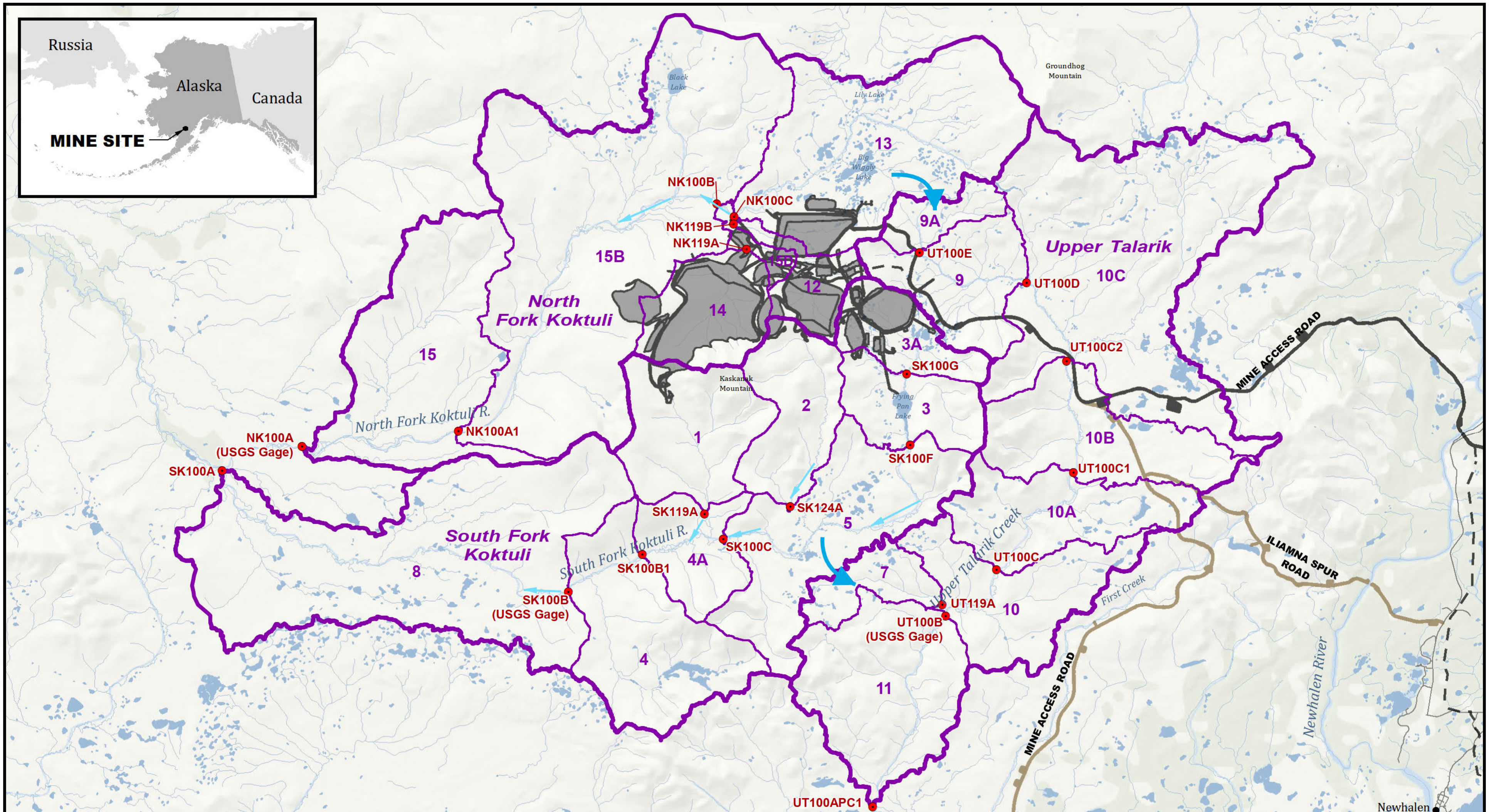
Local Roads

National Park

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

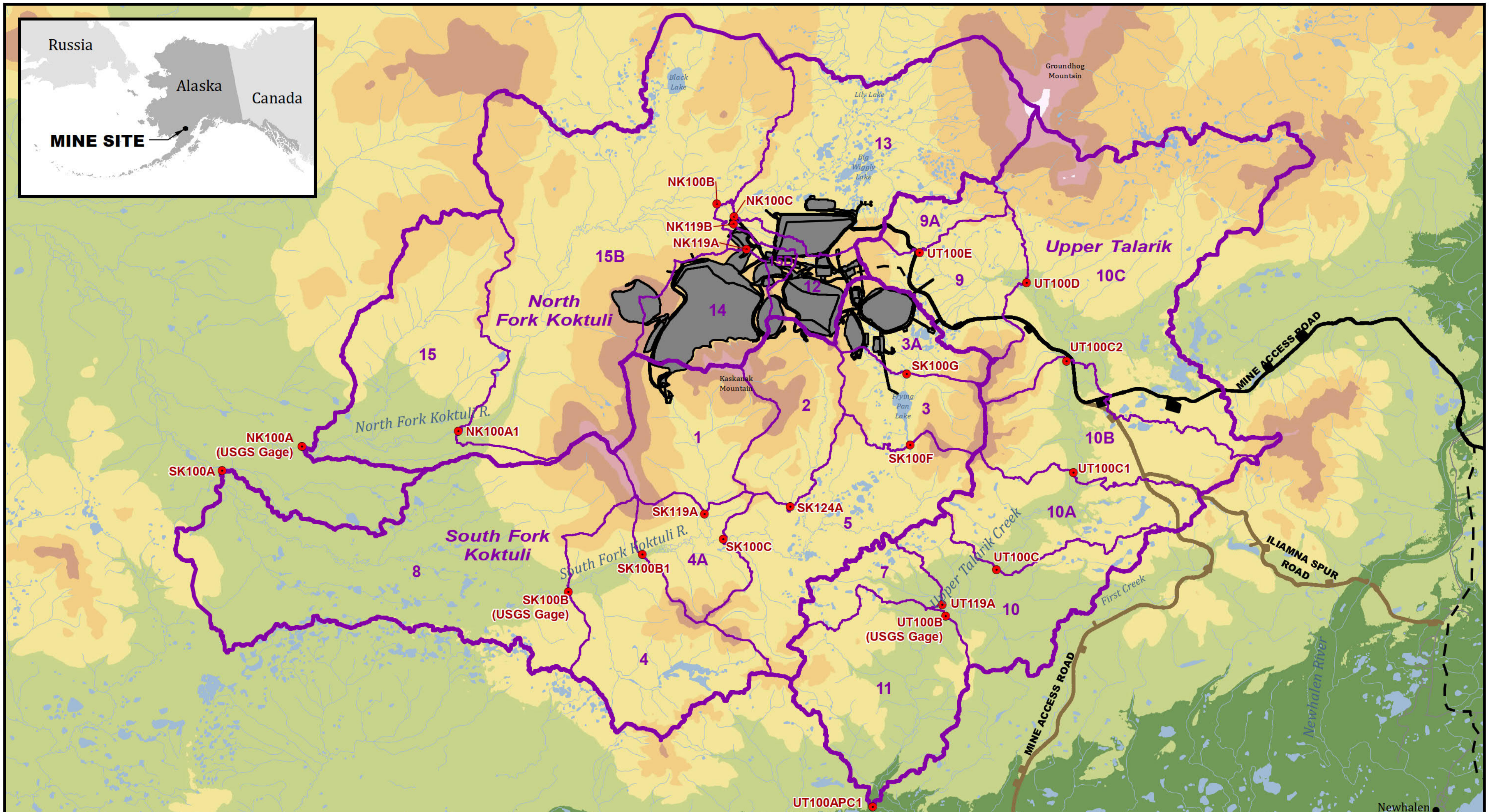
Action Alternatives

- Natural Gas Pipelines
- Alternative 1a
- Alternative 1

Other Features

- Local Roads

BASELINE WATERSHED MODEL SUB-CATCHMENT BOUNDARIES AND SIMULATED FLOW REGIME



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

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

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:

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

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:

$$Z_2 = (I + Z_1(1\text{-}jZ_1/2))/(1 + jZ_1/2)$$

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.

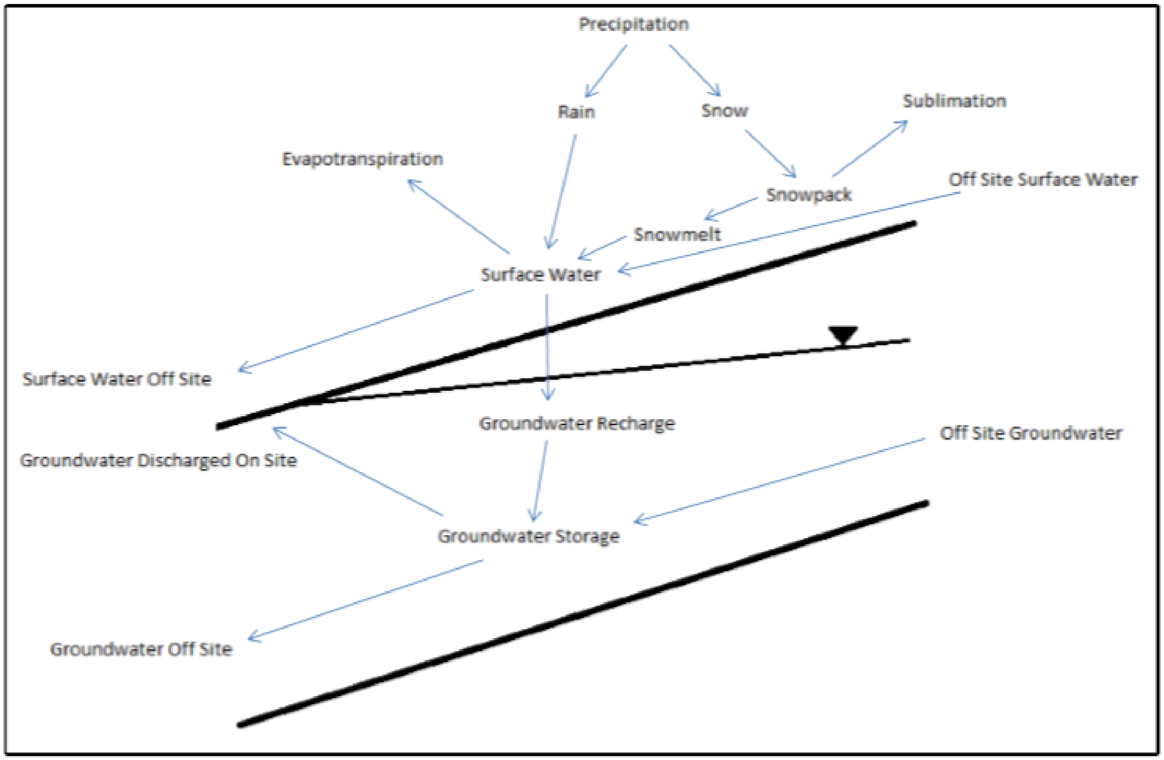
The volume of groundwater released from storage in excess of the groundwater flow off site is added to the surface water leaving the catchment. Groundwater storage and flow rates are calibrated primarily using streamflows measured at the site during the low-flow season. For a given volume of recharge, 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/mi²)	(ft²/day)	(feet)	(ft/ft)	(feet)	(%)	(cfs/mi²)
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/mi² = cubic feet per second square miles
ft²/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.