  

CHAPTER 7. MINE FOOTPRINT

This chapter addresses the stream habitat and streamflow risks associated with routine operations of the mine scenarios described in Chapter 6. It considers the unavoidable environmental effects associated with the footprint of each mine scenario, in the absence of failures of water collection or treatment facilities, tailings storage facilities (TSFs), the transportation corridor, or pipelines. This is not meant to suggest that the absence of failures is a realistic possibility, because accidents and failures do happen in complex and long-lasting operations. The risks and potential impacts of these failures are described in Chapters 8, 9, 10, and 11. In this chapter we evaluate the inevitable effects of the mine scenarios, rather than those that are the result of accidents and failures.

Potential pathways linking mine components, stream habitat and streamflow alterations, and biotic responses are highlighted in Figure 7-1. Key stressors associated with routine mine development and operation include elimination and modification of habitat (Section 7.2) and changes in downstream streamflow (Section 7.3), both of which can affect fish populations. The pathways associated with stream and wetland elimination highlighted in Figure 7-1 primarily reflect linkages occurring within the spatial extent of the mine footprint (Scale 4). Linkages and effects associated with streamflow alterations primarily operate from the edge of the footprint downstream to the extent of detectable streamflow changes (Scale 3). Effects on fish populations due to these modifications could extend beyond these geographic scales and into the larger Nushagak and Kvichak River watersheds (Scale 2), depending on the types and severity of impacts; these effects could not be quantified and are discussed qualitatively (see also Chapter 14). Routine effects of water collection, treatment, and discharge and the transportation corridor are discussed in Chapters 8 and 10, respectively.

7.1 Abundance and Distribution of Fishes in the Mine Scenario Watersheds

Potential effects of the mine footprint (addressed in this chapter) and of routine mine operations and failures (addressed in Chapters 8 through 11) on the assessment endpoints depend on the abundance and distribution of salmonids in the streams and rivers of the three watersheds draining the Pebble deposit area: the South Fork Koktuli River, North Fork Koktuli River, and Upper Talarik Creek watersheds (hereafter referred to as the mine scenario watersheds).

7.1.1 Fish Distribution

The mine scenario watersheds have been sampled extensively for summer fish distributions over several years. These data, collected by the Alaska Department of Fish and Game (ADF&G) and various consultants and non-profits, are captured in the *Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes—Southwestern Region* (also known as the Anadromous Waters Catalog [AWC]) (Johnson and Blanche 2012) and the Alaska Freshwater Fish Inventory (AFFI) (ADF&G 2012). The AWC is the State of Alaska's official record of anadromous fish distributions and, if available, the life stages present (categorized as spawning, rearing, or present but life stage unspecified) in individual stream reaches. The AFFI includes all fish species, including resident fishes, found at specific sampling points. The catalogued distributions of the five Pacific salmon species (sockeye, coho, Chinook, chum, and pink), Dolly Varden (both anadromous and non-anadromous forms are present), and resident rainbow trout in the mine scenario watersheds are shown in Figures 7-2 through 7-8. In addition, Alaskan or Arctic brook lamprey, longnose sucker, northern pike, humpback whitefish, least cisco, round whitefish, Arctic char, Arctic grayling, burbot, threespine stickleback, ninespine stickleback, and slimy sculpin occur in these watersheds (ADF&G 2012). Details of these species, including information on distributions, abundances, habitats, life cycles, predator-prey relationships, and harvests, are provided in Appendix B. AWC stream reach designations and AFFI observation points should be interpreted with care, because not all streams could be sampled and there are potential errors associated with fish identification and mapping. Additional caveats and uncertainties concerning interpretation of AWC and AFFI data are discussed in Section 7.2.5.

Figure 7-1. Conceptual model illustrating potential linkages between sources associated with the mine scenario footprints, changes in physical habitat, and fish endpoints.

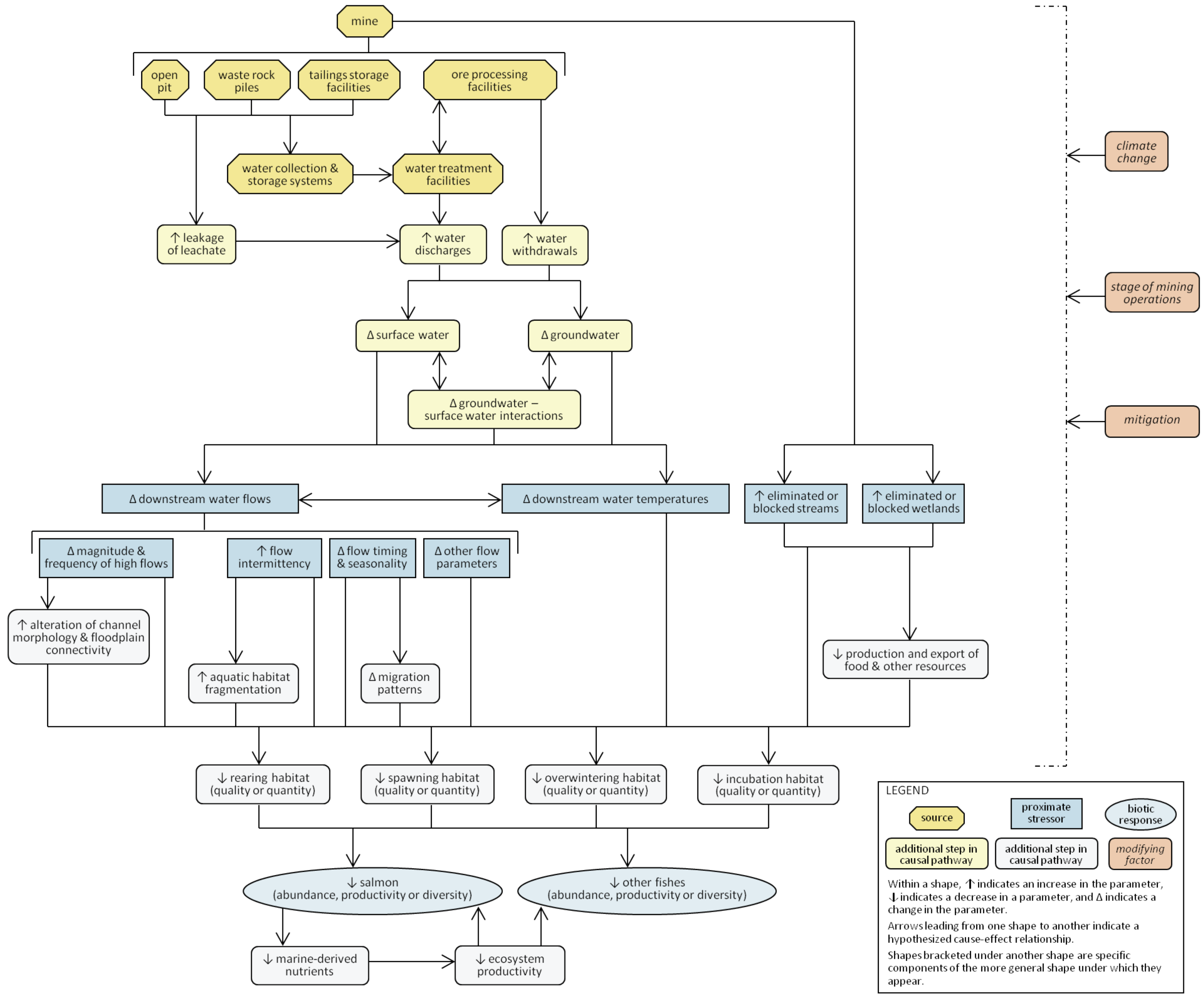

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Figure 7-2. Reported sockeye salmon distribution in the mine scenario watersheds. "Present" indicates species was present but life-stage use was not determined; "spawning" indicates spawning adults were observed; "rearing" indicates juveniles were observed. Present, spawning, and rearing designations are based on the Anadromous Waters Catalog (Johnson and Blanche 2012). Life-stage-specific reach designations are likely underestimates, given the challenges inherent in surveying all streams that may support life-stage use throughout the year (see Section7.2.5 for additional notes on interpretation of fish distribution data). Footprints of the major mine components for the three mine scenarios and the drawdown zone for the Pebble 6.5 scenario are shown for reference.

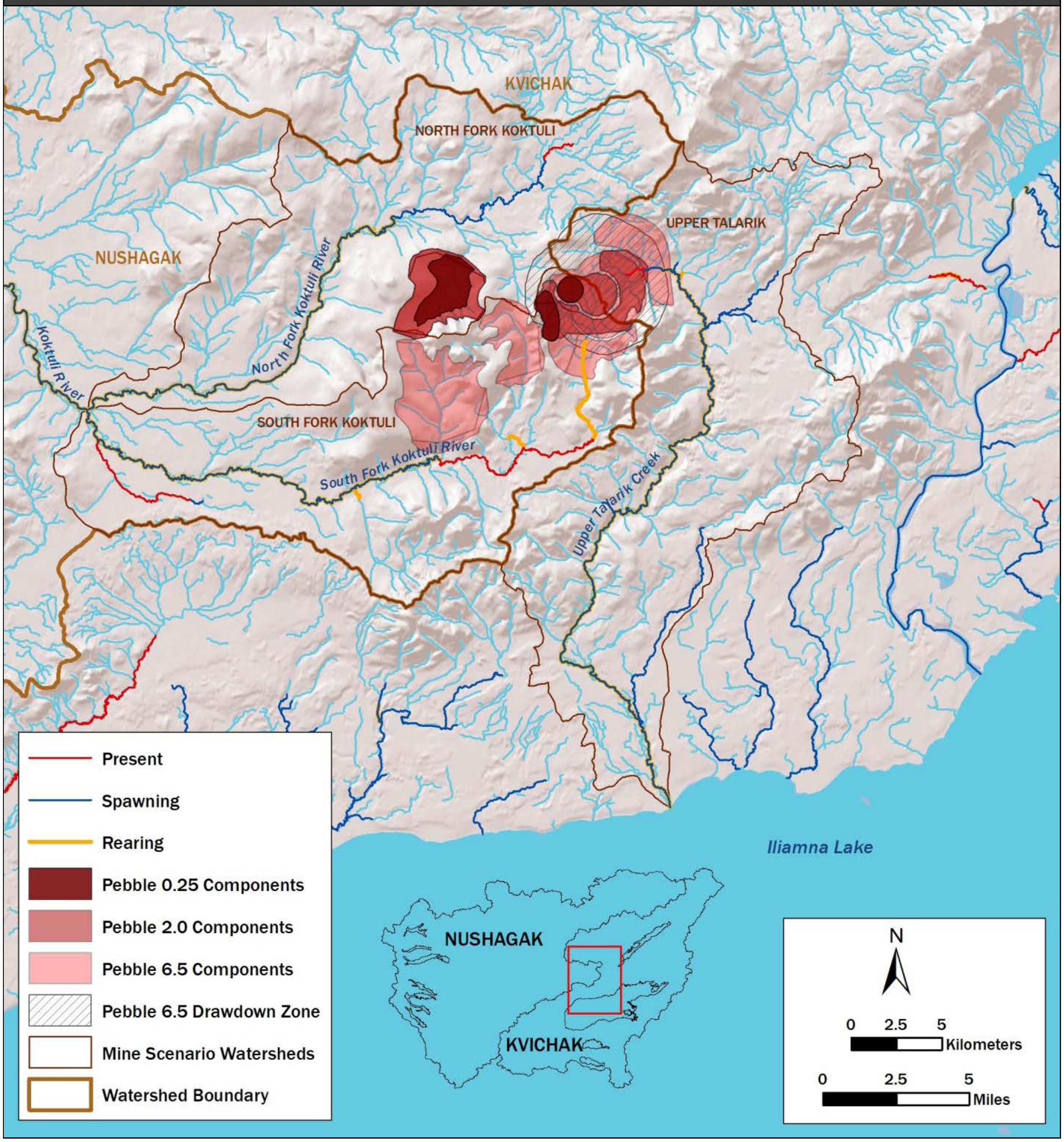


Figure 7-3. Reported coho salmon distribution in the mine scenario watersheds. "Present" indicates species was present but life-stage use was not determined; "spawning" indicates spawning adults were observed; "rearing" indicates juveniles were observed. Present, spawning, and rearing designations are based on the Anadromous Waters Catalog (Johnson and Blanche 2012). Life-stage-specific reach designations are likely underestimates, given the challenges inherent in surveying all streams that may support life-stage use throughout the year (see Section 7.2.5 for additional notes on interpretation of fish distribution data). Footprints of the major mine components for the three mine scenarios and the drawdown zone for the Pebble 6.5 scenario are shown for reference.

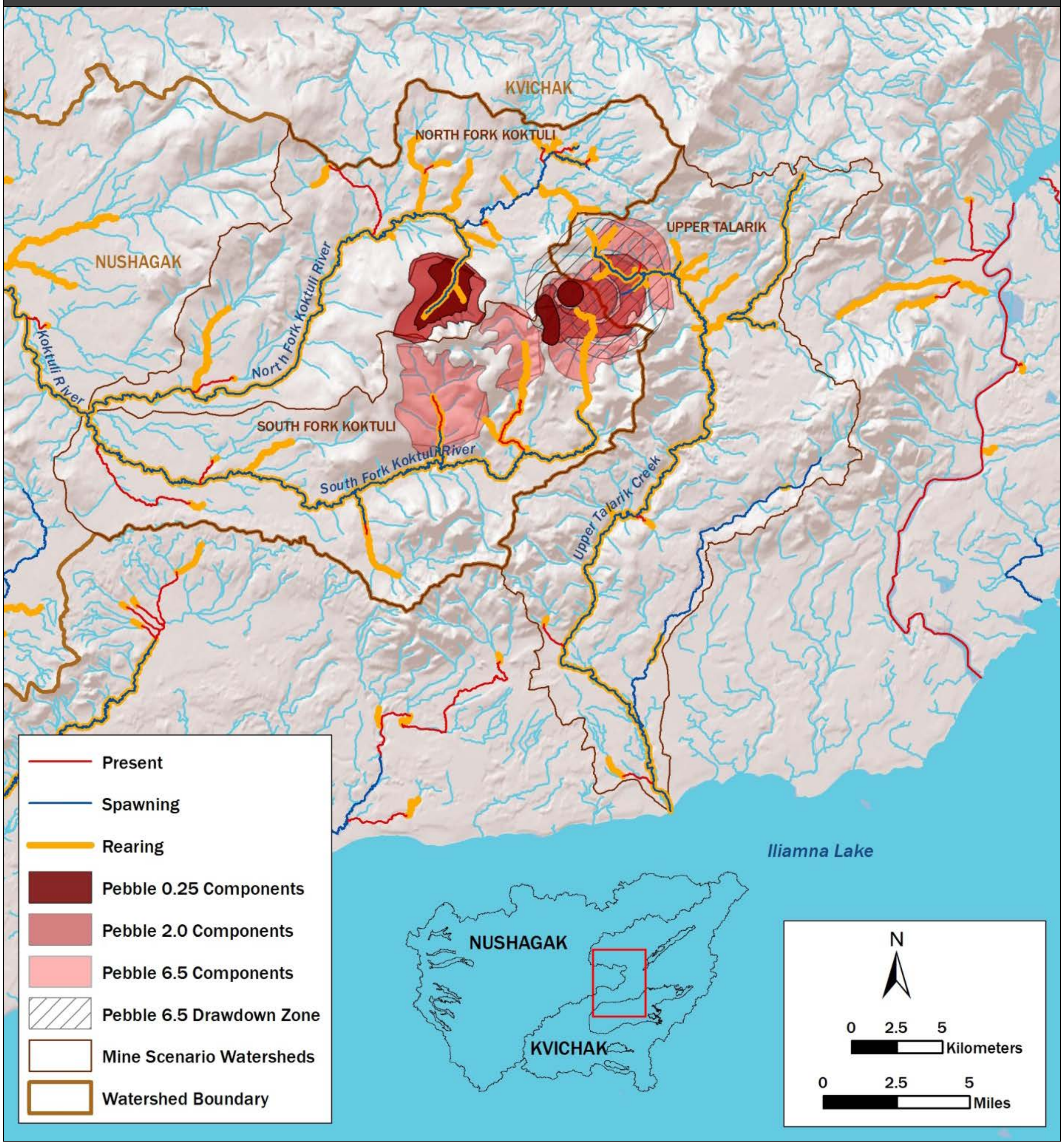


Figure 7-4. Reported Chinook salmon distribution in the mine scenario watersheds. "Present" indicates species was present but life-stage use was not determined; "spawning" indicates spawning adults were observed; "rearing" indicates juveniles were observed. Present, spawning, and rearing designations are based on the Anadromous Waters Catalog (Johnson and Blanche 2012). Life-stage-specific reach designations are likely underestimates, given the challenges inherent in surveying all streams that may support life-stage use throughout the year (see Section 7.2.5 for additional notes on interpretation of fish distribution data). Footprints of the major mine components for the three mine scenarios and the drawdown zone for the Pebble 6.5 scenario are shown for reference.

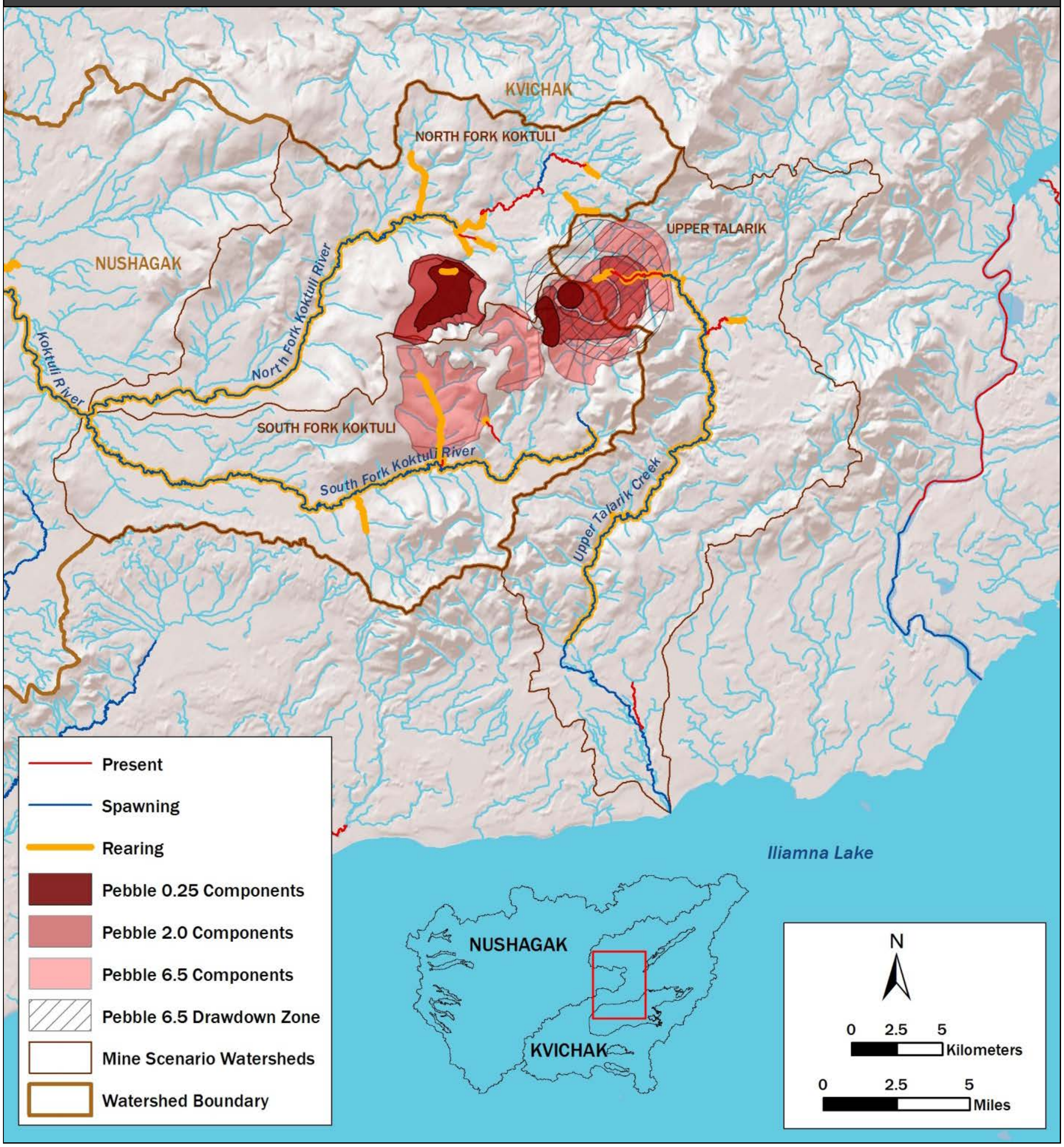


Figure 7-5. Reported chum salmon distribution in the mine scenario watersheds. "Present" indicates species was present but life-stage use was not determined; "spawning" indicates spawning adults were observed; "rearing" indicates juveniles were observed. Present, spawning, and rearing designations are based on the Anadromous Waters Catalog (Johnson and Blanche 2012). Life-stage-specific reach designations are likely underestimates, given the challenges inherent in surveying all streams that may support life-stage use throughout the year (see Section 7.2.5 for additional notes on interpretation of fish distribution data). Footprints of the major mine components for the three mine scenarios and the drawdown zone for the Pebble 6.5 scenario are shown for reference.

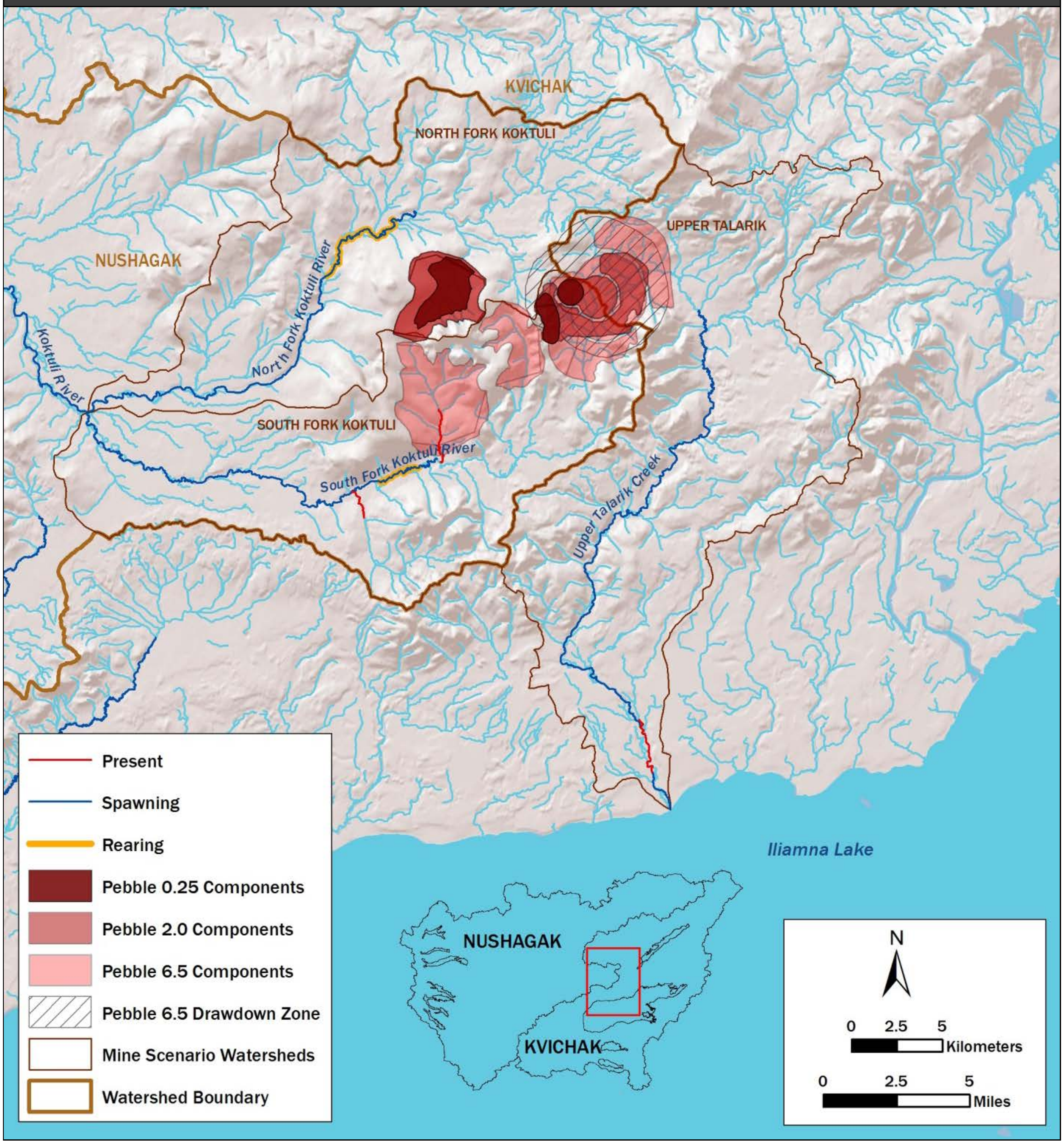


Figure 7-6. Reported pink salmon distribution in the mine scenario watersheds. "Present" indicates species was present but life-stage use was not determined; "spawning" indicates spawning adults were observed. Present and spawning designations are based on the Anadromous Waters Catalog (Johnson and Blanche 2012). Life-stage-specific reach designations are likely underestimates, given the challenges inherent in surveying all streams that may support life-stage use throughout the year (see Section 7.2.5 for additional notes on interpretation of fish distribution data). Footprints of the major mine components for the three mine scenarios and the drawdown zone for the Pebble 6.5 scenario are shown for reference.

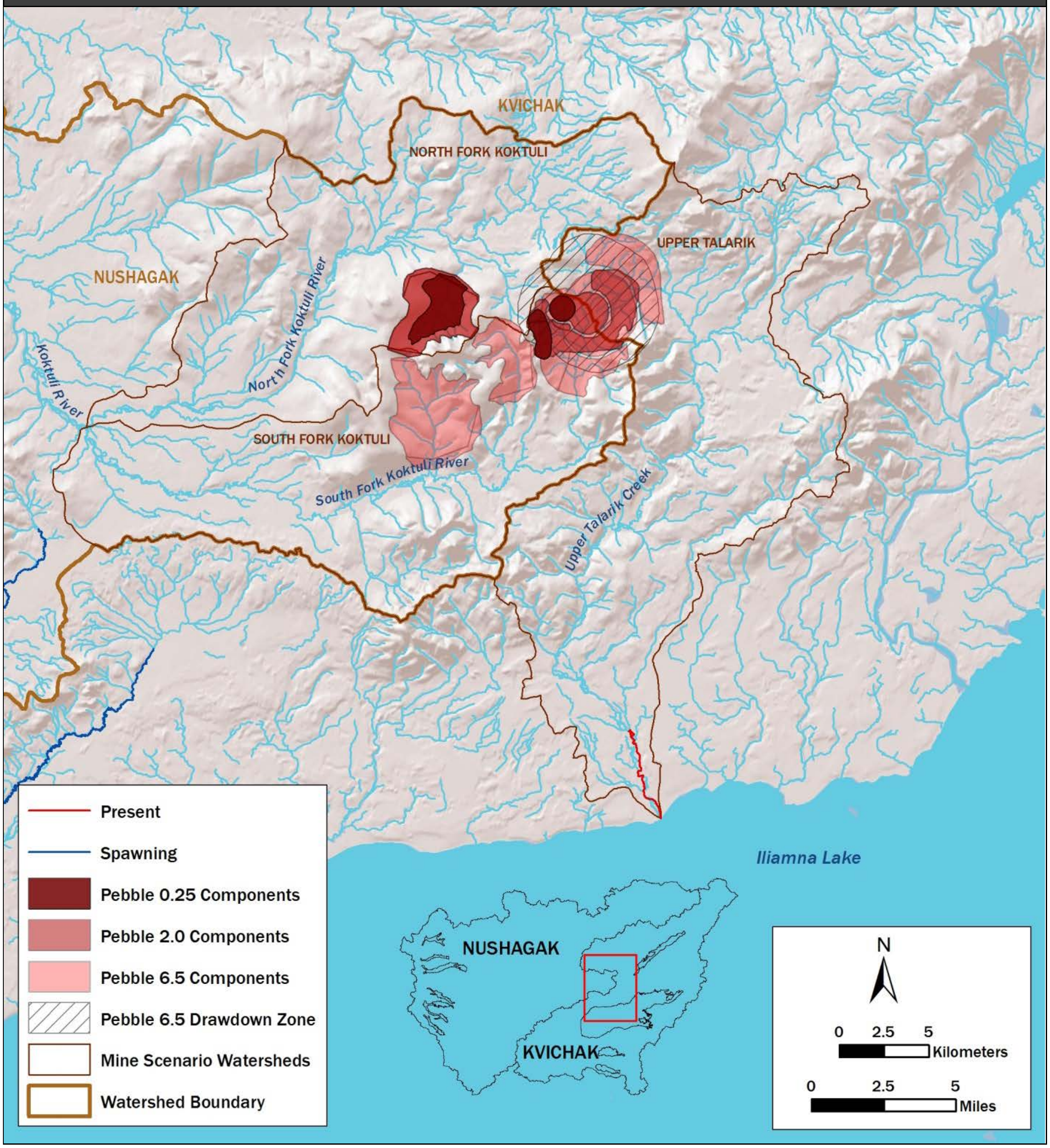


Figure 7-7. Reported Dolly Varden occurrence in the mine scenario watersheds. Designation of species presence is based on the Alaska Freshwater Fish Inventory (ADF&G 2012). Absence cannot be inferred from this map (see Section 7.2.5 for additional notes on interpretation of fish distribution data). Footprints of the major mine components for the three mine scenarios and the drawdown zone for the Pebble 6.5 scenario are shown for reference.

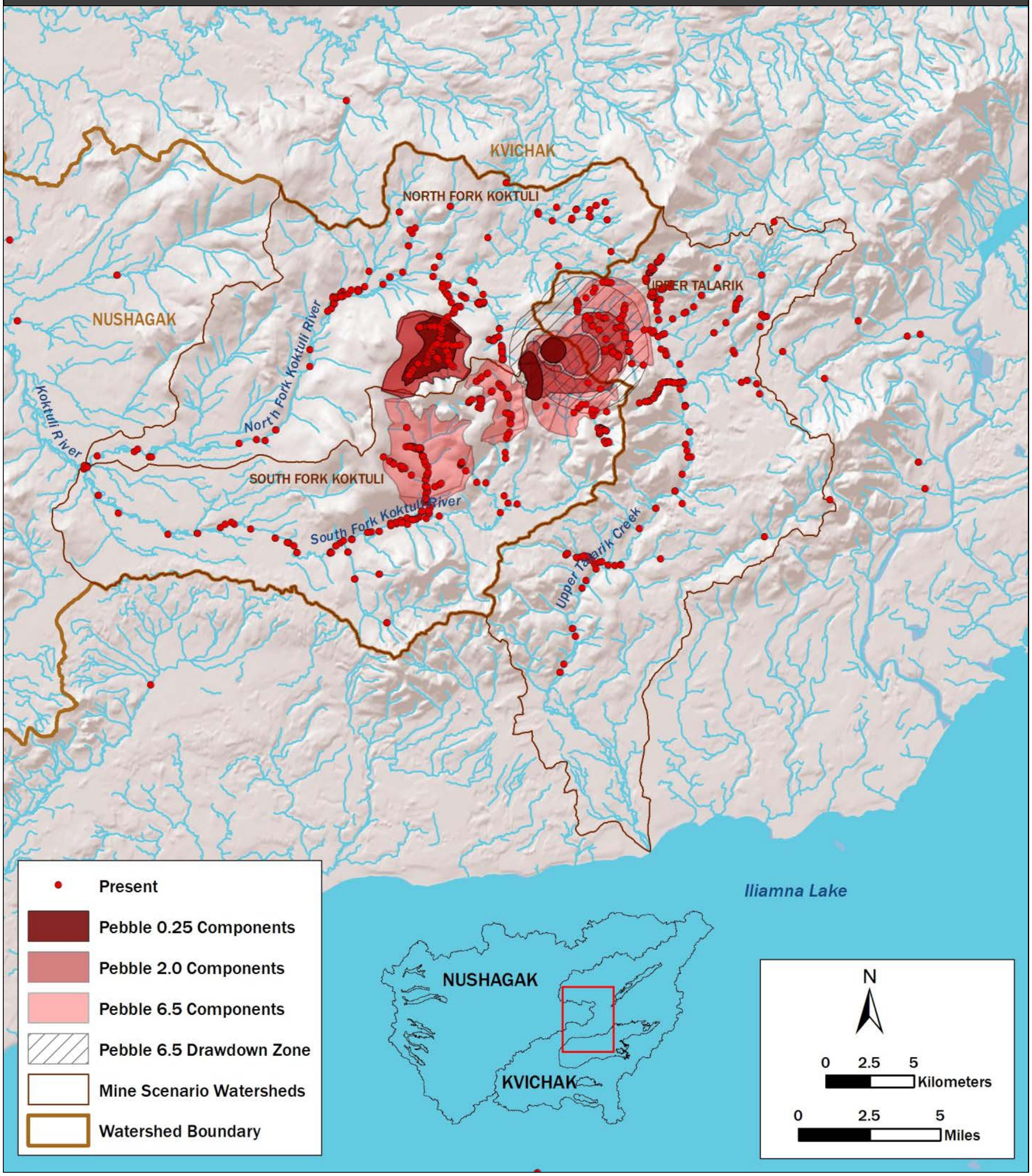
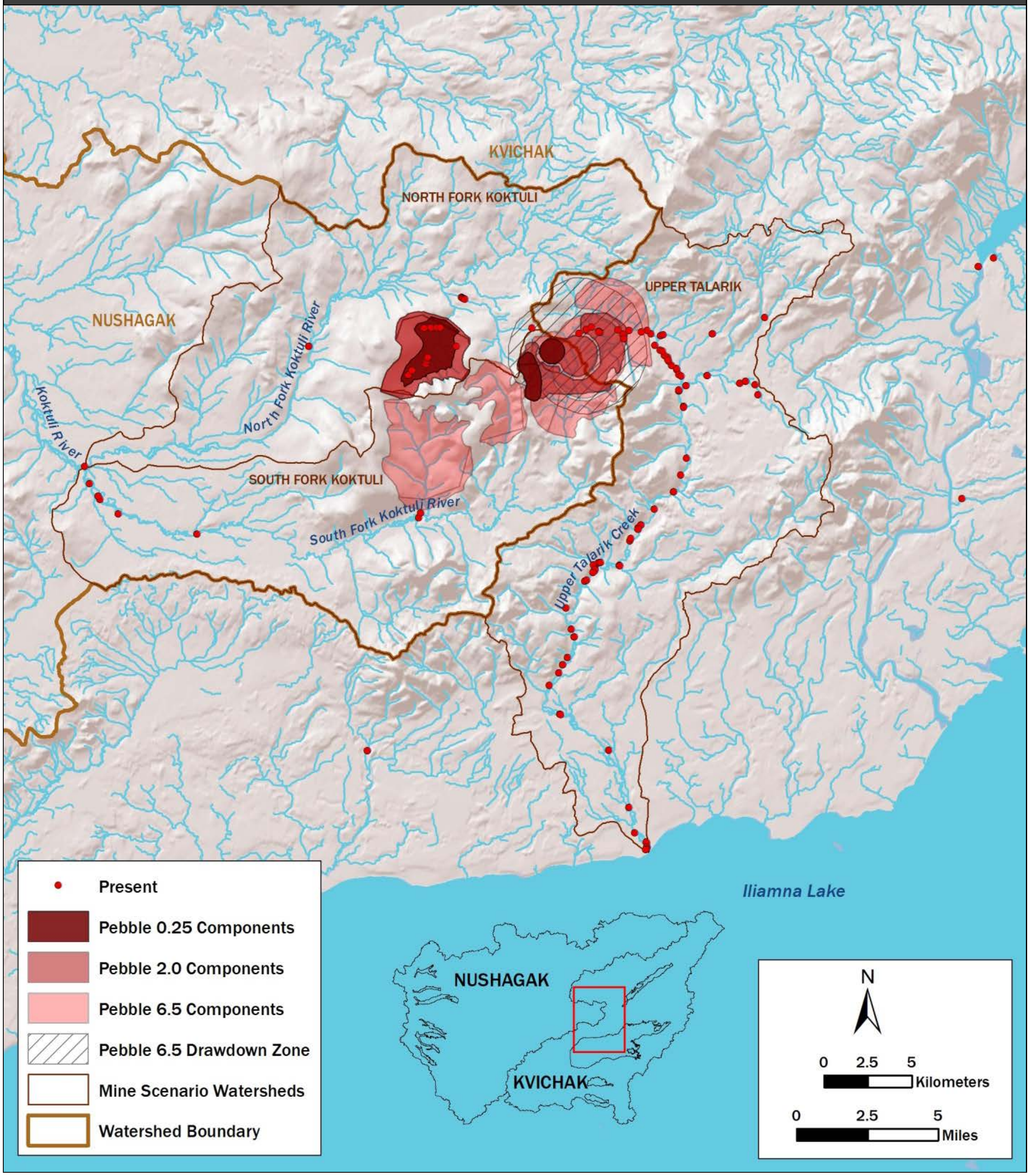


Figure 7-8. Reported rainbow trout occurrence in the mine scenario watersheds. Designation of species presence is based on the Alaska Freshwater Fish Inventory (ADF&G 2012). Absence cannot be inferred from this map (see Section 7.2.5 for additional notes on interpretation of fish distribution data). Footprints of the major mine components for the three mine scenarios and the drawdown zone for the Pebble 6.5 scenario are shown for reference.



Sockeye salmon use mainstem reaches of the mine scenario watersheds for spawning and rearing, including a portion of Upper Talarik Creek that is within the waste rock piles of the Pebble 2.0 and Pebble 6.5 scenarios (Figure 7-2). Coho salmon have the most widespread distribution of the five salmon species in the mine scenario watersheds, and make extensive use of mainstem and tributary habitats (Figure 7-3). Coho spawn and rear in headwater streams that would be eliminated, blocked, or dewatered by the mine pits, waste rock piles, and TSFs of the Pebble 0.25, 2.0, and 6.5 scenarios (Figure 7-3). Chinook salmon have been documented throughout mainstem reaches of the mine scenario watersheds (Figure 7-4). Chinook are known to use small streams for rearing habitat, and juveniles have been observed in streams that would be within the footprints of TSF 1 (North Fork Koktuli River), TSF 2 (South Fork Koktuli River), and the waste rock piles and mine pits (Upper Talarik Creek) (Figure 7-4). The distributions of chum and pink salmon are generally restricted to mainstem reaches where spawning and migration occur. Chum salmon have been found in all three mine scenario watersheds and in a stream within the footprint of TSF 2 (Figure 7-5). Pink salmon have only been reported at very low numbers in the lowest section of Upper Talarik Creek and in the Koktuli River below the confluence of the north and south forks (Figure 7-6, Figure 5-8). Dolly Varden are found throughout the mine scenario watersheds, and fish surveys indicate that they are commonly found in the smallest streams (i.e., first-order tributaries), including streams within the footprints of each of the TSFs (Figure 7-7). Rainbow trout have been collected at many mainstem locations, especially in Upper Talarik Creek, and their reported distribution extends upstream throughout the TSF 1 area and in the portions of Upper Talarik Creek within the waste rock pile footprints (Figure 7-8).

7.1.2 Spawning Salmon Abundance

Index estimates of relative spawning salmon abundance are available for sockeye, coho, Chinook, and chum salmon in the mine scenario watersheds. Aerial index counts of spawning salmon are available from ADF&G and the Pebble Limited Partnership (PLP). This type of survey is used primarily as an index to track variation in run size over time. We recognize that survey values tend to underestimate true abundance for several reasons. An observer in an aircraft is not able to count all fish in dense aggregations or those concealed under overhanging vegetation or undercut banks, and only a fraction of the fish that spawn at a given site are present at any one time (Bue et al. 1988, Jones et al. 2007). Weather, water clarity, and other factors that influence fish visibility can also contribute to underestimates. In addition, surveys intended to capture peak abundance may not always do so. For example, aerial surveys counted, on average, only 44% of the pink salmon counted by surveyors walking the same Prince William Sound spawning streams (Bue et al. 1988). Peak aerial counts of pink salmon in southeastern Alaska are routinely multiplied by 2.5 to represent more accurately the number of fish present at the survey time (Jones et al. 2007). Helicopter surveys of Chinook salmon on the Kenai Peninsula’s Anchor River over 5 years counted only 5 to 10% of the fish counted by a concurrent sonar/weir counting station (Szarzi et al. 2007).

ADF&G conducts aerial index counts that target peak sockeye salmon spawning periods on Upper Talarik Creek and peak Chinook salmon spawning periods on the Koktuli River system. Sockeye salmon counts have been conducted in most years since 1955 (Morstad 2003), and Chinook salmon counts in most years since 1967 (Dye and Schwanke 2009). Between 1955 and 2011, sockeye salmon counts in Upper Talarik Creek ranged from 0 to 70,600, with an average of 7,021 over 49 count periods (Morstad pers. comm.) Between 1967 and 2009, Chinook salmon counts in the Koktuli River system ranged from 240 to 10,620, with an average of 3,828 over 29 count periods (Dye and Schwanke 2009).

PLP (2011) provides aerial index counts for Chinook, chum, coho, and sockeye salmon adults in the mine scenario watersheds from 2004 to 2008. Surveys on the South and North Fork Koktuli Rivers began at the confluence and extended upward to the intermittent reach or Frying Pan Lake on the South Fork Koktuli River and upward to Big Wiggly Lake or river kilometer 56 on the North Fork Koktuli River. Surveys on Upper Talarik Creek ran from the mouth and extended upstream to Tributary 1.350 (just east of Koktuli Mountain) or to the headwaters. Multiple counts were usually made for each stream and species in a given year (Table 7-1). Repeat surveys of this type can be used to estimate the size of spawning populations using an area under the curve (AUC) approach if estimates of stream life (i.e., the number of days that salmon are present on the spawning grounds) and observer efficiency are available (Hilborn et al. 1999). However, PLP was unable to make reliable estimates of stream life and observer efficiency (PLP 2011: 15.1-14), a common shortcoming given the data-intensive demands of AUC estimates (Holt and Cox 2008). Mean index counts can be reliable indicators of spawning coho salmon abundance trends in simulation studies (e.g., Holt and Cox 2008), but optimum reliability is contingent on sampling date and frequency. Peak index counts have been used to monitor trends in spawner abundance, but these counts also have shortcomings associated with survey design and execution and require area- and species-specific expansion factors to allow escapement estimates (e.g., Parken et al. 2003). In addition, trend analysis needs to account for the high interannual variability in escapement estimates noted above, and likely requires many years of data. Streams or river segments lacking long-term survey data require a larger watershed and population context to approximate baseline conditions for those locations and populations.

Table 7-1 reports the highest of each year's index counts for each population, approximated from figures in PLP (2011: Chapter 15). We report peak index counts because only a portion of the spawning population is present on the spawning grounds on any given day. Thus, the highest index count is mathematically closer to the true abundance than is the average of multiple surveys, and it more closely matches ADF&G's index methods based on a single count that targets peak spawning. The highest peak index counts for coho and sockeye salmon were in Upper Talarik Creek, whereas the highest counts for Chinook and chum salmon were in the South and North Fork Koktuli Rivers (Table 7-1). The overall highest count was for sockeye salmon in Upper Talarik Creek and Tributary 1.60 in 2008, when approximately 82,000 fish were estimated (Table 7-1).

Table 7-1. Highest reported index spawner counts in the mine scenario watersheds for each year, 2004 to 2008.

Mine Scenario Watershed	Salmon Species	Highest Index Spawner Count Per Year (Number Of Counts)[a]				
		2004	2005	2006	2007	2008
South Fork Koktuli River	Chinook	2,750 (3)	1,500 (4)	250 (5)	300 (8)	500 (9)
	Chum	(0)	350 (4)	850 (7)	200 (11)	950 (7)
	Coho	250 (2)	550 (4)	1,375 (3)	250 (10)	1,875 (20)
	Sockeye	1,400 (2)	2,000 (5)	2,700 (8)	4,000 (11)	6,000 (13)
North Fork Koktuli River	Chinook	2,800 (3)	2,900 (4)	750 (4)	600 (8)	500 (8)
	Chum	400 (1)	350 (4)	750 (4)	800 (9)	1,400 (7)
	Coho	300 (3)	350 (1)	1,050 (4)	125 (8)	1,700 (15)
	Sockeye	550 (2)	1,100 (5)	1,400 (7)	2,200 (10)	2,000 (12)
Upper Talarik Creek	Chinook	275 (2)	100 (3)	80 (3)	150 (9)	100 (8)
	Chum	(0)	3 (1)	13 (2)	8 (8)	18 (5)
	Coho	3,000 (4)	(0)	6,300 (3)	4,400 (9)	6,300 (14)[b]
	Sockeye	33,000 (2)	15,000 (4)	10,000 (6)	10,000 (14)	82,000 (14)[b]

Notes:
[a] Values likely underestimate true spawner abundance.
[b] Tributary 1.60, a major tributary to Upper Talarik Creek, was included in this count.
Source: PLP 2011.

The spatial distribution of spawner counts in the study streams during the 2008 return year was provided by PLP (2011). Spawner counts were summarized by individual stream reaches throughout the mainstem of each of the mine scenario watersheds. Data were reported for three reaches in the South Fork Koktuli River (A through C, extending from the confluence upstream to the intermittent reach), five reaches in the North Fork Koktuli River (A through E, extending from the confluence upstream to beyond Big Wiggly Lake), and seven reaches in Upper Talarik Creek (A through G, extending from the mouth to the headwaters) (Figure 15.1-2 in PLP [2011] illustrates the stream reaches; Table 7-2 provides river kilometer boundaries for each reach). Count data (approximated from figures in PLP [2011]) and location (in river kilometers) for each of these reaches are shown in Table 7-2 to demonstrate the relative spatial distribution of salmon during the 2008 spawning period.

Table 7-2. Average 2008 index spawner counts by stream reach[a].								
Stream	Salmon Species	Stream Reach, Downstream to Upstream						
		A	B	C	D	E	F	G
South Fork Koktuli River	Reach Boundaries (river km)	0–24.9	24.9–34.3	34.3–51.7	-	-	-	-
	Chinook	200	70	0	-	-	-	-
	Chum	90	190	0	-	-	-	-
	Coho	200	250	8	-	-	-	-
	Sockeye	800	1,510	1	-	-	-	-
North Fork Koktuli River	Reach Boundaries (river km)	0–13.7	13.7–21.1	21.1–36.6	36.6–48.4	48.4–52.5	-	-
	Chinook	110	40	50	0	0	-	-
	Chum	50	50	320	0	0	-	-
	Coho	100	70	210	30	60	-	-
	Sockeye	530	<10	220	60	0	-	-
Upper Talarik Creek	Reach Boundaries (river km)	0–5.9	5.9–16.8	16.8–24.8	24.8–36.3	36.3–45.1	45.1–59.1	59.1–62.4
	Chinook	<10	<10	20	<10	20	<10	0
	Chum	<10	<10	<10	<10	<10	10	0
	Coho	100	50	40	180	280	180	<10
	Sockeye	10,000	4,500	3,000	3,000	500	47	0

Notes:
Dashes (-) indicate no applicable stream reach.
[a] Values likely underestimate true spawner abundance.
Source: PLP 2011.

7.1.3 Juvenile Salmon and Other Salmonid Abundance

PLP (2011) reports counts of juvenile salmon and other salmonids in the South and North Fork Koktuli Rivers and Upper Talarik Creek based on extensive sampling efforts from 2004 through 2008. Snorkel surveys were the primary data collection method, but electrofishing, minnow traps, beach seines, gill nets, angling, and dip netting were used in certain situations. It is not always possible to determine which survey methods generated which counts in PLP (2011). Raw field counts were frequently expressed as densities (count per 100-m reach was the only unit reported for all three streams). These counts should not be viewed as quantitative abundance estimates. They are very likely underestimates because of the extreme difficulty of observing or capturing all fish in complex habitats (Hillman et al. 1992). Density estimates with confidence bounds (e.g., mark-recapture or depletion estimates) were generated for some parts of the PLP (2011) studies (e.g., PLP 2011: Appendix 15.1D), but such efforts were uncommon as they are much more time-consuming and labor-intensive.

Reported fish densities summarized over the 5-year period vary widely by stream, sample reach, and habitat type (PLP 2011: Figures 15.1-23, 15.1-52, and 15.1-82). Species that attain densities of several hundred per 100-m reach in one setting were often absent or sparse in other habitat types or reaches in the same stream, which is typical for fish in heterogeneous stream environments. Table 7-3 presents maximum fish densities in the mainstem of each mine scenario watershed, approximated from figures in PLP (2011), for species that rear for extended periods in the surveyed streams and for which data are available: Chinook and coho salmon, Arctic grayling, and Dolly Varden. We report maximum density to give a sense of the magnitude attained in the surveyed streams, but it should be stressed that abundance varied widely by stream reach and habitat type within a given stream (PLP 2011: Figures 15.1-23, 15.1-52, and 15.1-82). Highest reported densities were approximately 2,500 Arctic grayling and 1,600 coho salmon per 100 m from adjacent reaches on Upper Talarik Creek, and 1,400 coho salmon per 100 m from a reach on the North Fork Koktuli River.

Table 7-3. Highest index counts of selected stream-rearing fish species from mainstem habitats of the mine scenario watersheds.

	Highest Reported Density (count per 100 m)[a]				
Stream	Chinook Salmon	Coho Salmon	Arctic Grayling	Dolly Varden	Source
South Fork Koktuli River	450	600	275	55	Figure 15.1-52 (PLP 2011)
North Fork Koktuli River	500	1,400	40	40	Figure 15.1-23 (PLP 2011)
Upper Talarik Creek	400	1,600	2,500	10	Figure 15.1-82 (PLP 2011)

Notes:
[a] Values were approximated from figures listed in the source column.

7.2 Habitat Modification

The footprints of the major mine components (mine pit, waste rock piles, and TSFs) would directly modify the amount of habitat available to salmon, rainbow trout, and Dolly Varden by eliminating headwater streams and wetlands within and up-gradient of their footprints. Potential effects of this habitat modification are described for the three mine scenarios in Sections 7.2.2, 7.2.3, and 7.2.4, and uncertainties and assumptions are described in Section 7.2.5.

7.2.1 Stream Segment Characteristics in the Mine Scenario Watersheds

The mine scenario watersheds encompass an area of 925 km^2 and contain 930 km of stream channels mapped for this analysis (methods described in Section 3.4). In this section, we summarize stream segment characteristics in the mine scenario watersheds to better characterize stream environments in and downstream of the mine footprints. In Section 7.2.2, we summarize the characteristics of stream segments that would be lost to the footprints of the major mine components themselves. Stream segments for the entire Nushagak and Kvichak River watersheds (Scale 2) are characterized in Chapter 3. This characterization is provided to help readers understand variation in the relative size (mean annual streamflow), channel gradient, and floodplain potential (proportion of flatland in lowland) among stream segments in the mine scenario watersheds. Because these characteristics can strongly influence the quality and suitability of stream habitats as fish habitat, they provide a way to evaluate the coarse-scale characteristics of streams at risk of impacts at various scales. This characterization helps highlight the fact that not all stream kilometers in these watersheds are equal in their potential to support salmon carrying capacity or productivity.

Results from this analysis are presented in tables that summarize the proportion of stream channel length within each stream size, gradient, and floodplain potential category. To allow direct visual comparison of the distribution of stream characteristics across scales, we present cumulative frequency plots (e.g., Figure 7-9). These plots show a frequency curve for each attribute at different geographic scales. Attributes are grouped into meaningful classes (Chapter 3), denoted by the vertical red classification bars. For example, the lowest gradient streams are classified as having gradients of less than 1% (Table 7-4), as shown by the vertical classification bar at 1% in Figure 7-9B. Cumulative frequency plots can be interpreted by evaluating the height at which the frequency curve is intersected by the red vertical classification bar. In Figure 7-9B, the 1% gradient classification bar intersects the Scale 3 frequency curve (solid black line) at a cumulative frequency value of approximately 50%. Thus, approximately 50% of the stream kilometers in the mine scenario watersheds (Scale 3) have less than 1% gradient. In comparison, approximately 64% of the stream kilometers in the Nushagak and Kvichak River watersheds (Scale 2) have less than 1% gradient.

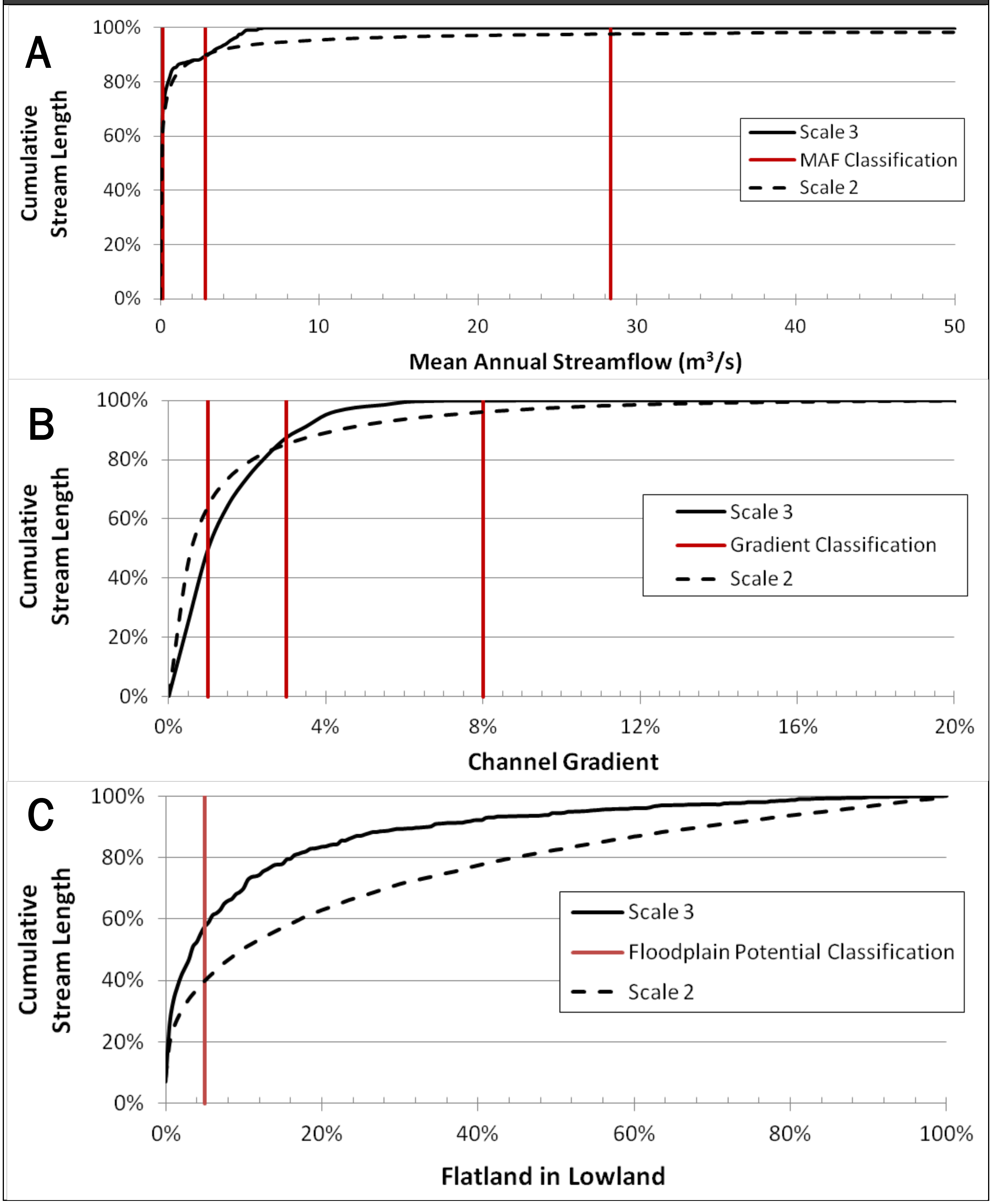
Table 7-4. Distribution of stream channel length classified by channel size (based on mean annual streamflow in m³/s), channel gradient (%), and floodplain potential (based on % flatland in lowland) for streams and rivers in the mine scenario watersheds. Gray shading indicates values greater than 5%; bold indicates values greater than 10%.

Channel Size	Gradient							
	<1%		≥1% and <3%		≥3% and <8%		≥8%	
	FP	NFP	FP	NFP	FP	NFP	FP	NFP
Small headwater streams[a]	**15%**	5%	5%	**28%**	0%	**12%**	0%	0%
Medium streams[b]	**14%**	6%	0%	3%	0%	1%	0%	0%
Small rivers[c]	8%	2%	0%	1%	0%	0%	0%	0%
Large rivers[d]	0%	0%	0%	0%	0%	0%	0%	0%

Notes:
[a] 0–0.15 m³/s; most tributaries in the mine footprints.
[b] 0.15–2.8 m³/s; upper reaches and larger tributaries of the South and North Fork Koktuli Rivers and Upper Talarik Creek.
[c] 2.8–28 m³/s; middle to lower portions of the South and North Fork Koktuli Rivers and Upper Talarik Creek, including mainstem Koktuli River.
[d] >28 m³/s; the Mulchatna River below the Koktuli confluence, the Newhalen River, and other large rivers.
FP = high floodplain potential (≥5% flatland in lowland); NFP = no or low floodplain potential (<5% flatland in lowland) (see Chapter 3 for additional explanation).

Similar to the larger Nushagak and Kvichak River watersheds (summarized in Table 3-3), streams in the mine scenario watersheds are generally low-gradient, with extensive flat floodplains or terraces in the larger valleys (Figure 7-9; also see PLP 2011: Chapter 15 and Appendix 15.1B). There are no large rivers (greater than 28 m³/s mean annual streamflow) in the mine scenario watersheds (Table 7-4). Compared to the larger Nushagak and Kvichak River watersheds, streams in the mine scenario watersheds have fewer very low gradient streams (mean gradient 0.7% versus 0.4%) and a higher proportion (58% versus 39%) of stream length flowing through valleys with low floodplain potential (i.e., less than 5% of flatland in lowland) (Table 7-4, Figure 7-9).

Figure 7-9. Cumulative frequency of stream channel length classified by (A) mean annual streamflow (MAF) (m^3/s), (B) channel gradient (%), and (C) floodplain potential (based on % flatland in lowland) for the mine scenario watersheds (Scale 3) versus the Nushagak and Kvichak River watersheds (Scale 2). See Section 3.4 for further explanation of MAF, gradient, and floodplain potential classifications.



Broadly classified, streams and rivers in the Nushagak and Kvichak River watersheds that are likely to provide high capacity and quality habitats for salmonids include streams with gradients less than 3% and of medium stream size (0.15 to 2.8 m^3/s mean annual streamflow) or greater. Such streams and rivers account for 36% of the stream network in the larger Nushagak and Kvichak River watersheds (Table 3-3), and account for 34% of the stream network in the mine scenario watersheds (Table 7-4). Smaller, steeper streams provide seasonal (and some year-round) habitat, and provide important provisioning services to downstream waters (Section 7.2.3). Although streams in the mine scenario watersheds are smaller and slightly steeper than streams and rivers throughout the entire Nushagak and Kvichak River watersheds, these results show the high proportion of stream channels in these basins with the broad geomorphic and hydrologic characteristics that support stream and river habitats highly suitable for fish species such as Pacific salmon, Dolly Varden, and rainbow trout.

7.2.2 Exposure: Habitat Lost to the Mine Scenario Footprints

For each mine scenario, the total mine footprint consists of the area devoted to the major mine components (mine pit, waste rock piles, and TSFs), the groundwater drawdown zone associated with the mine pit, and plant and ancillary facilities (e.g., ore-processing facilities and water collection and treatment facilities) (see Chapter 6 for additional details on each mine scenario). Portions of the mine scenario watersheds would be affected by mining activity in this footprint. Stream and wetland habitats would be lost within and upstream of the footprint (Figures 7-10 through 7-12), and downstream habitat would be degraded by the loss of the headwater streams and wetlands. Streams under or upstream of each mine footprint would be inaccessible by fish from downstream reaches because of the following factors.

- Elimination of streams and wetlands within the mine footprints, either due to removal (e.g., excavation of streams or wetlands in the mine pit area) or burial under a TSF or waste rock pile.
- Dewatering by capture into a groundwater drawdown zone associated with the pit. This effect is distinct from the effect of water removal and capture on streamflows downstream of the mine footprint, which is covered in Section 7.3.
- Blockage due to either of the above or channel diversion in a manner that prevents fish passage (e.g., via pipes or conveyances too steep for fish passage).

Streams and wetlands removed or altered via these various mechanisms are collectively referred to as “lost” in this assessment. Methods used to estimate these losses are described in Box 7-1.

Figure 7-10. Streams and wetlands lost (eliminated, blocked, or dewatered) in the Pebble 0.25 scenario. Light blue areas indicate streams and rivers from the National Hydrography Dataset (USGS 2012a) and lakes and ponds from the National Wetlands Inventory (USFWS 2012); dark blue areas indicate wetlands from the National Wetlands Inventory (USFWS 2012). See Box 7-1 for definitions and methods used for delineation.

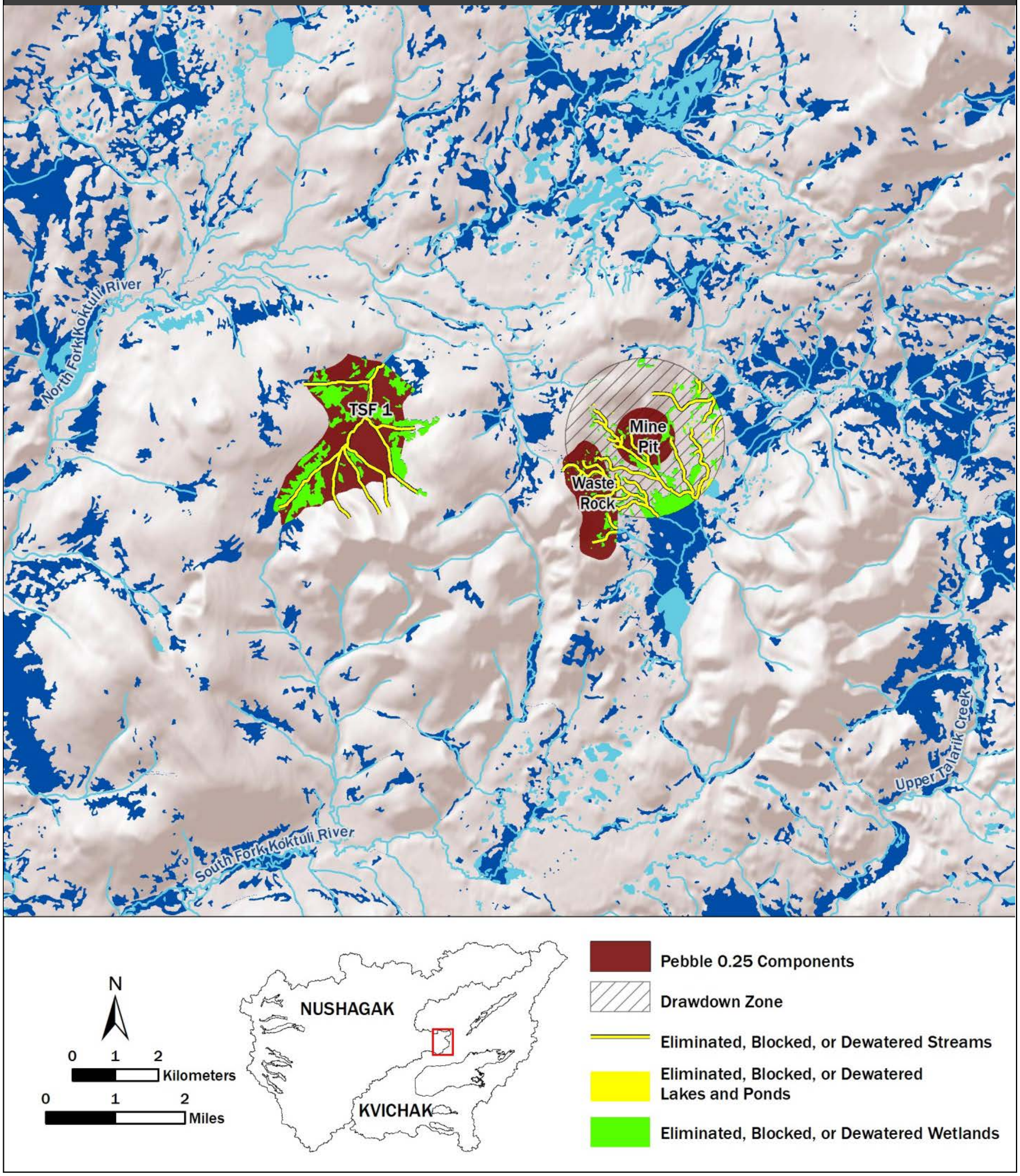


Figure 7-11. Streams and wetlands lost (eliminated, blocked, or dewatered) in the Pebble 2.0 scenario. Light blue areas indicate streams and rivers from the National Hydrography Dataset (USGS 2012a) and lakes and ponds from the National Wetlands Inventory (USFWS 2012); dark blue areas indicate wetlands from the National Wetlands Inventory (USFWS 2012). See Box 7-1 for definitions and methods used for delineation.

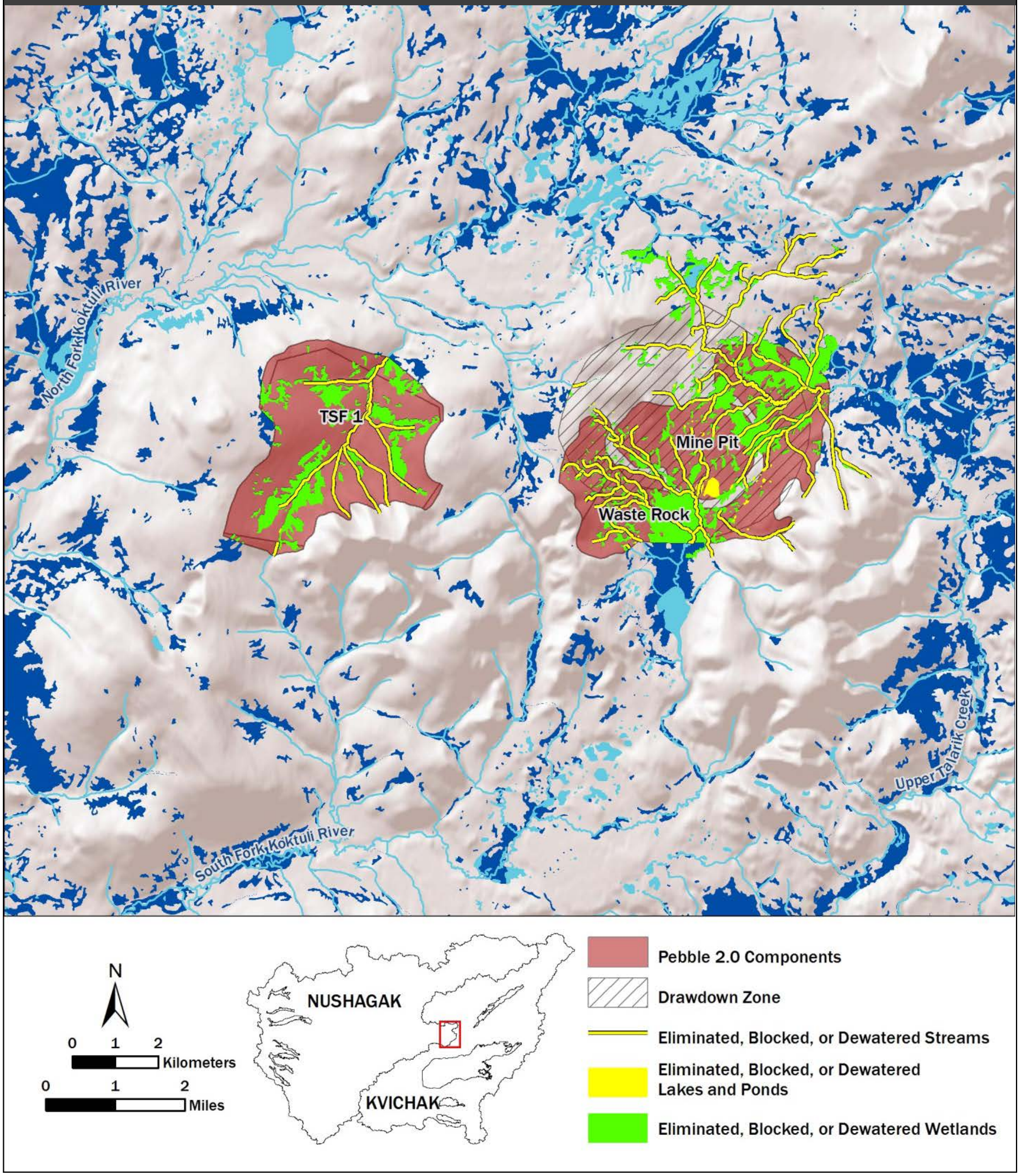
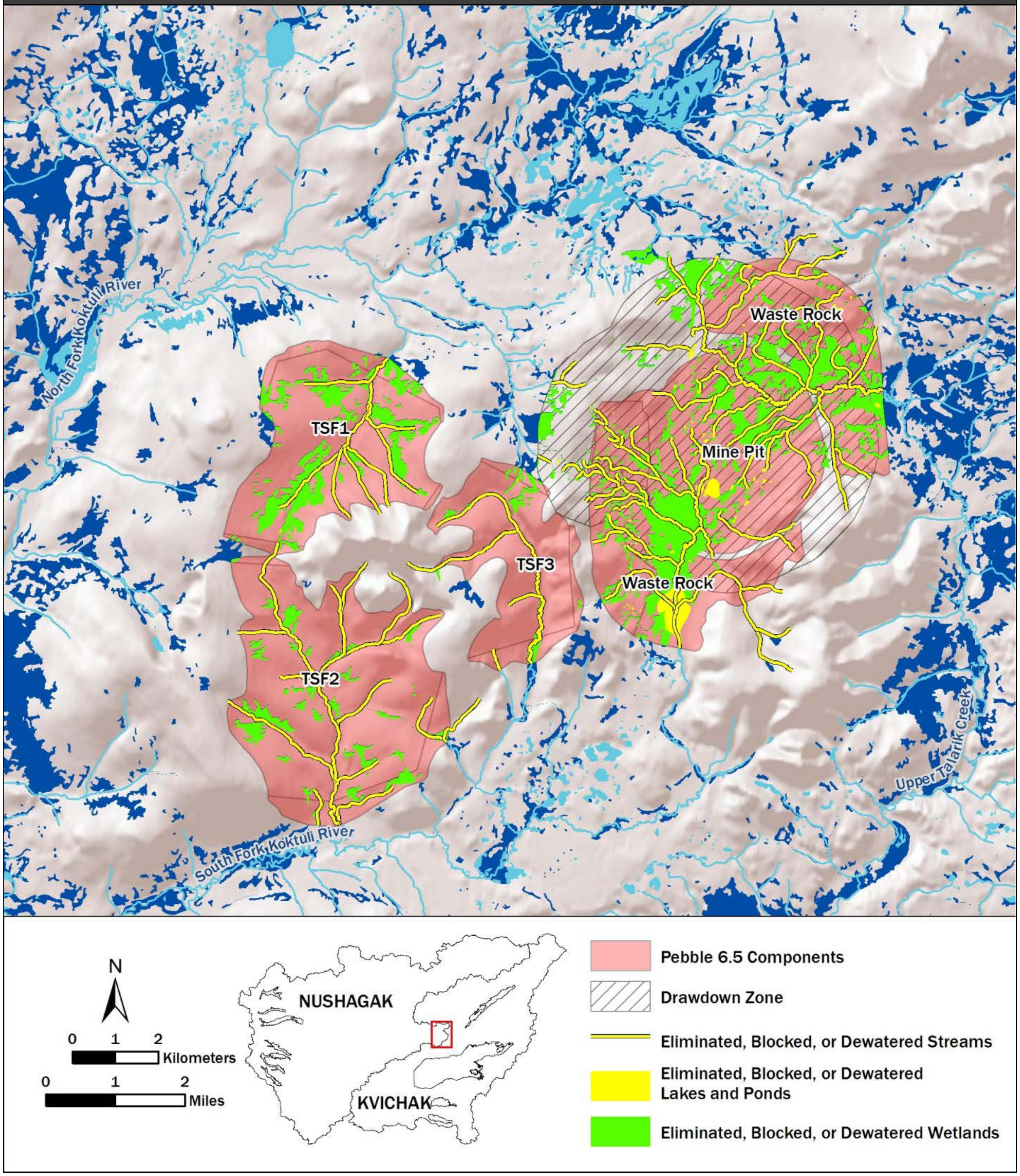


Figure 7-12. Streams and wetlands lost (eliminated, blocked, or dewatered) in the Pebble 6.5 scenario. Light blue areas indicate streams and rivers from the National Hydrography Dataset (USGS 2012a) and lakes and ponds from the National Wetlands Inventory (USFWS 2012); dark blue areas indicate wetlands from the National Wetlands Inventory (USFWS 2012). See Box 7-1 for definitions and methods used for delineation.



BOX 7-1. CALCULATION OF STREAMS AND WETLANDS AFFECTED BY MINE SCENARIO FOOTPRINTS

To calculate kilometers of streams eliminated, blocked, or experiencing streamflow alteration due to the footprints of the major mine components and the groundwater drawdown zone associated with the mine pit, we used the Alaska National Hydrography Dataset (NHD) (USGS 2012a). The scale of this dataset is 1:63,360. In this assessment, a stream segment is classified as eliminated if it falls within the boundaries of the mine pit, waste rock pile, or tailings storage facility (TSF). A segment is classified as blocked if it or a downstream segment it connects to directly intersects the mine pit, waste rock pile, or TSF. A stream segment not otherwise eliminated is classified as dewatered if it falls within the groundwater drawdown zone associated with the mine pit, or is classified as blocked and dewatered if it falls within the groundwater drawdown zone and a downstream segment it connects to directly intersects the mine pit. For calculation of stream kilometers either eliminated or blocked that are inhabited by anadromous and resident fish species, we used the Anadromous Waters Catalog (AWC) (Johnson and Blanche 2012) and the Alaska Freshwater Fish Inventory (AFFI) (ADF&G 2012). Stream lengths blocked, eliminated, or dewatered were summed across each classification for both NHD and AWC fish-inhabited stream segments (Table 7-5).

Estimates of wetland, pond, and lake areas eliminated, blocked, or dewatered by the mine scenario footprints were derived from the National Wetlands Inventory (NWI) (USFWS 2012). For the State of Alaska, the scale of this dataset is 1:63,360. In this assessment, wetland, pond, or lake area is classified as eliminated if it falls within the boundaries of the mine pit, waste rock pile, or TSF; dewatered if it falls within the groundwater drawdown zone associated with the mine pit; and blocked if it directly intersects a previously categorized blocked NHD stream. Wetland, pond, and lake areas blocked, eliminated, or dewatered were summed across each classification (Table 7-8).

The area covered by plant and ancillary facilities associated with mine site development (e.g., housing, crushing plant, wastewater treatment plant) is not considered in the calculation of eliminated and blocked streams and wetlands due to lack of knowledge about the orientation and placement of these structures on the landscape. Thus, the values reported in Tables 7-5 and 7-8 are conservative estimates, as additional development on the landscape would likely impact additional stream length and wetland area due to the abundance of aquatic habitats in this region.

It is important to note that estimates of stream length and wetland, pond, and lake areas affected represent a lower bound on the estimate. The NHD does not capture all stream courses and may underestimate channel sinuosity, resulting in underestimates of affected stream length. In addition, the AWC and the AFFI do not necessarily characterize all potential fish-bearing streams, because it is not possible to sample all streams and there may be errors in identification and mapping. The Alaska Department of Fish and Game, in its on-line AWC database, states: “Based upon thorough surveys of a few drainages it is believed that this number represents less than 50% of the streams, rivers and lakes actually used by anadromous species” (ADF&G 2013). The characterization of wetland area is limited by resolution of the available NWI data product, which is not available for the full assessment area. Other investigations have revealed high spatial variability in wetland density across the region (e.g., Hall et al. 1994). Others have conducted enhanced wetland inventories. For example, the Pebble Limited Partnership (2011) used multiple sources of high resolution remote imaging and ground-truthing to map wetlands in their mine mapping area, which focused on the proposed mine working area and major stream valleys. They reported wetland densities of approximately 29% for the mapping area (PLP 2011: Table 14.1-3), whereas preliminary NWI mapping identified approximately 20% of this same area as wetland (PLP 2011: Table 14.1-1). Furthermore, the major mine components of the mine scenarios often bisected wetland, pond, or lake features, and areas falling outside the boundary were assumed to maintain their functionality. We were also unable to determine the effect that mine site development may have on wetlands with no direct surface connection to a blocked NHD stream segment, but with a potential connection via groundwater pathways. Given these limitations, these estimates could be enhanced with improved, higher-resolution mapping, increased sampling of possible fish-bearing waters, and ground-truthing.

7.2.2.1 Stream Losses

In the Pebble 0.25 scenario, 38 km of streams would be eliminated, blocked, or dewatered by the mine footprint (Table 7-5, Figure 7-10). In the Pebble 2.0 scenario, over 89 km of streams would be eliminated, blocked, or dewatered by the mine footprint (Table 7-5, Figure 7-11). In the Pebble 6.5 scenario, an additional 20 km of streams in the pit and waste rock pile areas and 41 km of streams under TSF 2 and TSF 3 would be eliminated or blocked, for a total of 151 km of streams lost to the mine footprint (Table 7-5, Figure 7-12). These scenarios represent 4, 8, and 14% of the total stream length within the mine scenario watersheds. Of the streams lost to the mine footprint in the Pebble 6.5 scenario, 82% are headwater streams (less than 0.15 m^3/s mean annual streamflow); 76% have less than 3% gradient, and 26% have less than 1% gradient (Table 7-6, Figure 7-13). The majority (74%) of smaller streams lost to the mine footprint in the Pebble 6.5 scenario flow through valleys with limited flatland (Table 7-6).

Compared to the larger Nushagak and Kvichak River watersheds, streams lost to the mine footprints are smaller: 9% of stream length in the Nushagak and Kvichak River watersheds exceeds 2.8 m^3/s mean annual streamflow (Table 3-3), whereas no streams lost to the mine footprints exceed this size (Figure 7-13A). Streams within the mine footprints also have a lower proportion of stream length with less than 1% gradient (26% versus 64% of stream length in the Nushagak and Kvichak River watersheds) (Figure 7-13B), and more stream length with low floodplain potential (74% versus 39%) (Figure 7-13C).

These results provide some indication of the relative size, steepness, and geomorphic setting of streams that would be lost to the mine footprints. The streams that would be lost include a range of stream types that provide a variety of habitat functions for salmon, including as year-round or seasonal habitat for salmonids or other fishes or as important sources of water, macroinvertebrates, and other materials to downstream waters (Section 7.2.3). Of the 151 km of streams lost to the Pebble 6.5 footprint, 36 km are currently cataloged as anadromous fish streams in the AWC (Johnson and Blanche 2012). Most of these cataloged anadromous streams are in the medium stream size class (0.15 to 2.8 m^3/s), with gradients less than 3%. These include the upper reaches and larger tributaries of the South and North Fork Koktuli Rivers and Upper Talarik Creek, including smaller streams with documented occurrence of coho salmon (Figure 7-3). Many of the smaller, steeper tributaries have been documented to contain Dolly Varden (Figure 7-7).

Figure 7-13. Cumulative frequency of stream channel length classified by (A) mean annual streamflow (m^3/s), (B) channel gradient (%), and (C) floodplain potential (based on % flatland in lowland) for the mine footprints (Scale 4) versus the Nushagak and Kvichak River watersheds (Scale 2).

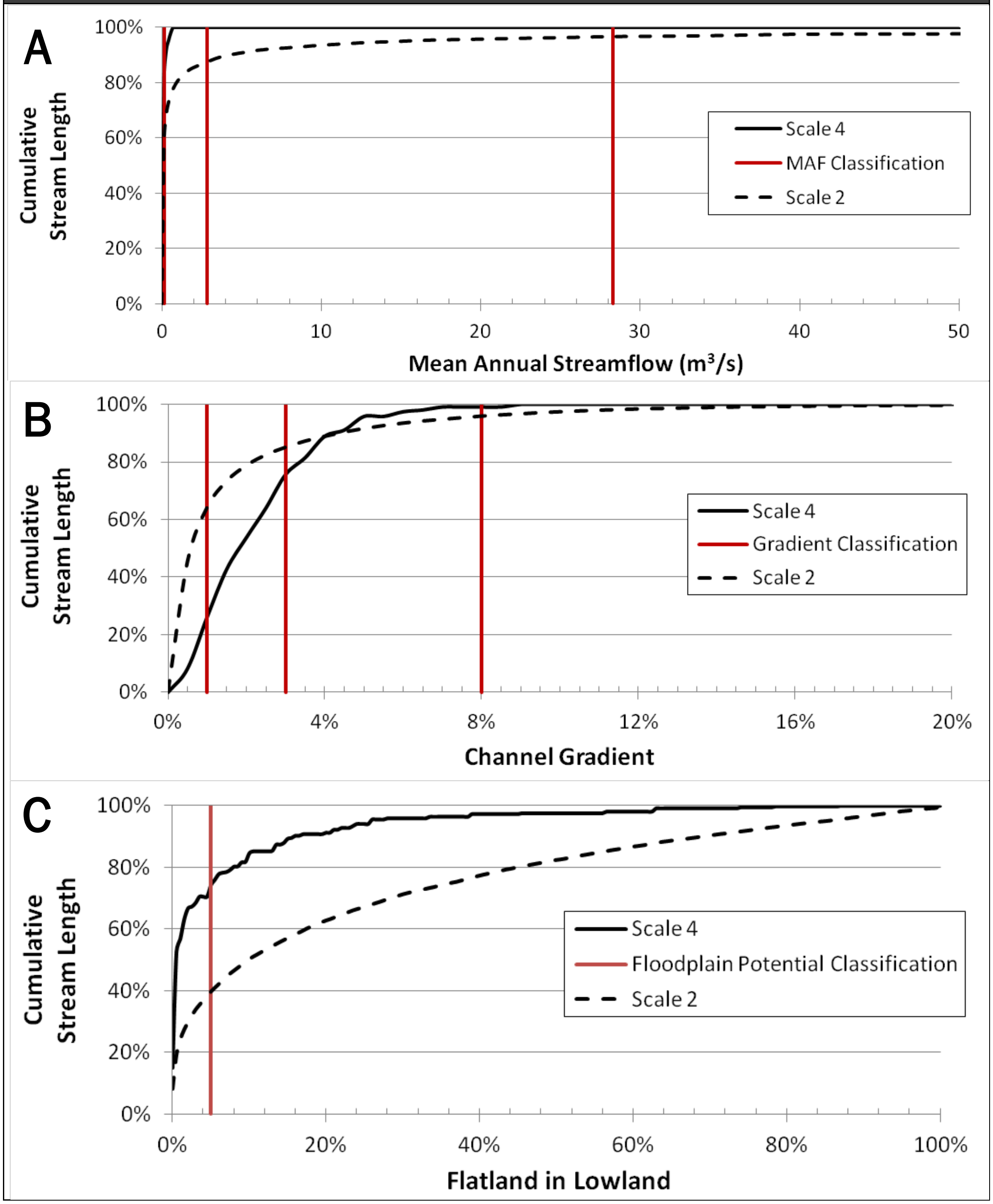


Table 7-5. Stream length (km) eliminated, blocked, or dewatered by the mine footprints in the Pebble 0.25, 2.0, and 6.5 scenarios. See Box 7-1 for methods.

Component	Stream Length[a]					AWC Stream Length[b]				Salmon Species Present in Lost[c] Streams	TOTAL AWC Stream Length Lost[c] to Footprint
	Eliminated by Footprint	Blocked by Footprint	Dewatered by Footprint	Blocked and Dewatered by Footprint	TOTAL Stream Length Lost[c] to Footprint	Eliminated by Footprint	Blocked by Footprint	Dewatered by Footprint	Blocked and Dewatered by Footprint		
Pebble 0.25											
Pit	3.0	0.0	13.4	1.4	17.8	0.0	0.0	1.5	0.0	Chinook, coho	1.5
Waste rock	5.1	<0.1	NA	NA	5.1	0.0	0.0	NA	NA		0.0
TSF 1[d]	12.3	2.7	NA	NA	15.0	6.1	0.0	NA	NA	Chinook, coho	6.1
TOTAL	**20.4**	**2.8**	**13.4**	**1.4**	**38.0**	**6.1**	**0.0**	**1.5**	**0.0**		**7.7**
Pebble 2.0											
Pit + waste rock	56.9	10.2	1.9	4.8	73.8	11.3	1.7	0.0	2.4	Chinook, coho, sockeye	15.4
TSF 1[d]	15.4	0.2	NA	NA	15.5	6.3	0.0	NA	NA	Chinook, coho	6.3
TOTAL	**72.3**	**10.4**	**1.9**	**4.8**	**89.4**	**17.6**	**1.7**	**0.0**	**2.4**		**21.7**
Pebble 6.5											
Pit + waste rock	76.9	5.9	3.4	7.7	93.9	18.7	0.0	0.0	1.6	Chinook, coho, sockeye	20.3
TSF 1	15.4	0.2	NA	NA	15.5	6.3	0.0	NA	NA	Chinook, coho,	6.3
TSF 2	28.3	2.2	NA	NA	30.5	6.1	0.0	NA	NA	Chinook, chum, coho	6.1
TSF 3	10.2	0.7	NA	NA	10.9	3.3	0.0	NA	NA	Coho	3.3
TOTAL	**130.8**	**9.0**	**3.4**	**7.7**	**150.9**	**34.4**	**0.0**	**0.0**	**1.6**		**36.0**

Notes:
[a] From the National Hydrography Dataset (USGS 2012a).
[b] From the Anadromous Waters Catalog (Johnson and Blanche 2012)
[c] Lost = eliminated + blocked + dewatered.
[d] TSF 1 expands in size in the Pebble 2.0 scenario.
TSF = tailings storage facility; AWC = Anadromous Waters Catalog; NA = not applicable as the mine pit dewatering zone does not overlap these individual components.

Table 7-6. Distribution of stream channel length classified by channel size (based on mean annual streamflow in m³/s), channel gradient (%), and floodplain potential (based on % flatland in lowland) for streams lost to the Pebble 6.5 mine footprint. Gray shading indicates proportions greater than 5%; bold indicates proportions greater than 10%.

Channel Size	Gradient							
	<1%		≥1% and <3%		≥3% and <8%		≥8%	
	FP	NFP	FP	NFP	FP	NFP	FP	NFP
Small headwater streams[a]	10%	4%	9%	**35%**	0%	**23%**	0%	1%
Medium streams[b]	6%	6%	1%	5%	0%	0%	0%	0%
Small rivers[c]	0%	0%	0%	0%	0%	0%	0%	0%
Large rivers[d]	0%	0%	0%	0%	0%	0%	0%	0%

Notes:

[a] 0–0.15 m^3/s; most tributaries in the mine footprints.

[b] 0.15–2.8 m^3/s; upper reaches and larger tributaries of the North and South Fork Koktuli Rivers and Upper Talarik Creek.

[c] 2.8–28 m^3/s; middle to lower portions of the North and South Fork Koktuli Rivers and Upper Talarik Creek, including the mainstem Koktuli River.

[d] >28 m^3/s; the Mulchatna River below the Koktuli confluence, the Newhalen River, and other large rivers.
FP = high floodplain potential (≥5% flatland in lowland); NFP = no or low floodplain potential (<5% flatland in lowland) (see Chapter 3 for additional details).

Table 7-7 provides a summary of the total documented anadromous fish stream length in the mine scenario watersheds (Johnson and Blanche 2012). Approximately 2, 7, and 11% of the total anadromous fish stream length in the mine scenario watersheds would be eliminated, blocked, or dewatered in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively (Table 7-5). In addition to these direct losses, loss of these headwater habitats would have indirect impacts on fishes and their habitats in downstream mainstem reaches of each watershed (Section 7.2.3).

Table 7-7. Total documented anadromous fish stream length and stream length documented to contain different salmonid species in the mine scenario watersheds.

	South Fork Koktuli River (km)	North Fork Koktuli River (km)	Upper Talarik Creek (km)	Total (km)
Total mapped streams[a]	315	343	427	1,085
Total anadromous fish streams[b]	95	104	123	322
By species				
Chinook salmon	59	61	63	183
Chum salmon	37	31	45	113
Coho salmon	93	103	122	318
Pink salmon	0	0	7	7
Sockeye salmon	64	47	80	191
Dolly Varden[c]	48	0	26	75

Notes:

[a] From the National Hydrography Dataset (USGS 2012a).

[b] From the Anadromous Waters Catalog (Johnson and Blanche 2012).

[c] Listed as Arctic char in some cases, but assumed to be Dolly Varden (Appendix B).

7.2.2.2 Wetland, Pond, and Lake Losses

In addition to the stream losses detailed above, 4.5, 12, and 18 km^2 of wetlands and 0.41, 0.93, and 1.8 km^2 of ponds and lakes would be lost in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively. (Table 7-8, Figures 7-10 through 7-12). Methods used to estimate these losses are described in Box 7-1.

7.2.3 Exposure-Response: Implications of Stream and Wetland Loss for Fish

7.2.3.1 Fish Occurrence in Streams and Wetlands Lost to the Mine Scenario Footprints

Tables 7-5 and 7-8 provide an estimate of salmon habitat directly affected by the mine footprint in the three mine scenarios. A total of 8, 22, and 36 km of documented anadromous fish streams would be eliminated, blocked, or dewatered by the mine footprints in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively. The distribution of anadromous Dolly Varden in the Nushagak and Kvichak River watersheds is not fully known, making our estimate of the total anadromous fish habitat affected by the mine scenarios incomplete. Of the total wetland area eliminated, blocked, or dewatered by each footprint, the proportion used by anadromous salmonids or resident fish species is unknown. Fish access to and use of wetlands are likely to be extremely variable in the deposit area, due to differences in the duration and timing of surface water connectivity with stream habitats, distance from the main channel, and physical and chemical conditions (e.g., dissolved oxygen concentrations) (King et al. 2012). Wetlands can provide refuge habitats (Brown and Hartman 1988) and important rearing habitats for juvenile salmonids by providing hydraulically and thermally diverse conditions. Wetlands can also provide enhanced foraging opportunities (Sommer et al. 2001). Given our insufficient knowledge of how fish use wetlands in the deposit area, it is not possible to calculate the effects of lost wetland connectivity and abundance on stream fish populations.

Among the Pacific salmon species, coho salmon occupy the highest proportion of designated AWC stream segments in the mine scenario watersheds (Table 7-7). Spawning habitat for coho salmon would be lost in the South and North Fork Koktuli River watersheds under TSF 1 and TSF 2, respectively (Figure 7-3); sockeye and coho salmon spawning habitat would be lost in the Upper Talarik Creek watershed under the waste rock piles (Figures 7-2 and 7-3) (Johnson and Blanche 2012). In other regions, anadromous and resident forms of Dolly Varden have been observed in the most upstream and high-gradient habitats available for spawning, indicating that headwaters may be important source areas for downstream populations (Bryant et al. 2004). Under the Pebble 6.5 footprint, 99% of stream kilometers are estimated to have gradients less than 8% and 76% are estimated to have gradients less than 3%, well within the range of gradients used by these species.

Table 7-8. Wetland, pond, and lake areas[a] (km^2) eliminated, blocked, or dewatered by the mine footprints in the Pebble 0.25, 2.0, and 6.5 scenarios.

	Eliminated by Footprint				Blocked by Footprint				Dewatered by Footprint				Blocked and Dewatered by Footprint				Total Area Lost to Footprint			
Component	**Wetland**	**Pond**	**Lake**	**Sum**	**Wetland**	**Pond**	**Lake**	**Sum**	**Wetland**	**Pond**	**Lake**	**Sum**	**Wetland**	**Pond**	**Lake**	**Sum**	**Wetland**	**Pond**	**Lake**	**Sum**
Pebble 0.25																				
Pit	0.26	0.02	0.00	0.27	0.00	0.00	0.00	0.00	1.30	0.28	0.02	1.60	0.03	0.03	0.00	0.06	1.59	0.32	0.02	1.93
Waste rock	0.29	0.07	0.00	0.36	0.00	0.00	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	0.29	0.07	0.00	0.36
TSF1	2.33	<0.01	0.00	2.34	0.31	0.00	0.00	0.31	NA	NA	NA	NA	NA	NA	NA	NA	2.64	<0.01	0.00	2.64
Total	2.88	0.09	0.00	2.97	0.31	0.00	0.00	0.31	1.30	0.28	0.02	1.60	0.03	0.03	0.00	0.06	4.52	0.39	0.02	4.93
Pebble 2.0																				
Pit + waste rock	5.86	0.63	0.12	6.61	1.67	0.06	0.00	1.73	0.33	0.08	0.00	0.41	0.15	0.04	0.00	0.19	8.01	0.81	0.12	8.94
TSF1[b]	3.56	<0.01	0.00	3.57	0.00	0.00	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	3.56	<0.01	0.00	3.57
Total	9.42	0.64	0.12	10.18	1.67	0.06	0.00	1.73	0.33	0.08	0.00	0.41	0.15	0.04	0.00	0.19	11.57	0.82	0.12	12.51
Pebble 6.5																				
Pit + waste rock	10.16	0.88	0.70	11.74	0.24	0.01	0.00	0.26	0.73	0.18	0.00	0.91	0.72	0.03	0.00	0.75	11.86	1.10	0.70	13.66
TSF1	3.56	<0.01	0.00	3.57	0.00	0.00	0.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	3.56	<0.01	0.00	3.57
TSF2	1.94	<0.01	0.00	1.94	0.02	0.00	0.00	0.02	NA	NA	NA	NA	NA	NA	NA	NA	1.96	<0.01	0.00	1.96
TSF3	0.54	0.01	0.00	0.55	0.02	0.00	0.00	0.02	NA	NA	NA	NA	NA	NA	NA	NA	0.56	0.01	0.00	0.57
Total	16.20	0.90	0.70	17.80	0.28	0.01	0.00	0.30	0.73	0.18	0.00	0.91	0.72	0.03	0.00	0.75	17.94	1.11	0.70	19.77

Notes:

[a] Based on the National Wetlands Inventory (USFWS 2012).

[b] TSF 1 expands in size in the Pebble 2.0 scenario.

TSF = tailings storage facility; NA = not applicable as the mine pit dewatering zone does not overlap with the footprints of these individual components.

In addition to spawning, streams in each mine footprint provide rearing habitat for fish of the mine scenario watersheds. Species known to rear in habitats in and upstream of the mine footprints are sockeye salmon (Figure 7-2), coho salmon (Figure 7-3), Chinook salmon (Figure 7-4), chum salmon (Figure 7-5), Dolly Varden (Figure 7-7), rainbow trout (Figure 7-8), Arctic grayling, slimy sculpin, northern pike, and ninespine stickleback (ADF&G 2012, Johnson and Blanche 2012).

7.2.3.2 Importance of Headwater Stream and Wetland Habitats

The majority of streams lost to the footprint of the Pebble 6.5 scenario are classified as small headwater streams (less than 0.15 m^3/s mean annual streamflow) (Table 7-6). Because of their narrow width, headwater streams receive proportionally greater inputs of organic material from the surrounding terrestrial vegetation than larger stream channels (Vannote et al. 1980). This material is either used locally (Tank et al. 2010) or transported downstream as a subsidy to larger streams in the network (Wipfli et al. 2007). Consumers in headwater stream foodwebs, such as invertebrates and juvenile salmon, can rely heavily on terrestrial inputs that enter the stream (Doucett et al. 1996, Dekar et al. 2012). Headwater streams also encompass the upper limits of anadromous fish distribution. These streams may receive fewer or no marine-derived nutrients (MDN) from spawning salmon relative to downstream portions of the river network, making terrestrial nutrient sources relatively more important (Wipfli and Baxter 2010). Because of their shallow depths and propensity to freeze, headwater streams may be largely uninhabitable in the winter (but see discussion of overwintering below), and fish distribution in headwater systems in southwestern Alaska is likely most extensive in late summer and early fall (Elliott and Finn 1983). This coincides with maximum growth periods for rearing juvenile salmon, as both stream temperatures and food availability increase (Quinn 2005).

Data on riparian vegetation communities specific to the mine footprints were not available, but vegetation in the deposit area is described generally by PLP (2011). Shrub vegetation communities account for 81% of the total area, with four dominant vegetation types: dwarf ericaceous shrub tundra, dwarf ericaceous shrub lichen tundra, open willow low shrub, and closed alder tall shrub (PLP 2011: Chapter 13:10). Riparian areas are dominated by willow and alder shrub communities (PLP 2011: Chapter 13:11). Deciduous shrub species such as alder and willow provide abundant and nutrient-rich leaf litter inputs, which are used more rapidly in stream foodwebs than coniferous plants or grasses (Webster and Benfield 1986). In addition, alder is a nitrogen-fixing shrub known to increase headwater stream nitrogen concentrations (Compton et al. 2003, Shaftel et al. 2012), which can result in more rapid litter processing rates (Ferreira et al. 2006, Shaftel et al. 2011). The presence of both willow and alder in headwater stream riparian zones implies high-quality basal food resources for stream fishes in the deposit area.

In addition to providing summer rearing habitat, lower-gradient headwater streams and associated wetlands may also provide important habitat for stream fishes during other seasons. Loss of wetlands is a common result of land development (Pess et al. 2005), and in more developed regions has been associated with reductions in habitat quality and salmon abundance, particularly for coho salmon (Beechie et al. 1994, Pess et al. 2002). Thermally diverse habitats in off-channel wetlands can provide rearing and foraging conditions that may be unavailable in the main stream channel (Sommer et al. 2001, Henning et al. 2006), increasing capacity for juvenile salmon rearing (Brown and Hartman 1988). Winter habitat availability for juvenile rearing has been shown to limit salmonid productivity in streams of the Pacific Northwest (Nickelson et al. 1992, Solazzi et al. 2000, Pollock et al. 2004) and may be limiting for fish in the mine scenario watersheds given the relatively cold temperatures and long winters in the region.

Overwintering habitats for stream fishes must provide suitable instream cover, dissolved oxygen, and protection from freezing (Cunjak 1996). Beaver ponds and groundwater sources in headwater streams and wetlands in the mine footprints likely meet these requirements. In winter, beaver ponds typically retain liquid water below the frozen surface, which makes them important winter refugia for stream fishes (Nickelson et al. 1992, Cunjak 1996). Beavers preferentially colonize headwater streams because of their shallow depths and narrow widths, and several studies have indicated that dam densities are reduced significantly at stream gradients above 6 to 9% (Collen and Gibson 2001, Pollock et al. 2003). Beaver ponds provide excellent habitat for rearing salmon by trapping organic materials and nutrients and creating structurally complex, large capacity pool habitats with potentially high macrophyte cover, low streamflow velocity, and/or moderate temperatures (Nickelson et al. 1992, Collen and Gibson 2001, Lang et al. 2006). Additionally, beaver dams, including ponds at a variety of successional stages, provide a mosaic of habitats for not just salmon but other fish and wildlife species.

An aerial survey of active beaver dams in the deposit area, conducted in October 2005 (PLP 2011: Chapter 16:16.2-8), mapped 113 active beaver colonies. The area surveyed did not include streams draining the TSF 1 area (PLP 2011: Figure 16.2-20). Several active beaver colonies were mapped in streams that would be eliminated or blocked by the mine pit and waste rock piles. These are lower-gradient habitats than the headwater streams draining the TSF areas. Beaver ponds provide important and relatively abundant habitat within the deposit area and may be particularly important for overwinter rearing of species such as coho salmon and for providing deeper pool habitats for additional species during low streamflow conditions (PLP 2011: Appendix 15.1D). Loss of beaver pond habitats in the headwaters of the South Fork Koktuli River and Upper Talarik Creek watersheds would reduce both summer and winter rearing opportunities for anadromous and resident fish species.

Inputs of groundwater-influenced streamflow from headwater tributaries likely benefit fish by moderating mainstem temperatures and contributing to thermal diversity in downstream waters (Cunjak 1996, Power et al. 1999, Huusko et al. 2007, Armstrong et al. 2010, Brown et al. 2011). PLP (2011) collected temperature data from stream sampling sites using in-situ field meters (PLP 2011: Appendix 15.1-E). Maximum summer (June through August) water temperatures recorded at gage NK119A, which drains the TSF 1 area, were approximately 5°C colder than the mainstem reach that it flows into (PLP 2011: Tables 15.1 through 15.4). This difference was not as pronounced at gage SK119A, which drains the TSF 2 area and where recorded maximum summer water temperatures were approximately 2°C colder than the mainstem reach that it flows into (PLP 2011: Tables 15.1 through 15.21).

Longitudinal temperature profiles for the South and North Fork Koktuli River watersheds from August and October indicate that the mainstem reaches just downstream of the tributaries draining TSF 1 and TSF 2 experience significant summer cooling and winter warming compared to adjacent upstream reaches (PLP 2011: Figures 15.1-11 and 15.1-41). Such thermal diversity can be an important attribute of stream systems in the region, providing localized water temperature patches that may offer differing trade-offs for species bioenergetics. For example, salmon may select relatively cold-temperature sites—often associated with groundwater upwelling—for spawning, whereas juvenile salmon rearing in those same streams may take advantage of warm-temperature patches for optimal food assimilation (e.g., Armstrong and Schindler 2013). Headwater streams in the South and North Fork Koktuli River watersheds may provide a temperature-moderating effect and serve as sources of thermal heterogeneity, providing cooler temperatures in summer and warmer temperatures in winter.

It has long been recognized that, in addition to providing habitat for stream fishes, headwater streams and wetlands serve an important role in the stream network by contributing water, nutrients, organic material, macroinvertebrates, algae, and bacteria downstream to higher-order streams in the watershed (Vannote et al. 1980, Meyer et al. 2007). However, only recently have specific subsidies from headwater streams been extensively quantified (Wipfli and Baxter 2010). Headwater contributions to downstream systems result from the high density of headwaters in the dendritic stream network. Headwater streams can also have high instream rates of nutrient processing and storage, thereby influencing downstream water chemistry due to relatively large organic matter inputs, high retention capacity, high primary productivity, bacteria-induced decomposition, and/or extensive hyporheic zone interactions (Richardson et al. 2005, Alexander et al. 2007, Meyer et al. 2007).

Wipfli and Gregovich (2002) demonstrated that invertebrates and detritus are exported from headwaters to downstream reaches and provide an important energy subsidy for juvenile salmonids. Wipfli and Baxter (2010) describe how the relative importance of energy subsidies from headwaters, terrestrial inputs, benthic production, and marine sources varies within salmon watersheds based on spatial and temporal context. For example, foodwebs in small headwater streams of the mine scenario watersheds may be proportionally more dependent on local terrestrial energy subsidies, whereas stream communities in downstream waters may be more dependent on large seasonal fluxes of MDN. Small headwater streams can be important exporters of subsidies to downstream waters, but the relative value of this contribution will depend on the quantity and energy content of headwater-derived subsidies relative to other energy sources (e.g., MDN, benthic production) that vary in time and space (Wipfli and Baxter 2010).

The export value of headwater streams can be mediated by the surrounding vegetation. In southeastern Alaskan streams, riparian alder (a nitrogen-fixing shrub) was positively related to aquatic invertebrate densities and the export rates of invertebrates and detritus (Piccolo and Wipfli 2002, Wipfli and Musslewhite 2004). In south-central Alaskan streams on the Kenai Peninsula, grass-dominated headwater wetlands and associated vegetation can also be important sources of dissolved organic matter, particulate organic matter, and macroinvertebrate diversity, contributing to the chemical, physical, and biological condition of streams draining these landscapes (Shaftel et al. 2011, Dekar et al.

2012, King et al. 2012, Walker et al. 2012). Because of their crucial influence on downstream water flow, chemistry, and biota, impacts on headwaters reverberate throughout entire watersheds downstream (Freeman et al. 2007, Meyer et al. 2007).

7.2.4 Risk Characterization

Direct loss of streams and wetlands to the mine footprints would make these habitats unavailable to fishes. Such losses would be unavoidable for projects of the sizes described in our mine scenarios, due to the density of streams and wetlands in the deposit area (combined 33% of the mine mapping area [PLP 2011: Table 14.1-5 and Figure 14.1-3]). Stream blockage is not necessarily unavoidable, but would require appropriate engineering and maintenance. Indirect effects of headwater stream and wetland losses due to the mine footprints would include reduced inputs of organic material, nutrients, water, and macroinvertebrates to downstream reaches, but the relative effects of losses of upstream subsidies would be highly context-dependent (Section 7.2.3).

The net effects of headwater stream and wetland losses would reduce the capacity and productivity of stream habitats. Together, these reductions would result in adverse impacts on fish populations (Figure 7-1). These streams provide known spawning and rearing habitats for anadromous and resident fish species, and their watersheds support some of region's highest diversity of salmonid species (Figure 5-3). The lengths of streams lost directly to the Pebble 0.25, 2.0, and 6.5 mine footprints represent losses of approximately 2, 7, and 11%, respectively, of the total AWC length in the mine scenario watersheds (Table 7-7). Stream habitat losses leading to losses of local, unique populations would erode the population diversity that is crucial to the stability of the overall Bristol Bay salmon fishery (Hilborn et al. 2003, Schindler et al. 2010).

Impact avoidance and minimization measures would not eliminate all the footprint impacts associated with the mine scenarios, given the large extent and wide distribution of wetlands and streams in the watersheds, the substantial infrastructure needed to support porphyry copper mining in this vast undeveloped area, and the constraints that the ore body location puts on infrastructure siting options. Compensatory mitigation measures could offset some of the stream and wetland losses described here (Box 7-2), although the potential efficacy, applicability, and sustainability of these measures to successfully offset adverse impacts face substantial challenges. Appendix J presents a more detailed discussion of these compensatory mitigation issues.

BOX 7-2. COMPENSATORY MITIGATION

Compensatory mitigation refers to the restoration, establishment, enhancement, and/or preservation of wetlands, streams, or other aquatic resources. Compensatory mitigation regulations jointly promulgated by the U.S. Environmental Protection Agency (USEPA) and the U.S. Army Corps of Engineers (USACE) state that "the fundamental objective of compensatory mitigation is to offset environmental losses resulting from unavoidable impacts to waters of the United States authorized by [Clean Water Act Section 404 permits issued by the USACE]" (40 Code of Federal Regulations [CFR] 230.93(a)(1)). Compensatory mitigation enters the analysis only after a proposed project design has incorporated all appropriate and practicable means to avoid and minimize adverse impacts on aquatic resources (40 CFR 230.91(c)). Compensatory mitigation measures are usually not part of project design, but are considered necessary to maintain the integrity of the nation's waters. In addition, guidance issued by the USACE Alaska District in 2009 clarifies that fill placed in streams or in wetlands adjacent to anadromous fish streams in Alaska will require compensatory mitigation (USACE 2009). A 2011 supplement to the Alaska District's 2009 guidance further recommends that projects in "difficult to replace" wetlands, fish-bearing waters, or wetlands within 500 feet of such waters will also likely require compensatory mitigation, as will "large scale projects with significant aquatic resource impacts," such as "mining development" (USACE 2011).

The mine scenarios evaluated in this assessment identify that the mine footprints alone will result in the loss (i.e., filling, blocking or otherwise eliminating) of high-functioning wetlands and tens of kilometers of salmon-supporting streams. Appendix J provides an overview of Clean Water Act (CWA) Section 404 compensatory mitigation requirements for unavoidable impacts on aquatic resources and discusses the likely efficacy of these potential compensation measures at offsetting potential adverse impacts. Note that any formal determinations regarding compensatory mitigation can only take place in the context of a regulatory action. This assessment is not a regulatory action, and thus a complete evaluation of compensatory mitigation is outside the scope of this assessment.

Potential compensatory mitigation measures discussed in Appendix J include mitigation bank credits, in-lieu fee program credits, and permittee-responsible compensatory mitigation projects, such as aquatic resource restoration and enhancement within the South and North Fork Koktuli River and Upper Talarik Creek watersheds as well as more distant portions of the Nushagak and Kvichak River watersheds. As discussed in Appendix J, there are significant challenges regarding the potential efficacy, applicability, and sustainability of compensation measures for use in the Bristol Bay region, raising questions as to whether compensation measures could realistically address impacts of this type and magnitude.

7.2.5 Uncertainties

Losses of anadromous fish-bearing streams in the mine scenario watersheds (Table 7-5) are likely underestimated because of the difficulty of accurately capturing data on all streams that may support fish use throughout the year. We rely on the AWC (Johnson and Blanche 2012) and the AFFI (ADF&G 2012) for documentation of species distributions, but these records are incomplete—not all stream reaches have been surveyed—and may be subject to errors in fish identification. Additionally, depictions of species and life history distributions in the AWC reflect a wide range of mapping policies, and it is difficult to interpret under which policies a particular water body was mapped. That said, the fish sampling documented by PLP (2011) is one of the highest-density efforts conducted to date in this portion of Alaska, such that estimates of anadromous fish distributions are likely better represented here than elsewhere in Alaska.

Losses of headwater streams and anadromous fish-bearing streams in the mine scenario watersheds may also be underestimated because of challenges associated with stream network mapping. Estimates of headwater stream extent were derived from the National Hydrography Dataset (NHD) for Alaska

(USGS 2012a), which does not capture all stream courses and may underestimate channel sinuosity, resulting in underestimates of stream length. A stream network map derived from a light detection and ranging (LiDAR) mapping system would likely yield substantially different results than those presented here. Similarly, actual wetland loss or blockage due to the mine footprints (Table 7-8) would likely be higher than estimated here, as the National Wetlands Inventory (USFWS 2012) is based on remotely-sensed imagery and generally underestimates wetland area. See Box 7-1 for additional discussion of uncertainties associated with stream and wetland mapping.

In the Bristol Bay region, hydrologically diverse riverine and wetland landscapes provide a variety of large river, floodplain, pond, and lake habitats for salmon spawning and rearing. Environmental conditions can be very different among habitats in close proximity. The spatial separation and unique spawning habitat features within the Bristol Bay watershed are associated with variation in life-history characteristics and body morphology (Blair et al. 1993), and have influenced genetic divergence among spawning populations of sockeye salmon at multiple spatial scales (Gomez-Uchida et al. 2011). These distinct populations can occur at very fine spatial scales, with sockeye salmon that use spring-fed ponds and streams approximately 1 km apart exhibiting differences in traits, such as spawn timing, spawn site fidelity, and productivity, that are consistent with discrete populations (Quinn et al. 2012). In the Bristol Bay region, phenotypic variation with apparent adaptive significance has been illustrated for sockeye salmon egg size and spawning gravel size (Quinn et al. 1995), and for sockeye salmon body shape and predation risk from brown bears (Quinn et al. 2001). Olsen et al. (2003) proposed that the fine-scale genetic differentiation they observed in Alaskan coho salmon may be associated with local adaptation to locally diverse freshwater selective pressures, but they did not examine phenotypic variation. These results highlight the potential for fine-scale salmon population structure in the Bristol Bay watershed. Current monitoring approaches are inadequate to fully assess population-level trends across the Bristol Bay watershed (Rand et al. 2007). Additional genetic and ecological research is needed to clarify the spatial scale of this population structure and the varying vulnerabilities of populations across the landscape.

7.3 Streamflow Modification

7.3.1 Exposure: Streamflow

In this section, we describe projected changes in the hydrology of the mine scenario watersheds and associated effects on downstream flows that would result from mine development and operation. We assume that streams in and downstream of the mine footprints would experience streamflow alterations due to water collection, treatment, and discharge to streams via wastewater treatment plant (WWTP) outfalls; leakage from TSFs; and leachate from waste rock piles. See Chapter 6 for a full description of water flows through the mine facilities.

Streamflow alterations resulting from mine operations were estimated by reducing the streamflows recorded at existing stream gages in the mine scenario watersheds (Table 7-9, Figures 7-14 through 7-

16) by the percentage of expected surface area lost to each mine footprint and water yield efficiencies for each watershed. Reductions also included losses to the drawdown zone, caused by the cone of depression at the mine pit, or other locations of dewatering (Table 7-9, Section 6.2.2). Discharges through the WWTP resulted in streamflow additions. Net effects on resulting streamflows were mapped and summarized for individual stream and river segments (Figures 7-14 through 7-16).

Table 7-9. Stream gages and related characteristics for the South and North Fork Koktuli Rivers and Upper Talarik Creek.

Stream and Gage	Drainage Area (km^2)	Mean Annual Streamflow[a] (m^3/s)	Mean Annual Unit Runoff ($m^3/s*km^2$)
South Fork Koktuli River			
SK100G	14	0.4	0.026
SK100F	31	0.8	0.026
SK124A	22	0.5	0.024
SK100C	99	1.3	0.013
SK119A	28	1.0	0.036
SK100B1	141	3.7	0.026
SK100B[b]	179	5.1	0.029
North Fork Koktuli River			
NK119A	20	0.7	0.034
NK119B	11	0.1	0.012
NK100C	65	1.3	0.020
NK100B	99	2.4	0.024
NK100A1	222	5.8	0.026
NK100A[c]	279	7.0	0.025
Upper Talarik Creek			
UT100E	10	0.3	0.027
UT100D	31	0.8	0.025
UT100C2	133	2.9	0.022
UT100C1	159	3.4	0.022
UT100C	185	4.5	0.024
UT119A	10	0.8	0.079
UT100B[d]	222	6.2	0.028

Notes:
[a] Calculated from stream gage data from PLP 2011.
[b] USGS 15302200.
[c] USGS 15302250.
[d] USGS 15300250.

Figure 7-14. Stream segments in the mine scenario watersheds showing streamflow changes (%) associated with the Pebble 0.25 footprint. Streamflow modification class is shown for each stream segment to indicate degree and direction of change. These classes are assigned at a gage and extend upstream to the next gage, confluence point, or mine footprint. Channels and tributaries not classified are shown for informational purposes. Gage locations based on U.S. Geological Survey (2012b) and Pebble Limited Partnership (2011).

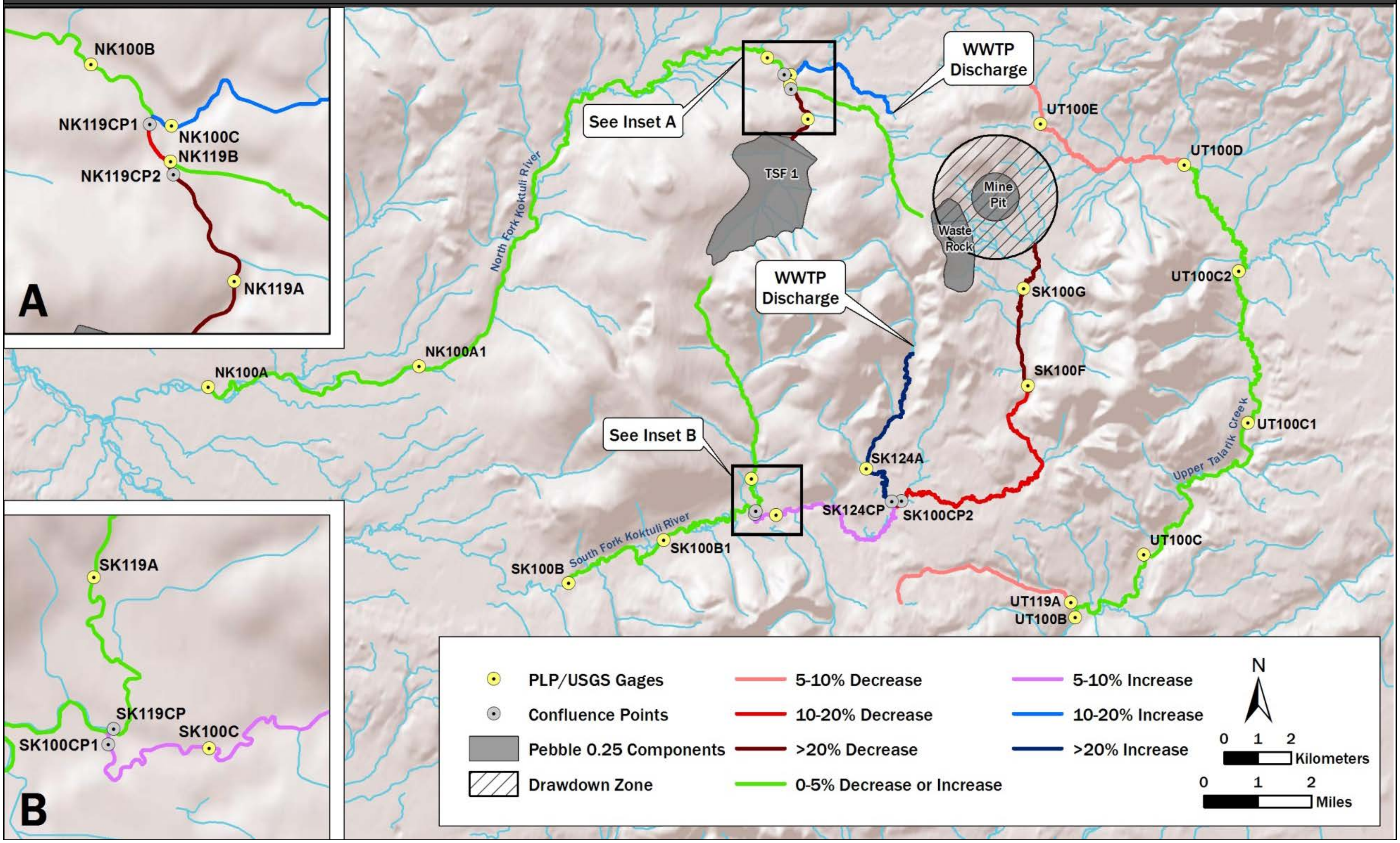


Figure 7-15. Stream segments in the mine scenario watersheds showing streamflow changes (%) associated with the Pebble 2.0 footprint. Streamflow modification class is shown for each stream segment to indicate degree and direction of change. These classes are assigned at a gage and extend upstream to the next gage, confluence point, or mine footprint. Channels and tributaries not classified are shown for informational purposes. Gage locations based on U.S. Geological Survey (2012b) and Pebble Limited Partnership (2011).

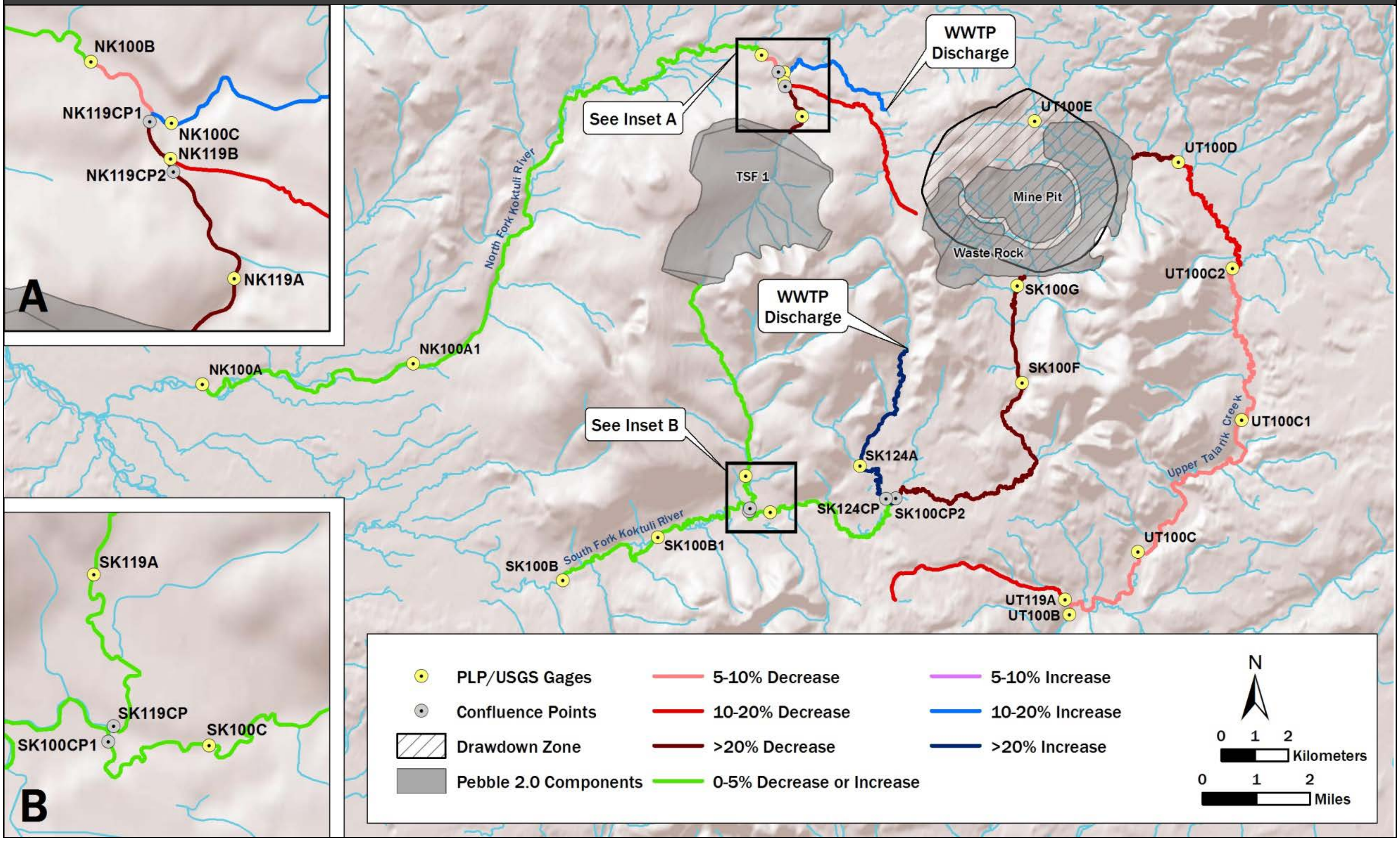
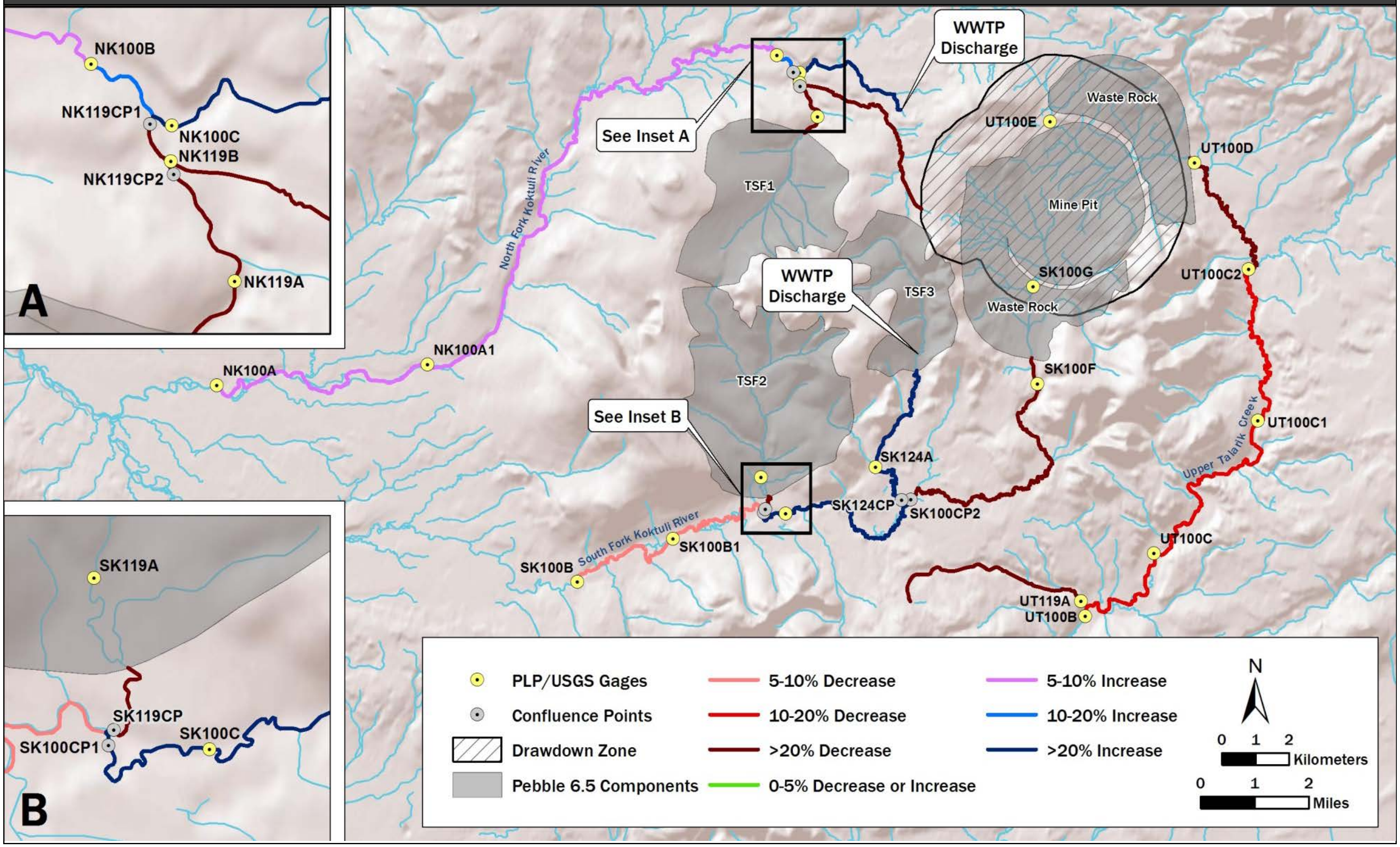


Figure 7-16. Stream segments in the mine scenario watersheds showing streamflow changes (%) associated with the Pebble 6.5 footprint. Streamflow modification class is shown for each stream segment to indicate degree and direction of change. These classes are assigned at a gage and extend upstream to the next gage, confluence point, or mine footprint. Channels and tributaries not classified are shown for informational purposes. Gage locations based on U.S. Geological Survey (2012b) and Pebble Limited Partnership (2011).



Daily streamflow data were obtained using data from seven gages in the South Fork Koktuli River, six gages in the North Fork Koktuli River, and seven gages in Upper Talarik Creek (Table 7-9) (PLP 2011). We calculated mean and minimum monthly streamflows for each gage under pre-mining baseline conditions (Tables 7-10 through 7-15, Figure 7-17). The periods of record varied for gages in the three mine scenario watersheds, but generally covered the period from 2004 to 2010.

In addition, we estimated streamflow at six confluence points where mining-related streamflow impacts were expected but where established stream gage records were lacking. This allowed for more discrete estimation of baseline streamflow, as well as expected streamflow modification in each mine scenario due to withdrawal, addition, or footprint loss. The tributary area to each stream gage or confluence point was calculated based on the National Elevation Dataset digital elevation model (Gesch et al. 2002, Gesch 2007, USGS 2013) in a geographic information system. We determined the area of each mine component (i.e., the mine pit, waste rock piles, plant and ancillary areas, and TSFs) (Tables 6-5 through 6-7) in each drainage basin (Tables 7-16 through 7-18), and calculated the percentage of watershed area covered by the mine components for each gage and confluence point subwatershed. Using the calculated percentage of watershed area covered by the mine components, mean annual streamflow records for each of the gages and confluence point subwatersheds were adjusted downward. Next, the annual volume of return streamflow expected to reach each gage was added back to the adjusted streamflow calculations based on the mine scenarios.

We assessed expected changes to surface water flows for the three mine scenarios (Tables 7-10 through 7-15). We also considered water balance issues for the post-closure period, but streamflow estimates were not assessed for this period. The Pebble 0.25 mine footprint consists of the mine pit, its drawdown zone (Section 6.2.2), one waste rock pile, plant and ancillary facilities, and TSF 1 (Table 6-5). The Pebble 2.0 footprint would add a second or expanded waste rock pile, larger areas for plant and ancillary facilities, an expanded TSF 1, and a larger drawdown zone from groundwater flow to the pit (Table 6-6). The Pebble 6.5 footprint would add effects associated with the fully expanded mine footprint (including TSF 2 and TSF 3) to accommodate expanded mine operations (Table 6-7). We assume that during the post-closure period, active dewatering of the pit would cease as the pit fills. Once the pit is filled, the water level would be maintained below equilibrium level by pumping or gravity drainage to maintain a gradient toward the pit. The pumped water would be treated for as long as it did not meet water quality standards. When treatment was no longer necessary, the pit would be allowed to have a natural outlet if the water level required one.

Table 7-10. Measured mean monthly pre-mining streamflow rates (m³/s) and estimated mean monthly streamflow rates (m³/s) in the Pebble 0.25, 2.0, and 6.5 scenarios, for gages along the South Fork Koktuli River.

Month	SK100G				SK100F				SK124A				SK100C				SK119A				SK100B1				SK100B[a]			
	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5
Jan	**0.23**	0.11	0.07	NA	**0.44**	0.32	0.28	0.17	**0.12**	0.16	0.16	0.26	**0.37**	0.39	0.38	0.51	**0.30**	0.30	0.30	NA	**1.54**	1.52	1.48	1.40	**2.47**	2.44	2.39	2.23
Feb	**0.14**	0.06	0.04	NA	**0.25**	0.18	0.16	0.09	**0.02**	0.03	0.03	0.05	**0.03**	0.03	0.03	0.04	**0.16**	0.16	0.15	NA	**0.79**	0.78	0.76	0.72	**1.40**	1.39	1.35	1.27
Mar	**0.11**	0.05	0.03	NA	**0.19**	0.14	0.12	0.07	**0.01**	0.01	0.01	0.01	**<0.01**	<0.01	<0.01	<0.01	**0.11**	0.11	0.11	NA	**0.57**	0.57	0.55	0.52	**1.09**	1.07	1.05	0.98
Apr	**0.18**	0.08	0.05	NA	**0.24**	0.18	0.16	0.09	**0.05**	0.06	0.06	0.10	**0.13**	0.13	0.13	0.18	**0.22**	0.22	0.22	NA	**0.80**	0.79	0.77	0.73	**1.41**	1.39	1.36	1.27
May	**0.72**	0.33	0.20	NA	**1.95**	1.44	1.26	0.74	**1.91**	2.54	2.49	4.10	**4.30**	4.52	4.37	5.87	**3.02**	3.02	2.97	NA	**10.75**	10.62	10.32	9.74	**12.70**	12.53	12.24	11.46
Jun	**0.50**	0.23	0.14	NA	**1.38**	1.02	0.90	0.53	**1.08**	1.43	1.41	2.32	**2.77**	2.90	2.81	3.77	**1.71**	1.71	1.69	NA	**6.67**	6.59	6.40	6.04	**8.56**	8.44	8.25	7.73
Jul	**0.29**	0.13	0.08	NA	**0.59**	0.44	0.38	0.23	**0.29**	0.39	0.38	0.63	**0.73**	0.77	0.75	1.00	**0.74**	0.74	0.73	NA	**2.56**	2.53	2.46	2.32	**3.85**	3.80	3.71	3.48
Aug	**0.42**	0.19	0.12	NA	**0.83**	0.62	0.54	0.32	**0.59**	0.78	0.77	1.27	**1.17**	1.23	1.19	1.60	**1.15**	1.15	1.13	NA	**4.05**	4.00	3.89	3.67	**5.92**	5.84	5.70	5.34
Sep	**0.55**	0.25	0.15	NA	**1.20**	0.89	0.78	0.46	**0.83**	1.10	1.08	1.79	**2.05**	2.15	2.08	2.79	**1.75**	1.75	1.73	NA	**5.18**	5.11	4.97	4.69	**7.75**	7.64	7.47	6.99
Oct	**0.64**	0.29	0.18	NA	**1.47**	1.08	0.95	0.56	**0.98**	1.29	1.27	2.10	**2.80**	2.93	2.84	3.81	**1.61**	1.61	1.59	NA	**6.12**	6.05	5.88	5.55	**9.08**	8.96	8.76	8.20
Nov	**0.35**	0.16	0.10	NA	**0.75**	0.55	0.48	0.28	**0.33**	0.43	0.43	0.70	**1.04**	1.09	1.06	1.42	**0.72**	0.72	0.70	NA	**2.84**	2.81	2.73	2.58	**4.44**	4.38	4.28	4.01
Dec	**0.28**	0.13	0.08	NA	**0.53**	0.39	0.35	0.20	**0.18**	0.24	0.23	0.38	**0.54**	0.57	0.55	0.74	**0.40**	0.40	0.39	NA	**1.92**	1.89	1.84	1.74	**3.02**	2.98	2.91	2.73

Notes:
[a] USGS 15302200.
NA = not applicable: SK100G would be eliminated by tailings storage facility (TSF) 2, and SK119A would be eliminated by TSF 3 in the Pebble 6.5 scenario.

Table 7-11. Measured mean monthly pre-mining streamflow rates (m³/s) and estimated mean monthly streamflow rates (m³/s) in the Pebble 0.25, 2.0, and 6.5 scenarios, for gages along the North Fork Koktuli River.

Month	NK119A				NK119B				NK100C				NK100B				NK100A1				NK100A[a]			
	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5
Jan	**0.15**	0.10	0.05	0.06	**0.03**	0.03	0.03	0.02	**0.71**	0.80	0.79	1.13	**1.04**	1.06	0.97	1.23	**2.08**	2.09	2.01	2.22	**2.85**	2.86	2.78	3.02
Feb	**0.10**	0.07	0.04	0.04	**0.01**	0.01	0.01	0.01	**0.48**	0.54	0.53	0.76	**0.67**	0.68	0.63	0.79	**1.44**	1.45	1.39	1.54	**1.88**	1.89	1.83	1.99
Mar	**0.08**	0.06	0.03	0.03	**<0.01**	<0.01	<0.01	<0.01	**0.39**	0.44	0.43	0.62	**0.54**	0.55	0.50	0.64	**1.23**	1.23	1.19	1.31	**1.55**	1.56	1.52	1.65
Apr	**0.21**	0.15	0.08	0.08	**0.03**	0.03	0.03	0.02	**0.54**	0.61	0.61	0.87	**0.88**	0.89	0.82	1.04	**2.17**	2.18	2.10	2.32	**2.66**	2.68	2.60	2.82
May	**2.28**	1.63	0.86	0.87	**0.54**	0.52	0.48	0.39	**3.48**	3.93	3.90	5.58	**7.03**	7.13	6.57	8.29	**16.57**	16.64	16.01	17.70	**20.10**	20.19	19.59	21.29
Jun	**1.15**	0.82	0.43	0.44	**0.20**	0.20	0.18	0.15	**1.91**	2.16	2.15	3.07	**3.64**	3.69	3.40	4.29	**9.48**	9.51	9.16	10.12	**11.39**	11.44	11.10	12.06
Jul	**0.55**	0.39	0.21	0.21	**0.05**	0.05	0.04	0.04	**1.11**	1.25	1.24	1.78	**2.04**	2.07	1.91	2.41	**5.13**	5.15	4.96	5.48	**5.88**	5.91	5.74	6.23
Aug	**0.71**	0.51	0.27	0.27	**0.10**	0.10	0.09	0.08	**1.24**	1.40	1.38	1.98	**2.44**	2.48	2.29	2.88	**6.21**	6.23	6.00	6.63	**7.40**	7.43	7.21	7.83
Sep	**1.10**	0.79	0.42	0.42	**0.20**	0.19	0.18	0.15	**1.75**	1.98	1.96	2.81	**3.31**	3.35	3.09	3.90	**7.98**	8.02	7.72	8.53	**9.35**	9.39	9.11	9.90
Oct	**1.10**	0.78	0.41	0.42	**0.26**	0.25	0.23	0.19	**2.20**	2.49	2.47	3.53	**4.01**	4.07	3.75	4.73	**9.40**	9.44	9.09	10.04	**11.14**	11.19	10.86	11.80
Nov	**0.52**	0.37	0.20	0.20	**0.09**	0.09	0.08	0.07	**1.24**	1.40	1.39	1.99	**2.12**	2.16	1.99	2.51	**4.79**	4.81	4.63	5.11	**5.95**	5.97	5.80	6.30
Dec	**0.24**	0.17	0.09	0.09	**0.04**	0.04	0.04	0.03	**0.88**	0.99	0.98	1.40	**1.35**	1.37	1.27	1.60	**2.89**	2.90	2.79	3.09	**3.84**	3.85	3.74	4.06

Notes:
[a] USGS 15302250.

Table 7-12. Measured mean monthly pre-mining streamflow rates (m^3/s) and estimated mean monthly streamflow rates (m^3/s) in the Pebble 0.25, 2.0, and 6.5 scenarios, for gages along Upper Talarik Creek.

	UT100E				UT100D				UT100C2				UT100C1				UT100C				UT119A				UT100B[a]			
Month	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5
Jan	**0.15**	0.14	NA	NA	**0.32**	0.32	0.29	0.18	**0.05**	1.32	1.29	1.18	**1.05**	1.74	1.71	1.59	**1.44**	2.45	2.41	2.27	**2.09**	0.76	0.69	0.67	**0.60**	3.62	3.54	3.34
Feb	**0.13**	0.13	NA	NA	**0.28**	0.28	0.25	0.16	**0.04**	1.15	1.13	1.03	**0.92**	1.55	1.52	1.41	**1.28**	2.25	2.22	2.08	**1.92**	0.75	0.69	0.66	**0.60**	3.31	3.23	3.05
Mar	**0.12**	0.11	NA	NA	**0.22**	0.22	0.20	0.12	**0.03**	0.93	0.91	0.84	**0.74**	1.28	1.26	1.17	**1.06**	1.98	1.95	1.83	**1.69**	0.74	0.67	0.65	**0.59**	2.88	2.81	2.66
Apr	**0.18**	0.17	NA	NA	**0.55**	0.55	0.50	0.31	**0.08**	2.06	2.02	1.85	**1.64**	2.51	2.47	2.30	**2.08**	3.44	3.38	3.18	**2.93**	0.78	0.71	0.69	**0.62**	4.79	4.68	4.42
May	**0.61**	0.57	NA	NA	**1.95**	1.95	1.77	1.09	**0.28**	6.64	6.50	5.96	**5.28**	7.43	7.30	6.79	**6.16**	9.11	8.97	8.43	**7.76**	0.88	0.80	0.77	**0.69**	12.80	12.49	11.81
Jun	**0.30**	0.28	NA	NA	**1.02**	1.02	0.93	0.57	**0.15**	4.04	3.96	3.63	**3.22**	4.29	4.22	3.93	**3.56**	5.63	5.55	5.21	**4.80**	0.82	0.75	0.72	**0.65**	7.40	7.22	6.83
Jul	**0.21**	0.19	NA	NA	**0.62**	0.62	0.56	0.34	**0.09**	2.40	2.35	2.16	**1.91**	2.76	2.72	2.53	**2.29**	3.77	3.72	3.49	**3.21**	0.80	0.72	0.70	**0.63**	5.13	5.00	4.73
Aug	**0.23**	0.22	NA	NA	**0.78**	0.78	0.71	0.43	**0.11**	2.81	2.75	2.52	**2.24**	3.30	3.25	3.02	**2.74**	4.38	4.32	4.06	**3.73**	0.81	0.74	0.72	**0.64**	6.48	6.32	5.97
Sep	**0.31**	0.29	NA	NA	**1.03**	1.03	0.94	0.58	**0.15**	4.21	4.12	3.78	**3.35**	4.67	4.59	4.27	**3.87**	6.09	6.00	5.63	**5.19**	0.86	0.78	0.76	**0.68**	7.82	7.63	7.21
Oct	**0.36**	0.34	NA	NA	**1.18**	1.18	1.07	0.66	**0.17**	4.69	4.59	4.21	**3.73**	5.26	5.17	4.81	**4.36**	6.67	6.57	6.18	**5.68**	0.88	0.81	0.78	**0.70**	9.08	8.86	8.37
Nov	**0.25**	0.23	NA	NA	**0.74**	0.74	0.68	0.41	**0.11**	2.98	2.91	2.67	**2.37**	3.67	3.60	3.35	**3.04**	4.59	4.52	4.25	**3.91**	0.84	0.76	0.74	**0.66**	6.33	6.18	5.84
Dec	**0.20**	0.19	NA	NA	**0.52**	0.52	0.47	0.29	**0.07**	2.05	2.01	1.84	**1.64**	2.61	2.57	2.39	**2.17**	3.37	3.31	3.12	**2.87**	0.80	0.73	0.71	**0.63**	5.00	4.88	4.61

Notes:
[a] USGS 15300250.
NA = not applicable: UT100E would be blocked by the waste rock pile in the Pebble 2.0 scenario (Figure 7-15), and by the mine pit in the Pebble 6.5 scenario (Figure 7-16).

Table 7-13. Measured minimum monthly pre-mining streamflow rates (m^3/s) and estimated minimum monthly streamflow rates (m^3/s) in the Pebble 0.25, 2.0, and 6.5 scenarios, for gages along the South Fork Koktuli River.

	SK100G				SK100F				SK124A				SK100C				SK119A				SK100B1				SK100B[a]			
Month	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5
Jan	**0.11**	0.05	0.03	NA	**0.20**	0.15	0.13	0.08	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.12**	0.12	0.11	NA	**0.60**	0.60	0.58	0.55	**1.13**	1.12	1.09	1.02
Feb	**0.08**	0.04	0.02	NA	**0.15**	0.11	0.10	0.06	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.08**	0.08	0.08	NA	**0.40**	0.40	0.39	0.37	**0.85**	0.84	0.82	0.77
Mar	**0.07**	0.03	0.02	NA	**0.11**	0.08	0.07	0.04	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.05**	0.05	0.05	NA	**0.27**	0.26	0.26	0.24	**0.65**	0.64	0.63	0.59
Apr	**0.04**	0.02	0.01	NA	**0.11**	0.08	0.07	0.04	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.05**	0.05	0.05	NA	**0.27**	0.26	0.26	0.24	**0.65**	0.64	0.63	0.59
May	**0.08**	0.04	0.02	NA	**0.14**	0.10	0.09	0.05	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.07**	0.07	0.07	NA	**0.38**	0.37	0.36	0.34	**0.79**	0.78	0.76	0.72
Jun	**0.20**	0.09	0.05	NA	**0.46**	0.34	0.30	0.18	**0.09**	0.12	0.11	0.19	**0.12**	0.12	0.12	0.16	**0.45**	0.45	0.45	NA	**1.51**	1.49	1.45	1.37	**2.49**	2.46	2.40	2.25
Jul	**0.08**	0.04	0.02	NA	**0.22**	0.16	0.14	0.08	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.23**	0.23	0.23	NA	**1.12**	1.10	1.07	1.01	**1.64**	1.62	1.58	1.48
Aug	**0.08**	0.04	0.02	NA	**0.16**	0.12	0.10	0.06	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.13**	0.13	0.13	NA	**0.67**	0.66	0.64	0.61	**1.25**	1.23	1.20	1.12
Sep	**0.06**	0.03	0.02	NA	**0.08**	0.06	0.05	0.03	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.09**	0.09	0.09	NA	**0.51**	0.50	0.49	0.46	**1.02**	1.01	0.98	0.92
Oct	**0.22**	0.10	0.06	NA	**0.63**	0.47	0.41	0.24	**0.23**	0.30	0.29	0.49	**0.71**	0.74	0.72	0.96	**0.45**	0.45	0.45	NA	**2.10**	2.07	2.01	1.90	**3.54**	3.49	3.41	3.19
Nov	**0.18**	0.08	0.05	NA	**0.34**	0.25	0.22	0.13	**0.04**	0.05	0.05	0.08	**0.12**	0.12	0.12	0.16	**0.23**	0.23	0.23	NA	**1.16**	1.14	1.11	1.05	**1.93**	1.90	1.86	1.74
Dec	**0.12**	0.05	0.03	NA	**0.21**	0.16	0.14	0.08	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.13**	0.13	0.13	NA	**0.66**	0.65	0.64	0.60	**1.22**	1.20	1.17	1.10

Notes:
[a] USGS 15302200.
NA = not applicable: SK100G would be eliminated by tailings storage facility (TSF) 2 and SK119A would be eliminated by TSF 3 in the Pebble 6.5 scenario.

Table 7-14. Measured minimum monthly pre-mining streamflow rates (m^3/s) and estimated minimum monthly streamflow rates (m^3/s) in the Pebble 0.25, 2.0, and 6.5 scenarios, for gages along the North Fork Koktuli River.

	NK119A				NK119B				NK100C				NK100B				NK100A1				NK100A[a]			
Month	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5
Jan	**0.08**	0.05	0.03	0.03	**0.00**	0.00	0.00	0.00	**0.33**	0.37	0.37	0.53	**0.43**	0.44	0.41	0.51	**0.93**	0.93	0.90	0.99	**1.10**	1.11	1.08	1.17
Feb	**0.07**	0.05	0.03	0.03	**0.00**	0.00	0.00	0.00	**0.34**	0.38	0.38	0.54	**0.44**	0.45	0.41	0.52	**0.95**	0.95	0.92	1.01	**1.13**	1.14	1.10	1.20
Mar	**0.06**	0.04	0.02	0.02	**0.00**	0.00	0.00	0.00	**0.23**	0.26	0.26	0.37	**0.33**	0.34	0.31	0.39	**0.80**	0.80	0.77	0.85	**0.91**	0.91	0.88	0.96
Apr	**0.04**	0.03	0.02	0.02	**0.00**	0.00	0.00	0.00	**0.13**	0.15	0.15	0.21	**0.18**	0.19	0.17	0.22	**0.84**	0.84	0.81	0.89	**0.96**	0.97	0.94	1.02
May	**0.01**	0.01	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.38**	0.43	0.43	0.61	**0.54**	0.55	0.51	0.64	**1.16**	1.16	1.12	1.23	**1.44**	1.45	1.41	1.53
Jun	**0.30**	0.22	0.11	0.11	**0.00**	0.00	0.00	0.00	**0.71**	0.80	0.80	1.14	**1.31**	1.33	1.23	1.55	**3.75**	3.76	3.62	4.00	**4.27**	4.29	4.17	4.53
Jul	**0.21**	0.15	0.08	0.08	**0.00**	0.00	0.00	0.00	**0.54**	0.61	0.60	0.86	**1.04**	1.05	0.97	1.23	**2.57**	2.58	2.48	2.75	**2.35**	2.36	2.29	2.49
Aug	**0.14**	0.10	0.05	0.05	**0.00**	0.00	0.00	0.00	**0.46**	0.52	0.52	0.74	**0.96**	0.97	0.89	1.13	**2.02**	2.03	1.96	2.16	**1.93**	1.93	1.88	2.04
Sep	**0.12**	0.09	0.05	0.05	**0.00**	0.00	0.00	0.00	**0.37**	0.42	0.41	0.59	**0.91**	0.92	0.85	1.07	**1.89**	1.90	1.83	2.02	**1.76**	1.76	1.71	1.86
Oct	**0.20**	0.14	0.08	0.08	**0.00**	0.00	0.00	0.00	**0.99**	1.11	1.10	1.58	**1.53**	1.55	1.43	1.80	**3.19**	3.20	3.08	3.41	**4.39**	4.41	4.28	4.65
Nov	**0.12**	0.09	0.05	0.05	**0.00**	0.00	0.00	0.00	**0.50**	0.56	0.56	0.80	**0.71**	0.72	0.67	0.84	**1.51**	1.51	1.46	1.61	**1.98**	1.99	1.93	2.10
Dec	**0.10**	0.07	0.04	0.04	**0.00**	0.00	0.00	0.00	**0.41**	0.46	0.46	0.66	**0.57**	0.58	0.53	0.67	**1.21**	1.21	1.17	1.29	**1.53**	1.54	1.49	1.62

Notes:
[a] USGS 15302250.

Table 7-15. Measured minimum monthly pre-mining streamflow rates (m^3/s) and estimated minimum monthly streamflow rates (m^3/s) in the Pebble 0.25, 2.0, and 6.5 scenarios, for gages along Upper Talarik Creek.

	UT100E				UT100D				UT100C2				UT100C1				UT100C				UT119A				UT100B[a]			
Month	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5	Pre	0.25	2.0	6.5
Jan	**0.09**	0.09	NA	NA	**0.12**	0.11	0.07	0.02	**0.53**	0.52	0.47	0.42	**0.80**	0.78	0.73	0.66	**1.55**	1.53	1.44	1.32	**0.72**	0.65	0.63	0.57	**2.09**	2.04	1.93	1.78
Feb	**0.09**	0.08	NA	NA	**0.10**	0.10	0.06	0.02	**0.47**	0.46	0.42	0.37	**0.73**	0.71	0.66	0.60	**1.48**	1.46	1.37	1.26	**0.71**	0.65	0.63	0.56	**1.98**	1.93	1.83	1.68
Mar	**0.08**	0.07	NA	NA	**0.12**	0.11	0.07	0.02	**0.53**	0.52	0.47	0.42	**0.80**	0.78	0.73	0.66	**1.37**	1.35	1.27	1.17	**0.72**	0.65	0.63	0.57	**2.09**	2.04	1.93	1.78
Apr	**0.07**	0.06	NA	NA	**0.11**	0.10	0.06	0.02	**0.50**	0.48	0.44	0.39	**0.76**	0.75	0.70	0.63	**1.42**	1.40	1.32	1.21	**0.71**	0.65	0.63	0.56	**2.04**	1.99	1.88	1.73
May	**0.10**	0.10	NA	NA	**0.22**	0.20	0.12	0.03	**0.91**	0.89	0.81	0.72	**1.25**	1.23	1.14	1.04	**2.02**	1.99	1.87	1.72	**0.63**	0.58	0.56	0.50	**2.83**	2.76	2.61	2.40
Jun	**0.15**	0.14	NA	NA	**0.23**	0.21	0.13	0.03	**1.46**	1.43	1.31	1.16	**1.57**	1.54	1.44	1.30	**2.85**	2.81	2.64	2.43	**0.62**	0.56	0.54	0.49	**2.58**	2.51	2.38	2.19
Jul	**0.14**	0.13	NA	NA	**0.21**	0.19	0.12	0.03	**1.46**	1.43	1.31	1.17	**1.37**	1.35	1.25	1.14	**2.50**	2.46	2.31	2.13	**0.65**	0.59	0.57	0.51	**2.55**	2.49	2.35	2.16
Aug	**0.12**	0.11	NA	NA	**0.22**	0.20	0.12	0.03	**1.35**	1.32	1.21	1.07	**1.58**	1.55	1.44	1.31	**2.40**	2.36	2.22	2.04	**0.62**	0.57	0.55	0.49	**2.97**	2.90	2.74	2.52
Sep	**0.11**	0.10	NA	NA	**0.20**	0.18	0.11	0.03	**1.29**	1.26	1.15	1.02	**1.52**	1.49	1.39	1.26	**2.37**	2.33	2.19	2.02	**0.67**	0.61	0.59	0.53	**2.83**	2.76	2.61	2.40
Oct	**0.17**	0.16	NA	NA	**0.33**	0.30	0.18	0.05	**1.71**	1.67	1.53	1.36	**2.24**	2.20	2.05	1.86	**3.03**	2.98	2.80	2.58	**0.69**	0.62	0.60	0.54	**3.82**	3.73	3.52	3.24
Nov	**0.16**	0.15	NA	NA	**0.31**	0.28	0.17	0.04	**1.34**	1.32	1.21	1.07	**2.04**	2.00	1.86	1.69	**2.36**	2.32	2.18	2.01	**0.78**	0.71	0.68	0.61	**3.68**	3.59	3.39	3.12
Dec	**0.12**	0.12	NA	NA	**0.22**	0.20	0.12	0.03	**0.91**	0.89	0.81	0.72	**1.25**	1.23	1.14	1.04	**1.83**	1.80	1.69	1.56	**0.74**	0.67	0.65	0.58	**2.83**	2.76	2.61	2.40

Notes:
[a] USGS 15300250.
NA = not applicable: UT100E would be blocked by the waste rock pile in the Pebble 2.0 scenario (Figure 7-15) and by the mine pit in the Pebble 6.5 scenario (Figure 7-16).

Table 7-16. Pre-mining watershed areas, mine footprint areas, and flows in the mine scenario watersheds for the Pebble 0.25 scenario.

	Pre-Mining				Returned Flow in Each Pathway (%)					85.9	8.8	75.3	0.0	Operational Flows			
					Volume from Water Balance (m^3/yr)					10,909,000	1,113,000	676,000	0				
Stream and Gage	Watershed Area (km^2)	Mean Annual Unit Runoff (m^3/s*km^2)	Runoff per Unit Area (m^3/yr*m^2)	Mean Annual Runoff (m^3/yr)	Total Mine Footprint Drainage Area (km^2)	Mine Footprint other than TSF, NAG, or PAG (km^2)	TSF 1 Footprint (km^2)	NAG Waste Rock Footprint (km^2)	PAG Waste Rock Footprint (km^2)	Flow Volume Returned through WWTP (m^3/yr)[a]	Flow Volume Returned as TSF Leakage (m^3/yr)	Flow Volume Returned as NAG Waste Rock Leachate (m^3/yr)	Flow Volume Returned as PAG Waste Rock Leachate (m^3/yr)	Flow Volume Remaining Due to Mine Footprint with No Returns (m^3/yr)	Captured Flow Volume Returned from Footprint (m^3/yr)	Total Flow Volume in Stream During Operations (m^3/yr)	Change in Average Annual Runoff (%)
South Fork Koktuli River																	
SK100G	14	0.026	0.82	11,618,000	8.0	7.5	-	0.5	-	-	-	207,000	-	5,080,000	207,000	5,287,000	−54
SK100F	31	0.026	0.83	25,842,000	8.8	<0.1	-	0.8	-	-	-	350,000	-	18,499,000	556,000	19,055,000	−26
SK100CP2[b] (total runoff)	54	0.026	0.83	44,681,000	8.8	-	-	-	-	-	-	-	-	-	-	-	-
SK100CP2[b] (losses to UTC)[c]	54	0.009	0.28	−14,894,000	8.8	-	-	-	-	-	-	-	-	−12,446,000	−185,000	-	-
SK100CP2[b] (net streamflow at gage)	54	0.018	0.55	29,788,000	8.8	-	-	-	-	-	-	-	-	24,892,000	371,000	25,263,000	−15
SK124A	22	0.024	0.76	16,811,000	0.0	-	-	-	-	5,454,000	-	-	-	16,811,000	5,454,000	22,265,000	32
SK124CP[b]	24	0.024	0.76	17,937,000	0.0	-	-	-	-	-	-	-	-	17,937,000	5,454,000	23,391,000	30
SK100C	99	0.013	0.42	41,858,000	8.8	-	-	-	-	-	-	-	-	38,117,000	5,825,000	43,942,000	5
SK100CP1[b]	99	0.013	0.42	42,029,000	8.8	-	-	-	-	-	-	-	-	38,288,000	5,825,000	44,113,000	5
SK119A	28	0.036	1.12	31,268,000	0.0	-	-	-	-	-	-	-	-	31,268,000	-	31,268,000	0
SK119CP[b]	30	0.036	1.12	33,124,000	0.0	-	-	-	-	-	-	-	-	33,124,000	-	33,124,000	0
SK100B1	141	0.026	0.82	115,110,000	8.8	-	-	-	-	-	-	-	-	107,911,000	5,825,000	113,737,000	−1
SK100B[d]	179	0.029	0.91	162,122,000	8.8	-	-	-	-	-	-	-	-	154,112,000	5,825,000	159,937,000	−1
North Fork Koktuli River																	
NK119A	20	0.034	1.08	21,515,000	6.8	<0.1	6.5	0.3	-	-	1,113,000	120,000	-	14,146,000	1,233,000	15,378,000	−29
NK119CP2[b]	22	0.034	1.08	24,155,000	6.9	0.1	-	-	-	-	-	-	-	16,691,000	1,233,000	17,923,000	−26
NK119B	11	0.012	0.38	4,081,000	0.3	0.3	-	-	-	-	-	-	-	3,975,000	-	3,975,000	−3
NK119CP1[b]	33	0.027	0.85	28,431,000	7.2	<0.1	-	-	-	-	-	-	-	22,279,000	1,233,000	23,512,000	−17
NK100C	65	0.020	0.64	41,853,000	0.0	<0.1	-	-	-	5,454,000	-	-	-	41,828,000	5,454,000	47,282,000	13
NK100B	99	0.024	0.77	76,408,000	7.2	<0.1	-	-	-	-	-	-	-	70,826,000	6,687,000	77,513,000	1
NK100A1	222	0.026	0.82	182,297,000	7.3	<0.1	-	-	-	-	-	-	-	176,335,000	6,687,000	183,022,000	<1
NK100A[e]	279	0.025	0.79	220,715,000	7.3	-	-	-	-	-	-	-	-	214,981,000	6,687,000	221,668,000	<1
Upper Talarik Creek																	
UT100E	10	0.027	0.84	7,996,000	0.6	0.6	-	-	-	-	-	-	-	7,474,000	-	7,474,000	−7
UT100D	31	0.025	0.78	24,201,000	2.8	2.2	-	-	-	-	-	-	-	22,008,000	-	22,008,000	−9
UT100C2	133	0.022	0.70	92,734,000	2.8	0.0	-	-	-	-	-	-	-	90,768,000	-	90,768,000	−2
UT100C1	159	0.022	0.68	107,971,000	2.8	-	-	-	-	-	-	-	-	106,050,000	-	106,050,000	−2
UT100C	185	0.024	0.76	141,213,000	2.8	-	-	-	-	-	-	-	-	139,053,000	-	139,053,000	−2
UT119A (local runoff)	10	0.033	1.04	10,655,000	0.0	-	-	-	-	-	-	-	-	10,655,000	-	-	-
UT119A (gains from SFK)[c]	10	0.046	1.45	14,894,000	0.0	-	-	-	-	-	-	-	-	12,446,000	185,000	-	-
UT119A (net streamflow at gage)	10	0.079	2.48	25,549,000	0.0	-	-	-	-	-	-	-	-	23,101,000	185,000	23,286,000	−9
UT100B[f]	222	0.028	0.88	196,182,000	2.8	-	-	-	-	-	-	-	-	191,238,000	185,000	191,423,000	−2

Notes:
Dashes (-) indicate that values are either not applicable or are equal to zero.
[a] WWTP discharges 50% of flow to South Fork Koktuli River, 50% of streamflow to North Fork Koktuli River (no WWTP flows are directed to Upper Talarik Creek).
[b] Confluence point where virtual gage was created because physical gage does not exist.
[c] 1/3 of total return flow is transferred from SK100CP2 to UT119A to represent interbasin transfer at this location. Interbasin transfer flows are represented by negative flow values from SK100CP2 (losses to UTC) and equivalent positive flow values for UT119A (gains from SFK).
[d] USGS 15302200.
[e] USGS 15302250.
[f] USGS 15300250.
TSF = tailings storage facility; PAG = potentially acid-generating; NAG = non-acid-generating; WWTP = wastewater treatment plant; UTC = Upper Talarik Creek; SFK = South Fork Koktuli.

Table 7-17. Pre-mining watershed areas, mine footprint areas, and flows in the mine scenario watersheds for the Pebble 2.0 scenario.

Stream and Gage	Pre-Mining				Returned Flow in Each Pathway (%)					66.7	15.2	16.7	1.4	Operational Flows			
					Volume from Water Balance (m^3/yr)					10,304,000	2,351,000	2,576,000	216,000				
	Watershed Area (km^2)	Mean Annual Unit Runoff ($m^3/s*km^2$)	Runoff per Unit Area ($m^3/yr*m^2$)	Mean Annual Runoff (m^3/yr)	Total Mine Footprint Drainage Area (km^2)	Mine Footprint other than TSF, NAG, or PAG (km^2)	TSF 1 Footprint (km^2)	NAG Waste Rock Footprint (km^2)	PAG Waste Rock Footprint (km^2)	Flow Volume Returned through WWTP (m^3/yr)[a]	Flow Volume Returned as TSF Leakage (m^3/yr)	Flow Volume Returned as NAG Waste Rock Leachate (m^3/yr)	Flow Volume Returned as PAG Waste Rock Leachate (m^3/yr)	Flow Volume Remaining Due to Mine Footprint with No Returns (m^3/yr)	Captured Flow Volume Returned from Footprint (m^3/yr)	Total Flow Volume in Stream During Operations (m^3/yr)	Change in Average Annual Runoff (%)
South Fork Koktuli River																	
SK100G	14	0.026	0.82	11,618,000	11.2	9.2	-	1.5	0.5	-	-	633,000	213,000	2,420,000	846,000	3,266,000	−72
SK100F	31	0.026	0.83	25,842,000	12.6	0.2	-	1.2	<0.01	-	-	507,000	3,000	15,389,000	1,356,000	16,745,000	−35
SK100CP2[b] (total runoff)	54	0.026	0.83	44,681,000	12.6	-	-	-	-	-	-	-	-	-	-	-	-
SK100CP2[b] (losses to UTC)[c]	54	0.009	0.28	−14,894,000	12.6	-	-	-	-	-	-	-	-	−11,409,000	−452,000	-	-
SK100CP2[b] (net streamflow at gage)	54	0.018	0.55	29,788,000	12.6	-	-	-	-	-	-	-	-	22,819,000	904,000	23,723,000	−20
SK124A	22	0.024	0.76	16,811,000	0.1	0.1	<0.1	0.1	-	5,152,000	2,000	22,000	-	16,702,000	5,175,000	21,878,000	30
SK124CP[b]	24	0.024	0.76	17,937,000	0.1	-				-	-	-	-	17,829,000	5,175,000	23,004,000	28
SK100C	99	0.013	0.42	41,858,000	12.7	<0.1	-	-	-	-	-	-	-	36,472,000	6,079,000	42,552,000	2
SK100CP1[b]	99	0.013	0.42	42,029,000	12.7	-				-	-	-	-	36,643,000	6,079,000	42,722,000	2
SK119A	28	0.036	1.12	31,268,000	0.6	0.1	0.1	0.4	-	-	21,000	151,000	-	30,602,000	172,000	30,774,000	−2
SK119CP[b]	30	0.036	1.12	33,124,000	0.6	-				-	-	-	-	32,458,000	172,000	32,630,000	−1
SK100B1	141	0.026	0.82	115,110,000	13.3	-	-	-	-	-	-	-	-	104,262,000	6,251,000	110,513,000	−4
SK100B[d]	179	0.029	0.91	162,122,000	13.3	-	-	-	-	-	-	-	-	150,051,000	6,251,000	156,302,000	−4
North Fork Koktuli River																	
NK119A	20	0.034	1.08	21,515,000	14.9	0.1	13.9	0.9	-	-	2,305,000	402,000	-	5,405,000	2,707,000	8,111,000	−62
NK119CP2[b]	22	0.034	1.08	24,155,000	15.3	0.4	<0.1	<0.1	-	-	1,000	13,000	-	7,627,000	2,720,000	10,347,000	−57
NK119B	11	0.012	0.38	4,081,000	1.2	1.1	-	<0.1	-	-	-	3,000	-	3,638,000	3,000	3,641,000	−11
NK119CP1[b]	33	0.027	0.85	28,431,000	16.5	-	-	-	-	-	-	-	-	14,346,000	2,723,000	17,069,000	−40
NK100C	65	0.020	0.64	41,853,000	0.2	0.2	-	-	-	5,152,000	-	-	-	41,753,000	5,152,000	46,905,000	12
NK100B	99	0.024	0.77	76,408,000	16.6	<0.1	-	-	-	-	-	-	-	63,577,000	7,875,000	71,452,000	−6
NK100A1	222	0.026	0.82	182,297,000	17.3	0.1	0.1	0.5	-	-	23,000	204,000	-	168,068,000	8,102,000	176,169,000	−3
NK100A[e]	279	0.025	0.79	220,715,000	17.3	-	-	-	-	-	-	-	-	207,031,000	8,102,000	215,132,000	−3
Upper Talarik Creek																	
UT100E	10	0.027	0.84	7,996,000	3.2	3.2	-	-	-	-	-	-	-	5,290,000	-	5,290,000	−34
UT100D	31	0.025	0.78	24,201,000	14.5	9.8	-	1.5	-	-	-	642,000	-	12,839,000	642,000	13,481,000	−44
UT100C2	133	0.022	0.70	92,734,000	14.6	0.1	-	-	-	-	-	-	-	82,573,000	642,000	83,215,000	−10
UT100C1	159	0.022	0.68	107,971,000	14.6	-	-	-	-	-	-	-	-	98,042,000	642,000	98,684,000	−9
UT100C	185	0.024	0.76	141,213,000	14.6	-	-	-	-	-	-	-	-	130,049,000	642,000	130,691,000	−7
UT119A (local runoff)	10	0.033	1.04	10,655,000	-	-	-	-	-	-	-	-	-	10,655,000	-	-	-
UT119A (gains from SFK)[c]	10	0.046	1.45	14,894,000	-	-	-	-	-	-	-	-	-	11,409,000	452,000	-	-
UT119A (net streamflow at gage)	10	0.079	2.48	25,549,000	-	-	-	-	-	-	-	-	-	22,064,000	452,000	22,516,000	−12
UT100B[f]	222	0.028	0.88	196,182,000	14.6	-	-	-	-	-	-	-	-	179,795,000	1,094,000	180,889,000	−8

Notes:
Dashes (-) indicate that values are either not applicable or are equal to zero. UT100E is blocked by the mine footprint in this scenario.
[a] WWTP discharges 50% of flow to South Fork Koktuli River, 50% of flow to North Fork Koktuli River (no WWTP flows are directed to Upper Talarik Creek).
[b] Confluence point where virtual gage was created because physical gage does not exist.
[c] 1/3 of total return flow from is transferred from SK100CP2 to UT119A to represent interbasin transfer at this location. Interbasin transfer flows are represented by negative flow values from SK100CP2 (losses to UTC) and equivalent positive flow values for UT119A (gains from SFK).
[d] USGS 15302200.
[e] USGS 15302250.
[f] USGS 15300250.
TSF = tailings storage facility; PAG = potentially acid-generating; NAG = non-acid-generating; WWTP = wastewater treatment plant; UTC = Upper Talarik Creek; SFK = South Fork Koktuli.

Table 7-18. Pre-mining watershed areas, mine footprint areas, and flows in the mine scenario watersheds for the Pebble 6.5 scenario.

					Returned Flow in Each Pathway (%)							79.4	11.2	7.7	1.6				
	Pre-Mining				Volume from Water Balance (m^3/yr)							50,988,000	7,203,000	4,971,000	1,032,000	Operational Flows			
Stream and Gage	Watershed Area (km^2)	Mean Annual Unit Runoff ($m^3/s*km^2$)	Runoff per Unit Area ($m^3/yr*m^2$)	Mean Annual Runoff (m^3/yr)	Total Mine Footprint Drainage Area (km^2)	Mine Footprint other than TSF, NAG, or PAG (km^2)	TSF 1 Footprint (km^2)	TSF 2 Footprint (km^2)	TSF 3 Footprint (km^2)	NAG Waste Rock Footprint (km^2)	PAG Waste Rock Footprint (km^2)	Flow Volume Returned through WWTP (m^3/yr)[a]	Flow Volume Returned as TSF Leakage (m^3/yr)	Flow Volume Returned as NAG Waste Rock Leachate (m^3/yr)	Flow Volume Returned as PAG Waste Rock Leachate (m^3/yr)	Flow Volume Remaining Due to Mine Footprint with No Returns (m^3/yr)	Captured Flow Volume Returned from Footprint (m^3/yr)	Total Flow Volume in Stream During Operations (m^3/yr)	Change in Average Annual Runoff (%)
South Fork Koktuli River																			
SK100G	14	0.026	0.82	11,618,000	14.0	14.0	-	-	-	-	-	-	-	-	-	95,000	-	-	-
SK100F	31	0.026	0.83	25,842,000	22.1	2.5	-	-	0.1	3.0	2.4	-	20,000	1,278,000	1,032,000	7,480,000	2,330,000	9,810,000	−62
SK100CP2[b] (total runoff)	54	0.026	0.83	44,681,000	22.1	-	-	-		<0.1	-	-	-	5,000	-	26,309,000	2,335,000	-	-
SK100CP2[b] (losses to UTC)[c]	54	0.009	0.28	−14,894,000	22.1	-	-	-	-	-	-	-	-	-	-	−8,770,000	−778,000	-	-
SK100CP2[b] (net flow at gage)	54	0.018	0.55	29,788,000	22.1	-	-	-	-	-	-	-	-	-	-	17,540,000	1,557,000	19,096,000	−36
SK124A	22	0.024	0.76	16,811,000	11.4	0.1	<0.1	1.8	7.8	1.7	-	25,494,000	1,626,000	713,000	-	8,216,000	27,833,000	36,049,000	114
SK124CP[b]	24	0.024	0.76	17,937,000	11.4	-	-	-	-	-	-	-	-	-	-	9,342,000	27,833,000	37,175,000	107
SK100C	99	0.013	0.42	41,858,000	33.6	-	-	<0.1	-	0.1	-	-	-	54,000	-	27,627,000	29,443,000	57,070,000	36
SK100CP1[b]	99	0.013	0.42	42,029,000	33.6	-	-	-	-	-	-	-	-	-	-	27,798,000	29,443,000	57,241,000	36
SK119A	28	0.036	1.12	31,268,000	18.0	0.1	0.1	17.2	-	0.6		-	2,930,000	242,000	-	11,091,000	3,171,000	-	-
SK119CP[b]	30	0.036	1.12	33,124,000	19.2	-	-	0.3	-	1.0		-	50,000	413,000	-	11,537,000	3,635,000	15,172,000	−54
SK100B1	141	0.026	0.82	115,110,000	54.3	<0.1	-	0.9	-	0.6	-	-	145,000	260,000	-	70,839,000	33,482,000	104,322,000	−9
SK100B[d]	179	0.029	0.91	162,122,000	54.3	-	-	-	-	-	-	-	-	-	-	112,863,000	33,482,000	146,346,000	−10
North Fork Koktuli River																			
NK119A	20	0.034	1.08	21,515,000	14.9	0.1	13.9	-	-	0.9	-	-	2,360,000	402,000	-	5,405,000	2,762,000	8,167,000	−62
NK119CP2[b]	22	0.034	1.08	24,155,000	15.3	0.4	<0.1	-	-	<0.1	-	-	1,000	13,000	-	7,627,000	2,775,000	10,402,000	−57
NK119B	11	0.012	0.38	4,081,000	3.3	2.7	-	-	0.3	0.3	-	-	48,000	144,000	-	2,812,000	192,000	3,004,000	−26
NK119CP1[b]	33	0.027	0.85	28,431,000	18.6	-	-	-	-	-	-	-	-	-	-	12,506,000	2,967,000	15,473,000	−46
NK100C	65	0.020	0.64	41,853,000	0.5	0.5	-	-	-	-	-	25,494,000	-	-	-	41,559,000	25,494,000	67,053,000	60
NK100B	99	0.024	0.77	76,408,000	19.1	-	-	-	-	-	-	-	-	-	-	61,683,000	28,461,000	90,144,000	18
NK100A1	222	0.026	0.82	182,297,000	19.8	0.1	0.1	-	-	0.5	-	-	23,000	204,000	-	166,049,000	28,688,000	194,738,000	7
NK100A[e]	279	0.025	0.79	220,715,000	19.8	-	-	-	-	-	-	-	-	-	-	205,090,000	28,688,000	233,778,000	6
Upper Talarik Creek																			
UT100E	10	0.027	0.84	7,996,000	7.4	6.6	-	-	-	0.8	-	-	-	346,000	-	1,779,000	346,000	2,125,000	−73
UT100D	31	0.025	0.78	24,201,000	27.8	18.7	-	-	-	1.7	-	-	-	739,000	-	2,398,000	1,085,000	3,482,000	−86
UT100C2	133	0.022	0.70	92,734,000	29.0	0.8	-	-	-	0.4	-	-	-	160,000	-	72,570,000	1,245,000	73,815,000	−20
UT100C1	159	0.022	0.68	107,971,000	29.0	-	-	-	-	-	-	-	-	-	-	88,266,000	1,245,000	89,511,000	−17
UT100C	185	0.024	0.76	141,213,000	29.0	-	-	-	-	-	-	-	-	-	-	119,058,000	1,245,000	120,303,000	−15
UT119A (local runoff)[c]	10	0.033	1.04	10,655,000	-	-	-	-	-	-	-	-	-	-	-	10,655,000	-	-	-
UT119A (gains from SFK)	10	0.046	1.45	14,894,000	-	-	-	-	-	-	-	-	-	-	-	8,770,000	778,000	-	-
UT119A (net flow at gage)	10	0.079	2.48	25,549,000	-	-	-	-	-	-	-	-	-	-	-	19,425,000	778,000	20,203,000	−21
UT100B[f]	222	0.028	0.88	196,182,000	29.1	-	-	-	-	-	-	-	-	-	-	164,453,000	2,023,000	166,476,000	−15

Notes:

Dashes (-) indicate that values are either not applicable or are equal to zero. UT100E is blocked and SK100G and SK119A are eliminated by the mine footprint in this scenario.

[a] WWTP discharges 50% of flow to South Fork Koktuli River, 50% of flow to North Fork Koktuli River (no WWTP flows are directed to Upper Talarik Creek).

[b] Confluence point where virtual gage was created because physical gage does not exist.

[c] 1/3 of total return flow from is transferred from SK100CP2 to UT119A to represent interbasin transfer at this location. Interbasin transfer flows are represented by negative flow values from SK100CP2 (losses to UTC) and equivalent positive flow values for UT119A (gains from SFK).

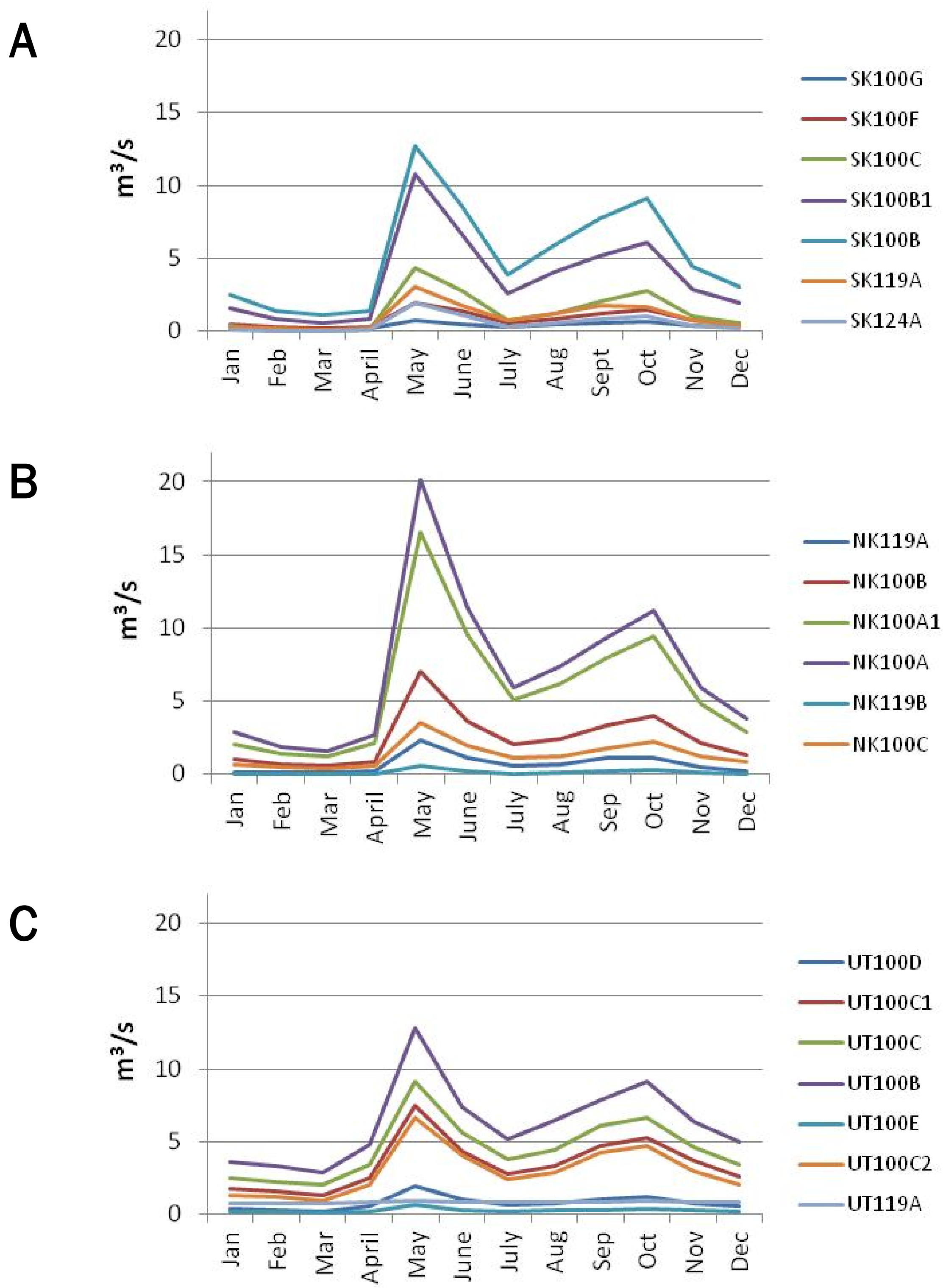
[d] USGS 15302200.

[e] USGS 15302250.

[f] USGS 15300250.

TSF = tailings storage facility; PAG = potentially acid-generating; NAG = non-acid-generating; WWTP = wastewater treatment plant; UTC = Upper Talarik Creek; SFK = South Fork Koktuli.

Figure 7-17. Monthly mean streamflows for stream gages in the (A) South Fork Koktuli River, (B) North Fork Koktuli River, and (C) Upper Talarik Creek watersheds, based on water years 2004 through 2010.



For the three mine scenarios, it was assumed that some water captured from each mine footprint would be treated and reintroduced to downstream areas. For the Pebble 0.25, 2.0, and 6.5 scenarios, we estimated that 76.3, 37.5, and 70.5% of the total water captured, respectively, would be reintroduced (Table 6-3). Figures 6-8 through 6-10 illustrate the various flowpaths expected in the three mine scenarios. For each of the watersheds, reintroduced flow was returned to the appropriate gage based on the expected flowpath as defined by the mine scenarios. Some upper tributaries would experience reduced streamflows from watershed area losses, whereas others would experience increased annual runoff from mining operation discharges.

Although some surface runoff might be collected, most of the precipitation in the drawdown zone would flow as groundwater into the mine pit and be removed by pumping to the WWTP. Much of the flow from components outside the drawdown zone, such as leachate from TSFs and waste rock piles, would be captured and directed to the WWTP, but some would escape the collection systems and flow back to the downstream receiving waters (Tables 7-16 through 7-18, Figures 6-8 through 6-10). It is important to note that the WWTP is assumed to discharge to the South and North Fork Koktuli River watersheds via the WWTP outfalls (after Ghaffari et al. 2011), so no treated flow would be reintroduced to streams in the Upper Talarik Creek watershed. An area of interbasin groundwater transfer has been observed between the South Fork Koktuli River and Upper Talarik Creek (PLP 2011: Chapter 7). This transfer was accounted for by allowing one-third of the flow at gage SK100F to transfer to gage UT119A (Tables 7-16 through 7-18, Figures 6-8 through 6-10). The spatial extent of these projected changes in streamflow and implications for fish and aquatic habitat are discussed in Section 7.3.2.

7.3.1.1 Pebble 0.25 Scenario

Water balance estimates for the Pebble 0.25 scenario considered an operational facility that intercepts precipitation from a footprint encompassing portions of the mine scenario watersheds (Table 7-16, Figure 7-14). Based on these conditions, we estimate that in each watershed the uppermost gages closest to the mine footprint would experience the most significant streamflow reductions. Overall, it is projected that 76.3% of captured watershed flows would be returned (Table 6-3), but the location of return would vary depending on mine needs for process water and the location of mine facilities and water treatment (Table 7-16). In the Upper Talarik Creek watershed in the Pebble 0.25 scenario, streamflow would be reduced by 7% at gage UT100E and 9% at gage UT100D due to capture in the mine footprint. The most significant streamflow reductions in the South Fork Koktuli River would be expected at gages SK100G (54%) and SK100F (26%) (Table 7-16). In the North Fork Koktuli River, the greatest changes would be expected at gage NK119A (29% reduction) (Table 7-16), as much of the watershed would be occupied by TSF 1 (Figure 7-14).

Streamflow reductions due to water capture in the mine footprint would be partially offset by water return via the WWTP, leakage through the TSF, and leaching through the waste rock piles. Water balance calculations for these water budget components are described in Chapter 6. Excess captured water would be treated at the WWTP and discharged upstream of gage SK124A in the South Fork Koktuli River and gage NK100C in the North Fork Koktuli River (Figure 7-14). It is assumed that the

WWTP would discharge equally to both outfalls, creating a 50/50 volume split for treated flows on an annual basis, but that on-site storage would allow management of environmental streamflows to match seasonal hydrographs to the degree possible. Flows from the WWTP outfalls would be projected to increase streamflows by 32% at gage SK124A, in a tributary to the South Fork Koktuli River. In the North Fork Koktuli River watershed, streamflows would be projected to increase by 13% at gage NK100C, downstream of the WWTP outfall. In the mainstem South and North Fork Koktuli Rivers downstream of these points, WWTP outfall flows (approximately 5.4 million m^3/year from each outfall) (Table 7-16), leakage from the TSF, and waste rock leaching would partially offset streamflow reductions expected from water capture within the mine footprint. Projected streamflow changes for gages farther downstream of the WWTP outfalls are within 5% of pre-project streamflows (Tables 7-16 and 7-19, Figure 7-14).

Because of the natural interbasin streamflow transfer from the South Fork Koktuli River watershed to the Upper Talarik Creek watershed (described above), decreased streamflows in the South Fork Koktuli River resulting from capture by the mine footprint would translate to decreased rates of interbasin transfer. As a result, there would be a projected 9% decrease in streamflow to the tributary of Upper Talarik Creek where the interbasin transfer flows emerge (gage UT119A) (Tables 7-16 and 7-19, Figure 7-14).

7.3.1.2 Pebble 2.0 Scenario

In the Pebble 2.0 scenario, area lost to the mine footprint would increase from the addition of a second or expanded waste rock pile that would occupy much of the Upper Talarik Creek valley between gages UT100E and UT100D (Figure 7-15). An expanded groundwater drawdown zone would develop around the larger mine pit and further reduce water flowing to surrounding streams, and TSF 1 would expand in size (Figure 7-15). Approximately 37.5% of the total water captured would be returned to the three watersheds (Table 6-3). However, as in the Pebble 0.25 scenario described above, flow returns in the upper watersheds via the WWTP outfalls would not necessarily be returned to their source stream reaches.

After accounting for water captured in the footprint, leakage, leachate, and reintroduced water, streamflow reductions in Upper Talarik Creek would be most severe for gage UT100D (44% reduction) (Tables 7-17 and 7-19). In the South Fork Koktuli River, gages SK100G, SK100F, and confluence point SK100CP2 would experience reductions of 72, 35, and 20%, respectively. In the North Fork Koktuli River, the most severe effects would be seen in the watershed occupied by TSF 1, with gages on this tributary predicted to experience streamflow reductions ranging from 40 to 62% (Tables 7-17 and 7-19, Figure 7-15). Contributions of the WWTP flow to the South Fork Koktuli River watershed would cause an increase in streamflow at gage SK124A (30%) and the associated confluence point SK124CP (28%). WWTP contributions to the North Fork Koktuli River watershed would cause a 12% streamflow increase at gage NK100C. At the lowermost gages in each watershed, projected reductions in streamflow would be 8% (Upper Talarik Creek), 4% (South Fork Koktuli River), and 3% (North Fork Koktuli River) (Tables 7-17 and 7-19).

Table 7-19. Estimated changes in streamflow (%) and subsequent stream lengths affected (km) in the mine scenario watersheds in the Pebble 0.25, Pebble 2.0, and Pebble 6.5 scenarios. Italics indicates changes greater than 10% (minor effects on salmon populations expected); bold indicates changes greater than 20% (moderate to major effects on salmon populations expected).

Stream and Gage	Pebble 0.25		Pebble 2.0		Pebble 6.5	
	Estimated Change in Streamflow	Stream Length Affected	Estimated Change in Streamflow	Stream Length Affected	Estimated Change in Streamflow	Stream Length Affected
South Fork Koktuli River—Mainstem						
SK100G	**−54**	1.9	**−72**	0.5	NA	NA
SK100F	**−26**	3.3	**−35**	3.3	**−62**	0.8
SK100CP2	*−15*	10.7	**−20**	10.7	**−36**	10.7
SK100C	5	6.3	2	6.3	**36**	6.3
SK100CP1	5	1.2	2	1.2	**36**	1.2
SK100B1	−1	4.3	−4	4.3	−9	4.3
SK100B[a]	−1	4.5	−4	4.5	*−10*	4.5
South Fork Koktuli River—Tributaries						
SK119A	0	7.0	−2	6.7	NA	NA
SK119CP	0	1.6	−1	1.6	**−54**	0.7
SK124A	**32**	5.0	**30**	5.0	**114**	4.2
SK124CP	**30**	2.6	**28**	2.6	**107**	2.6
North Fork Koktuli River—Mainstem						
NK100C[b]	*13*	4.5	*12*	4.5	**60**	4.5
NK100B	1	0.8	−6	0.8	*18*	0.8
NK100A1	0	20.4	−3	20.4	7	20.4
NK100A[c]	0	8.4	−3	8.4	6	8.4
North Fork Koktuli River—Tributaries						
NK119A	**−29**	0.8	**−62**	0.7	**−62**	0.7
NK119CP2	**−26**	1.3	**−57**	1.3	**−57**	1.3
NK119B	−3	6.8	*−11*	6.8	**−26**	6.5
NK119CP1	*−17*	0.4	**−40**	0.4	**−46**	0.4
Upper Talarik Creek—Mainstem						
UT100E	−7	2.3	NA	NA	NA	NA
UT100D	−9	7.1	**−44**	2.1	**−86**	0.3
UT100C2	−2	6.1	−10	6.1	**−20**	6.1
UT100C1	−2	6.9	−9	6.9	*−17*	6.9
UT100C	−2	7.5	−7	7.5	*−15*	7.5
UT100B[d]	−2	4.3	−8	4.3	*−15*	4.3
Upper Talarik Creek Tributary—Tributaries						
UT119A	−9	6.5	*−12*	6.5	**−21**	6.5

Notes:
Stream lengths are typically calculated from the gage upstream to the next gage or the mine footprint (but see below); stream lengths affected do not include portions of stream lost in the pit drawdown zone.
For gages UT100D, SK100G, SK100F, SK119A, SK124A, and NK119A, stream lengths include mainstem length upstream to edge of mine footprint only, and do not include upstream lengths, including tributaries, that would be blocked or eliminated by the mine footprint.
[a] USGS 15302200.
[b] Upstream to wastewater treatment plant outfall point.
[c] USGS 15302250.
[d] USGS 15300250.
NA = not applicable; the stream at the gage would be eliminated or blocked by the mine footprint

7.3.1.3 Pebble 6.5 Scenario

In the Pebble 6.5 scenario, area lost to the mine footprint would increase with inclusion of a larger pit and its associated drawdown zone, a substantially larger waste rock pile, and the development of TSF 2 on a tributary of South Fork Koktuli River upstream of gage SK100B1 and TSF 3 on a tributary upstream of gage SK124A (Table 7-18, Figure 7-16). Gage SK100G would be eliminated under the Pebble 6.5 waste rock piles, gage UT100E would be isolated upstream of the mine footprint, and gage SK119A would be buried under the TSF 2 dam (Figure 7-16). Although the larger mine footprint would result in the capture of much greater quantities of water in the Pebble 6.5 scenario, annual water consumption would not be appreciably higher than in the Pebble 2.0 scenario. Thus, an estimated 70.5% of the captured water would be available for reintroduction to streams (Table 6-3). The net effects of lost effective watershed area and the reintroduction of treated water would result in streamflow reductions that would be most severe for gages UT100D (86% reduction), SK100F (62% reduction), and NFK119A (62% reduction) (Tables 7-18 and 7-19).

WWTP flows would be increased greatly over the Pebble 2.0 scenario and would create increased streamflow at SK124A (114%) and SK124CP (107%). This increase would continue to influence streamflows downstream to gage SK100C (36% increase), but the large reduction attributed to the TSF on the tributary measured by gage SK119A again creates streamflow deficits downstream at gages SK100B1 and SK100B relative to pre-mining conditions (9 and 10% reductions, respectively) (Tables 7-18 and 7-19, Figure 7-16). In the North Fork Koktuli River watershed, WWTP contributions would lead to streamflow increases of 60% at gage NK100C and increased streamflows at all downstream gages (Table 7-18). Upper Talarik Creek would experience streamflow reductions of 15% or more at all mainstem gages. Upper Talarik Creek tributary gage UT119A would experience a 21% decrease in streamflow due to reduced interbasin transfer resulting from streamflow losses in the South Fork Koktuli River watershed. At the lowermost gages in each watershed, projected streamflow changes would be a 15% reduction for Upper Talarik Creek, a 10% reduction for the South Fork Koktuli River, and a 6% increase for the North Fork Koktuli River (Tables 7-18 and 7-19).

7.3.1.4 Post-Closure

After the mine closes, pit dewatering would cease, leading to pit filling. As the pit fills, water from the pit that had been returned to streams via pumping to the WWTP would no longer be available for streamflow. This period is projected to last from about 20 years for the Pebble 0.25 scenario to over 200 years for the Pebble 6.5 scenario, after which the pit would approach equilibrium with surrounding groundwater. The pit water level could be controlled by pumping or gravity drainage to maintain a hydraulic gradient toward the pit for as long as water needed treatment. When treatment was no longer necessary and active control was abandoned, water from the filled mine pit would eventually discharge to down-gradient streams, ponds, and wetlands (Section 6.3) under steady-state flow conditions. Given uncertainties in the post-closure water balance, we have not attempted to estimate streamflows during that period.

7.3.1.5 Uncertainties and Assumptions

Our assessment of streamflow changes distributes losses according to the percentage of the area lost to the mine footprint in a given watershed. The analysis uses flow per unit area derived from stream gage data, and allocates water routing through the three mine scenarios based on decisions about mine processes that will consume and reintroduce water to the watersheds. We assume that water captured within the footprint and requiring treatment would be routed through the WWTP and discharged to the two locations specified by Ghaffari et al. (2011). We assume that reduced streamflows would follow the same spatial patterns of gaining or losing groundwater reaches as would initial (pre-mine) conditions. We acknowledge, however, that mine operations could alter the relative importance of groundwater flowpaths, and thus result in a different spatial distribution of streamflow changes than we have reported.

7.3.2 Exposure-Response: Streamflow

Water from streams originating upstream of the mine footprints (i.e., blocked streams) could be captured at the footprint for use or stored on site for eventual treatment and return to the stream downstream of the footprint, either directly or via the WWTP. Water from blocked streams could be returned to downstream stream segments via diversion channels or pipes. Habitat upstream of the footprint would no longer be accessible to fish downstream because of the inability of fish to move upstream through diversion channels or pipes.

7.3.2.1 Altered Streamflow Regimes

Altered streamflows can have various effects on aquatic life. Short-term effects include reduced habitat availability resulting from water withdrawal (effects on winter habitat reviewed by West et al. 1992, Cunjak 1996) and reduced habitat quality resulting from extreme and rapid fluctuations in streamflow if withdrawals are intermittent (Curry et al. 1994, Cunjak 1996). Temporal variability in streamflows is a natural feature of stream ecosystems (Poff et al. 1997), although the degree of variability differs depending on hydrologic controls such as climate, geology, landform, human land use, and relative groundwater contributions (Poff et al. 2006). Fish populations may be adapted to periodic disturbances such as droughts and may quickly recover under improved hydrologic conditions, but this is contingent on many factors (Matthews and Marsh-Matthews 2003). Longer-term effects of prolonged changes in streamflow regime can have lasting impacts on fish populations (Lytle and Poff 2004).

The natural flow paradigm is widely supported and based on the premise that natural streamflow variability, including the magnitude, frequency, timing, duration, rate of change, and predictability of streamflow events and the sequence of streamflow conditions, is crucial to maintaining healthy aquatic ecosystems (Postel and Richter 2003, Arthington et al. 2006, Poff et al. 2009). However, numerous human demands can directly alter natural streamflows, potentially affecting ecosystem function and structure. Guidelines for minimizing impacts of altered hydrologic regimes have been offered by several researchers (Poff et al. 1997 and 2009, Richter 2010). Determining the natural streamflow regime is a data-intensive process, but it is crucial to understanding how to manage streamflows within a system (Arthington et al. 2006).

Given the high likelihood of complex groundwater–surface water connectivity in the deposit area, predicting and regulating flows to maintain key ecosystem functions associated with groundwater–surface water exchange would be particularly challenging. PLP has invested in a relatively intensive network of stream gages, water temperature monitoring sites, fish assemblage sampling sites, groundwater monitoring wells, and geomorphic cross-section locations. The integration of information gathered by these efforts will help identify relationships among surface-water flow, groundwater and surface-water temperatures, and instream fish habitat (Bartholow 2010). However, until linkages between biology, groundwater, surface water, and potential mining activities can be better evaluated, predicted, and understood, a protective approach is warranted to maintain surface-water and groundwater flows and natural streamflow regimes across the mine scenario watersheds.

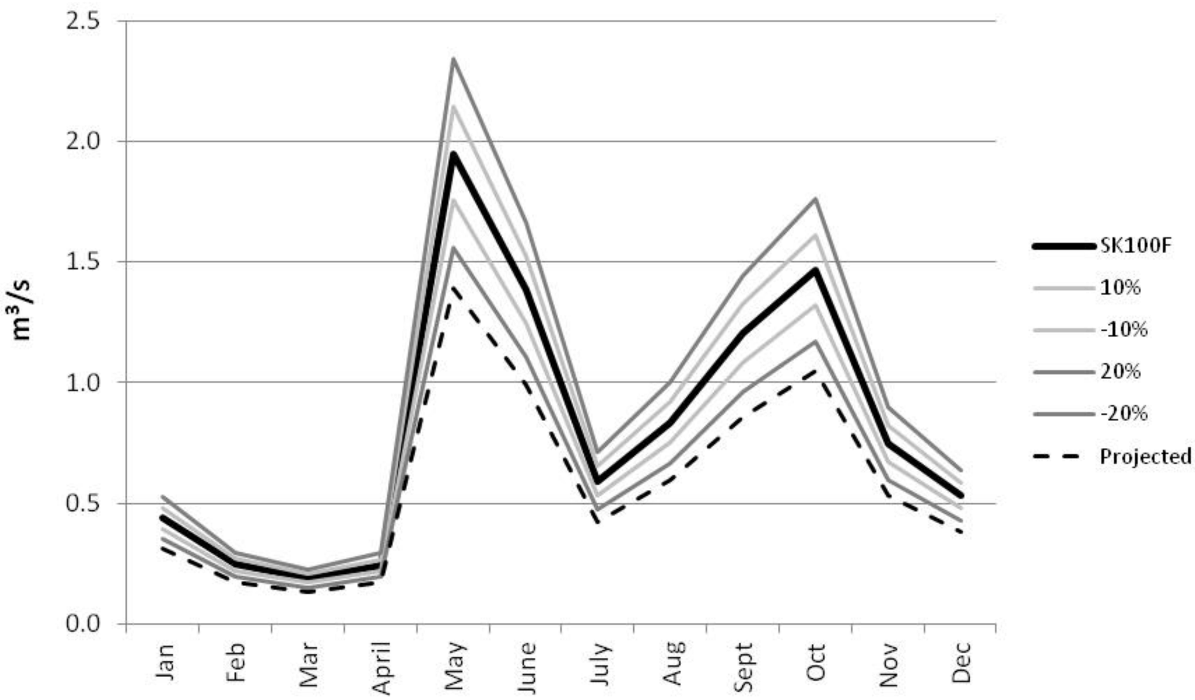
The sustainability boundary approach offers such a protective approach for balancing the maintenance of aquatic ecosystems with human demands (Richter et al. 2012). Under this approach, percentage-based deviations from natural conditions are used to set streamflow alteration limits. These percentages are based on the natural flow regime and do not focus on the more simplistic approach of setting a percentage based on a high-streamflow or low-streamflow event. Rather than a salmon-specific instream flow habitat model, this is a system-based approach targeting the entire aquatic ecosystem. Numerous case studies have tested this type of approach, and the percentage bounds of streamflow alteration around natural daily streamflow that caused measurable ecological harm were determined to be similar regardless of geographic location (Richter et al. 2012). Based on these studies, Richter et al. (2012) proposed that streamflow alteration be managed based on the following thresholds of daily percentage alteration.

- Streamflow alteration below 10% would cause minor impacts on the ecosystem with a relatively high level of ecosystem protection.
- Streamflow alteration of 11 to 20% would cause measurable changes in ecosystem structure and minor impacts on ecosystem function.
- Streamflow alteration greater than 20% would cause moderate to major changes in ecosystem structure and function. Increasing alteration beyond 20% would cause significant losses of ecosystem structure and function.

Losses of ecosystem structure and function could include reduced habitat availability for salmon and other stream fishes, particularly during low-streamflow periods (West et al. 1992, Cunjak 1996); reductions in macroinvertebrate production (Chadwick and Huryn 2007); and increased stream habitat fragmentation due to increased frequency and duration of stream drying. Increases in streamflow above background levels could result in altered sediment transport dynamics with increased scour and transport of gravels. Increased streamflows could also be associated with altered distributions of water velocities favorable for various fish life stages. These alterations, depending on magnitude, could significantly decrease salmon habitat quantity and quality in these watersheds (Figure 7-1).

We compared predicted streamflows for the Pebble 0.25, 2.0, and 6.5 scenarios (Tables 7-10 through 7-15) with the sustainability boundary limits of 10 and 20% streamflow alteration around mean monthly flow. As an example, mean monthly streamflows for the South Fork Koktuli River at gage SK100F during the pre-mining period, projected streamflows in the Pebble 0.25 scenario and the 10 and 20% sustainability boundaries for the baseline streamflow are shown in Figure 7-18.

Figure 7-18. Monthly mean pre-mining streamflow for South Fork Koktuli River gage SK100F (bold solid line), with 10 and 20% sustainability boundaries (gray lines) and projected monthly mean streamflows, in the Pebble 0.25 scenario (dashed line).



We used this sustainability boundary approach to evaluate risks associated with potential streamflow alterations throughout the mine scenario watersheds. To estimate the spatial extent of potential deleterious streamflow alterations, we calculated the length of stream network upstream of the uppermost stream gage to the edge of each mine footprint, and the length of each segment between stream gages in each mine scenario watershed. This stream length is in addition to the length of stream that would be eliminated or blocked by the mine footprint—that is, this and all subsequent references to stream lengths affected by flow modification reflect stream lengths downstream of the mine footprint for each scenario, and thus do not include stream lengths eliminated, blocked, or dewatered by each footprint (Section 7.2). Table 7-19 summarizes estimated percent changes in streamflow at each gage location, and the length of stream affected by each streamflow alteration in each mine scenario. Figures 7-14 through 7-16 illustrate the spatial extent and location of streamflow alterations in relation to gage sites. These estimates are for direct effects only. Stream sections throughout the stream network could be affected indirectly, via streamflow reductions downstream that could preclude use of downstream habitats by fish that move seasonally between headwater and mainstem habitats. Similarly, these stream sections could be isolated by downstream flow reductions that reduce or eliminate the potential for fish movement into those areas from downstream.

Pebble 0.25 Scenario

During operation of the Pebble 0.25 scenario, streamflow reductions exceeding 20% sustainability boundaries would occur in 7 km of streams beyond the mine footprint. Substantial reductions in fish habitat capacity and productivity could be expected for these streams. Streamflow increases greater than 20% are expected for 8 km of streams downstream of the WWTP outfall, and would likely lead to substantial changes in sediment dynamics and habitat suitability for fish. An additional 16 km of streams would experience streamflow alterations of 13 to 17%, with anticipated minor effects on ecosystem structure and function.

In the upper South Fork Koktuli River, gages SK100G and SK100F would experience 54 and 26% reductions in streamflow, respectively, affecting 5 km of streams (Table 7-19). The tributary to the South Fork Koktuli River receiving outfall from the WWTP would experience increased streamflows (28 to 30%), affecting 8 km of streams. In the North Fork Koktuli River, the tributary downstream of TSF 1 would experience 17 to 26% reductions in streamflow, affecting 2 km of streams (Table 7-19).

Several sections of the South Fork Koktuli River and tributaries below Frying Pan Lake are losing reaches (i.e., discharge decreases in a downstream direction), which under pre-mine conditions experience periods of zero minimum monthly discharge (e.g., gage SK100C and WWTP-receiving stream gage SK124A) (Table 7-13). We assumed that streamflow increases due to the WWTP would follow the natural hydrograph, reflecting the amount of precipitation and runoff that must be captured and treated. As a result, WWTP outfall flows would be lowest during periods when these streams typically go dry based on pre-mine baseline data, and would be highest during period of snowmelt runoff and fall storms.

Pebble 2.0 Scenario

In the Pebble 2.0 scenario, streamflow reductions exceeding 20% sustainability boundaries would occur in 19 km of streams downstream of the mine footprint. For these streams, substantial reductions in fish habitat capacity and productivity would be expected. Increases in streamflow of 28 to 30% would be expected for 8 km of streams downstream of the WWTP in the South Fork Koktuli River, and increases of 12% would be expected for 4 km of the WWTP-receiving tributary to the North Fork Koktuli River, leading to changes in sediment dynamics and habitat suitability for fish. An additional 6 km of streams in Upper Talarik Creek and 7 km of streams in the North Fork Koktuli River would experience flow reductions of 10 to 11%, with anticipated minor effects on ecosystem structure and function.

In the Pebble 2.0 scenario, the mine footprint captures 47% of the Upper Talarik Creek watershed above gage UT100D (Table 7-17). As a result, most of the total stream length in its upstream reaches, including the mainstem and all tributaries above gage UT100D, would experience either total loss of habitat from the mine footprint or indirect effects of fragmentation (Section 7.2, Figure 7-15). Of this stream length, 2 km of mainstem downstream of the footprint would experience a significant loss of habitat and decline in habitat quality from the predicted 44% streamflow reduction at gage UT100D (Figure 7-15). Downstream of gage UT100D in Upper Talarik Creek, streamflow reductions would range from 8 to 10% (Table 7-19). Impacts on salmon habitat from streamflow reductions would be moderated by tributary and groundwater inputs that may help ameliorate flow losses originating upstream, assuming that groundwater sources and flowpaths are not also altered by the mine footprint. This assumption is questionable (Section 7.3.2.3). For instance, the groundwater-dominated Upper Talarik Creek tributary monitored at gage UT119A would experience a 12% streamflow reduction due to reduced flow in portions of the South Fork Koktuli River resulting from losses to the mine footprint. This was the only case of interbasin hydrologic connectivity explicitly modeled, but other undocumented connections are likely to occur.

In the South Fork Koktuli River, streamflow reductions would exceed the 20% sustainability threshold at gages SK100G, SK100F, and SK100CP2 (Table 7-19, Figure 7-15). In the South Fork Koktuli River mainstem and tributaries upstream of gage SK100G, the majority of stream length would be eliminated by the mine footprint (Figure 7-15), resulting in severe streamflow reductions at gages SK100G (72%) and SK100F (35%) (Table 7-19). Streamflows in the South Fork Koktuli River at gage SK100C would increase by 2% because of WWTP releases discharged at tributary gage SK124A, which would experience a 28% increase in streamflow at the confluence with the South Fork Koktuli River (Table 7-19, Figure 7-16).

In the North Fork Koktuli River, the majority of stream length above gage NK119A would be eliminated by construction of TSF 1 (Figure 7-15), resulting in substantial streamflow losses (62% reduction at gage NK119A) for approximately 2 km of streams between TSF 1 and the North Fork Koktuli River (Table 7-19, Figure 7-15). Approximately 7 km of streams in the tributary measured by gage NK119B would experience 11% reductions in streamflow. Increases in streamflow downstream of the WWTP discharge point would increase streamflows by 12% in 4 km of the North Fork Koktuli River upstream of gage NK100C (Table 7-19, Figure 7-15).

Pebble 6.5 Scenario

The Pebble 6.5 scenario would capture an even larger portion of the South and North Fork Koktuli Rivers and Upper Talarik Creek watersheds in its footprint. During operation of the Pebble 6.5 scenario, streamflow reductions exceeding 20% sustainability boundaries would occur in 34 km of streams. For these streams, reductions in fish habitat capacity and productivity could be expected. An additional 19 km of streams in Upper Talarik Creek would experience streamflow reductions exceeding 10%, with anticipated minor effects on ecosystem structure and function. Increases in streamflow exceeding 20% are expected for 14 km of streams downstream of the WWTP in the South Fork Koktuli River and for 4 km of the WWTP-receiving tributary to the North Fork Koktuli River, and would likely lead to substantial changes in sediment dynamics and habitat suitability for fish.

In the Upper Talarik Creek watershed, substantial streamflow reductions are projected at gages UT100D (86%) and UT100C2 (20%), affecting 6 km of streams. Streamflow alterations exceeding 10% would occur in an additional 19 km of streams at gages UT100C1, UT100C, and UT100B (Table 7-19). In the

South Fork Koktuli River, gages SK100G and SK119A would be buried under the expanded mine footprint. A 62% reduction in streamflow would be expected for 1 km of the upper South Fork Koktuli River downstream from the edge of the waste rock to gage SK100F (Table 7-19, Figure 7-16).

In the Pebble 6.5 scenario, the WWTP is estimated to discharge over 50 million m^3 of water per year (Table 7-18). This discharge would result in a 36% increase in streamflow for 8 km in the South Fork Koktuli River above gage SK100CP1, and a 107% increase in streamflow for 7 km of streams above gage SK124CP (Table 7-19, Figure 7-16). In the North Fork Koktuli River, WWTP outfalls would result in a 60% increase in streamflows for 4 km of streams above gage NK100C, and an 18% increase in streamflows for 1 km of streams upstream of gage NK100B.

Streamflow reductions and stream habitat losses of the magnitudes estimated in the Pebble 0.25, 2.0, and 6.5 scenarios represent substantial risks to spawning and rearing habitat for populations of coho, sockeye, and Chinook salmon, Dolly Varden, and rainbow trout in the upper portions of the mine scenario watersheds. Habitat quantity and quality would be significantly diminished by the loss of streamflow from the mine footprint, via multiple mechanisms such as direct reduction in habitat area and volume, the loss of channel to off-channel habitat connectivity, increased periods of zero streamflow, and reduced food production. Streamflow increases could alter channel morphologies, induce higher rates of sediment transport and erosion, and change the distribution of water velocities within habitats used by spawning and rearing salmon and other fishes. Although the loss of salmonid production has not been estimated, streamflow alterations greater than 20% would be expected to have substantial effects (Richter et al. 2012).

7.3.2.2 Connectivity, Timing, and Duration of Off-Channel Habitats

Losses of streamflow resulting from the mine footprints and potential water withdrawals described above would affect connectivity between the main channel and off-channel habitats important to juvenile salmonids. Losses of flood peaks could alter groundwater recharge rates and influence characteristics of floodplain percolation channels, seeps, or other expressions of the hyporheic zone (Hancock 2002). Rapid streamflow reductions that exceed recession rates typically experienced by fish in these systems could result in stranding or isolation of fish in off-channel habitats (Bradford et al. 1995). Off-channel habitats, particularly those with groundwater connectivity, are critical rearing habitats for several species of juvenile salmonids and can be important sockeye salmon spawning habitats (Quinn 2005). Maintaining connectivity and the physical and chemical attributes of these habitats in conditions similar to baseline conditions would be important for minimizing risks to salmon and other native fishes.

Wetlands that are hydrologically connected to affected streams would also respond to alterations in streamflow and groundwater. Fish access to and use of wetlands are likely to be extremely variable in the mine footprint areas because of differences in the duration and timing of surface water connectivity with stream habitats, distance from the main channel, or physical and chemical conditions (e.g., dissolved oxygen concentrations) (King et al. 2012). Projecting the effects of lost wetland connectivity and abundance on stream fish populations is beyond the scope of this assessment, but could be a significant unknown.

Flow regulation through the WWTP could be designed to somewhat approximate natural hydrologic regimes during periods when sufficient water and water storage capacity were available, which could provide appropriate timing and duration of connectivity with off-channel habitats. Channel cross-section data and gage data (PLP 2011) would provide useful insights into streamflow connectivity relationships and could help guide a streamflow management plan.

7.3.2.3 Changes in Groundwater Inputs and Importance to Fish

There is limited information describing potential surface water–groundwater interactions in the mine scenario watersheds, but groundwater is likely the dominant source of streamflow in these streams (Rains 2011) and can be very important locally. High baseflow levels in the monthly hydrographs of the mine scenario watersheds illustrate groundwater's important influence on these streams (Figure 3-10).

Aerial winter open-water surveys consistently suggest the presence of upwelling groundwater, which maintains ice-free conditions in portions of area streams and rivers. Highly permeable glacial outwash deposits create a complex mosaic within less permeable, clay to silt-dominated Pleistocene lake deposits and bedrock outcrops, which can control surface water–groundwater interactions in landscapes like this one (Power et al. 1999). Mine operations that reduce surface water contributions in the natural drainage course or that lower groundwater tables may influence groundwater paths and connections within and among streams in the mine area in ways that are not predicted in this assessment, but that could have significant impacts on fish. In our analyses of the water management regimes for the mine scenarios, we project increasing proportions of streamflow derived from water released from the WWTP as the mine develops. These increased releases would result from increased interception of groundwater associated with the mine pit cone of depression, rainwater, and surface runoff collection. Water treated and discharged would replace a portion of the groundwater that would otherwise be feeding stream systems, and could have substantially different chemical characteristics (Chapter 8).

Fish in the region are highly attuned to groundwater signals in the hydrologic and thermal regimes (Power et al. 1999). Spatial heterogeneity in streamflow and temperature, largely mediated by groundwater–surface water exchange, provides a template for diverse sockeye salmon life histories and migration timing (Hodgson and Quinn 2002, Rogers and Schindler 2008, Ruff et al. 2011). For example, groundwater moderates winter temperatures, which strongly control egg development and hatch and emergence timing (Brannon 1987, Hendry et al. 1998). Spatial thermal heterogeneity allows diverse foraging strategies for consumers of sockeye salmon and their eggs, such as brown bear and rainbow trout, thereby benefitting not only sockeye salmon populations but also the larger foodweb (Armstrong et al. 2010, Ruff et al. 2011).

Altered groundwater contributions to surface waters in the mine area could have profound effects on the thermal regimes and thermally cued life histories of aquatic biota. Curry et al. (1994) examined the influence of altered hydrologic regimes on groundwater–surface water interchange at brook trout spawning locations in an Ontario stream. Responses of groundwater–surface water exchange to changes in river discharge varied among sites, precluding predictable responses. The complexity that can be inherent in groundwater–surface water interactions can make regulating or controlling such interactions during large-scale landscape development very difficult (Hancock 2002). Adequately protecting the critical services that groundwater provides to fish is complicated by the fact that flowpaths vary at multiple scales, and connections between distant recharge areas and local groundwater discharge areas are difficult to predict (Power et al. 1999).

7.3.2.4 Stream Temperature

Projecting specific mine-associated changes to groundwater and surface water interactions and corresponding effects on surface water temperature in the mine area is not feasible at this time. Disruptions or changes to groundwater flowpaths could have significant adverse effects on winter habitat suitability for fish, particularly if groundwater-dominated stream reaches are converted to surface water-dominated systems. Irons et al. (1989 in Reynolds 1997) reported that groundwater-mediated unfrozen refugia were dependent on fall rains maintaining groundwater, but that during a dry year, groundwater levels declined and allowed full freezing of stream surface waters and the streambed. This suggests that the threshold between completely frozen and partially frozen streams can be a narrow one, particularly for small streams with low winter discharge. The duration of freezing and the extent and type of ice formation, including anchor ice, frazil, or surface ice (Slaughter 1990), can severely limit habitat availability during the winter and spring months.

Two aerial surveys of the mine scenario watersheds provide additional information on groundwater inputs to headwater streams and ice cover conditions in streams draining the mine footprints (PLP 2011, Woody and Higman 2011). PLP conducted aerial and foot surveys during late-winter low-flow conditions in 2006, 2007, and 2008 to determine the extent of open water and ice cover (PLP 2011: Appendix 7.2B). Open-water reaches were consistently observed in strongly gaining reaches in the South and North Fork Koktuli Rivers and Upper Talarik Creek. Open-water reaches corresponded to areas of relatively warm groundwater that helped keep portions of the river network relatively ice-free (PLP 2011: Appendix 15.1E). Aerial surveys documented by Woody and Higman (2011) in March 2011 showed broadly similar patterns of open water, suggesting that the general patterns reflect consistent areas of strong groundwater–surface water interaction. Maintaining winter groundwater connectivity may be critical for fish in such streams (Cunjak 1996, Huusko et al. 2007, Brown et al. 2011).

7.3.3 Risk Characterization

The water consumption predicted for our mine scenarios would require large volumes of water from surface streams or groundwater, inevitably resulting in alterations to streamflows. Streamflow alterations exceeding 20% would occur in 15, 27, and 53 km of streams in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively, leading to significant adverse effects on fish and other aquatic life. The seasonal timing and magnitude of streamflow alterations would be contingent on water storage and management systems and strategies, but would be constrained by the fundamental needs for water at specific times and locations in the mining process (Chapter 6). Impacts on fish habitat and fish populations would likewise depend on the magnitude and timing of streamflow changes, but would be most severe for streams close to the mine footprint.

The volume of water that would require treatment by the mine's WWTP would range from 11 million m^3/yr for Pebble 0.25 (Table 7-16) to over 50 million m^3/yr for Pebble 6.5 (Table 7-18). To avoid or minimize risks associated with altered streamflows in downstream effluent-receiving areas, water storage and release capacities would be required to maintain natural streamflow regimes or to maintain any minimum streamflows required by regulatory agencies. Application of the Instream Flow Incremental Methodology (IFIM) Physical Habitat Simulation (PHABSIM) system modeling approach (Bovee 1982, Bovee et al. 1998) is being used by PLP to assess streamflow-habitat relationships (PLP 2011: Chapter 15), and could provide additional guidance for establishing streamflow requirements (Estes 1998) beyond those identified in this document.

Maintenance of mine discharges, in terms of water quality, quantity, and timing, to avoid adverse impacts would require long-term monitoring and facility maintenance commitments. As with other long-term maintenance and monitoring programs, the financial and technological requirements could be very large, and the cumulative risks (and likely instantaneous consequences) of potential accidents, failures, and human error would increase with time. In addition, climate change and projected changes in temperature and precipitation in the region (Section 3.8) would result in potential changes in streamflow magnitude and seasonality. These climate-related changes would interact with mining-related flow impacts (Box 14-2), requiring adaptation to potentially new streamflow regimes. We know of no precedent for the long-term management of water quality and quantity on this scale at an inactive mine.

7.3.4 Uncertainties and Assumptions

Projecting changes to groundwater–surface water interactions in the mine footprint area with any specificity is not feasible at this time. Local geology and stream hydrographs are indicative of systems that are largely driven by groundwater. Disruptions or changes to groundwater flowpaths in the footprint area could have significant adverse effects on winter habitat suitability for fish, particularly if groundwater-dominated stream reaches are converted to stream reaches dominated by WWTP effluent. Given the high likelihood of complex groundwater–surface water connectivity in the mine area, predicting and regulating streamflows to maintain key ecosystem functions associated with groundwater–surface water exchange would be particularly challenging.

Our approach for assessing potential risks of streamflow alteration rests on simplifying assumptions regarding changes to the natural streamflow regime in the three mine scenarios (Section 7.3.2). The natural streamflow regime consists of multiple components, including flow magnitude, frequency, duration, timing, and rate of change, all of which can have important implications for fish and other aquatic life (Poff et al. 1997). We were unable to anticipate changes to the streamflow regime beyond simplistic alterations in flow magnitude. However, it is very likely that other aspects of the streamflow regime would be modified as well, depending on how flows respond to water management at the mine site. In addition, any changes in the duration of open-water freezing conditions associated with mining activities could alter seasonal streamflow regimes differently than we assume here. Our analysis does not account for these possibilities.

We assumed that streamflow modifications would follow the natural hydrograph, reflecting the amount of precipitation and runoff that was intercepted and thus must be captured and treated. As a result, WWTP outfall flows are lowest during periods when these streams typically go dry based upon pre-mine baseline data, and are highest during snowmelt runoff and fall storms. Alternative flow management strategies may be feasible, depending on the capacity to store and release flows to meet environmental streamflow objectives (see Appendix J for additional discussion).

Additionally, we assume that larger deviations from the natural streamflow regime pose greater risks of ecological change. The scientific literature supports this assumption as a general trend (Poff et al. 2009, Poff and Zimmerman 2010, Richter et al. 2012). However, as pointed out by Poff and Zimmerman (2010), specific responses to changes in streamflow vary. Although all stream studies reviewed by Poff and Zimmerman (2010) showed declines in fish abundance, diversity, and demographic rates with any level of streamflow modification, other ecological responses (e.g., macroinvertebrate abundance, riparian vegetation metrics) sometimes increased. Responses of fish populations and other ecological metrics to streamflow modification would depend on a suite of interacting factors, including but not limited to stream structural complexity, trophic interactions, and the ability of fish to move seasonally (Anderson et al. 2006).

Potential impacts of the mine footprints discussed in this chapter do not explicitly take into account the effects of climate change. Over the time scale at which large-scale mining would potentially affect the assessment area, projected increases in temperature and precipitation may substantially change the physical environment (Section 3.8 and Box 14-2). Such changes could significantly alter the variability and magnitude of streamflows. Seasonal transitions between frozen and unfrozen conditions can strongly influence groundwater–surface water interactions and streamflow dynamics (Callegary et al. 2013). Duration of freezing conditions and timing of snowmelt may be highly sensitive to climate change, with significant implications for flow regimes. Increases in rain-on-snow events are likely, but the potential implications for flooding are unclear. Nevertheless, these changes in streamflow regime would likely lead to changes in sediment transport, bed stability, and channel morphology with potential adverse impacts to fish habitat and population genetic diversity and resiliency.

7.4 Summary of Footprint Effects

Streams eliminated, blocked, or dewatered by the mine footprints in the Pebble 0.25, 2.0, and 6.5 scenarios would result in the loss of 8, 22, or 36 km, respectively, of documented anadromous waters as defined in the AWC (Johnson and Blanche 2012). These lengths represent a loss of 2 to 11% of the total AWC length in the mine scenario watersheds (total AWC length = 322 km) (Johnson and Blanche 2012). An additional 30 to 115 km of headwater streams supporting habitat for non-anadromous fish species would be lost to the mine footprint in these scenarios. Loss of headwater streams to the footprints would alter groundwater–surface water hydrology, nutrient processing, and export rates of resources and materials to downstream aquatic ecosystems. Losses of wetlands would be 4.5, 12, and 18 km^2 in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively. In addition, the Pebble 0.25, 2.0, and 6.5 scenarios would result in losses of 0.41, 0.93, and 1.8 km^2 of ponds and lakes, respectively. An unquantified area of riparian floodplain wetland habitat would either be lost or suffer substantial changes in hydrologic connectivity with streams because of reduced streamflow from the mine footprint.

Reduced streamflow resulting from water consumption in mine operations, ore processing, transport, and other processes, would further reduce the amount and quality of fish habitat downstream of the mine footprints. Changes in streamflow exceeding 20% would adversely affect habitat in an additional 15, 27, and 53 km of streams in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively, reducing production of coho salmon, sockeye salmon, Chinook salmon, rainbow trout, and Dolly Varden. Losses of stream habitat leading to losses of local, unique populations would erode the population diversity that is essential to the stability of the overall Bristol Bay salmon fishery (Schindler et al. 2010).