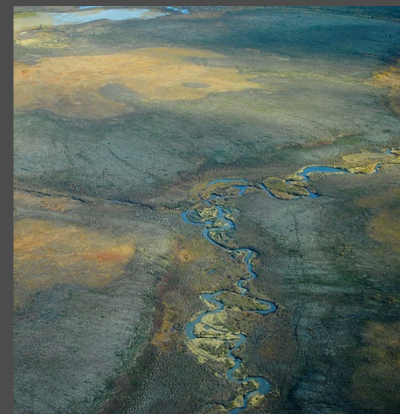




CHAPTER 6. MINE SCENARIOS

6.1 Basic Elements of the Mine Scenarios

For this assessment, we used information on porphyry copper deposits and mining practices summarized in Chapter 4 to develop three mine size scenarios: Pebble 0.25 with 0.25 billion ton (0.23 billion metric tons) of ore, Pebble 2.0 with 2.0 billion tons (1.8 billion metric tons) of ore, and Pebble 6.5 with 6.5 billion tons (5.9 billion metric tons) of ore. The word Pebble in the names of the scenarios represents the fact that we place our scenarios at the Pebble deposit. These three mine size scenarios, as well as other scenario types considered in later chapters of the assessment, are summarized in Table 6-1.

The three mine size scenarios evaluated in the assessment represent realistic, plausible descriptions of potential mine development phases, consistent with current engineering practice and precedent. The scenarios are not mine plans: they are not based on a specific mine permit application and are not intended to be the detailed plans by which the components of a mine would be designed. However, the scenarios are based on preliminary mine details put forth in Northern Dynasty Minerals' *Preliminary Assessment of the Pebble Mine* (Ghaffari et al. 2011), as well as information from scientific and industry literature for mines around the world (see Chapter 4 and Appendix H for background information on mining and the geology of porphyry copper deposits). Thus, the mine scenarios reflect the general activities and processes typically associated with the kind of large-scale porphyry copper mine development likely to be proposed once a specific mine application is developed. We use these scenarios to benchmark potential risks resulting from this type of development, to provide decision makers with a better understanding of potential risks associated with any specific action proposed in the future.

Table 6-1. Summary of scenarios considered in the assessment.

Scenario Type	Scenario	Description	Assessment Chapter(s)
Mine size	Pebble 0.25	Mine size of 0.25 billion ton (0.23 billion metric ton) of ore.	7, 8
	Pebble 2.0	Mine size of 2.0 billion tons (1.8 billion metric tons) of ore.	
	Pebble 6.5	Mine size of 6.5 billion tons (5.9 billion metric tons) of ore.	
Water collection, treatment, and discharge	Routine operations[a]	All water collection and treatment at site works properly, and wastewater is treated to meet state and national standards before release; however, some leachate from waste rock and TSFs is not captured.	8
	Wastewater treatment plant failure[a]	Wastewater treatment plant fails and releases untreated wastewater through its two outfalls.	
	TSF spillway release	Excess water stored in TSF 1 is released over the spillway.	
Tailings dam failure	Pebble 0.25	Failure of 92-m dam at TSF 1.	9
	Pebble 2.0	Failure of 209-m dam at TSF 1.	
Transportation corridor		113-km gravel road with four pipelines, within the Kvichak River watershed.	10
Pipeline failure	Product concentrate pipeline failure[b]	Complete break or equivalent failure of the product concentrate pipeline.	11
	Return water pipeline failure[b]	Complete break or equivalent failure of the return water pipeline.	
	Diesel pipeline failure[b]	Complete break or equivalent failure of the diesel pipeline.	

Notes:
[a] Scenario was considered for each mine size scenario.
[b] Each pipeline failure scenario was considered at two locations: Chinkelyes Creek and Knutson Creek.
TSF = tailings storage facility.

In the scenarios, we make decisions concerning mine placement; the size of the mine and the time over which mining would occur; the size, placement, and chemistry of waste rock; the size, placement, and chemistry of tailings storage facilities (TSFs); on-site processing of the ore; and the removal of processed ore concentrate from the site. For comparison purposes, Table 4-1 provides similar information for other past, existing, and potential large mines in Alaska. The mine components described in the scenarios are placed on the landscape based on information either from Ghaffari et al. (2011) or where, in our experience, modern mining practice suggests a component would be placed. For example, the pit is located on the deposit; TSFs are placed in locations described by Ghaffari et al. (2011) and where topography provides an efficient location to store a large volume of tailings; waste rock is placed around the pit to minimize the cost of hauling millions to billions of metric tons of material (Table 6-2); and the transportation system is located within the corridor described by Ghaffari et al. (2011).

We focus on the major mine components (mine pit, waste rock piles, and TSFs) that have the potential to adversely affect aquatic resources regulated under the federal Clean Water Act (33 USC 1251–1387) (Box 6-1). Smaller mine facilities such as crushing and screening areas, the mill, laydown areas, workshops, offices, and housing would be expected to be placed in uplands to avoid wetlands, ponds, and streams; thus, they are only addressed as they relate to stormwater runoff.

BOX 6-1. CUMULATIVE IMPACTS OF A LARGE-SCALE PORPHYRY COPPER MINE

In this assessment, we focus on the areas of the major mine components (mine pit, tailings storage facilities, and waste rock piles) and the transportation corridor. The actual infrastructure needed to operate any large-scale mine would be significantly more extensive than these four components and would result in larger cumulative impacts of a single mine. These additional infrastructure needs (based on Ghaffari et al. 2011) would include, but are not limited to, the following.

- **Mining and processing facilities**, including grinding mills, ore stockpiles, conveyers, a wastewater treatment plant, and process water ponds and distribution lines.
- **Drainage management structures**, such as seepage cutoff walls, stream diversion channels, drainage ditches, and sediment control ponds.
- **Other storage and disposal facilities**, such as overburden and topsoil stockpiles, explosives storage, a non-hazardous waste landfill, process water storage tanks, waste incinerators, a fuel storage compound, and hazardous waste storage.
- **Other operational infrastructure**, such as administrative buildings, dormitories, a sewage treatment plant, a power generation plant, power distribution lines, potable water treatment plant and distribution lines, and a truck shop.

These cumulative plant and ancillary areas are included in the total mine footprint for each scenario (Tables 6-5 through 6-7) but are not specifically placed on the landscape because of the greater uncertainty regarding their placement.

The cumulative impacts of a large-scale mine at the Pebble deposit likely would be much larger than the footprints evaluated in the mine scenarios.

- According to Ghaffari et al. (2011), the total area of direct impact for a 25-year mine at the Pebble deposit would cover approximately 125 km^2; in comparison, the mine footprint for the 25-year mine scenario (Pebble 2.0) considered in this assessment covers approximately 45 km^2 (Table 6-6).
- Net power generation for such a mine would be approximately 378 megawatts (Ghaffari et al. 2011). This is more than 100 times the maximum electrical load of the largest population center in the Bristol Bay watershed, the Dillingham/Aleknagik area (Marsik 2009), and slightly less than half of the combined capacity of the two electric utilities that serve more than 40% of Alaska's total population (CEA 2011, ML&P 2012).
- Dormitories for such a mine would house more than 2,000 people during construction and more than 1,000 people during mine operation (Ghaffari et al. 2011). Thus, the mine site would rival Dillingham as the largest population center in the Bristol Bay watershed during construction and would remain the second largest population center during operation.
- The mine site could contain more than 19 km of main roads, as well as numerous pit and access roads, and would depend on a fleet of 50 to 100 vehicles, in addition to 150 or more large ore-hauling trucks (Ghaffari et al. 2011). Potential risks associated with these roads would be similar in type to those described in Chapter 10.

We specify that all mine components would be developed using modern conventional design and technologies and operated under standard industry practices. Our purpose in this assessment is to evaluate the potential effects of mining porphyry copper deposits in the Nushagak and Kvichak River watersheds given design and operation to these standards. We have included basic descriptions of design features intended to mitigate potential adverse effects of mine operation.

In spite of these design and operation standards, however, any large-scale mine in the Bristol Bay region would have a footprint that would affect aquatic resources (Figures 6-1 through 6-3). These footprint-related impacts are addressed in Chapter 7. Additional impacts that may result from human error, mechanical failure, accidents, and other unplanned events are considered in Chapters 8 through 11. Compensatory mitigation for effects on aquatic resources that cannot be avoided or minimized by mine design and operation is discussed in Appendix J.

It is important to remember that this is an assessment of mine scenarios, and that like any predictive assessment it is hypothetical. Although major features of the scenarios will undoubtedly be correct (e.g., a pit at the location of the ore body and the generation of a large volume of tailings), some specifics would inevitably differ in an official mine plan submitted for permitting. All plans—even those submitted to and approved by state and federal regulators—are scenarios, and unforeseen changes in design and practice inevitably occur over the course of mine development and operation. The Fort Knox Mine near Fairbanks, Alaska, provides an example. On October 1, 2012, an Alaska Pollution Discharge Elimination System permit authorized the Fort Knox Mine to discharge wastewater to nearby Fish Creek, although the mine was originally designed and permitted in 1994 as a no-discharge facility.

It is also important to note that the largest scenario considered in this assessment, based upon 6.5 billion tons (5.9 billion metric tons) of ore, does not represent complete extraction of the Pebble deposit. Ghaffari et al. (2011) estimate the entire Pebble mineral resource at 11.9 billion tons (10.8 billion metric tons); were a mine to be developed that fully extracted this amount of ore, potential effects could be significantly greater than those estimated in the assessment.

This section describes the mine components common to the three mine size scenarios (and most other mines of this type, as described in Chapter 4). Section 6.2 describes specific characteristics of each mine size scenario relevant to our assessment, including water treatment and discharge. Section 6.3 describes closure of the mines, and Section 6.4 provides conceptual models of the relationships between mine components, potential stressors, and biotic responses.

Figure 6-1. Footprint of the major mine components (mine pit, waste rock piles, and tailings storage facility [TSF]) 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).

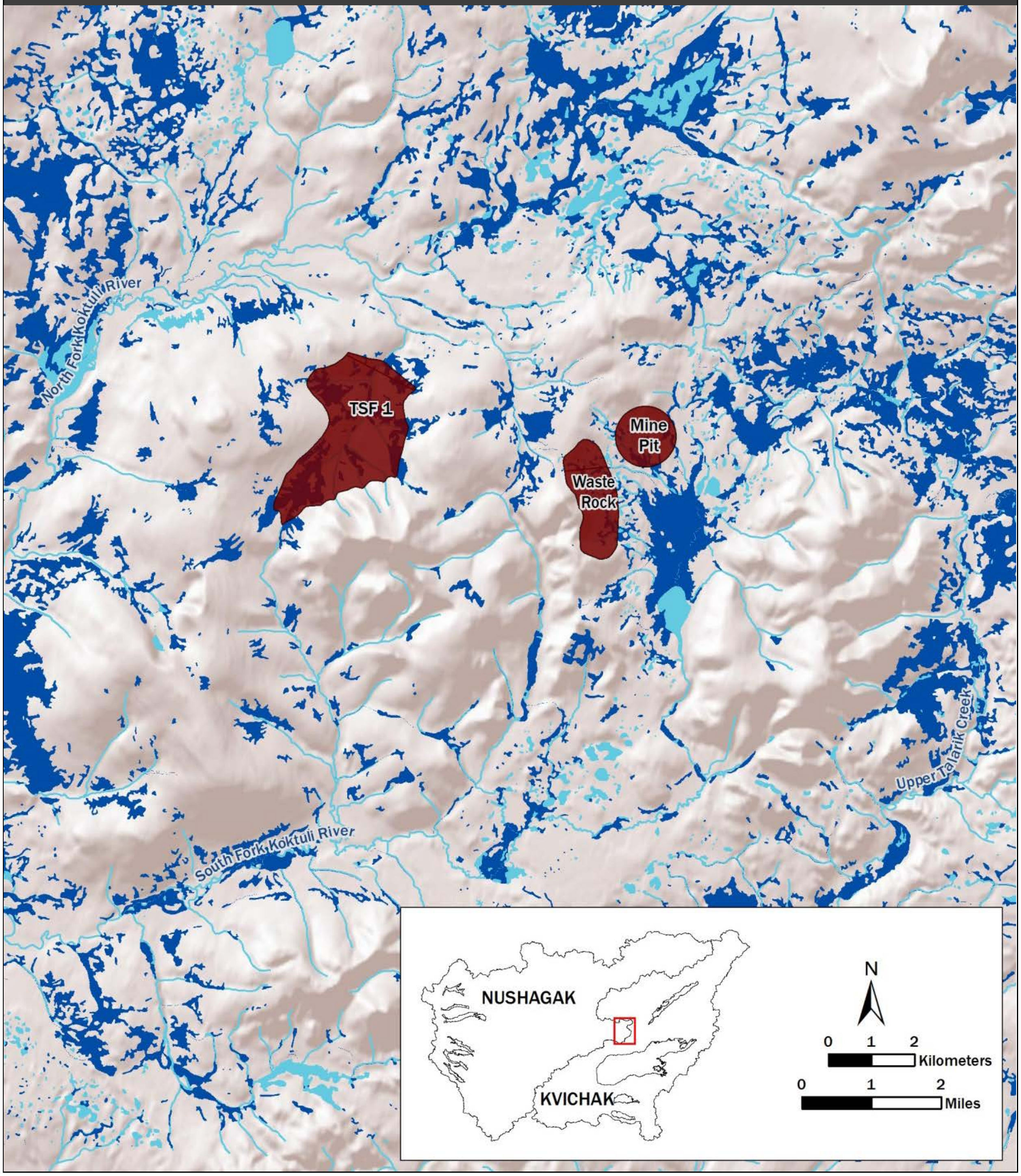


Figure 6-2. Footprint of the major mine components (mine pit, waste rock piles, and tailings storage facility [TSF]) in the Pebble 2.0 scenario. Light blue areas indicate streams and rivers from the National Hydrography Dataset (USGS 2012a) and lakes and ponds from the National Wetlands Inventory (USFWS 2012); dark blue areas indicate wetlands from the National Wetlands Inventory (USFWS 2012).

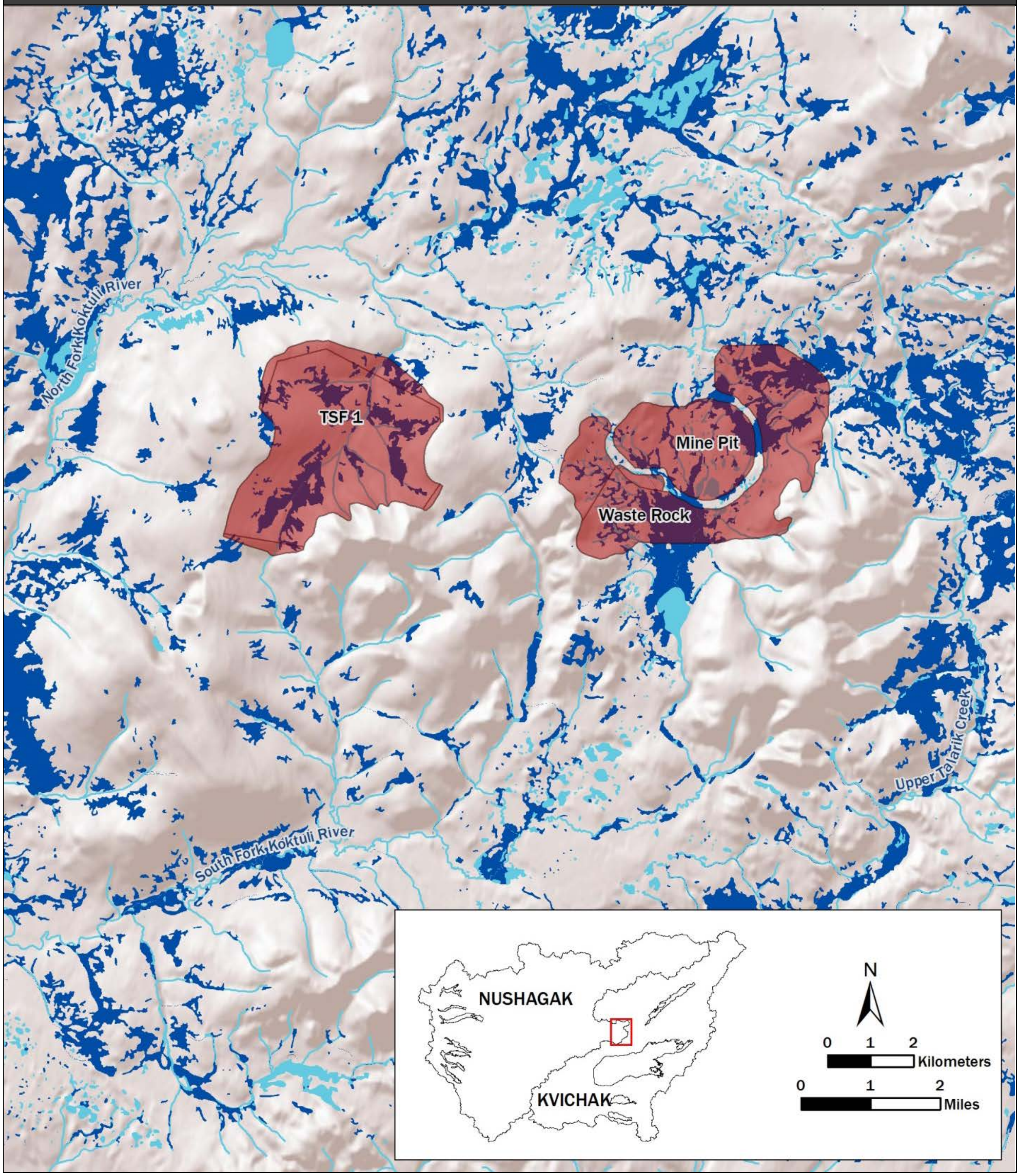
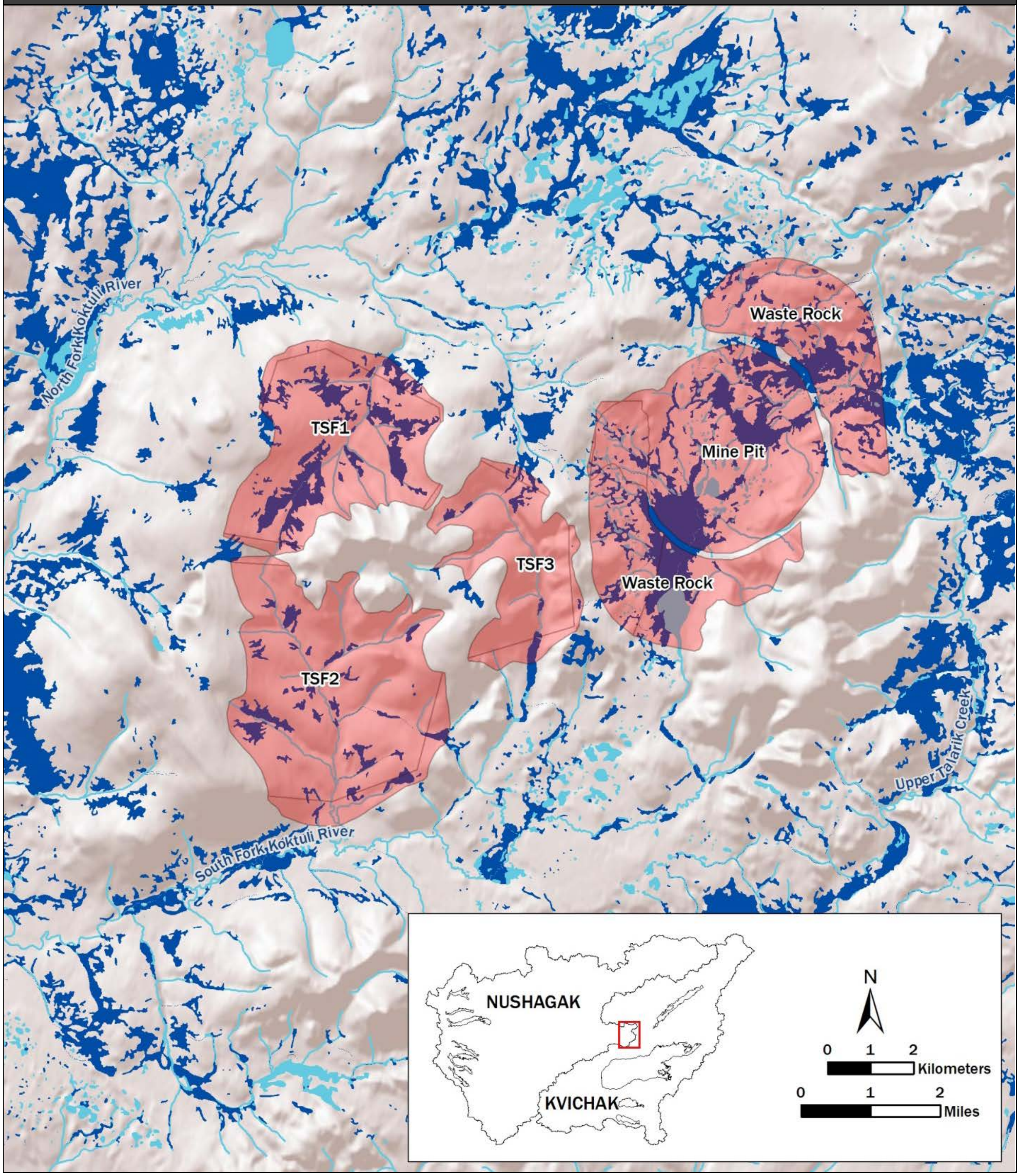


Figure 6-3. Footprint of the major mine components (mine pit, waste rock piles, and tailings storage facilities [TSFs]) in the Pebble 6.5 scenario. Light blue areas indicate streams and rivers from the National Hydrography Dataset (USGS 2012a) and lakes and ponds from the National Wetlands Inventory (USFWS 2012); dark blue areas indicate wetlands from the National Wetlands Inventory (USFWS 2012).



6.1.1 Location

The mine scenarios considered in this assessment are sited at the Pebble deposit, in headwaters of the Nushagak and Kvichak River watersheds where the South and North Fork Koktuli Rivers and Upper Talarik Creek originate (Figure 2-5). The Pebble deposit represents the most likely site for near-term, large-scale mine development in the Bristol Bay watershed. Many other mineral exploration sites in the Nushagak and Kvichak River watersheds report findings consistent with a porphyry copper deposit similar to the Pebble deposit (see Table 13-1 and Figure 13-1 for other mineral prospects in the area). Non-porphyry copper deposits being explored in the area are likely to require similar mining facilities such as an open pit, a tailings impoundment, and waste rock dumps, and may produce acid-generating materials. Salmon and other fishes occur in streams throughout the Nushagak and Kvichak River watersheds (Chapter 5; Appendices A and B). Thus, much of our analysis is transferable to other portions of the two watersheds, in that a mining operation at any one of these sites could have qualitatively similar impacts to a mine operation at the Pebble deposit. However, we recognize that specific component placement could differ based on site-specific factors at each mine. Because our scenarios are located at the Pebble deposit, we refer to them throughout the text as Pebble 0.25, Pebble 2.0, and Pebble 6.5. This distinguishes the site of the analysis from other potential mine sites in the Nushagak and Kvichak River watersheds that are included in the evaluation of potential impacts of multiple mines (Chapter 13).

6.1.2 Mining Processes

6.1.2.1 Extraction

Ore associated with the western portion of the Pebble deposit is near-surface and, in our scenarios, would be mined via conventional open-pit mining methods of drilling and blasting. Pit depth and width would be increased progressively to recover the ore. Pit walls and benches would be constructed to stabilize slopes for safety and to direct runoff. Dusts would be controlled by wetting surfaces with site water and covering truck beds during transport of excavated rock. Groundwater flow into the pit would be managed by pumping to storage ponds or TSFs for later treatment or use in mine processes. Although our scenarios describe open pit mining, underground methods could be used, particularly for the deeper eastern portion of the ore body. Many of the impacts would be similar in type and magnitude to those of surface mining (Section 4.2.3.1).

6.1.2.2 Ore Processing

In the mine scenarios, an in-pit crusher would reduce the ore to particles below a maximum size and a conveyor would bring the crushed ore to processing facilities. Ore would be processed in a flotation circuit similar to that described in Section 4.2.3.3. The milling process would generate two tailings streams, one from the rougher flotation circuit (bulk tailings having undergone a single grind sequence) and another from the secondary cleaner circuit (cleaner scavenger tailings) (Figure 4-3). Selective flotation would be used to minimize the amount of potentially acid-generating (PAG) tailings. Copper (+gold) and molybdenum concentrates would be produced as described in Section 4.2.3.3, with the copper (+ gold) slurry concentrate pumped via pipeline to Cook Inlet and the final molybdenum concentrate dried, bagged, and trucked off site for processing. Gold associated with the copper minerals in the slurry concentrate would be recovered at an off-site smelter. Pyrite tailings would be directed either to the TSF for subaqueous disposal or to a vat leach cyanidation operation for removal of gold (Box 4-6), after which sulfide-rich tailings would be directed to the TSF for subaqueous disposal. A cyanide destruction unit would be used at the end of the leaching process (Box 4-6).

All chemical reagents used in ore processing (Box 4-5) would be transported to the mine site, then prepared and stored in areas with secondary containment and instrumentation to detect any spills or leaks. All pipelines would be designed to standards of the American Society of Mechanical Engineers (ASME), which include the use of liners to minimize abrasion and corrosion, freeze protection, secondary containment over water bodies, and leak monitoring and detection. Dusts would be controlled in the processing area through use of cartridges, wet scrubbers, and/or enclosures.

6.1.2.3 Waste Rock

Waste rock consisting of both PAG and non-acid-generating (NAG) materials would be stored around the mine pit, at least partially within the groundwater drawdown zone from mine pit dewatering. PAG waste rock would be stored separately from NAG waste rock. Over the life of the mine, PAG waste rock would be blended with processed ore to allow consistency in chemical usage and to remove material from surface storage prior to its expected time of acid generation (e.g., within 20 years of its excavation). Any PAG material remaining unprocessed at the end of mining would be processed separately prior to closure.

During operation, waste rock piles would be constructed with a 2:1 slope for structural stability and minimization of the amount of runoff requiring treatment. Waste rock piles would occupy approximately 2.3, 13.0, and 22.6 km^2 in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively (Table 6-2). Water quality of the leachate from waste rock is described in Tables 8-6 and 8-7. Monitoring and recovery wells and seepage cutoff walls would be placed downstream of waste rock piles to manage seepage, with seepage and contaminated groundwater directed either into collection ponds for use in mine processes or for treatment and release to the environment, or into the mine pit. Stormwater falling upslope of waste rock piles would be diverted around the piles and directed toward sedimentation ponds for settling of suspended solids prior to discharge to a nearby stream, or for treatment if determined to be contaminated. Embankments would be constructed above the seepage cutoff walls to contain any excess stormwater runoff that could not be contained in collection ponds. Water captured in these embankments would be released or directed to treatment as appropriate. Because the Tertiary volcanic rocks are classified as NAG (Ghaffari et al. 2011, PLP 2011), they may be useful for building purposes such as TSF construction. However, because of the potential for metals leaching, use would be appropriate only where leachate would be collected for treatment as necessary.

Table 6-2. Mine scenario parameters. These scenarios were developed by the U.S. Environmental Protection Agency for the purposes of this assessment, but draw heavily on specifics put forth by Ghaffari et al. (2011).

Parameter	Mine Scenario		
	Pebble 0.25	Pebble 2.0	Pebble 6.5
Amount of ore mined (billion metric tons)	0.23	1.8	5.9
Ore volume (million m^3)	86.9	697	2270
Approximate duration of mining	20 years	25 years	78 years
Ore processing rate (metric tons/day)	31,100	198,000	208,000
Tailings produced, dry (billion metric tons)	0.225	1.80	5.86
Tailings produced, volume (million m^3)	158	1,270	4,130
Mine Pit			
Surface area (km^2)	1.5	5.5	17.8
Depth (km)	0.30	0.76	1.24
Waste Rock Pile			
Surface area (km^2)	2.3	13.0	22.6
PAG waste rock (million metric tons)	86	580	4,700
PAG waste rock bulk density (metric tons/m^3)	2.08	2.08	2.08
PAG waste rock area (km^2)	0.55	1.79	6.77
NAG waste rock (million metric tons)	320	2,200	11,000
NAG waste rock bulk density (metric tons/m^3)	2.08	2.08	2.08
NAG waste rock area (km^2)	1.78	11.2	15.8
TSF 1[a]			
Capacity, dry weight (billion metric tons)	0.25	1.97	1.97
Surface area, interior (km^2)[b]	6.5	14.2	14.2
Surface area, exterior (km^2)	6.8	16.1	16.1
Maximum dam height (m)	92	209	209
Maximum number of dams	1	3	3
Capacity, volume (million m^3)	177	1,390	1,390
Tailings dry density (metric tons/m^3)[c]	1.42	1.42	1.42
NAG density, embankment (metric tons/m^3)[c]	2.31	2.31	2.31
TSF 2[a]			
Capacity, dry weight (billion metric tons)	NA	NA	3.69
Surface area, interior (km^2)[b]	NA	NA	20.1
Surface area, exterior (km^2)	NA	NA	22.7
Maximum dam height (m)	NA	NA	Not determined
Maximum number of dams	NA	NA	3
Capacity, volume (million m^3)	NA	NA	2,600
TSF 3[a]			
Capacity, dry weight (billion metric tons)	NA	NA	0.96
Surface area, interior (km^2)[b]	NA	NA	8.23
Surface area, exterior (km^2)	NA	NA	9.82
Maximum dam height (m)	NA	NA	Not determined
Maximum number of dams	NA	NA	2
Capacity, volume (million m^3)	NA	NA	680
Total TSF surface area, exterior (km^2)	6.8	16.1	48.6
Transportation Corridor			
Total length (km)	138	138	138
Length in assessment watersheds (km)	113	113	113

Notes:
[a] Final value when TSF is full.
[b] Area does not include TSF dams.
[c] Values are the same for TSF 2 and TSF 3, so not repeated under those TSFs.
NA = not applicable; TSF = tailings storage facility; PAG = potentially acid-generating; NAG = non-acid-generating.

6.1.2.4 Tailings Storage Facilities

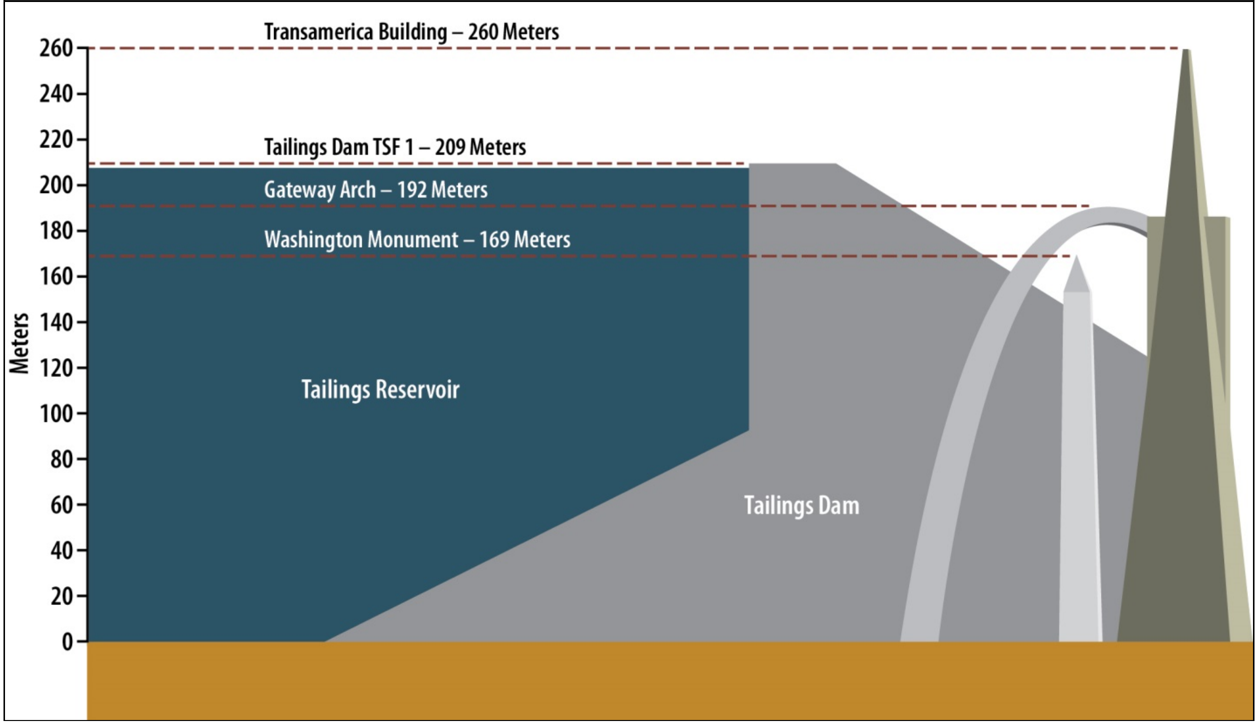
In the mine scenarios, TSF dam design would proceed as described by Ghaffari et al. (2011). The number and size of TSFs in each scenario (Figures 6-1 through 6-3) would be commensurate with tailings storage requirements. The water rights application submitted by Northern Dynasty Minerals to the State of Alaska in 2006 described several potential locations for TSFs (NDM 2006). Drawing on this information, and given site-specific geotechnical, hydrological, and environmental considerations, we assume that the higher mountain valleys similar to the site of TSF 1, on the flanks of Kaskanak Mountain, are the most plausible TSF sites for a mine at the Pebble deposit. This placement does not imply that these sites would not pose unacceptable environmental harm, or that they would be the least environmentally damaging practicable alternatives for purposes of Clean Water Act permitting. Permit-specific study, which is beyond the scope of this assessment, would determine if these or other sites met these criteria.

At each TSF, a rockfill starter dam would be constructed, with a liner (high-density polyethylene geomembrane on top of a geosynthetic clay liner) extending up the upstream dam face. Seepage capture and toe drain systems would be installed at the upstream toe, with perpendicular drains installed to direct seepage toward collection ponds. Each TSF would be unlined other than on the upstream dam face, and there would be no impermeable barrier constructed between tailings and underlying groundwater. As tailings accrued near the top of the starter dam, dam height would be raised using the downstream construction method (Figure 4-4) (Ghaffari et al. 2011). At some point, dam construction would shift to the centerline method (Figure 4-4), and a new stage would be constructed as the capacity of each previous stage was approached. TSF 1 would require maximum dam heights of approximately 92 m for the Pebble 0.25 scenario and 209 m for both the Pebble 2.0 and Pebble 6.5 scenarios (Table 6-2, Figure 6-4).

Given the low grade of ore expected in the region, our mine scenarios would produce large amounts of tailings: approximately 99% of the mass of ore processed would be tailings, with 85% as NAG bulk tailings and 14% as PAG (pyritic) tailings (Ghaffari et al. 2011). Both types of tailings would be directed to TSFs (Figures 6-1 through 6-3). The discharge of bulk tailings would be managed such that the coarsest materials (fine sand) would be discharged at intervals along the inside perimeter of the TSF to form beaches, while finer materials (silt) would be carried with discharged water toward the center of the impoundment. Pyritic tailings would be discharged below the water surface of the tailings pond and encapsulated in NAG tailings to retard the rate of pyrite oxidation.

The capacity and dimensions of each TSF are listed in Table 6-2. Pebble 6.5, the largest size scenario considered, would require the construction of TSFs 1, 2, and 3, with a combined tailings capacity exceeding 6 billion metric tons. We estimate that these three TSFs would have a combined surface area of more than 48 km^2 (Table 6-2).

Figure 6-4. Height of the dam at tailing storage facility (TSF) 1 in the Pebble 2.0 and Pebble 6.5 scenarios, relative to U.S. landmarks.



During operation, water quality in TSF ponds would be similar to process water. At the end of mining, process water would no longer enter the TSF, so it is expected that, over time, dilution from precipitation would cause the composition of tailings pond water to approach that of local surface water. Seepage from the base of the tailings impoundment, either during operation or after closure, would be expected to be similar to water quality estimates based on pre-mining humidity-cell test results (Appendix H). The low solubility of oxygen in water (less than 15 mg/L) limits the access of oxygen to submerged unreacted sulfide minerals in the tailings, reducing dissolution reaction rates and thus the concentration of solutes. In addition, trace amounts of carbonate or silicate minerals may partially neutralize acid under anoxic conditions commonly encountered in sulfidic tailings, further limiting the solubility of metals and other trace elements (Blowes et al. 2003). However, a good deal of uncertainty exists because the humidity cell tests used to predict pore water chemistry represent a small sample of the ore body. Thus, actual water quality in the tailings impoundment may differ significantly from what is estimated (Appendix H). For example, lower concentrations of metals than those reported in humidity cells tests would likely be seen in TSF water if pH was buffered by reactions with carbonate and silicate minerals (see Section 8.1.1.1 for discussion of tailings leachate quality).

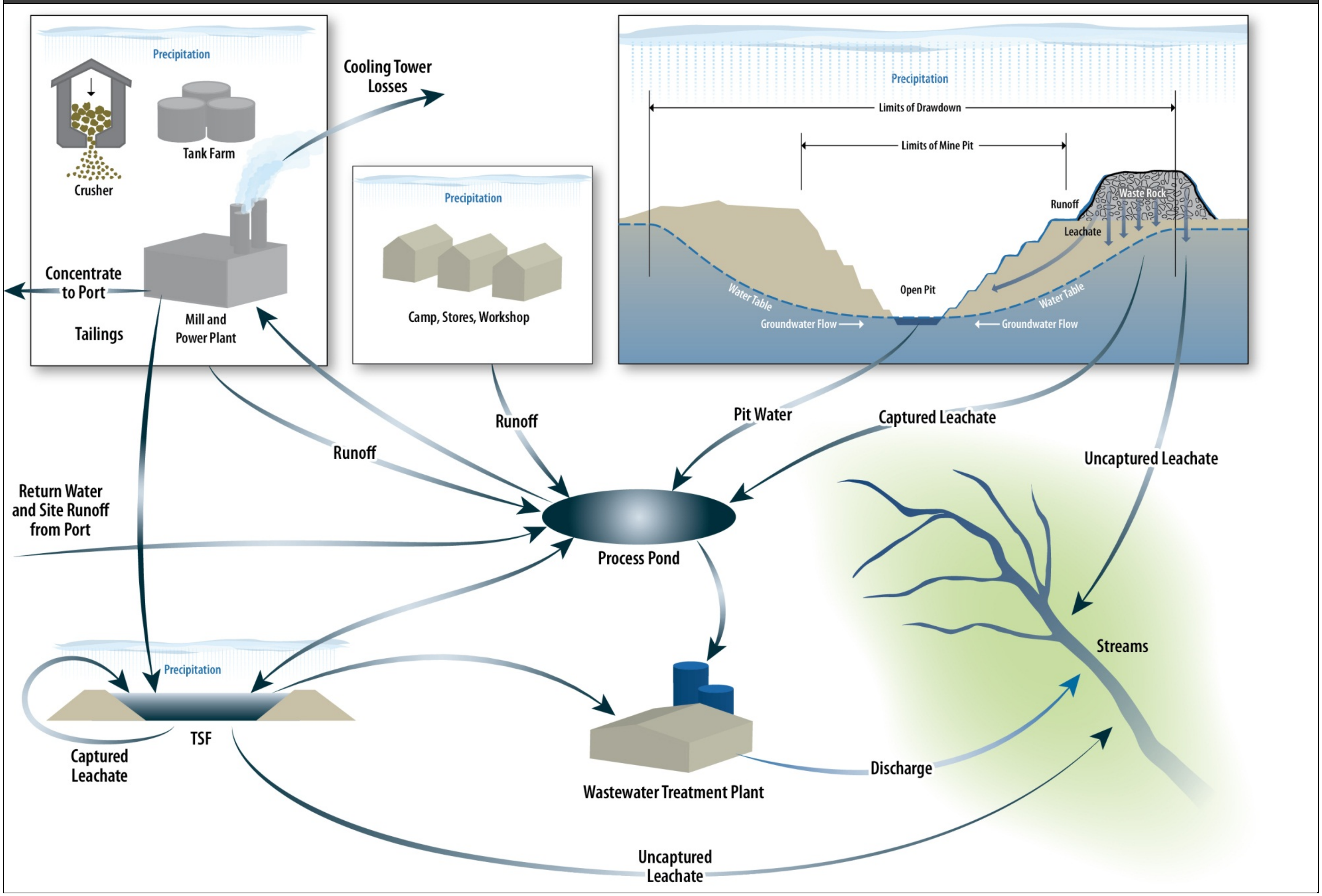
Well fields spanning the valley floor would be installed at the downstream base of all tailings dams to monitor groundwater flow down the valley, including potential uncaptured seepage from the TSF. If contaminated groundwater was detected, monitoring wells would be converted to collection wells or new recovery wells would be installed, and water from the well field would be pumped back into the TSF or treated and released to stream channels.

6.1.2.5 Water Management and Treatment

Water uses in the mine scenarios would include ore processing, tailings slurry transport, and transport of copper concentrate slurry in the product pipeline. In this section, we provide an overview of water management and treatment in the three mine scenarios. Figure 6-5 presents a schematic illustration of these components (note that, for clarity, diversions of stormwater around mine components are not shown on the schematic).

- **Stormwater runoff that did not contact potential contaminants** would be diverted around mine components (e.g., waste rock piles, processing facilities) in ditches directed toward sediment settling ponds.
- **Stormwater runoff from waste rock piles and water from pit dewatering** would be pumped to lined process water ponds; water reclaimed from tailings impoundments or tailings thickening also would be stored in the process water storage ponds for reuse in ore processing.
- **Stormwater falling onto TSFs** would be stored in the tailings impoundments and used in the process water cycle.
- **Seepage collected from waste rock piles and TSFs** would be directed to lined seepage collection ponds or TSFs for later treatment.
- **Seepage escaping the waste rock and TSF leachate collection systems** would be monitored with monitoring wells. If groundwater contamination was detected, wells would be converted to recovery wells or new recovery wells would be installed, and the groundwater pumped to either a TSF or a storage pond for later treatment.
- **Water reclaimed from the copper concentrate after transport to the port** would be returned to process water storage ponds via pipeline from the port.
- **Streams blocked by the mine pit or waste rock piles** would be diverted, where practicable, around and downstream of the mine. However, the zone of groundwater depression around the mine pit and the slow filling of the post-operation pit would likely dewater these streams for as long as it took the pit to fill, which could be hundreds of years.
- **Prior to being discharged, water would be treated** to meet effluent limits using chemical precipitation methods and/or reverse osmosis. Water would be discharged to the South and North Fork Koktuli Rivers according to permit conditions for composition, flow, and temperature. Sludge and brine from the treatment process would be disposed in the TSF.

Figure 6-5. Water management and water balance components for the three mine scenarios.



Water balances for both the operation and post-closure phases of our mine scenarios are discussed in detail in Section 6.2.2. Development of these water balances is important, because they estimate the amount of water available to contribute to downstream flows. Calculating these water balance components is challenging, however, and requires a number of assumptions (e.g., estimates of the amount of water needed to support mining operations, the amount of water delivered to the site via precipitation, the amount of water lost due to evaporation, and the net balance of water to and from groundwater sources). Information exists to estimate precipitation and evaporation, and estimates of water needed for mining operations are available based on typical mining practices (Ghaffari et al. 2011). More challenging—and potentially the largest source of uncertainty in these calculations—is the net balance of water from groundwater sources.

Mining operations would affect the quantity, quality, timing, and distribution of surface flows. Mining operations always consume some water, so there would be less water available in the landscape during active mining than before the mine was present. Major stream flow reductions during mine operation would result from the capture of precipitation falling on the mine pit, waste rock piles, and TSFs (Table 6-3, Figure 6-5). The mine pit would capture precipitation directly, but pit dewatering would also draw down the water table beyond the rim of the pit, creating a cone of depression that would extend underneath the waste rock piles (Figure 6-5). Leachate recovery wells for any detected groundwater contamination downstream of the waste rock piles would extend the cone of depression. Because the mine pit would be located on a water divide, we estimate that there would be little net contribution from groundwater flow into the area defined by the cone of depression, and that the cone of depression would expand until water flow into the mine pit was balanced by recharge from precipitation over the cone of depression. The cone of depression would lower the groundwater table, drying up streams, ponds, and wetlands that depend on groundwater discharge and turning areas of groundwater discharge into areas of groundwater recharge. Precipitation and other water collected in the mine pit or from recovery wells would be pumped to a process water pond or to one of the TSFs. Water falling within the perimeter of a TSF would be captured directly in the TSF, but runoff from catchment areas up-gradient of the TSF would be diverted downstream. Runoff at the port site would be pumped to the mine site in the return water pipeline, contributing to the mine's water supply and avoiding the need for treatment at the port.

Prior to active mining, but after the starter dam was built for TSF 1, site water would be diverted to TSF 1 to allow sufficient water for process plant startup. During mine operation, groundwater and precipitation would be pumped from the mine pit to prevent flooding of the mine workings (Figure 6-5). Water would be needed for the flotation mill, to operate the TSF, and to maintain concentrated slurry in the product pipeline.

Table 6-3. Summary of annual water balance flows (million m^3/year) during operations for the three mine scenarios.

Flow Component	Pebble 0.25	Pebble 2.0	Pebble 6.5
Captured at mine pit area	9.77	22.4	44.1
Captured at TSF 1	5.86	13.8	13.8
Captured at TSF 2	NA	NA	19.5
Captured at TSF 3	NA	NA	8.43
Captured at mill & other facilities	0.629	2.69	2.69
Potable water supply well(s)	0.031	0.124	0.124
Water in ore (3%)	0.340	2.17	2.27
Total Captured	**16.6**	**41.2**	**91.0**
Cooling tower losses	0.211	1.32	1.32
In concentrate to port	0.166	1.04	1.04
In concentrate return	−0.149	−0.934	−0.934
Runoff collected from port	−0.125	−0.251	−0.251
Stored in TSF as pore water	3.72	23.8	24.9
Stored in mine pit	0	0	0
Crusher use	0.113	0.722	0.758
Total Consumptive Losses	**3.93**	**25.7**	**26.8**
Returned to streams via wastewater treatment plant	10.9	10.3	51.0
Returned as NAG waste rock leachate	0.676	2.58	4.97
Returned as PAG waste rock leachate	0	0.216	1.03
Returned as TSF leakage	1.11	2.35	7.20
Total Reintroduced	**12.7**	**15.4**	**64.2**
Percent of Captured Water Reintroduced	**76.3%**	**37.5%**	**70.5%**

Notes:
TSF = tailings storage facility; NA = not applicable; NAG = non-acid-generating; PAG = potentially acid-generating.

In hard rock metal mining, most water use occurs during milling and separation operations; however, much of this water is recycled and reused. For example, much of the water used to pump the tailings slurry from the mill to a TSF becomes available when the tailings solids settle, and excess overlying water is pumped back to the mill. Water losses occur when there is a consumptive use and that water is no longer available for reuse (Table 6-3, Section 6.2.2). Consumptive losses would be made up by withdrawing water stored in a TSF or by pumping directly from the mine pit. Some of this captured water (approximately 38 to 76%, Table 6-3) would not be needed at the mine site. This excess captured water would be treated to meet existing water quality standards and discharged to nearby streams (Figure 6-5), partially mitigating streamflow lost due to eliminated or blocked upstream reaches (Chapter 7).

6.1.3 Transportation Corridor

6.1.3.1 Roads

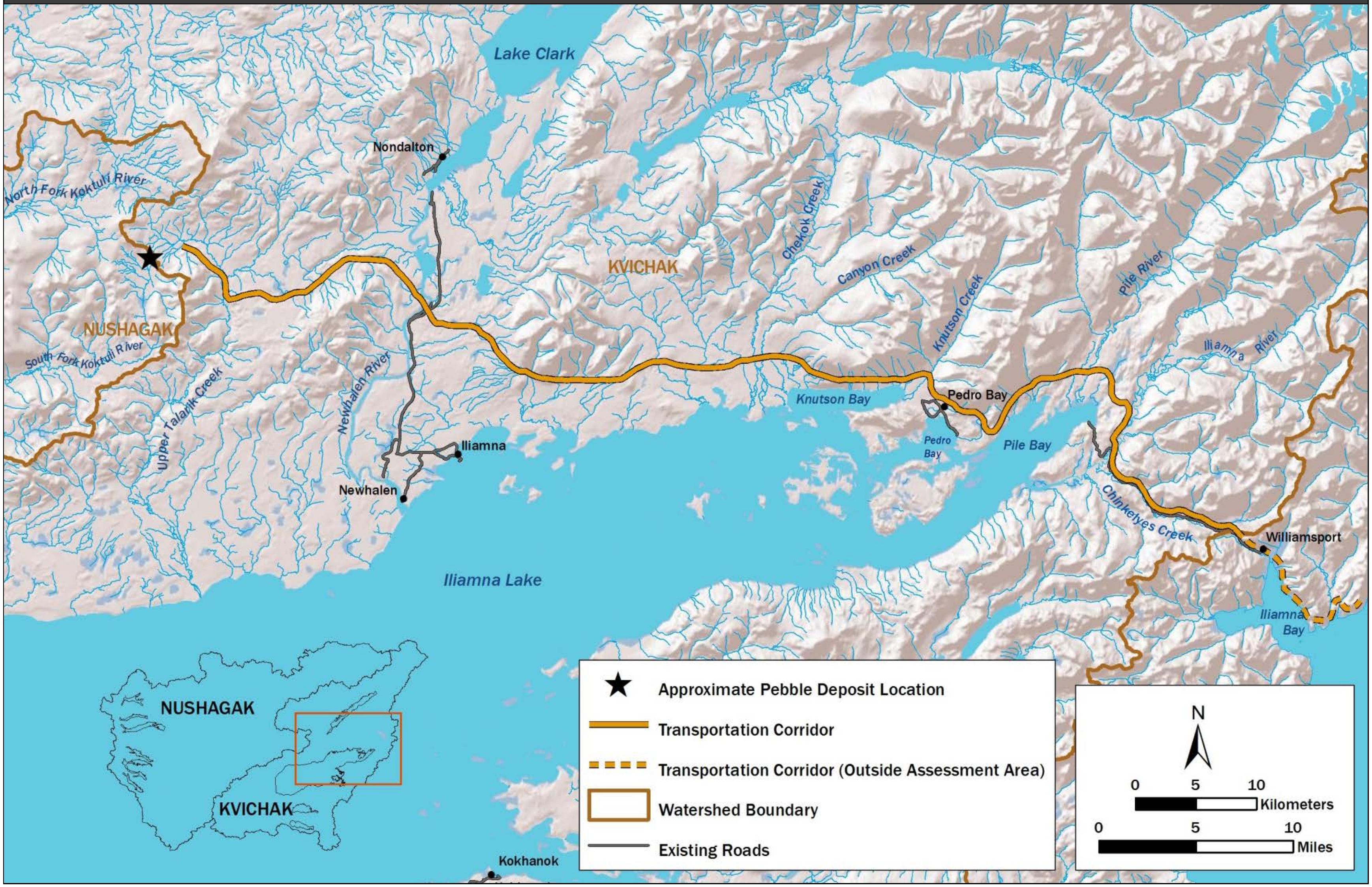
Development of any mine in the Bristol Bay watershed would require substantial expansion and improvement of the region's transportation infrastructure. The Bristol Bay watershed is located in one of the last remaining, virtually roadless regions in the United States. There are no improved federal or state highways, and no railroads, pipelines, or other major industrial transportation infrastructure. Roadways presently link Iliamna Lake (Pile Bay) to Cook Inlet (tidewater at Williamsport) and the Iliamna area (including the Iliamna airport) north to the site of a proposed bridge over the Newhalen River near the village of Nondalton. Two other short road segments link Dillingham to Aleknagik and Naknek to King Salmon (Figure 6-6). Local roads also exist in villages throughout the Nushagak and Kvichak River watersheds. Most people travel by air or boat during the ice-free season, and by air or snow machine in winter.

In our mine scenarios, a 138-km, two-lane (approximately 9-meter-wide), gravel surface, all-weather permanent access road would connect the mine site to a new deep-water port on Cook Inlet (Figure 6-6), from which concentrate would be shipped elsewhere for processing (Ghaffari et al. 2011). An estimated 113 km of this corridor would fall within the Kvichak River watershed (this distance does not include the portion of the road occurring within the potential mine site). This route would traverse highly variable terrain and variable subsurface soil conditions, including extensive areas of rock excavation in steep mountainous terrain.

The primary purpose of this road would be to transport freight by conventional highway tractor-trailers, although critical design elements would be dictated by specific oversize and overweight loads associated with project construction. Material sources for road embankment fill, road topping, and riprap (e.g., borrow and gravel pits and rock quarries) would be available at regular intervals along the road route. We assume state-of-the-art practices for design, construction, and operation of the road infrastructure, including design of bridges and culverts for fish passage. Permanent structures would be designed for a service life of 50 years. Because the access road would be kept open for ongoing care, maintenance, and environmental monitoring at the site post-closure, maintenance and resurfacing of the access road would necessarily be required over the same time period, which may extend in perpetuity.

The transportation corridor would cross many streams (including unmapped tributaries), rivers, wetlands, and extensive areas with shallow groundwater, all of which drain to Iliamna Lake (Figure 6-6, Section 10.1). We used a mean annual streamflow threshold of >0.15 m^3/s to designate stream crossings that would be bridged (this threshold was also used to separate small headwater streams from medium streams in broad-scale characterization of stream and river habitats; see Section 3.1.4.2). Bridges, with spans ranging from approximately 12 to 183 m, would be constructed over 12 known anadromous streams and seven additional streams likely to support salmonids. Culverts would be place at all remaining stream crossings. In addition, there would be a 573-m (1,880-foot) causeway across the upper end of Iliamna Bay, and approximately 8 km of embankment construction along coastal sections in Iliamna Bay and Iniskin Bay (Ghaffari et al. 2011).

Figure 6-6. Transportation corridor connecting the Pebble deposit area to Cook Inlet.



Avalanche hazards exist in isolated locations along the alignment, but routing would attempt to avoid any avalanche chutes and runout areas. Because of steep mountain slopes and the lack of significant vegetation at high elevations, storm runoff can rapidly accumulate and result in intense local runoff conditions. Road areas near the south slope of Knutson Mountain and the southeast slope of the mountain above Lonesome Bay and Pile Bay (Figure 6-6) may be especially susceptible to these runoff events, as demonstrated in late 2003 when storm runoff washed out several culverts on the state-maintained Pile Bay Road.

6.1.3.2 Pipelines

The transportation corridor would include four pipelines, which would carry copper (+gold) concentrate, return water, natural gas (to fuel a natural gas-fired power generating plant), and diesel fuel between the mine site and the Cook Inlet port (Table 6-4). All pipelines would be designed following ASME standards. Except at stream and river crossings, pipelines would be buried together in a trench adjacent to the road alignment, in the right-of-way. At short stream and river crossings, pipelines would be bored under channels to minimize waterway impacts. At longer crossings, pipelines would be supported aboveground on road bridges. Any aboveground pipeline sections would be constructed of double-walled pipe. Freeze protection would be provided by insulation (aboveground pipes) or burial (1.5 meters below ground surface). External corrosion would be prevented by a cathodic protection system. A leak detection system would be built into the pipelines, which would also assist in the detection and prevention of slack flows. A supervisory control and data acquisition (SCADA) system would monitor and control pumping facilities via a fiber optic line buried alongside the pipelines. Instruments such as pressure and temperature transducers located along the pipeline route would be tied into the fiber optic link.

Table 6-4. Characteristics of pipelines in the mine scenarios.

Pipeline (number of pipes)	Route	Pipe Material	Nominal Diameter (cm)
Along Transportation Corridor			
Copper (+gold) concentrate (1)	Mine to port	HDPE-lined steel	20
Reclaimed water (1)	Port to mine	HDPE-lined steel	18
Natural gas (1)	Port to mine	Steel	5
Diesel fuel (1)	Port to mine	Steel	13
At Mine Site			
Bulk tailings (2)	Process plant to TSF	Steel with liner	86
Pyritic tailings (2)	Process plant to TSF	Steel with liner	46
Reclaimed water (1)	TSF barge to TSF head tank	HDPE	107
Reclaimed water (1)	TSF head tank to process pond	Steel	107
Mine pit dewatering (1)	Pit to process pond or TSF	Steel	TBD

Notes:
HDPE = high-density polyethylene; TSF = tailings storage facility; TBD = to be determined.
Source: Ghaffari et al. 2011.

On the mine site, pipelines would carry tailings slurry from the process plant to the TSFs and reclaimed water from the TSFs to the process water storage ponds (Table 6-4). There also would be smaller pipelines for water supply, firefighting, and process flows within the plant. In this assessment, we assume that any leakage from pipelines in the process plant area would be captured and controlled by the plant's drainage system and either be treated prior to discharge or pumped to the process water storage pond or the TSFs. Failures of these on-site pipelines could result in uncontrolled releases in the mine site, but these failures are not evaluated in this assessment. At mine closure, concentrate and return water pipelines would be removed. Diesel and natural gas pipelines would be retained as long as fuel was needed at the site for monitoring, treatment, and site maintenance. It is also possible that local communities would select to retain the pipelines for continued use.

6.2 Specific Mine Scenarios

In this assessment we evaluate three specific mine scenarios representing mines of different sizes. The smallest mine scenario, Pebble 0.25, represents a median-sized porphyry copper deposit of 250 million tons (230 million metric tons) (Singer et al. 2008). The second mine scenario, Pebble 2.0, is based largely on the 25-year, 2 billion tons (1.8 billion metric tons) case described by Ghaffari et al. (2011) for initial development at the Pebble deposit. The third mine scenario, Pebble 6.5, is based largely on the 78-year, 6.5 billion tons (5.9 billion metric tons) case described by Ghaffari et al. (2011) for further resource development at the Pebble deposit.

Pebble 2.0 and Pebble 6.5 reflect projects based on extensive exploration, assessment, and preliminary engineering, which are described by Ghaffari et al. (2011) as "economically viable, technically feasible and permittable." They are among the most likely to be developed in the Bristol Bay watershed and are site-specific to the Pebble deposit. For the purposes of this assessment, we have also placed the Pebble 0.25 scenario at the Pebble deposit because of the availability of site-specific information. If mines are developed at other exploration sites in the watershed (Figure 13-1), they are likely to have characteristics and impacts much closer to those of the Pebble 0.25 scenario. Table 6-2 provides detailed parameters for each of our three mine scenarios, and Figures 6-1 through 6-3 show the general layout of each scenario's major mine components.

6.2.1 Mine Scenario Footprints

The major mine components contributing to each mine scenario footprint are the mine pit, waste rock piles, and TSFs. Placement of these components for each of the scenarios is shown in Figures 6-1 through 6-3. In each case, these layouts represent one possible configuration for the mine. Other configurations are possible, but would be expected to have impacts of similar types and magnitudes. Each mine scenario footprint also includes two additional components: the groundwater drawdown zone, or the area over which the water table is lowered due to pit dewatering (Figure 6-5), and the area covered by plant and ancillary facilities (e.g., ore-crushing and screening areas, processing mill, storage and stockpile areas, workshops, roads within the mine site, pipeline corridors, and other disturbed areas). Summing these areas (mine pit, waste rock piles, TSFs, drawdown zone, and plant and ancillary facilities) and correcting for any overlap among them yields an estimate for total mine footprint area in each scenario (Tables 6-5 through 6-7).

6.2.1.1 Pebble 0.25 Footprint

Figure 6-1 shows the general layout of the mine pit, waste rock piles, and TSF for the Pebble 0.25 scenario. The TSF, identified as TSF 1, is located in a natural valley in a headwater tributary of the North Fork Koktuli River located to the west of the Pebble deposit. The valley would be closed off by the construction of a rockfill dam 92 m in height (Table 6-2). The waste rock pile area was determined by calculating the area that would be covered by the expected volume of waste rock, assuming approximately 100-m-high piles and taking advantage of natural landforms near the mine pit. In this scenario, separate PAG and NAG waste rock would be created during mine operation. PAG waste rock would be processed as mill conditions permit throughout the mine life, with the intent to process all of the PAG waste rock before mine closure. The area of the plant and ancillary facilities is estimated to account for approximately 4% of the total mine footprint area (Table 6-5). The drawdown zone (Table 6-5) includes the mine pit and the area beyond the mine pit perimeter, including some of the waste rock piles, up to the limit of the cone of depression (see Box 6-2 for discussion of mine pit drawdown calculations).

Table 6-5. Estimated areas for individual mine components in the Pebble 0.25 scenario.

Component	Area (km^2)
Drawdown zone	10.1
Mine pit	1.54
NAG waste rock in drawdown zone	0.49
PAG waste rock in drawdown zone	0.55
Other area in drawdown zone	7.49
NAG waste rock not in drawdown zone or TSFs	1.29
PAG waste rock not in drawdown zone	0.00
Cumulative plant and ancillary areas	0.73
TSFs[a]	6.82
TSF 1	6.82
TOTAL MINE FOOTPRINT	18.9

Notes:
[a] Exterior TSF area.
[b] NAG = non-acid-generating; PAG = potentially acid-generating; TSF = tailings storage facility.

6.2.1.2 Pebble 2.0 Footprint

Figure 6-2 depicts the general layout of the major mine components for the Pebble 2.0 scenario, including the mine pit, the waste rock piles, and the TSF. The TSF is located in the same valley as TSF 1 in the Pebble 0.25 scenario (Figure 6-2), but it is increased in size to accommodate the additional tailings expected with this larger mine size. Plant and ancillary facilities are estimated to account for approximately 7% of the total disturbed area (Table 6-6).

Waste rock piles are located around the perimeter of the mine pit, with separate areas designated for NAG and PAG waste rock. As in the Pebble 0.25 scenario, PAG and NAG waste rock would be stored in separate waste rock piles during mine operation, and the PAG rock would be processed as mill conditions permit throughout the mine life with the intent to process all of the PAG waste rock before mine closure. Dewatering of the mine pit would generate a cone of depression around the pit, and more than half of the area of the waste rock piles would fall within the resulting drawdown zone (Table 6-6).

Table 6-6. Estimated areas for individual mine components in the Pebble 2.0 scenario.

Component	Area (km^2)
Drawdown zone	21.4
Mine pit	5.50
NAG waste rock in drawdown zone	7.08
PAG waste rock in drawdown zone	1.29
Other area in drawdown zone	7.52
NAG waste rock not in drawdown zone or TSFs	4.14
PAG waste rock not in drawdown zone	0.50
Cumulative plant and ancillary areas	3.13
TSFs[a]	16.1
TSF 1	16.1
TOTAL MINE FOOTPRINT	45.3

Notes:
[a] Exterior TSF area.
[b] NAG = non-acid-generating; PAG = potentially acid-generating; TSF = tailings storage facility.

6.2.1.3 Pebble 6.5 Footprint

The general layout of the Pebble 6.5 scenario is similar to that of the Pebble 2.0 scenario, with major differences being a larger open pit, different and expanded areas for the waste rock piles, and the inclusion of two additional TSFs (TSF 2 and TSF 3) to store the increased tailings volume (Figure 6-3, Table 6-7). Placement of TSF 2 and TSF 3 in this scenario draws upon some of the TSF options presented in Northern Dynasty Minerals' water rights application (NDM 2006) and takes advantage of natural landforms in the Pebble deposit area.

The mine pit is located as shown by Ghaffari et al. (2011), based on evaluation of the Pebble deposit. Waste rock piles are located around the perimeter of the expanded mine pit, with some portion of the PAG waste rock stored in the mine pit to utilize storage within the drawdown zone prior to PAG waste rock being taken to the surface for processing. This practice would reduce the amount of PAG waste rock that must be stored outside the drawdown zone and, therefore, the amount of PAG leachate that could seep into the South Fork Koktuli River.

Areas of the plant and ancillary facilities are the same as those described for the Pebble 2.0 scenario; because production rates of the Pebble 2.0 and Pebble 6.5 scenarios are similar, no increase in these areas is needed for the larger mine scenario.

Table 6-7. Estimated areas for individual mine components in the Pebble 6.5 scenario.

Component	Area (km²)
Drawdown zone	43.4
Mine pit	17.8
NAG waste rock in drawdown zone	10.3
PAG waste rock in drawdown zone	4.37
Other area in drawdown zone	10.9
NAG waste rock not in drawdown zone or TSFs	5.50
PAG waste rock not in drawdown zone or mine pit	2.40
Cumulative plant and ancillary areas	3.13
TSFs[a]	48.6
TSF 1	16.1
TSF 2	22.7
TSF 3	9.8
TOTAL MINE FOOTPRINT	103

Notes:
[a] Exterior TSF area.
[b] NAG = non-acid-generating; PAG = potentially acid-generating; TSF = tailings storage facility.

6.2.2 Water Balance

Many of the potentially significant impacts of large-scale mining relate to a mine's use of water and its impact on water resources. To understand potential impacts of water use in our mine scenarios, we developed an annual water balance for each scenario that accounts for major flows into and out of the mine area. Three major categories of flows make up each water balance estimate: water inputs, consumptive losses, and water outputs; these categories are discussed in detail in the following sections. These water balances focus on changes in flows entering or leaving the mine site, relative to pre-mining conditions. Changes are divided into flows that would be withdrawn or captured from the natural system and flows that would be released to the natural system. Each water balance subtracts consumptive water losses within mine operations from water inputs to determine the water available for release. This water balance analysis does not attempt to describe or quantify internal flows among mine components, although some are mentioned when necessary to explain the analysis. The water balance analysis also does not attempt to quantify any flows that are recycled within the mine site, because these do not capture water from the environment or release water to it.

6.2.2.1 Water Inputs

Water inputs for each of the three scenarios are summarized in Table 6-3. These inputs are derived primarily from net precipitation (total precipitation minus any losses due to evapotranspiration) that falls on the mine footprints and is captured by water collection and management systems within the mine site. We assume that all captured flows would be available for use by the mine operator. Three gages surrounding the mine site were used to calculate net precipitation at the mine site: gage SK100B (USGS gage 15302200) on the South Fork Koktuli River, gage NK100A (USGS gage 15302250) on the North Fork Koktuli River, and gage UT100B (USGS gage 15300250) on Upper Talarik Creek. Net precipitation (or measured runoff) at each gage represents precipitation minus evapotranspiration, plus or minus interbasin storage, plus or minus internal groundwater storage. We assumed interbasin and groundwater storage were zero since we were averaging across the three watersheds. Therefore, the runoff measured at each gage represents net precipitation (precipitation minus evapotranspiration). Monthly mean flows for each gage were summed across the year, producing an area-weighted average of net runoff of 860 mm per year.

Water inputs resulting from the mine footprints are calculated as the product of footprint areas multiplied by annual net precipitation. For the TSFs, the volume of water captured is based on the interior area of the TSF, defined as the area within the dam crests and excluding the downstream faces of the rockfill dams.

Dewatering the mine pit would create a cone of depression around the mine extending beyond the limits of the mine pit. Because the mine pit would be located very close to the water divide between the South Fork Koktuli River, North Fork Koktuli River, and Upper Talarik Creek watersheds, we assume that there would be negligible net influx of groundwater from beyond the cone of depression. Most of the groundwater outside the cone of depression would flow away from the site. Therefore, the area of the cone of depression would be determined by matching net precipitation falling within the drawdown zone with the calculated groundwater inflow into the mine pit (Box 6-2).

Precipitation falling on areas outside of these disturbed footprints would infiltrate as groundwater or flow into streams without treatment. Flow in upstream tributaries blocked by the mine footprint would be piped or otherwise diverted around the footprint and discharged back into streams without treatment, where practicable. Because this diverted flow is not captured by the mine operations, it is not explicitly included in the water balance tabulations and is assumed to remain part of the background flow.

6.2.2.2 Consumptive Losses

Consumptive losses for each mine scenario are summarized in Table 6-3. To estimate the amount of water available for release, we subtracted consumptive losses associated with mining activities from the captured flows (Table 6-3). Consumptive losses would include water pumped to the port in the copper (+gold) concentrate pipeline minus return water, cooling tower evaporation and drift losses, interstitial water trapped in the pores of stored tailings, water used for dust suppression, and water stored in the mine pit after closure. The tailings pore water accounts for over 90% of consumptive loss during mine operations (Table 6-3). When the tailings settle, about 46% of the volume would consist of voids between solid particles; the water trapped in these pore spaces would no longer be available for use at the mine or release to streams.

BOX 6-2. MINE PIT DRAWDOWN CALCULATIONS

Groundwater flow into the mine pit was calculated using a simplified model based on the Dupuit-Forcheimer discharge formula for steady-state radial flow into a fully penetrating well in a phreatic aquifer with a diameter equal to the average mine pit diameter. The hydraulic conductivity data gathered in the Pebble deposit area during geologic investigations show significant scatter (Figure 6-7). We based our analysis on the hydraulic conductivity (k) varying with depth, with log k varying linearly from the surface to a depth of 200 m ($k = 1 \times 10^{-4}$ m/s at the surface and $k = 1 \times 10^{-8}$ m/s at depths greater than or equal to 200 m). Given these values, negligible flow occurs below a depth of 200 m, so our analytical model included a no-flow boundary at that depth. To apply the Dupuit-Forcheimer formula, we needed to transform the cross-section into an equivalent isotropic section by transforming the vertical dimension so that the thickness at any depth was proportional to the hydraulic conductivity at that depth. The initial water table in our simplified model was at the ground surface and assumed to be horizontal.

Our analysis assumed that the drawdown at the mine pit was 100 m, but we also verified that the results were not very sensitive to this assumption. The radius of influence was determined by balancing the net precipitation falling within the cone of depression with the calculated flow into the mine pit. Inflows were calculated to be 0.274 m^3/s (4,350 gpm), 0.584 m^3/s (9,250 gpm) and 1.19 m^3/s (18,800 gpm) for the Pebble 0.25, 2.0, and 6.5 scenarios, respectively. The Pebble 2.0 mine inflow agrees closely with the estimate provided by Ghaffari et al. (2011).

The cone of depression was determined to extend 1,148 m, 1,222 m, and 1,260 m from the edge of the idealized circular mine pit in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively. In a geographic information system (GIS), we established the boundary of the cone of depression at those distances from the actual perimeter of the mine pits to derive the drawdown zones presented in Tables 6-5 through 6-7.

The waste rock piles do not lie completely within the drawdown zones. This is important in assessing water quality because precipitation falling on the waste rock piles within the drawdown zone is presumed to be collected within the mine pit, whereas precipitation falling outside of the drawdown zone is presumed to migrate away from the mine pit. To assess more accurately the waste rock pile positions relative to the drawdown zones, we distorted the shape of the cone of depression by superimposing the drawdown zone on a uniform flow field with a southern gradient of 0.0354, approximately equal to the slope of the ground surface across the mine pit from north to south. The effect of this distortion is a shift in the boundaries of the cone of depression to the north, resulting in larger areas of waste rock outside of the drawdown zones.

Information on flows in the concentrate and return water pipelines and on cooling tower losses is reported by Ghaffari et al. (2011). The return water pipeline reduces consumptive losses by returning water from the port (e.g., from dewatering the copper [+gold] concentrate and from stormwater runoff collected at the port site). We estimated the area of the port facilities over which runoff was likely to be collected (137,160 m^2) and multiplied that area by the precipitation rate at the port (1,830 mm/year) to determine contributions from port site runoff (Table 6-3). We also included a consumptive loss at the crusher and screening site for dust control equal to 1% of the mass of the material being crushed.

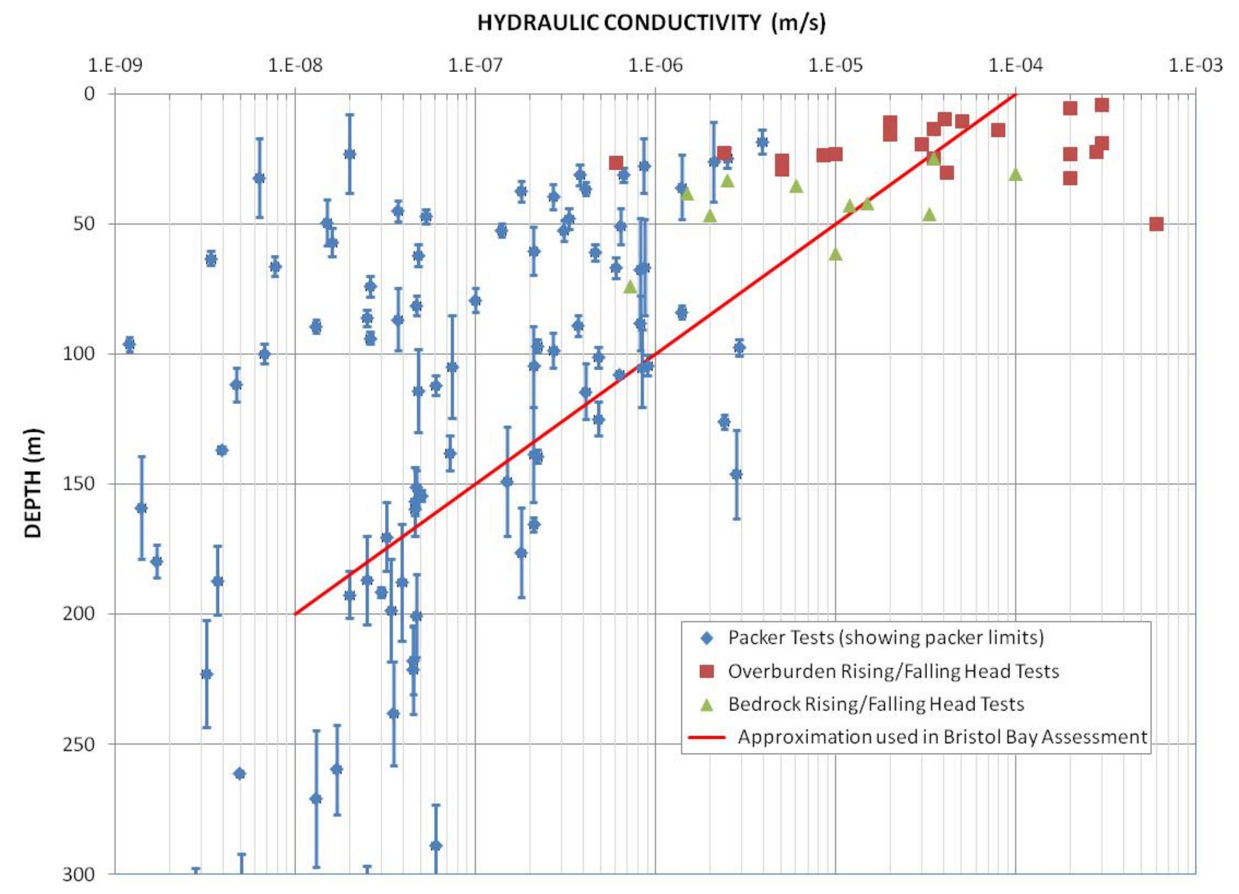
6.2.2.3 Water Outputs

When the amount of captured water exceeds consumptive losses, water would be available, after testing and treatment, for release into area streams. This released water may differ from natural stream water in chemistry and temperature, but would comply with permitted discharge requirements. Water may be reintroduced at locations, flow rates, or times of year that differ from baseline conditions.

The water deficit for each scenario—that is, the amount of water extracted from the environment and not returned to streams—is presented in Table 6-3. These water deficits equal the total consumptive losses of approximately 3.9 million m^3/year, 26 million m^3/year, and 27 million m^3/year for the Pebble

0.25, 2.0, and 6.5 scenarios, respectively. The percentage of water reintroduced to streams, including uncaptured leachate, would equal approximately 76, 38, and 71% of the total water captured in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively.

Figure 6-7. Hydraulic conductivity in the Pebble deposit area. Data are from three test types: bedrock packer (Lugeon) tests (blue diamonds, with error bars indicating upper and lower limits of zone tested) (PLP 2011: Chapter 8 and Appendix 8.1N); overburden rising or falling head tests (red squares) (PLP 2011: Chapter 8 and Appendix 8.1C); and bedrock rising or falling head tests (green triangles) (PLP 2011: Chapter 8 and Appendix 8.1C). Red line indicates values used in the assessment's mine pit drawdown and tailings storage facility leakage calculations.



6.2.2.4 Additional Water Balance Issues

During the early life of each mine, there is one other significant source of water that a mine operator would need to manage that is not considered in Table 6-3: the water obtained from dewatering the sandy and gravelly overburden overlying the waste rock and ore. Based on an average overburden thickness of 30.5 m and a porosity of 0.40, dewatering the overburden would produce one-time quantities of 19 million m^3, 67 million m^3, and 220 million m^3 of water over the mine pit areas in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively. This water would be expected to be relatively clean and, if properly managed to control turbidity, could most likely be released without chemical treatment to maintain or augment stream flow.

Water treated at the wastewater treatment plant (WWTP) might not be discharged to the same streams that were dewatered. In accordance with the WWTP discharge points shown by Ghaffari et al. (2011), the WWTP is assumed to discharge to the South and North Fork Koktuli Rivers, but not to Upper Talarik Creek (Figures 6-8 through 6-11).

6.3 Closure and Post-Closure Site Management

As discussed in Section 4.2.4, the assessment examines potential impacts both during mine operations and after mining activities have ceased, either as planned or prematurely. In this section, we consider how the mine scenarios would be handled during and after closure of the mine.

We assume that the mine would be closed after all economically profitable ore was removed from the site, leaving behind the mine pit, NAG waste rock piles, and TSFs. Water at the site would require capture and treatment for as long as it did not meet water quality standards. Weathering of exposed waste rock and pit walls would release ions of potential concern, such as sulfates and metals. Weathering to the point where these contaminants decreased toward their pre-mining background concentrations would likely take hundreds to thousands of years, resulting in the need for monitoring and management of exposed materials and leachate over that time (Blight 2010). To minimize exposure of waste rock and pit walls to weathering, we assume that they would be reclaimed. We also assume that existing water management structures and the WWTP would be monitored and maintained as part of post-closure operations.

Seepage and leachate monitoring and collection systems, as well as the WWTP, might need to be maintained for hundreds to thousands of years. It is impossible to evaluate the success of such long-term collection and treatment systems for mines. No examples exist, because these timeframes exceed both existing systems and most human institutions. Throughout this section, we refer to the potential need for treatment over extended periods. The uncertainty that human institutions have the stability to apply treatment for these timeframes applies to all treatment options.

Figure 6-8. Water flow schematic for the Pebble 0.25 scenario. Flows include water from the non-acid-generating waste rock pile and tailings storage facility (TSF) 1 (dashed black arrows), discharge from the wastewater treatment plant (solid black arrows), flow along the stream channels (solid blue arrows), and known groundwater transfers (dashed blue arrow). For clarity, only flows greater than 5% of total outflows from the TSF and waste rock pile are shown. Gage locations are based on U.S. Geological Survey (2012b) and Pebble Limited Partnership (2011). Confluence points represent virtual gages that were created for analysis purposes (see Section 7.3 for additional details). Note that the spatial orientation of streams and mine components is for schematic purposes only and is not to scale (see Figure 6-11 for a spatially accurate map).

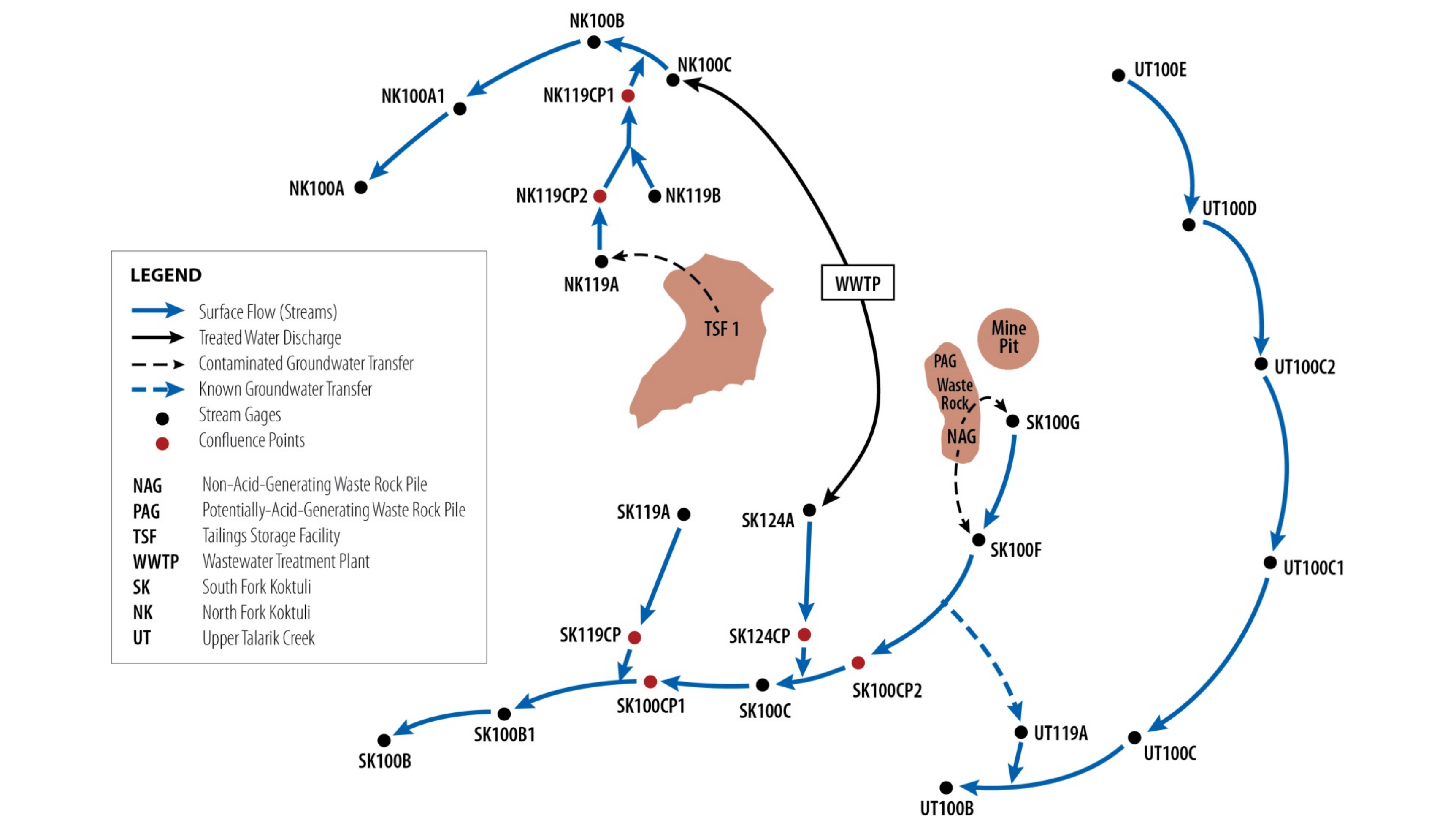


Figure 6-9. Water flow schematic for the Pebble 2.0 scenario. Flows include water from the potentially acid-generating and non-acid-generating waste rock piles and tailings storage facility (TSF) 1 (dashed black arrows), discharge from the wastewater treatment plant (solid black arrows), flow along the stream channels (solid blue arrows), and known groundwater transfers (dashed blue arrow). For clarity, only flows greater than 5% of total outflows from the TSF and waste rock pile are shown. Gage locations are based on U.S. Geological Survey (2012b) and Pebble Limited Partnership (2011). Confluence points represent virtual gages that were created for analysis purposes (see Section 7.3 for additional details). Note that the spatial orientation of streams and mine components is for schematic purposes only and is not to scale (see Figure 6-11 for a spatially accurate map).

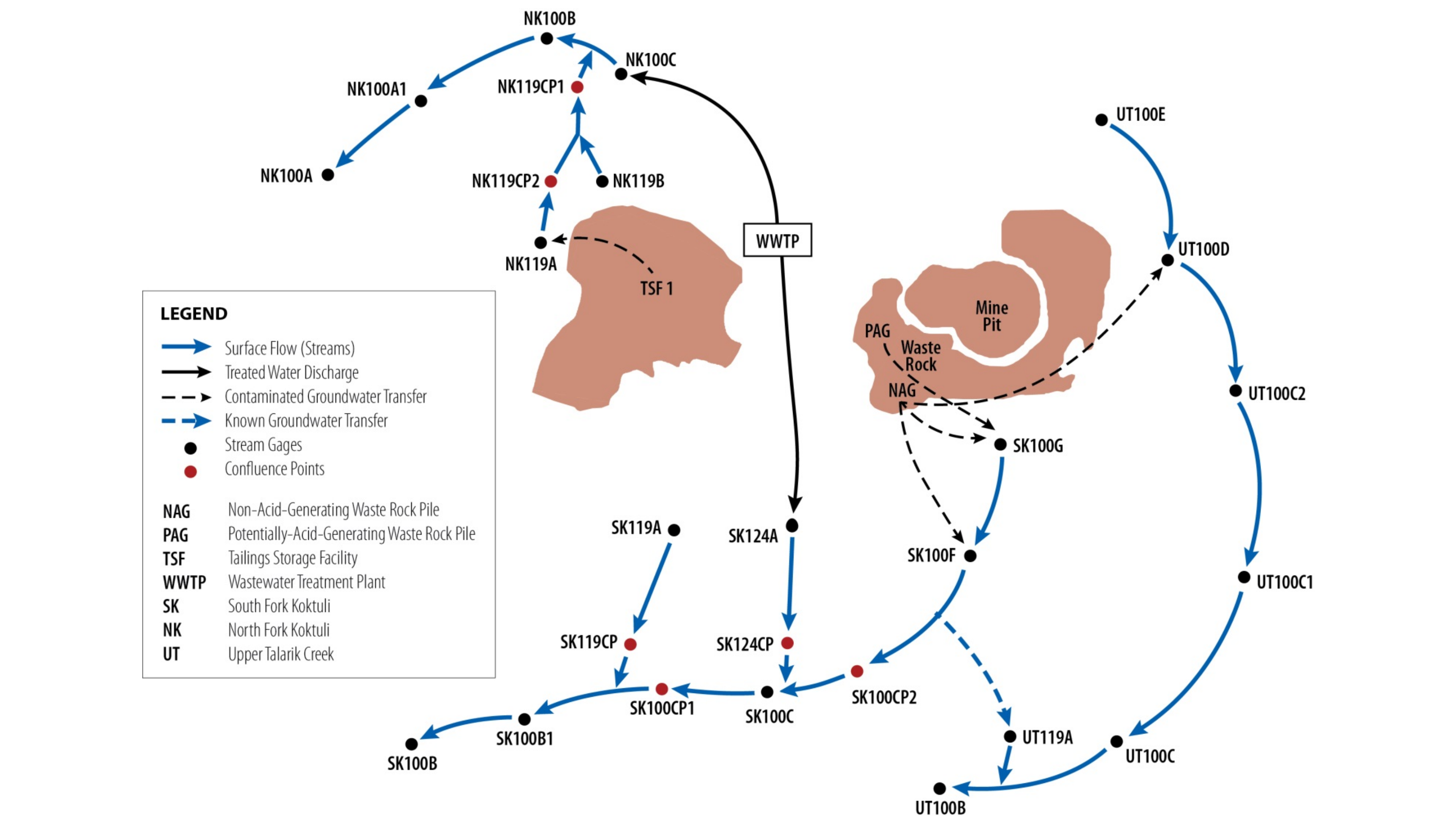


Figure 6-10. Water flow schematic for the Pebble 6.5 scenario. Flows include water from the potentially acid-generating and non-acid-generating waste rock piles and tailings storage facilities (TSFs) 1, 2, and 3 (dashed black arrows), discharge from the wastewater treatment plant (solid black arrows), flow along the stream channels (solid blue arrows), and known groundwater transfers (dashed blue arrow). For clarity, only flows greater than 5% of total outflows from the TSFs and waste rock piles are shown. Gage locations are based on U.S. Geological Survey (2012b) and Pebble Limited Partnership (2011). Confluence points represent virtual gages that were created for analysis purposes (see Section 7.3 for additional details). Note that the spatial orientation of streams and mine components is for schematic purposes

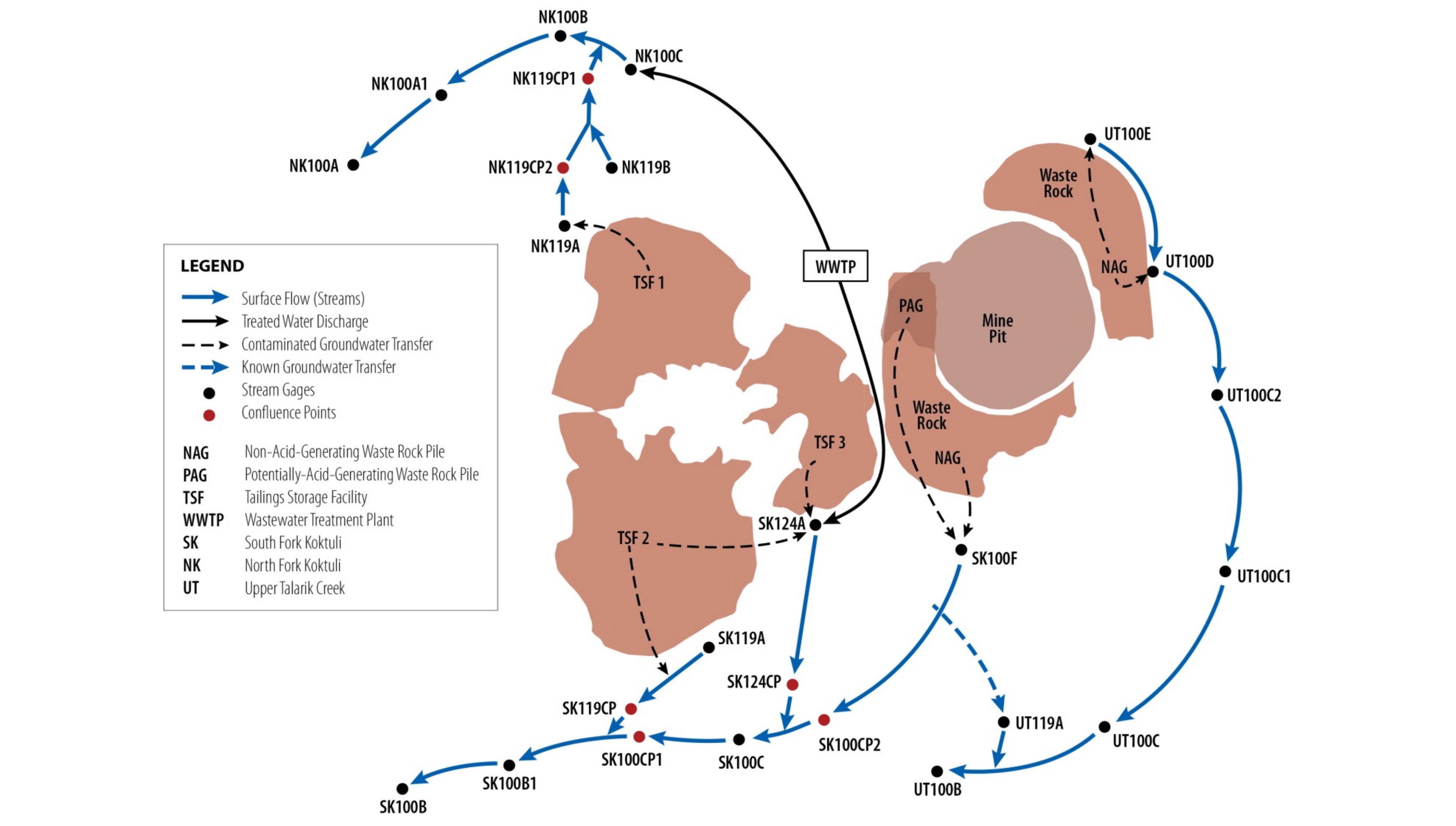
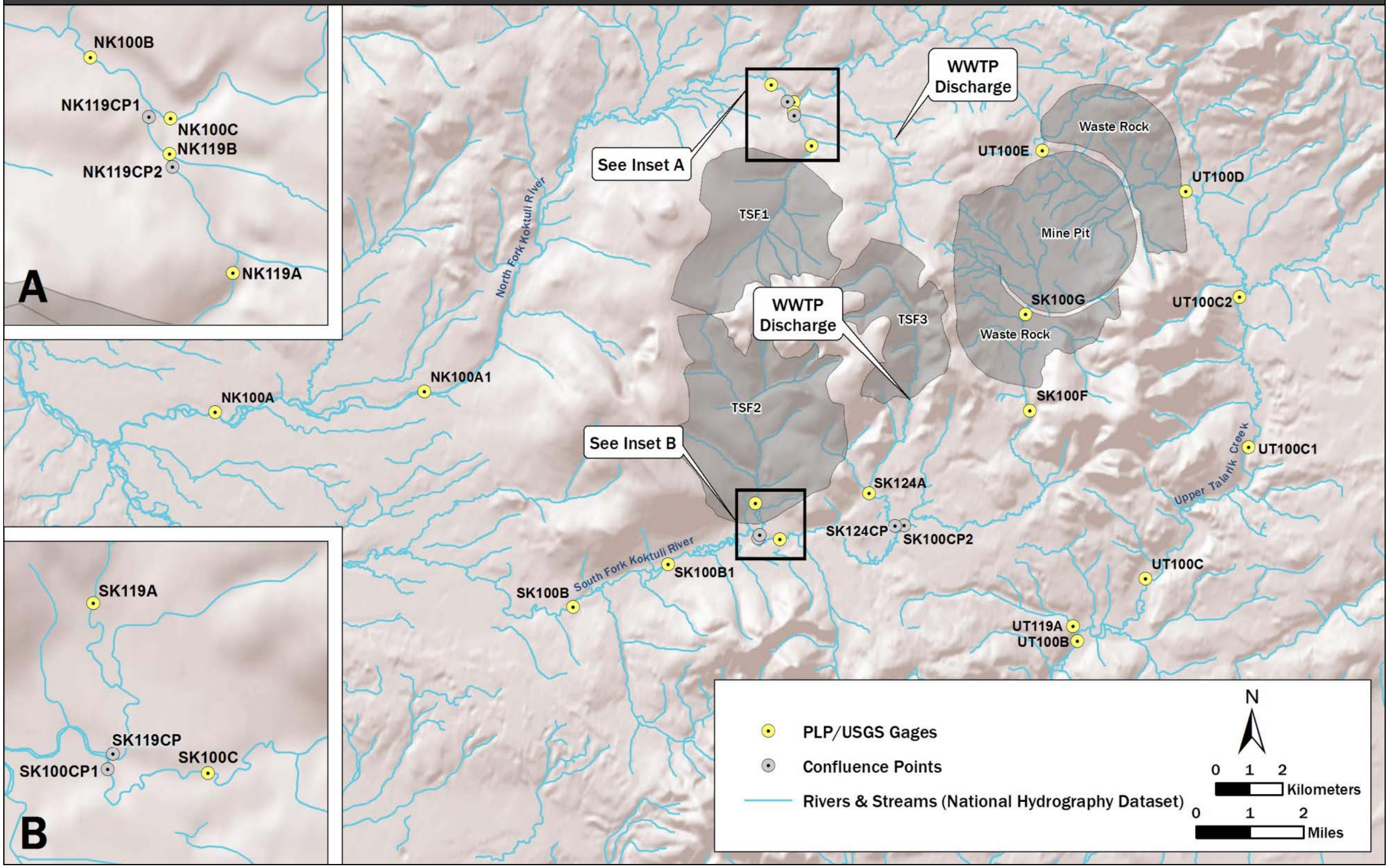


Figure 6-11. Approximate locations of stream gages and wastewater treatment plant (WWTP) discharges represented in Figures 6-8 through 6-10. Gages denoted with CP indicate confluence points, where virtual gages were created for analysis purposes. Footprint of the major mine components of the Pebble 6.5 scenario are shown for reference. Gage locations are based on U.S. Geological Survey (2012b) and Pebble Limited Partnership (2011).



6.3.1 Mine Pit

Upon mine closure, pit dewatering pumps would be turned off. The cone of depression would persist around the pit for a time, and groundwater would flow toward the pit in response to the local gradient. Eventually, the water level in the pit would recover toward equilibrium with the surrounding water table. Any water exiting the pit through surface channels or pumped from the pit would be tested, and treated if necessary, prior to discharge to surrounding surface waters. Based on our calculations for groundwater and precipitation inflows to the pit after operations have ceased, we estimate that the time required for the pit to fill ranges from approximately 20 years for the Pebble 0.25 scenario to more than 200 years for the Pebble 6.5 scenario. If additional runoff or TSF discharges were directed to the pit instead of allowed to flow into streams, these time frames would be considerably shorter (e.g., approximately 100 years for the Pebble 6.5 scenario).

Upper benches of the pit would be partially backfilled, regraded, covered with plant-growth medium, and vegetated. Some areas may be flattened to enable construction of wetlands for passive water treatment. At least portions of the pit walls, as well as rocks on the pit bottom or on side benches, would consist of mineralized rock that was not economical to mine. Any exposed rock containing sulfide minerals would likely be acid-generating for as long as it remained above the water surface in the pit, resulting in water with low pH and dissolved metals running down the sides of the pit into the water body at the bottom. As water level in the pit rose, pit walls would become submerged and exposure to oxygen would be reduced. Eventually, acid generation would be expected to cease from rocks below the water's oxic zone. Exposed rock above the water surface or within the oxic zone would continue to produce acidic metal-sulfate salts that would run into the pit lake with precipitation and snowmelt. Surfaces anticipated to produce acidic drainage could be sealed against exposure to oxygen. However, this might not be effective for a pit of this size, since it might be difficult to seal all cracks and fissures in the pit walls. There could be degradation of sealants from exposure to sun and air, and freeze-thaw fracturing of rock could reduce acid-preventing efficacy over time. Predicting pit water quality has a high degree of uncertainty (Section 8.1.4; Appendix I) (Gammons et al. 2009), but water would need to be monitored and treated to meet effluent requirements prior to being discharged to streams, for as long as the water remained contaminated.

6.3.2 Tailings Storage Facilities

At closure, tailings beaches in the TSFs would be covered with NAG waste rock and a plant-growth medium, then vegetated with native species (Ghaffari et al. 2011). Embankments and crests also would be covered with a growth medium and vegetated. The tailings pond would be drawn down to prevent flooding and to maintain stability, but a pond of sufficient depth would be retained to keep the core of PAG tailings hydrated and minimize oxidation. Retaining water in the tailings maintains a higher potential for tailings dam failure than if the tailings were drained; however, draining the tailings to stabilize them could allow oxygen-rich water to percolate through the tailings and oxidize the sulfides. As long as a cover of water is maintained, oxygen movement into the tailings would be retarded, minimizing acid generation. Drawing down the water level in the TSF would also provide capacity for unusual precipitation events, reducing the likelihood that a storm would provide enough precipitation to overwhelm capacity and cause tailings dam failure or overtopping. Additionally, wetlands might be included in reclamation to provide additional stormwater retention, passive water treatment, and significantly increased evapotranspiration (Reeve and Gracz 2008).

TSFs would require active management for hundreds to thousands of years (Blight 2010). A tailings dam is an engineered structure that requires monitoring to ensure structural and operational integrity. An assumption in the mining industry is that tailings continue to compact, expelling interstitial water and becoming more stable over time. However, there appears to be little data available that document the magnitude of this stability gain. A recent analysis suggests that densification of oil sands tailings may stop after a period of time (Wells 2011). Although oil sands tailings are different from porphyry copper tailings, the principle is the same. Lack of data specific to porphyry copper tailings suggests a cautious approach, so we do not assume that tailings consolidate to a fully stable land form. Even if the tailings did consolidate over time, they would remain susceptible to erosion if the tailings dam were compromised. Thus, the system may require continued monitoring to ensure hydraulic and physical integrity in perpetuity.

6.3.3 Waste Rock

Some NAG waste rock would be used to cover tailings beaches, and some would be used to backfill upper portions of the mine pit. The remaining NAG waste rock would be sloped to a stable angle (e.g., less than 15 degrees [Blight and Fourie 2003]), covered with soil and plant-growth medium, and vegetated with native species. No PAG waste rock would remain on the surface, as it would have been processed either as blending material during operations or at the end of operations.

6.3.4 Water Management

Table 6-8 summarizes the flow components of the water balance after closure, both during the period in which the mine pit is filling and the steady state condition after the mine pit reaches its maximum water level. During the post-closure period, the mine would still capture water from precipitation over the mine pit, waste rock piles, and the TSFs. Groundwater would continue to flow into the mine pit, so precipitation over the cone of depression would continue to contribute to the captured water. Consumptive losses from operation would cease, but water stored in the mine pit would constitute a new consumptive loss until the mine pit water level reaches equilibrium with the surrounding groundwater level.

The footprint of the mine would be reduced as land occupied by production facilities is reclaimed. For purposes of estimating water inputs, we assume that 80% of the areas disturbed by the plant and ancillary facilities would be reclaimed, but that some facilities (e.g., the fuel depot, the WWTP, some pipelines, and part of the camp) would remain.

Table 6-8. Summary of annual water balance flows (million m^3/year) during the post-closure period for the Pebble 6.5 scenario.

Flow Component	During Mine Pit Filling	Post-Closure
Captured at mine pit area	39.7	26.1
Captured at TSF 1	13.0	13.0
Captured at TSF 2	18.4	18.4
Captured at TSF 3	7.76	7.76
Captured at mill & other facilities	0.538	0.538
Potable water supply well(s)	0	0
Water in ore (3%)	0	0
Total Captured	**79.4**	**65.8**
Cooling tower losses	0	0
Water in concentrate to port	0	0
Water in concentrate return	0	0
Runoff collected from port	0	0
Stored in TSF as pore water	0	0
Stored in mine pit	37.3	0
Crusher use	0	0
Total Consumptive Losses	**37.3**	**0**
Returned to streams via wastewater treatment plant	33.9	57.6
Returned as NAG waste rock leachate	0.947	0.947
Returned as PAG waste rock leachate	0	0
Returned as TSF leakage	7.20	7.20
Total Reintroduced	**42.1**	**65.8**
Percent of Captured Water Reintroduced	53.0%	100%

Notes:
TSF = tailings storage facility; NAG = non-acid-generating; PAG = potentially acid-generating.

As the mine pit fills, the cone of depression would shrink to the point that most or all of the waste rock would be outside of the drawdown zone. Runoff from the reclaimed NAG waste rock piles would either seep into the ground, travel as overland flow, or be diverted to streams. Some precipitation would be expected to infiltrate through the NAG waste rock cover, drain through the waste rock piles, and become groundwater. Runoff from the reclaimed NAG waste rock piles is not anticipated to require treatment, but would be monitored periodically to confirm this assumption.

The elevation of the north rim of the Pebble 6.5 mine pit would be over 100 m higher than the elevation of the south rim, so that even when the mine pit reaches its maximum water level there would still be seepage into the pit from the higher ground. For water balance purposes, we estimate that the post-closure cone of depression would extend an average of 100 m beyond the pit rim as a result of surface outflow or pumping.

Precipitation falling on the post-closure tailings would be monitored and discharged downstream or diverted for treatment in the WWTP, as necessary, to meet water quality standards. Stormwater diversions and collection systems from the operations phase would be maintained and water directed away from the TSF, or, if risk of contamination existed, toward the WWTP for treatment prior to discharge to streams. Interstitial water within the tailings would continue to seep into naturally fractured bedrock below the TSF. The well field placed downstream from the TSF during operations would be retained and monitored post-closure, with water pumped and treated if determined to be contaminated by leachate from the TSF. The pit water would be monitored and treated prior to being released to streams, for as long as concentrations of contaminants exceeded effluent limits.

6.3.5 Premature Closure

Many mines close before their ore reserves are exhausted. In one study of international mine closures between 1981 and 2009, 75% of the mines considered were closed before the mine plan was fully implemented (Laurence 2011). The Illinois Creek and Nixon Fork mines are examples of mines that have closed prematurely in Alaska.

Closure before originally planned—that is, premature closure—may occur for many reasons, including technical issues, project funding, deteriorating markets, operational issues, or strategic financial issues of the owner. Premature closures can range from cessation of mining with continued monitoring of the site to complete abandonment of the site. As a result, environmental conditions at a prematurely closed mine may be fully reclaimed or equivalent to those under a planned closure, may be severely contaminated and require extensive remediation, or may fall anywhere between these extremes. Environmental impacts associated with premature closure may be more significant than impacts associated with planned closure, as mine facilities may not be at the end condition anticipated in the closure plan and there may be uncertainty about future re-opening of the mine. For example, PAG waste rock in our mine scenarios would likely still be on the surface in the event of a premature closure. If the mine closed because of a drop in commodity price, there would be little economic incentive to incur the cost of moving or processing millions of metric tons of PAG waste rock, and water treatment systems might be insufficient to treat the volume of low pH water containing high metal concentrations from this previously unplanned source. Some method of financial assurance generally is required by state and federal agencies to ensure closure if a mine company defaults on its responsibility (Box 4-3). To be effective, financial assurance must be based on accurate estimates of reclamation costs. In the past, financial assurance often has not been adequate, and taxpayers have been left with substantial cleanup costs (USEPA 1997). This may be changing, as agencies update bonding requirements to reflect cleanup costs more accurately, but projecting these costs far into the future is a difficult task.

When a mine re-opens after premature closure, the owners might change the mining plan, implement different mitigation practices, or negotiate new effluent permits. An example is the Gibraltar copper mine in British Columbia. The Gibraltar mine began operations permitted as a zero-discharge operation. However, when it was re-opened under new ownership after having closed prematurely, the new permit allowed treated water to be discharged to the Fraser River with a 92-m dilution zone for copper and other metals.

6.4 Conceptual Models

The development of conceptual models is a key component of the problem formulation stage of an ecological risk assessment (USEPA 1998), and in Chapter 2 we introduced the use of conceptual models as tools to help structure ecological risk assessments. At the outset, we broadly define the scope of this assessment to be potential effects of a large-scale mine and a transportation corridor on freshwater habitats, resulting effects on fish, and consequent fish-mediated effects on wildlife and Alaska Native populations (Section 2.2.1, Figure 2-1). To conduct a risk analysis, this scope needs to be refined and the specific sources, stressors, and endpoints to be evaluated must be explicitly identified.

In this section, we summarize the specific sources, stressors, and endpoints considered in the assessment, as informed by the background information on the region, type of development, and endpoints of interest presented in the preceding chapters, and based on the mine scenarios described in this chapter. We then integrate these components into conceptual model diagrams that illustrate hypothesized cause-effect linkages among these sources, stressors, and endpoints.

6.4.1 Sources Evaluated

The two main sources considered in this assessment are the mine and the transportation corridor, each of which can be subdivided into several components. These components are summarized below, and discussed in greater detail in Section 6.1.

- The **mine infrastructure** includes the major mine components (open mine pit, waste rock piles, TSFs), the groundwater drawdown zone associated with the mine pit, and plant and ancillary facilities (e.g., water collection and storage facilities, a WWTP, ore-processing facilities, and chemical storage facilities).
- The **transportation corridor** comprises a road and four pipelines (one each for product slurry, diesel fuel, natural gas, and return water) connecting the mine site area to Cook Inlet.

6.4.2 Stressors Evaluated

As discussed above and in Chapter 4, large-scale mining is a complex process that typically involves both physical alteration of the environment and the release of pollutants. The specific stressors considered for inclusion in the assessment were identified based on their potential to significantly affect our primary endpoint of interest—the region's salmon resources—and their relevance to the U.S. Environmental Protection Agency's (USEPA's) regulatory authority and decision-making context. Stakeholders also identified potential stressors of concern, which were considered by the assessment team. These stressors are summarized in Table 6-9 and discussed in detail below. Those stressors that are analyzed in the assessment or are of particular concern to stakeholders are discussed in the following subsections.

Table 6-9. Stressors considered in the assessment and their relevance to the assessment's primary endpoint (salmonids) and the U.S. Environmental Protection Agency's regulatory authority.

Stressor	Description	Relevance to Salmonids	Relevance to Decision-Making
Excavation	Removal of streams and wetlands due to creation of the mine pit and other excavations.	Relevant	Directly relevant to Section 404 of the Clean Water Act
Filling	Filling in of streams and wetlands due to waste rock piles, tailings impoundments, and roads.	Relevant	Directly relevant to Section 404 of the Clean Water Act
Water diversion and withdrawal	Reduced flow in streams and wetlands due to removal of water.	Relevant	Consequence of excavation and filling
Water temperature	Changes in water temperature associated with discharges of treated water or reduced groundwater flows.	Relevant	Consequence of excavation and filling
Product metal (copper)	Copper occurring in the product concentrate, waste rock, or tailings could enter streams and wetlands.	Relevant	Consequence of excavation and filling
Other metals	Metals other than copper occurring in the product concentrate, waste rock, or tailings could enter streams and wetlands.	Relevant	Consequence of excavation and filling
pH	Oxidation of sulfides could result in acidification of waste and receiving waters.	Relevant	Consequence of excavation and filling
Process chemicals	Chemicals used in ore processing would occur in tailings and product concentrate and could spill.	Relevant	Consequence of excavation and filling
Nitrogen	Nitrogen compounds released during blasting would deposit on the landscape. Nitrates could also reach groundwater via leachate from waste rock piles.	Weakly relevant	Consequence of excavation and filling
Tailings and other fine sediment	Tailings, product concentrate, and other fine particles could fill streams or wetlands or, at lower concentrations, could change substrate texture and abrade fish gills.	Relevant	Directly relevant to Section 404 of the Clean Water Act (if particles act as fill) and consequence of excavation and filling
Diesel fuel	Spilled diesel fuel could enter streams and wetlands.	Relevant	Necessary for excavation and filling
Natural gas	Leaking natural gas could combust.	Not relevant	Peripheral to excavation and filling
Dust	Dust from blasting, tailings beaches, and vehicle traffic could deposit on the landscape and wash into streams.	Weakly relevant	Consequence of excavation and filling
Noise	Noise from blasting or other activities.	Not relevant	Consequence of excavation and filling
Rock slide	Slides from waste rock piles or roads.	Relevant	Consequence of excavation and filling
Blocked or perched culvert	Inhibition of fish passage due to malfunctioning culverts.	Relevant	Consequence of excavation and filling for a road
Washed out culvert	Downstream siltation or inhibition of fish passage due to washed out culverts.	Relevant	Consequence of excavation and filling for a road
Invasive plants	Changes in habitat quality due to invasion by plants carried by road traffic.	Weakly relevant	Peripheral to excavation and filling
Climate change	Altered risk of mine failures, and changes in marine and freshwater habitat quality and life history timing, associated with increased precipitation and temperature.	Indirectly relevant	Not related to excavation and filling, but modifies other consequences of excavation and filling

6.4.2.1 Physical Habitat Alteration

Large-scale mining in the Bristol Bay region would necessarily involve the destruction of streams and wetlands through excavation and filling associated with the mine pit, waste rock piles, TSFs, borrow pits, and the transportation corridor. This excavation and filling would directly affect anadromous and resident salmonid habitats and directly involve USEPA under Section 404 of the Clean Water Act.

Mining-related excavation and filling would also result in water diversion and withdrawal. Stream and overland flow must be diverted around the mine site to keep it dry and minimize erosion; the mine pit must be dewatered to continue excavation; and water must be obtained for use in ore processing, tailings and product transport, and other purposes. These diversions and withdrawals would redirect and reduce flow and plausibly affect fish via reduced habitat quality or quantity.

6.4.2.2 Water Temperature

Stream and wetland water temperatures could be affected by the capture, storage, use, treatment, and discharge of water throughout the mining process. Elevated temperatures could result from warm water discharges or, in summer, from reduced groundwater inputs. In winter, reduced groundwater inputs could result in reduced temperatures. Because water temperature affects fish development and habitat, any temperature changes could plausibly influence fish populations.

6.4.2.3 Chemical Contaminants

A range of chemical contaminants associated with mining may enter surface waters and pose risks to fish. These contaminants include rock-derived inorganic contaminants (metals and acidity), ore-processing chemicals, fuels, and nitrogen compounds.

Rock-Derived Inorganic Contaminants

Mines are developed because rocks at the site have high metal concentrations, which are further concentrated as ore is isolated from waste rock and as product concentrate is created from the ore. These metals may enter surface waters from uncollected leachate and runoff, from WWTP discharges, or from spills of product concentrate and its associated water. Metals are known to cause toxic effects on aquatic biota, including fish; however, when combined with low pH (acidity), metals become especially problematic. Acid rock drainage occurs when PAG rocks are present at the mine site. Acidity can be directly deleterious to aquatic biota, but it also increases the solubility of minerals, which results in increased concentrations of metals in solution.

Because copper is the major resource metal in the Pebble deposit and is particularly toxic to aquatic organisms, it is the metal most likely to cause toxic effects at this site. Copper toxicity also has been a primary concern of stakeholders, including the National Oceanic and Atmospheric Administration, the federal agency responsible for salmon management. Thus, copper criteria, standards, and toxicity are considered in detail in the assessment.

Other metals are considered if their concentrations in test leachates from the Pebble deposit indicate that they are potentially toxic, based on benchmark values. When possible, national ambient water quality criteria are used as screening benchmarks. Both criterion maximum concentrations (CMCs) and criterion continuous concentrations (CCCs) are used to account for acute and chronic exposures, respectively. When U.S. criteria are not available, the most similar available value is used (e.g., Canadian benchmarks, the lowest acute and chronic values from the USEPA's ECOTOX database, or the European Chemical Agency and Organization for Economic Cooperation and Development's eChemPortal) (Table 6-10).

Table 6-10. Screening benchmarks for metals with no national ambient water quality criteria.

Metal	Acute/Chronic Benchmarks (µg/L)	Source and Notes
B	29,000/1,500	Canadian acute and chronic guidelines based on SSDs (CCME 2009)
Ba	46,000/8,900	*Austroptamobius pallipes* 96-hour LC_{50} (Boutet and Chaisemartin 1973) and *Daphnia magna* 21-day reproductive EC_{50} (Biesinger and Christensen 1972)
Co	89/2.5	Acute value is the lowest acute test datum and the chronic value is the 5th centile of a chronic species sensitivity distribution (Environment Canada and Health Canada 2011)
Fe[a]	350/-	Chronic data were inadequate to set a value, but the Canadian authors believed that it would not be much lower than this acute value (BC 2008)
Mn	760/693	Hardness adjusted (for 20 mg/L) acute and chronic guidelines (BC 2001)
Mo	32,000/73	*Daphnia magna* 48-hour LC_{50} (Kimball 1978) and Canadian chronic guideline (CCME 1999)
Sb	14,400/1,600	Lowest acute and chronic values from a fathead minnow early life-stage test (USEPA 1980, Swedish Chemicals Inspectorate 2008, Environment Canada and Health Canada 2010)

Notes:
[a] The listed U.S. iron criterion, from the 1976 Red Book (USEPA 1976), is less reliable than this more recent benchmark.
SSD = species sensitivity distribution; LC_{50} = median lethal concentration; EC_{50} = median effective concentration.

Some metals, such as calcium, magnesium, and sodium, are not screened because of their low toxicity. Molybdenum is treated as a contaminant of concern because it is a specific product of the mine, even though it would not be retained based on the comparison of test leachates with benchmark values. Molybdenum concentrate would be trucked to the port, and spills of the sand-like material could occur. Gold is also a product, but is not evaluated because it has very low solubility and toxicity and would not be transported in a form likely to result in aqueous exposures.

Screening against tailings and waste rock leachates are presented in Tables 8-4 through 8-8. The metals of concern are aluminum, cadmium, cobalt, copper, manganese, nickel, lead, selenium, and zinc based on average concentrations exceeding either acute or chronic benchmarks for at least one leachate. However, most of the estimated total toxicity is due to copper.

Major Ions (Total Dissolved Solids)

Total dissolved solids (TDS) comprise all organic and inorganic materials dissolved in a water sample, which can be measured directly or estimated from conductivity measurements (specific conductance is the term for conductivity values that have been temperature-compensated to 25°C). Mining inevitably involves crushing rocks, and the leaching of crushed rock results in enhanced dissolution and elevated concentrations of dissolved major ions (calcium, magnesium, sodium, potassium, chlorine, sulfate, and bicarbonate). These major ions generally contribute the most mass to TDS measurements, especially sulfate in waters influenced by metal mining. Some metals, such as calcium, magnesium, potassium, and sodium are not screened because of their low toxicity, but they contribute to ionic stress. Thus, even if this mixture of TDS is not acidic, it can be toxic to aquatic biota, particularly in this region's waters, which have low ambient concentrations of these ions. Examples of toxicity due to leaching of major ions from mine-derived waste rock are discussed in USEPA (2011) and Chapman et al. (2000). Also, the history of TDS compliance problems at the Red Dog Mine near Kotzebue, Alaska, suggests that dissolved major ions should be a stressor of concern.

Ore-Processing Chemicals

Chemicals used to process the ore and separate product from tailings have the potential to enter the environment as a result of truck wrecks, on-site spills, tailings slurry spills, product concentrate slurry spills, or water collection and treatment failures. Tests of the Pebble deposit ore used alkaline flotation to separate product concentrate from tailings (Ghaffari et al. 2011). The collector was sodium ethyl xanthate, the frother was methyl isobutyl carbinol, and lime was used to adjust pH. Molybdenum separation also requires fuel oil as a collector (Box 4-5). Of these, xanthate is clearly a contaminant of concern because it is highly toxic to aquatic life (Hidalgo and Gutz 2001). Methyl isobutyl carbinol has been poorly tested but appears to have relatively low toxicity (acute lethality to African clawed frogs and goldfish requires a relatively high concentration, 360 to 656 mg/L [USEPA 2013]). Lime would contribute to the risk from major ions (TDS). Fuel oil use for this purpose would be small relative to its use as fuel.

In addition, cyanide might be used to recover gold from pyritic tailings (Box 4-6). It is expected that a cyanide destruction unit would be used at the end of the leaching process to achieve the acute and chronic water quality criteria for free cyanide of 22 and 5.2 µg/L, respectively. Cyanide in the TSF is likely to be rapidly diluted and degraded. Accidental releases and on-site spills, as recently occurred at the Fort Knox mine (ADEC 2012), are possible but are not judged to be as directly significant to our endpoints as other accidents considered. However, because cyanide is assumed to be transported as a solid, as is common at other mines, truck accidents could result in cyanide spills to streams.

Fuels

Both diesel oil and natural gas would be piped to the mine site and could enter the environment via pipeline leaks or failures. Diesel spills could enter surface waters and have been known to adversely affect aquatic biota, so diesel is considered in the assessment. Natural gas could combust, but a natural gas fire is unlikely to significantly affect salmon populations.

Nitrogen Compounds

Nitrogen compounds, expected to be predominantly nitrate due to combustion, would be released during the blasting associated with excavation. Some of these compounds would deposit on waste rock piles and the landscape and could enter surface water and groundwater. However, it is likely that these streams are phosphorus-limited, not nitrogen-limited (Goldman 1960, Moore and Schindler 2004), and the consequences of an increase in nitrogen/phosphorus ratio for salmonids are unknown but judged to be minimal. Thus, nitrogen residues are not considered in the assessment.

6.4.2.4 Fine Sediment

If tailings, product concentrate, unpaved road materials, or other fine particles are spilled or eroded, they could fill streams and wetlands, alter streambed substrates, or abrade the gills of fish.

6.4.2.5 Dust

Blasting and vehicle traffic, both at the mine site and along the transportation corridor, would generate dust. Exposed tailings beaches within the TSFs also could result in dust generation. This dust could contribute to the sedimentation of streams and, depending on the composition of the rock, could contribute toxic metals to surface waters. Dust from unpaved roads is known to affect streams, so it is included in this assessment. In contrast, the occurrence of dust from blasting and tailings beaches is poorly documented, highly site-specific, and its effects are unknown. We anticipate that much of the dust generated from blasting and tailings beaches would settle on the site and be collected with runoff water. Wind may carry dust off site, but would also disperse it across the landscape. We do not judge dust from blasting or tailings beaches to be an important contributor to risks to salmonids (although this judgment is uncertain), and do not consider it in the assessment.

6.4.2.6 Noise

Noise would be generated by blasting at the mine site and vehicle traffic along the transportation corridor. Although noise may directly affect wildlife, it is unlikely to affect salmonids and is not considered in the assessment.

6.4.2.7 Culverts

Blocked or perched culverts could significantly reduce fish passage, thereby reducing salmon migrations or movement among habitats by resident salmonids. Culverts also may wash out during floods, temporarily inhibiting fish movement and reducing habitat due to siltation by the deposited roadbed material. Culverts are a component of roads that fill wetlands and the floodplains of streams. They may significantly affect salmon in the surface waters they intersect and thus are considered in the assessment.

6.4.2.8 Invasive Species

Several dozen species of plants, animals, and micro-organisms are considered to be or have the potential to be invasive in Alaska (ADF&G 2013, Eddmaps 2013). Of those currently present, reed canarygrass (*Phalaris arundinacea*) is widespread on the Kenai Peninsula (HSWCD 2007) and elodea (*Elodea canadensis*) exists in Stormy Lake on the northern Kenai Peninsula (Etcheverry 2012). These plants have the potential to degrade salmon habitat (Merz et al. 2008). The improved and expanded road from Cook

Inlet may facilitate the spread of reed canary grass and elodea from the Kenai Peninsula to the Bristol Bay watershed, where they may adversely affect salmon habitat.

6.4.3 Endpoints Evaluated

In this assessment, the primary endpoint of interest is the region's key salmonid populations (Pacific salmon, rainbow trout, and Dolly Varden) in terms of abundance, productivity, or diversity. Given the importance of salmonids to the region's ecosystems and culture, we also consider the effects of potential changes in fish populations on wildlife abundance, productivity, or diversity and on Alaska Native culture. These endpoints are discussed in detail in Chapter 5.

6.4.4 Conceptual Model Diagrams

To frame the assessment, we developed conceptual model diagrams illustrating potential pathways linking the sources, stressors, and endpoints detailed above (see Box 2-1 for an overview of how the assessment's conceptual models are structured). These diagrams went through several iterations, from initial brainstorming of all potential pathways associated with large-scale mine development in the Bristol Bay region (both with the assessment team and other stakeholders) to focusing on those pathways considered both within the assessment's scope (Chapter 2) and likely to affect endpoints of interest.

Through this iterative process, we developed a series of three conceptual model diagrams illustrating hypothesized cause-effect relationships leading from mine-related sources to endpoints of interest. These diagrams illustrate potential effects of routine mine construction and operation on physical habitat (Figure 6-12), potential effects of routine mine construction and operation on water chemistry (Figure 6-13), and potential effects of unplanned events on physical habitat and water chemistry (Figure 6-14). Note that the distinction between physical habitat and water chemistry was made for presentation purposes, though we recognize that water chemistry can be an important component of the physical habitat. These diagrams provide a framework for the analysis sections of the assessment, and the relevant portions of these diagrams evaluated in each analysis section are highlighted throughout the remaining chapters of the assessment. Note that not all pathways included in each conceptual diagram are necessarily evaluated in the assessment. For example, in some cases, we hypothesized pathways that may be significant, but data were not sufficient for quantitative analysis.

We also developed three more general conceptual model diagrams for specific topics (wildlife, Alaska Native cultures, and cumulative effects of multiple mines) that were defined as outside of the assessment's scope but that are of key importance to stakeholders (Chapters 12 and 13).

Figure 6-12. Conceptual model illustrating potential effects of routine mine construction and operation on physical habitat.

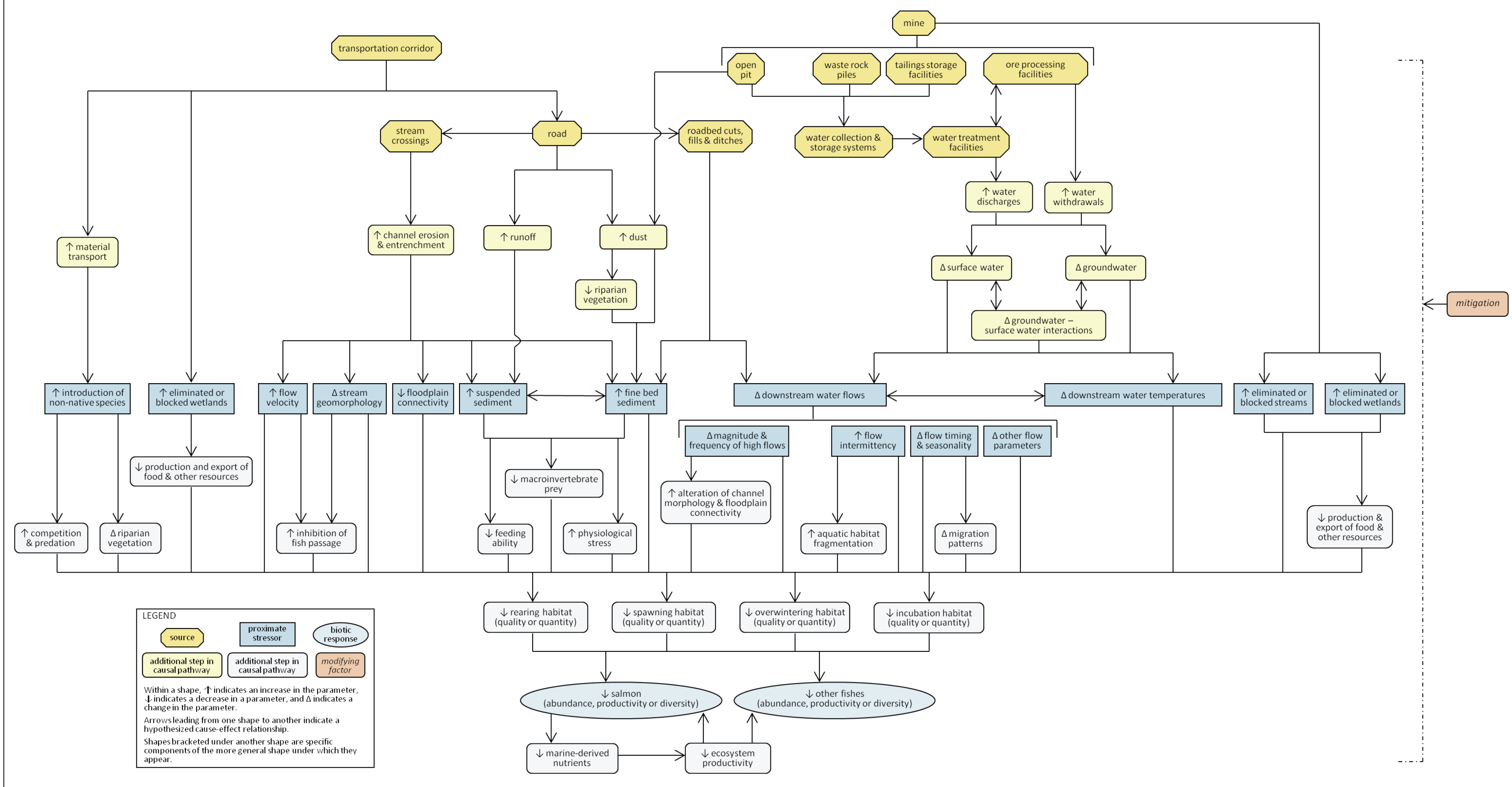


Figure 6-13. Conceptual model illustrating potential effects of routine mine construction and operation on water chemistry.

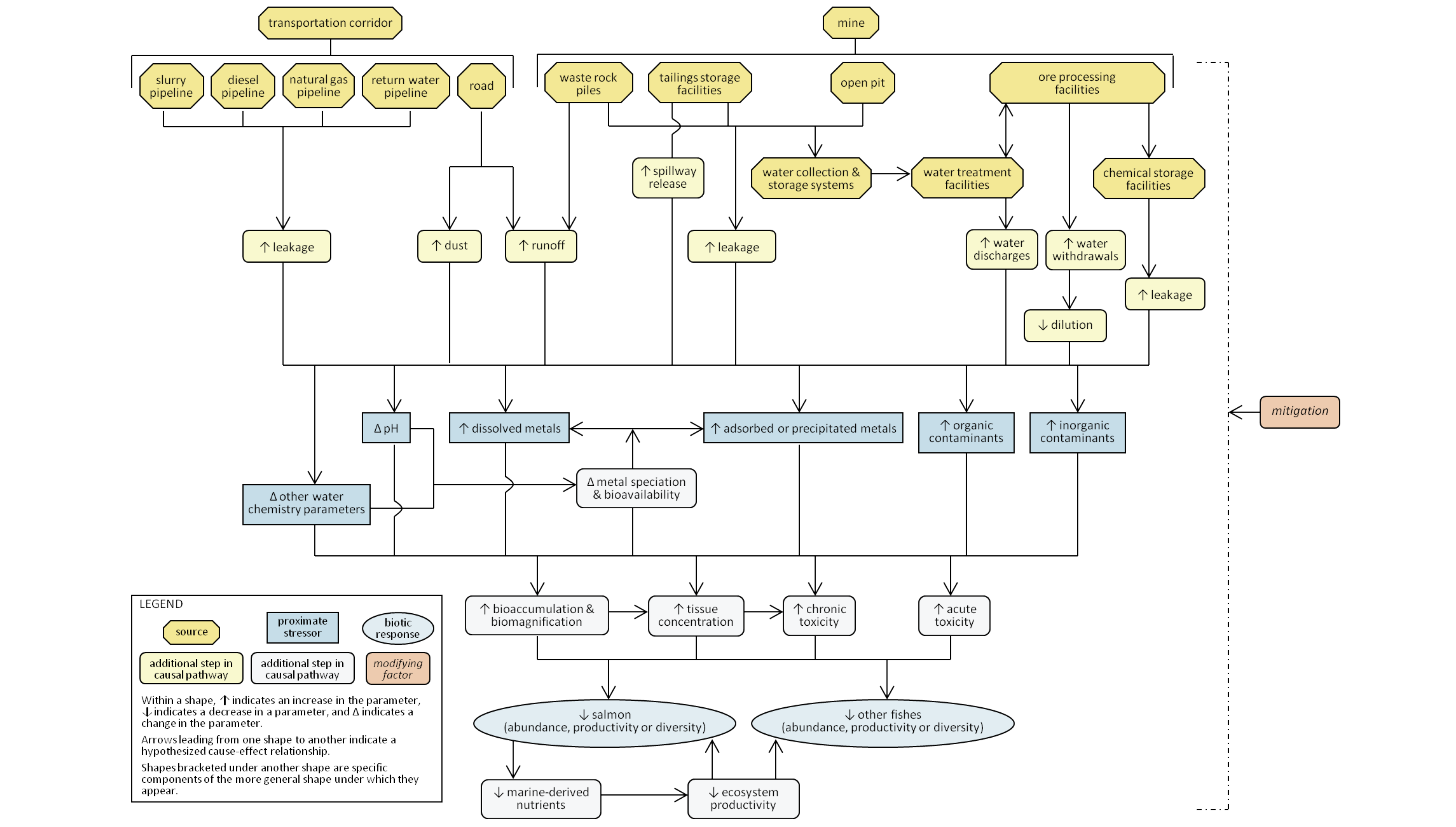


Figure 6-14. Conceptual model illustrating potential effects of unplanned events on physical habitat and water chemistry.