

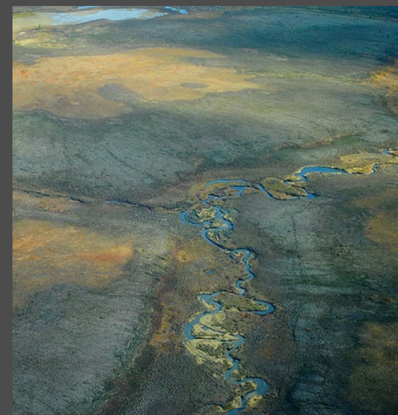

CHAPTER 14. INTEGRATED RISK CHARACTERIZATION

This chapter summarizes the risk analysis results, organized by assessment endpoint, for a potential mine at the Pebble deposit. For each endpoint, it integrates the various sources of risk, including those from routine operations and accidents and failures, different physical and chemical exposures, and different pathways of exposure and mechanisms of effects. In addition, it combines multiple types of evidence, including evidence from analysis of the mine scenarios and from knowledge of analogous mining operations. Limitations and uncertainties in the risk characterization are also summarized. Finally, these results are extrapolated to the cumulative effects of multiple mines. See Chapters 7 through 13 for the derivation of these conclusions.

14.1 Overall Risk to Salmon and Other Fishes

14.1.1 Routine Operation

During routine operations, mining would be conducted according to modern conventional practices, including common mitigation measures at the mine site and along the transportation corridor. Toxic effects would be minimized by collection of nearly all water from the site and treatment of collected water to meet state standards and national criteria before discharge. However, toxic effects would still occur, primarily due to the inevitable leakage of leachates. In addition, habitat loss and modification would occur due to destruction of streams and wetlands and water withdrawals. As a result, local populations of salmonids would decline in abundance and production. Compensatory mitigation of these losses in the Bristol Bay watershed would be problematic at best (Appendix J).

14.1.1.1 Mine Footprint

Even in the absence of accidents or failures, the development of a mine at the Pebble deposit would result in the destruction or modification of streams, wetlands, and ponds. Local habitat loss would be significant, because losses of stream habitat leading to losses of local, unique populations would erode the population diversity key to the stability of the overall Bristol Bay salmon fishery (Schindler et al. 2010).

- In the Pebble 0.25, 2.0, and 6.5 scenarios, **38, 89, and 151 km of streams, respectively, would be lost** to (eliminated, blocked, or dewatered by) each mine footprint (the area covered by the mine pit, waste rock piles, tailings storage facilities [TSFs], drawdown zone, and plant and ancillary facilities). This translates to losses of 8, 22, and 36 km of streams known to provide spawning or rearing habitats for coho salmon, sockeye salmon, Chinook salmon, and Dolly Varden.
- Altered streamflow resulting from retention and discharge of water used in mine operations, ore processing, transport, and other processes would reduce the amount and quality of fish habitat. **Streamflow alterations exceeding 20% would adversely affect habitat in an additional 15, 27, and 53 km of streams** in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively, reducing production of coho salmon, sockeye salmon, Chinook salmon, rainbow trout, and Dolly Varden. Reduced streamflows would also result in the loss or alteration of an unquantified area of riparian floodplain wetland habitat due to loss of hydrologic connectivity with streams.
- Off-channel habitats for salmon and other fishes would be reduced due to **losses of 4.5, 12, and 18 km^2 of wetlands and 0.41, 0.93, and 1.8 km^2 of ponds and lakes** to the Pebble 0.25, 2.0, and 6.5 mine footprints, respectively. These losses would reduce availability of and access to hydraulically and thermally diverse habitats that provide foraging opportunities and important rearing habitats for juvenile salmon.
- **Indirect effects of stream and wetland losses** would include reductions in the quality of downstream habitat in the three headwater streams draining the mine footprints, affecting the same species as the direct effects. Modes of action for these effects would include the following.
  - A reduction in food resources would result from the loss of organic material and drifting invertebrates exported from the 38 to 151 km of streams lost to the mine footprints.
  - The balance of surface water and groundwater inputs to downstream reaches would change. Shifting from groundwater to surface-water sources is expected to reduce winter habitat (i.e., unfrozen stream reaches) and make streams less suitable for spawning and rearing.
  - Water treatment and discharge, resulting in reduced passage through groundwater flowpaths, are expected to alter summer and winter water temperatures and make streams less suitable for Pacific salmon, rainbow trout, and Dolly Varden.

These indirect effects on the abundance and production of salmonids cannot be quantified due to lack of data. However, it is expected that one or more of these mechanisms would diminish fish production downstream of the mine footprints in each watershed.

14.1.1.2 Water Collection, Treatment, and Discharge

Water in contact with tailings, waste rock, or the pit walls would leach copper and other metals. Our assessment evaluates the discharge of treated wastewater and the realistic expectation that leachate would escape the waste rock pile and TSF water collection systems in the three mine size scenarios. Routine discharges from the wastewater treatment plant (WWTP) to the South and North Fork Koktuli Rivers should be non-toxic due to treatment to achieve permit requirements. However, they may be somewhat toxic due to combined effects of multiple chemicals, poorly known and unregulated contaminants, and untested species in the receiving waters.

The retention and collection of leachates are inevitably incomplete. In our routine operations scenario, leakage in the Pebble 2.0 and Pebble 6.5 scenarios would be sufficient to cause toxic levels of copper and, to a much lesser extent, other metals in the streams draining the mine footprints. The most severe effects, including death of salmonids, would occur in the South Fork Koktuli River, which would receive leachate from the acid-generating waste rock. Upper Talarik Creek would experience death of invertebrates only below the station at which it receives interbasin transfer from the South Fork Koktuli River. The North Fork Koktuli River would experience death of invertebrates below TSF 1. Death or inhibited reproduction of aquatic invertebrates, which are food for fish, is estimated to occur in 21, 40 to 62, and 60 to 82 km of streams in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively. Avoidance of streams by salmonids would occur in 24 and 34 to 57 km of streams in the Pebble 2.0 and Pebble 6.5 scenarios, respectively. Death or reduced reproduction of salmonids would occur in 3.8 and 12 km of streams in the Pebble 2.0 and Pebble 6.5 scenarios, respectively.

The magnitude and extent of these predicted effects suggest the need for mitigation measures beyond the conventional practices assumed in the routine operations scenario to reduce the input of leached copper and other metals. A design based on conventional practices may be sufficient for a typical porphyry copper mine (i.e., equivalent to the Pebble 0.25 scenario), but not the massive Pebble 2.0 and 6.5 scenarios. Simply improving the efficiency of the capture wells or adding a larger wall or trench is unlikely to achieve water quality criteria in those scenarios. Additional measures might include lining the waste rock piles, reconfiguring the piles, or processing the acid-generating waste rock as it is produced.

In the event of TSF 1 overfilling, supernatant water would be released via a spillway. If the water was equivalent to the test tailings supernatant, 2.6 km of stream would be avoided by fish and 3.4 to 23 km would be toxic to invertebrates, independent of other sources.

14.1.1.3 Road Construction and Operation

The assessment's transportation corridor, including a road and four pipelines, would cross approximately 64 streams and rivers, of which 55 are known or likely to support migrating and resident salmonids. Nearly 272 km of streams between the road and Iliamna Lake would be affected. Risks to salmonids from the construction and operation of the transportation corridor are as follows.

- Loss and alteration of habitat through filling of wetlands for the road.

- Increased suspended and deposited sediment washed from the road, shoulders, ditches, cuts, and fills.
- Increased stormwater runoff leading to increased suspended sediment, fine-bed sediment, salts, and, at the mine site, metals.
- Increased dust leading to a direct increase in fine-bed sediment in the mining area, and an indirect increase along the entire transportation corridor via reduced riparian vegetation.
- Possible introduction of invasive species, particularly plants and fish pathogens.

All of the above sources and stressors would likely lead to degraded or reduced habitat for salmon and other fish.

14.1.2 Accidents and Failures

Any complex activity such as the mine described in this assessment inevitably experiences accidents and failures. The number of ways in which failures and accidents can occur—their magnitudes, their locations, and the circumstances of their occurrence—are effectively infinite. Hence, a complete and specific assessment of risks from potential accidents and failures is not possible. Rather, a few failure scenarios are presented, which emphasize the consequences of failures rather than the means by which they are initiated. These scenarios address potential failures that could occur during mine operations or after mine closure in perpetuity: failure to treat contaminated water; tailings dam failure; failures of roads and culverts; wreck of a truck carrying a process chemical; and failure of diesel, product concentrate, or return water pipelines. Many other potential failures are not analyzed, including failures of the on-site pipelines, spills of ore-processing chemicals on site, failures of tailings dams on streams other than the North Fork Koktuli River, wildfires, waste rock slides, or failures at the port.

The probabilities and consequences of the failures analyzed in the assessment are summarized in Table 14-1. The derivation of these estimates is discussed in Box 14-1, and the interpretation of failure probabilities is discussed in Box 9-3. Probabilities of occurrence were estimated using the best available information. Some estimates are qualitative, because no applicable data are available. Those that are quantitative are somewhat uncertain and their interpretation is not straightforward. For example, the range of annual probabilities of a tailings dam failure is based on design expectations rather than actual performance data, which are unavailable for recently constructed large earthen dams. The actual observed frequency of tailings dam failures is near the upper end of that range, which suggests that the range is reasonable at that bound. However, the lower bound (1 in 250,000 per year) is purely aspirational, in that it has no empirical basis.

Table 14-1. Probabilities and consequences of potential failures in the mine scenarios.

Failure Type	Probability[a]	Consequences
Tailings dam	4×10^{-4} to 4×10^{-6} per dam-year = recurrence frequency of 2,500 to 250,000 years[b]	More than 29 km of salmonid stream would be destroyed or degraded for decades.
Product concentrate pipeline	10^{-3} per km-year = 95% chance per pipeline in 25 years	Most failures would occur between stream or wetland crossing and might have little effect on fish.
Concentrate spill into a stream	1.5×10^{-2} per year = 1 stream-contaminating spill in 78 years	Fish and invertebrates would experience acute exposure to toxic water and chronic exposure to toxic sediment in a stream and potentially extending to Iliamna Lake.
Concentrate spill into a wetland	2.6×10^{-2} per year = 2 wetland-contaminating spills in 78 years	Invertebrates and potentially fish would experience acute exposure to toxic water and chronic exposure to toxic sediment in a pond or other wetland.
Return water pipeline spill	Same as product concentrate pipeline	Fish and invertebrates would experience acute exposure to toxic water if return water spilled to a stream or wetland.
Diesel pipeline spill	Same as product concentrate pipeline	Acute toxicity would reduce the abundance and diversity of invertebrates and possibly cause a fish kill if diesel spilled to a stream or wetland.
Culvert, operation	Low	Frequent inspections and regular maintenance would result in few impassable culverts, but for those few, blockage of migration could persist for a migration period, particularly for juvenile fish.
Culvert, post-operation	3×10^{-1} to $\sim 6 \times 10^{-1}$ per culvert; instantaneous = 11 to 22 culverts	In surveys of road culverts, 30 to 61% are impassable to fish at any one time. This would result in 11 to 22 salmonid streams blocked at any one time. In 10 to 19 of the 32 culverted streams with restricted upstream habitat, salmon spawning may fail or be reduced and the streams would likely not be able to support long-term populations of resident species.
Truck accidents	1.9×10^{-7} spills per mile of travel = 4 accidents in 25 years and 2 near-stream spills in 78 years	Accidents that spill processing chemicals into a stream or wetland could cause a fish kill. A spill of molybdenum concentrate may also be toxic.
Water collection and treatment, operation	0.93 = proportion of recent U.S. porphyry copper mines with reportable water collection and treatment failures	Water collection and treatment failures could result in exceedance of standards potentially including death of fish and invertebrates. However, these failures would not necessarily be as severe or extensive as estimated in the failure scenario, which would result in toxic effects from copper in more than 60 km of stream habitat.
Tailings storage facility spillway release	No data, but spills are known to occur and are sufficiently frequent to justify routine spillway construction	Spilled supernatant from the tailings storage facility could result in toxicity to invertebrates and fish avoidance for the duration of the event.
Water collection and treatment, managed post-closure	Somewhat higher than operation	Post-closure collection and treatment failures are very likely to result in release of untreated or incompletely treated leachates for days to months, but the water would be less toxic due to elimination of potentially acid-generating waste rock.
Water collection and treatment, after site abandonment	Certain, by definition	When water is no longer managed, untreated leachates would flow to the streams. However, the water may be less toxic.

[a] Because of differences in derivation, the probabilities are not directly comparable.

[b] Based on expected state safety requirements. Observed failure rates for earthen dams are higher (about 5×10^{-4} per year or a recurrence frequency of 2,000 years).

BOX 14-1. FAILURE PROBABILITIES

Table 14-1 presents probability estimates and consequences of different kinds of failures. Here, we explain the derivation of these estimates. As much as possible, multiple methods are used within a failure type to determine how robust the estimates may be. The methods differ among failure types and the results are not strictly equivalent, but they do convey the likelihood of occurrence. More details can be found in Chapters 8 through 11.

Tailings dam failure. The most straightforward method of estimating the annual probability of failure of a tailings dam is to use the failure rates of existing dams. Three reviews of earthen dam failures produced an average rate of 1 failure per 2,000 dam-years (i.e., a recurrence frequency of 2,000 years), or 5×10^{-4} per year. The argument against this approach is that it does not reflect current engineering practice. The State of Alaska's guidelines suggest that an applicant follow accepted industry design practices such as those provided by U.S. Army Corps of Engineers and the Federal Energy Regulatory Commission. Both regulatory agencies require a minimum factor of safety of 1.5 for the loading condition corresponding to steady seepage at the maximum storage facility. An assessment of the correlation of dam failure probabilities with safety factors against slope instability suggests an annual probability of failure of 1 in 1,000,000 years for Category I Facilities (those designed, built, and operated with state-of-the-practice engineering) and 1 in 10,000 years for Category II Facilities (those designed, built, and operated using standard engineering practice). This corresponds to risks of 10^{-4} to 10^{-6} per year. The advantage of this approach is that it addresses current regulatory expectations and engineering practices. The disadvantage is that we do not know whether standard practice or state-of-the-practice dams designed with safety factors would perform as expected. Slope instability is only one type of failure; other failure modes, such as overtopping during a flood, would increase overall failure rates. Slope stability failures account for about one-fourth of tailings dam failures, so the probability of failure from all causes could be estimated to be 1 in 250,000 (Category I) to 1 in 2,500 (Category II). The mine scenarios include up to three tailings storage facilities (TSFs), two with multiple dams, so the annual probability of any dam failing would be approximately equal to the annual probability of a single dam failure times the number of dams.

Pipeline failure. A review of observed pipeline failure rates for oil and gas pipelines yields an average annual probability of failure per kilometer of pipeline of 10^{-3} or a frequency of 1 failure per 1,000 km per year. This average risk comes very close to estimating the observed failure rate of the copper concentrate pipeline at the Minera Alumbrera mine, Argentina. This annual failure probability, over the 113-km length of each pipeline within the Kvichak River watershed, results in a 0.11 probability of a failure in each of the four pipelines each year, or a recurrence frequency of 8.5 years. If the probability of a failure is independent of location, and if it is assumed that spills within 100 m of a stream could flow to that stream, a spill would have a 0.14 probability of entering a stream within the Kvichak River watershed. This would result in an estimate of 0.015 stream-contaminating spills per year or 1 stream-contaminating spill over the duration of the Pebble 6.5 scenario (approximately 78 years). Similarly, a spill would have a 0.24 probability of entering a wetland, resulting in an estimate of 0.026 wetland-contaminating spills per year or 2 wetland-contaminating spills over the duration of the Pebble 6.5 scenario.

Water collection and treatment failure. During mine operation, collection or treatment of leachate from mine tailings, pit walls, or waste rock piles would be incomplete and could fail in various ways. In the routine operations scenario, leachate from the unlined TSFs and waste rock piles would not be fully collected. Equipment and operation failures and inadequate designs would also result in failures to avoid toxic emissions. Reviews of mine records found that 93% of operating porphyry copper mines in the United States reported a water collection or treatment failure (Earthworks 2012). Improved design and practices should result in lower failure rates, but given this record it is unlikely that failure rates would be lower than 10% over the life of a mine. During operation, failures should be brief (less than 1 week) unless they involve a faulty system design or parts that are difficult to replace. After a mine is abandoned (potentially many years after closure), water management would end and the discharge of untreated water would become inevitable but may not be problematic.

TSF spillway release. Releases of supernatant water from TSFs through spillways are unintended but are not uncommon (e.g., the release at Nixon Fork Mine described in Box 8-1). However, data on the frequency of such releases are unavailable. They are apparently sufficiently common that inclusion of a spillway in a tailings dam is a standard practice. Hence, it is judged likely that a release would occur over the 78-year life of the mine in the Pebble 6.5 scenario.

Culvert failure. Culvert failure is defined as a condition that blocks fish passage. Empirical data for culvert failures are not based on rates of failure of culverts but rather on instantaneous frequencies of culverts that were found to have failed in road surveys. The frequencies in recent surveys range from 0.30 to 0.61 (3 to 6×10^{-1}) per culvert. In the Kvichak River watershed, 35 streams that are believed to support salmonids (salmon, trout, or Dolly Varden) have culverts, so at any time 11 to 22 culverted streams would be expected to have blocked fish passage at the published frequencies. The proportion of failed culverts during mine operation should be much lower.

It is important to remember that this is an assessment of mine scenarios. It is based on modern conventional mining practices, especially the plan proposed for the Pebble site by Northern Dynasty Minerals (Ghaffari et al. 2011). However, like any predictive assessment, it is hypothetical. Although the major features of the scenarios will undoubtedly be correct (e.g., a pit at the location of the ore body, waste rock deposited near the pit, the generation of a large volume of tailings), some specifics would inevitably differ. This would be true of any scenario, including a mining plan submitted for permitting or even a plan approved by the state. All plans are scenarios, and although each new plan is expected to be closer to actual operations than the ones before, unforeseen circumstances and events and new technologies inevitably compel changes in practice.

14.1.2.1 Tailings Dam Failure

Failure of a tailings dam would have a one in 2,500 to one in 250,000 probability of occurrence per year for each TSF. Probability of a tailings dam failure increases with an increase in the number of dams. The Pebble 0.25 and Pebble 2.0 scenarios include one TSF, and the Pebble 6.5 scenario includes three. Two of these TSFs would have multiple dams. However, the probability of a spill from these TSFs would not increase in proportion to the number of dams for an individual TSF, because failures would not be independent events. The failure of one dam on a TSF would relieve pressure on others, reducing the probability of multiple failures; conversely, common mode failures could occur, increasing the probability of multiple failures. The dam failure analyses in this assessment simulated the release of 20% of the tailings (a conservative estimate) from the failure of a 92-m (Pebble 0.25) and a 209-m (Pebble 2.0) dam at TSF 1.

Failure of the TSF 1 dam would result in the release of a flood of tailings slurry into the North Fork Koktuli River, scouring the valley and depositing tailings. The complete loss of suitable salmonid habitat in the North Fork Koktuli River (29 km of habitat in the Pebble 0.25 scenario and more than 30 km, our model limit, in the Pebble 2.0 scenario) in the short-term (less than 10 years). The high likelihood of very low-quality spawning and rearing habitat in the long-term (decades) would result in the nearly complete loss of mainstem North Fork Koktuli River fish populations below the dam. Even salmon at sea during the failure would not find suitable spawning habitat on their return to the North Fork Koktuli River as adults. The river currently supports spawning and rearing populations of sockeye, Chinook, and coho salmon, spawning populations of chum salmon, and rearing populations of Dolly Varden and rainbow trout. Suspended mine tailings sediments would continue for an unknown (due to model and data limitations) distance farther down the Koktuli River, and probably into the Mulchatna and Nushagak Rivers, causing degraded spawning habitat and reduced food resources. Fish anywhere in the flowpath below a tailings dam failure would be killed or forced downstream. Fish migrating into tributaries of affected rivers would be inhibited from migration for some period of time, which our model could not predict.

Following the slurry flood, deposited tailings would continue to erode from the North Fork Koktuli and Koktuli River valleys. After many years, a new channel with gravel substrate and a natural floodplain structure would become established. However, that recovery would come at the expense of the downstream Mulchatna and Nushagak Rivers, as much of the spilled tailings initially deposited in the North Fork Koktuli and Koktuli Rivers would be resuspended by erosion and transported down the drainage. This process could not be modeled with existing data and resources, but would be inevitable if a tailings spill occurred.

High concentrations of suspended tailings would occur following a tailings dam failure, but over time they would decline as erosion progressed. For some years, periods of high streamflow would be expected to suspend sufficient concentrations of tailings to cause avoidance, reduced growth and fecundity, and possibly even death of fish. Migration to and from any affected tributaries would be impeded if streamflow from the tributaries was not sufficient to adequately dilute suspended sediment concentrations, meaning that fish would not reach spawning grounds, winter refugia, or seasonal feeding habitats.

Deposited tailings would degrade habitat quality for both fish and the invertebrates they eat. Pacific salmon, Dolly Varden, and rainbow trout spawn in gravels, and their eggs and larvae require sufficient space within the gravel for water to circulate. Juvenile salmonids require even larger clear spaces for concealment from predators and for overwintering habitat. Tailings would fill those interstitial spaces. An increase in fines of more than 5% causes detectable effects on salmonid reproduction. Until considerable erosion occurred and a gravel-bedded channel was re-established, female salmonids would be unable to clean the gravel to spawn. Even where gravel was available, high deposition from upstream erosion of tailings could smother eggs and larvae. Recovery of suitable substrates via mobilization and transport of tailings fines would take decades, and would affect much of the watershed downstream of the failed dam.

In addition to degrading fish habitat, deposited tailings would be potentially toxic. Based largely on their copper content, deposited tailings would be toxic to benthic macroinvertebrates, although existing data concerning fish toxicity is less clear. Estimated pore water concentrations are below published thresholds for chronic effects in fish, but directly relevant tests of salmonid early life stages have not been conducted. The combined effects of copper toxicity and poor habitat quality (particularly low dissolved oxygen concentrations) caused by fine sediment are unknown. Dietary exposures of salmonids via invertebrate prey exposed to tailings are estimated to be marginally toxic.

In sum, a TSF 1 dam failure would have severe direct and indirect effects on aquatic resources, and specifically on salmonids. In the short-term (less than 10 years), certainly the North Fork Koktuli River below the TSF 1 dam failure location and very likely much of the Koktuli River would not support salmonids. For a period of decades, those waters would provide very low-quality spawning and rearing habitat, likely resulting in the nearly complete loss of North Fork Koktuli River fish populations. Deposition, resuspension, and redeposition of tailings would likely cause serious habitat degradation in the Koktuli River and downstream into the Mulchatna River. Ultimately, spring floods and stormflows would carry some portion of the tailings into the Nushagak River. Effects would be qualitatively the same for both the Pebble 0.25 and Pebble 2.0 dam failures, although effects from the Pebble 2.0 dam failure would extend farther and last longer.

The Koktuli River watershed is an important producer of Chinook salmon for the larger Nushagak Management Zone. The Nushagak River watershed is the largest producer of Chinook salmon in the Bristol Bay region, with an average annual escapement of nearly 190,000 Chinook salmon from 2002 through 2011 (Buck et al. 2012). Assuming Alaska Department of Fish and Game aerial survey counts (Dye and Schwanke 2009) reflect the proportional distribution of Chinook salmon within the Nushagak River watershed, the tailings dam failure would eliminate 29% of that run due to loss of the Koktuli River salmon population; an additional 10 to 20% could be lost because tailings deposited in the Mulchatna River would affect its tributaries. Sockeye salmon are the most abundant salmon returning to the Nushagak River watershed, with annual runs averaging more than 1.9 million fish. However, the proportion of sockeye and other salmon species that originates in the Koktuli and Mulchatna River watersheds is unknown. Similarly, populations of rainbow trout and Dolly Varden of unknown size would be lost for decades.

Remediation of a tailings spill would be difficult and problematic. The affected area is roadless, and the rivers are too small to float a dredge. If the spill occurred after mine closure, people and equipment to repair the dam and begin remediation would be absent. Remediation may be slow to start due to the need to develop a plan, create a facility to receive the recovered tailings, build roads, and bring in personnel and equipment. Even in the Pebble 0.25 dam failure, complete removal of this material would require a substantial earth-moving effort, including over 3 million round trips by 20-ton dump trucks. Dredging tailings from rivers and streams would cause considerable habitat damage.

The dam failures evaluated in the assessment used TSF 1 as a plausible location. Failure of the other tailings dams at TSF 2 and TSF 3 were not modeled, but would have similar types of effects in the South Fork Koktuli River and downstream.

14.1.2.2 Wastewater Treatment Plant Failure

In the WWTP failure scenario, untreated wastewater would be discharged. The most severe effects, including lethality to invertebrates and fish, would occur in the South Fork Koktuli River where untreated effluent would mix with toxic waste rock leachate. The North Fork Koktuli River, where the untreated waste would mix with tailings leachate, would experience lethality to invertebrates and, depending on the season, reduced growth or survival of early fish life stages. In this scenario, Upper Talarik Creek would receive no wastewater discharge and would experience no additional effects. The WWTP failure is estimated to result in lethality or reduced reproduction of invertebrates in 78 to 100 km of streams in all three mine sizes. For salmonids, it is estimated to cause avoidance of 74 to 97 km of streams, sensory inhibition in 70 to 92 km, reduced reproduction in 61 to 84 km, and mortality in 31 km in the Pebble 6.5 scenario. Direct effects on fish would be less extensive in the Pebble 2.0 scenario, with avoidance in 64 to 87 km, sensory inhibition in 27 km, reduced reproduction in 11 km, and kills in 3.8 km—and would be limited to avoidance in 27 km of streams in the Pebble 0.25 scenario.

14.1.2.3 Culvert Failure

The most likely serious failure associated with the potential transportation corridor would be blockage or failure of culverts. Culverts commonly fail to allow fish passage. They can become blocked by debris or ice that may not stop water flow but that create a barrier to fish movement. Fish passage also may be blocked or inhibited by erosion below a culvert that "perches" the culvert and creates a waterfall, by shallow water caused by a wide culvert and periodic low streamflows, or by excessively high channel gradients. If blockages occurred during adult salmon immigration or juvenile salmon emigration and were not cleared for several days, production of a year-class (i.e., fish spawned in the same year) would be lost from or diminished in the stream above the culvert.

Culverts can also fail to convey water due to landslides or, more commonly, floods that wash out undersized or improperly installed culverts. In such failures, the stream would be temporarily impassible to fish until the culvert is repaired or until erosion re-establishes the channel. If the failure occurs during a critical period in salmon migration, effects would be the same as with a debris blockage (i.e., a lost or diminished year-class).

Culvert failures also would result in the downstream transport and deposition of sediment. This could cause returning salmonids to avoid the stream, if they arrived during or immediately following the failure. More likely, the deposition of fine sediment from the washed-out culvert would smother salmonid eggs and larvae, if they were present, and would degrade the downstream habitat for salmonids and the invertebrates that they eat. It would also change stream hydraulics and channel morphology, generally diminishing habitat value.

Blockage of fish passage at road crossings would be infrequent during operation, because our scenarios assume daily inspection and maintenance. However, after mine operations end, the road may be maintained less carefully or maintenance may be transferred to a state or a local governmental entity. In that case, the proportion of culverts that are impassable would be expected to revert to the levels found in published surveys (30 to 61% inhibit fish passage at any time) (Langill and Zamora 2002, Gibson et al. 2005, Price et al. 2010). Of the 45 culverts that would be required, 36 would be on streams that are believed to support salmonids. Hence, 11 to 22 streams would be expected to lose passage of salmon or resident trout or Dolly Varden and some proportion of those would have degraded downstream habitat resulting from sedimentation caused by road washout.

Of the 36 culverted salmonid streams, 32 contain restricted (less than 5.5 km) upstream habitat. Assuming typical maintenance practices after mine operations, approximately 10 to 19 of the 32 streams would be entirely or partially blocked at any time. As a result, isolation of resident species such as rainbow trout or Dolly Varden in such short stream segments would likely result in failure of the populations, if that isolation was sustained.

It should be noted that high streamflows in and immediately downstream of a culvert and the structure of the culvert may inhibit fish passage even if movement is not blocked. Culvert-induced erosion could cause channel entrenchment, disrupting floodplain habitat and floodplain/channel ecosystem processes.

14.1.2.4 Truck Accidents

Trucks would carry ore-processing chemicals to the mine site and molybdenum product concentrate to the port. Truck accident records indicate that truck accidents near streams are likely over the long period of mine operation. These accidents could release sodium ethyl xanthate, cyanide, other process chemicals, or molybdenum product concentrate to streams or wetlands, resulting in toxic effects on invertebrates and fish. However, the risk of spills could be mitigated by using impact-resistant containers.

14.1.2.5 Pipeline Failure

The primary product of the mine would be a copper concentrate that would be pumped as a slurry in a pipeline to a Cook Inlet shipping facility. Water that carried the sand-like concentrate would be returned to the mine site in a second pipeline. Based on the record of pipelines in general, and metal concentrate pipelines in particular, one near-stream failure and two near-wetland failures of each of these pipelines would be expected to occur over the duration of the Pebble 6.5 scenario (approximately 78 years). In either case, metal-contaminated water would be released, potentially killing fish and invertebrates in the affected stream over a relatively brief period. The aqueous phase of the concentrate slurry would be lethal to sensitive invertebrates and potentially to fish larvae, but a kill of adult fish is not expected. If the concentrate pipeline spilled into a stream, concentrate would, depending on streamflows, settle and form bed sediment, be carried downstream and deposited in low-velocity areas, or be carried to Iliamna Lake and deposited near the shore. Deposited concentrate is predicted to be highly toxic based on its high copper content and the acidity of its leachate. Unless the receiving stream was dredged, causing physical damage, this sediment would persist for decades before ultimately being washed into Iliamna Lake. Potential concentrations in the lake could not be predicted; however, near the pipeline route, Iliamna Lake contains important beach spawning areas for sockeye salmon that could be exposed to a spill. Sockeye also spawn in the lower reaches of streams that could be directly contaminated by a spill.

Spills from a diesel pipeline are estimated to have the same probability of occurrence as concentrate spills. Based on multiple lines of evidence, a spill in the diesel pipeline failure scenario would be sufficient to kill invertebrates and possibly fish. Remediation is expected to have little success, but recovery would likely occur within 3 years.

14.1.2.6 Common Mode Failures

Multiple failures could result from a common event, such as an earthquake or a severe storm with heavy precipitation (particularly heavy rain on snow). Failures resulting from such an event could include multiple tailings dam failures that spill tailings slurry to streams and rivers, road culvert washouts that send fine sediment downstream and potentially block fish passage, and product slurry and return water pipeline failures resulting from culvert washout and scouring of the streambed or a slide of the roadbed. The effects of these accidents individually would be the same as discussed previously, but the co-occurrence of these failures would cause cumulative effects on salmonid populations and would make any mitigative response more difficult.

Over the perpetual timeframe that the tailings, mine pit, road, and waste rock piles would be in place, the likelihood of multiple extreme precipitation events, earthquakes, or combinations of these events becomes much greater. Multiple events further increase the chances of weakening and eventual failure of facilities that are still in place.

14.2 Overall Loss of Wetlands, Ponds, and Lakes

Wetlands are a dominant feature of the landscape in the Pebble deposit area and are important habitats for salmon and other fish. Ponds and riparian wetlands provide spawning, rearing, and refuge habitat for both anadromous and resident fish. Other wetlands moderate streamflows and water quality, and can influence downstream delivery of dissolved organic matter, particulate organic matter, and aquatic macroinvertebrates that supply energy sources to fish. In the Pebble 0.25, 2.5, and 6.5 scenarios, 4.5, 12, and 18 km^2 of wetlands and 0.41, 0.93, and 1.8 km^2 of ponds and lakes, respectively, would be filled or excavated. In addition, an unquantifiable area of riparian floodplain would be lost or would suffer substantial changes in hydrologic connectivity with streams, due to reduced flow from the mine footprint. Another 0.11 km^2 of wetlands would be filled in the Kvichak River watershed by the roadbed of the transportation corridor. By interrupting flow and adding silt and salts, the roadbed would also influence approximately 4.7 km^2 of wetlands, ponds, and lakes occurring within 200 m of the roadbed. Finally, a diesel or product concentrate spill could damage wetlands and eliminate or degrade their capacity to support fish.

14.3 Overall Fish-Mediated Risk to Wildlife

Interactions between salmon and wildlife and the potential for disruption of these interactions are complex. Annual salmon runs provide food for brown bears, bald eagles, other land birds, and wolves. In addition, wildlife abundance and production are enhanced by the marine-derived nutrients that salmon carry on their spawning migration. Those nutrients are released into streams when the salmon die, enhancing the production of other aquatic species that feed wildlife. Salmon predators deposit nutrients on the landscape, fertilizing the vegetation and increasing the abundance and production of moose, caribou, and other wildlife.

The effects of reduced Pacific salmon, Dolly Varden, and rainbow trout production on wildlife would be complex, may not be linearly proportional, and cannot be quantified at this time. Factors such as the magnitude, seasonality, duration, and location of salmon losses would determine the specific species affected and the magnitude of effects. However, some degree of reduction in wildlife would be expected due to the mine footprint and routine operations in each mine size scenario. Because salmon provide a food source for brown bears, wolves, bald eagles, and other birds, it is likely these species would be directly affected by a reduction in salmon abundance. Indirect effects on water birds and land birds through a loss of aquatic invertebrates and on moose and caribou through a loss of marine-derived nutrients to vegetation are likely, but research is needed to document those linkages.

Fish-eating wildlife species are also potentially exposed to contaminants bioaccumulated by fish. However, analyses based on the concentrations of metals in waste rock, tailings, and product concentrate leachates suggest that toxic effects to wildlife via this route of exposure are unlikely.

14.4 Overall Fish-Mediated Risk to Alaska Native Cultures

Alaska Natives are particularly vulnerable to any changes in the quantity or quality of wild salmon resources, due to the importance of salmon in terms of both subsistence and cultural identity. Any change in salmon resources would likely change the diet, social networks, cultural cohesion, and spiritual well-being of the Alaska Native cultures in the region. These changes could, in turn, result in the following.

- Effects on human health from loss of a highly nutritious subsistence food and the physical and mental benefits of a subsistence way of life.
- Degradation of a social support system based on food sharing.
- Decrease in family cohesion and cultural continuity from a loss of family-based subsistence work.
- Mental health degradation from the disruption of spiritual practices and beliefs centered on salmon and clean water.

Human health and cultural effects related to decreases in salmon resources would vary with the magnitude of these reductions and cannot be predicted quantitatively. Some fish-mediated effects on Alaska Native cultures are likely due to the mine footprint or routine operations in any of the mine size scenarios considered. At minimum, there would be a loss of subsistence use areas and the risk of decreased use of fish because of a perceived change in quality of the fish due to mine operations. Along the transportation corridor, complex and unpredictable changes to subsistence use would result from increased access (by both Alaska Natives and others) and possible habitat changes. If significant failures of water treatment or other infrastructure that greatly affect salmon resources occur during or after mine operation, large-scale impacts on both subsistence food resources and the cultural, social, and spiritual cohesion of the local indigenous cultures would occur.

Because the Alaska Native cultures in the Bristol Bay watershed have significant ties to specific land and water resources that have evolved over thousands of years, it is not possible to replace the value of any subsistence use areas lost to mine operations elsewhere. As a result, compensatory mitigation, restoration, or replacement in the case of a failure would be difficult, if not impossible.

It should be noted that, although this assessment focuses on potential effects on Alaska Native cultures, many of the non-Alaska Natives that reside in the area also practice a subsistence way of life and have strong long-term cultural ties to the landscape that go back generations. In addition, a large group of seasonal commercial fishers and cannery workers depend on these resources and have strong, multi-generational cultural connections to the region. These groups also would be vulnerable to negative impacts on salmon.

14.5 Summary of Uncertainties and Limitations in the Assessment

This assessment makes various reasonable assumptions about the mining, processing, and transporting of the porphyry copper resources in the Pebble deposit and elsewhere in the Nushagak and Kvichak River watersheds. If those resources are mined in the future, actual events would not be identical to the mine scenarios considered here. This is not treated as a source of uncertainty, because it is an inherent aspect of any predictive assessment. Even an environmental assessment of a mining company's proposed plan would be an assessment of a scenario that undoubtedly would differ from actual events.

As discussed in the individual chapters, this assessment does have uncertainties and limitations in the extent to which the potential effects of these scenarios can be estimated. Major uncertainties are summarized below.

- The estimated annual probability of a tailings dam failure is uncertain and based on design goals rather than historical experience. Actual failure rates could be higher or lower than the estimated range of probabilities.
- The proportion of the tailings that would spill in the event of a dam failure could be larger than the largest value modeled (20%). However, even this conservative assumption results in an initial outflow beyond the 30-km limit of the model in the Pebble 2.0 dam failure scenario.
- The ultimate fate of spilled and deposited tailings in the event of a dam failure could not be quantified. From principles of geohydrology and review of analogous cases, we know that slurry would erode from areas of initial deposition and move downstream over more than a decade. However, the data needed to model that process and the resources to develop the model are not currently available.
- It is uncertain whether and how a tailings spill into a remote roadless area would be remediated, how long it would take to remediate, and to what extent remediation could reduce effects downstream of the initial slurry runout.
- The effects of mining on fish populations could not be quantified because of the lack of quantitative information concerning Pacific salmon, Dolly Varden, and rainbow trout populations and their responses. The occurrence of salmonid species in the region's rivers and major streams is generally known, but not their abundances, productivities, or limiting factors. Estimating changes in populations would require population modeling, which requires knowledge of life-stage-specific survival and production as well as knowledge of limiting factors and processes that were not available for this case. Further, it requires knowledge of how temperature, habitat structure, prey availability, density dependence, and sublethal toxicity influence life-stage-specific survival and production, which is not available. Obtaining that information would require more detailed monitoring and experimentation. Salmon populations naturally vary in size because of a great many factors that vary among locations and years, and collecting sufficient data to establish reliable

salmon population estimates takes many years. Thus, we used estimated effects of mining on habitat as a reasonable surrogate for estimated effects on fish populations.

- Standard leaching test data are available for test tailings and waste rocks from the Pebble deposit, but these results are uncertain predictors of the actual leachate composition from a tailings impoundment, tailings deposited in streams and on their floodplains, and waste rocks piles. Test conditions are artificial, and the materials tested may not be representative. In particular, the pyritic tailings were not tested. Additionally, data and resources were insufficient to allow geochemical modeling of water quality expected in the TSF or downstream of the mine site under varied chemical and hydrological conditions, or to model expected pit water chemistry at closure.
- The effects of tailings and product concentrate deposited in spawning and rearing habitat are uncertain. It is clear that they would be harmful to salmonid eggs, alevins, or sheltering fry due to both physical and toxicological effects, but the concentration in spawning gravels required to reduce reproductive success of salmonids is unknown.
- The actual response of Alaska Native cultures to any of these scenarios is uncertain. Interviews with tribal Elders and culture bearers and other evidence suggest that responses would involve loss of food resources and cultural disruption, but it is not possible to predict specific changes in demographics, cultural practices, or physical and mental health.
- Although some tailings would eventually reach the estuarine portions of the Nushagak River and even Bristol Bay, exposures at that distance could not be estimated. Therefore, risks to salmonids resulting from marine and estuarine contamination could not be addressed.
- The assessment is limited by its focus on the effects of mining on salmonids and consequent indirect effects of diminished fish resources on wildlife and people. Direct effects of mining on humans, wildlife, and terrestrial ecosystems, as well as induced development associated with mine-related activities, are not evaluated in this assessment.
- Some sources, such as air pollution from a power plant, were not addressed because they are less related to the Clean Water Act or because they were judged to pose less risk to salmonids.
- Climate change will affect both the probability and magnitude of mine-related failures, as well as change the habitat quality and biology of salmonids. These climate effects are highly uncertain, but their likely qualitative influences are described in Box 14-2.

BOX 14-2. CLIMATE CHANGE AND POTENTIAL RISKS OF LARGE-SCALE MINING

Climate change in the Bristol Bay region (Section 3.8) will likely result in changes in snowpack and the timing of snowmelt, a greater chance for rain-on-snow events, and an increase in flooding. These changes are likely to affect multiple aspects of any large-scale mining in the area, including mine infrastructure, the transportation corridor, water treatment and discharge, and post-closure management (Pearce et al. 2011).

Mine infrastructure (e.g., buildings, waste rock piles, tailings storage facilities [TSFs], and water retention facilities) and the transportation corridor likely would be affected by extreme weather events resulting in increased flooding (Instanes et al. 2005, Pearce et al. 2011). These components would need to be designed for potential increases in flood frequency and magnitude and changes in storm patterns, because these changes could weaken structural integrity, increase embankment instability, and accelerate erosion (Instanes et al. 2005, Pearce et al. 2011).

Water management would be a major challenge at the mine site, and changes resulting from climate change could exacerbate the challenge. Climate change would contribute to future changes in temperature, precipitation, evapotranspiration, hydrology, and seasonal flooding and drying patterns. Changes in water availability and groundwater recharge would affect the amount and timing of water available and the hydrologic gradients of groundwater in and around the mine site, thereby requiring changes to water management in the mine pit and other areas of the mine site.

Under future climate conditions, the return intervals of various sized storms could change (e.g., medium-sized storms could become more frequent or the frequency of current 100-year storms could change). Possible increases in flood magnitudes would require the need to plan for larger and more frequent flood events at the mine site. This in turn may affect the likelihood of a tailings dam failure, overtopping of ponds, and/or flooding of water management facilities. Failure to plan for these conditions could result in unintended environmental releases. For example, Minto Mine, a copper-gold mine in Canada, was forced to release untreated water into the Yukon River system in 2008, due to torrential rains and the mine's inability to manage this increased water (Pearce et al. 2011).

Mine infrastructure would need to be designed to account for projected climatic changes, such that its structural integrity can be maintained in perpetuity, even under potentially more extreme climatic conditions. In addition, any mine reclamation plan would need to consider changing climate conditions and how those changes will directly affect fish and wildlife populations. The following list includes infrastructure and operations design, maintenance, and management that would need to consider climate change.

- **Mine footprint.** Climate change may affect water availability both within and across seasons (e.g., via changes in snowmelt patterns; amount, type, and timing of precipitation; frequency of large storms; and groundwater inputs). Water processing associated with these changes would alter flow and temperature in downstream water bodies.
- **Water treatment and discharge.** Climate change might result in greater volumes of water requiring treatment, changes in the dilution provided by receiving streams, changes in temperature that would affect management of discharged water, and potential overload due to lack of storage and treatment capacity.
- **TSF failure.** TSFs may be exposed to greater volumes of water, and the probability of dam failure due to overtopping may increase with changes in precipitation patterns and/or rapid snowmelt.
- **Transportation corridor.** Greater flood frequencies and an increase in erosion and sedimentation are likely to affect streams and wetlands along the transportation corridor.
- **Culvert, pipeline, and bridge failures.** These failures may be more likely due to changes in precipitation patterns, rapid snowmelt, larger water volumes, debris issues, and sedimentation.
- **Cumulative effects of multiple mines.** Climate change issues are likely to affect any mining operation in the area. As the number of mines increases, the likelihood of having mine and climate change interactions might increase.

Climate change could obscure or complicate efforts to monitor habitat and fish population responses to mine-related activities. Survey and monitoring designs would need to take potential climate change effects into account through strategic measurement of stream and lake temperatures, precipitation, water flow, and fish populations throughout the Bristol Bay watershed. Monitoring design could be aided by models able to downscale climate effects and project changes at watershed scales. Population monitoring should take salmon adaptation and metapopulation dynamics into account, and be cognizant of the many interacting processes influencing populations. Protecting salmon sustainability in an uncertain future will require adaptability of both management and monitoring strategies (Schindler et al. 2008).

14.6 Summary of Uncertainties in Mine Design and Operation

In addition to uncertainties in the assessment, uncertainties are inherent in planning, designing, constructing, operating, and closing a mine. Such uncertainties are inherent in any complex enterprise, particularly when it involves an incompletely characterized natural system. However, the large scales and long durations of any effort to mine the Pebble deposit make these inherent uncertainties more prominent.

- Mines are complex systems requiring skilled engineering, design, and operation. The uncertainties facing mining and geotechnical engineers include unknown geological features, uncertain values in geological properties, limited knowledge of mechanisms and processes at the site, and human error in design, construction, and operation. Vick (2002) notes that models used to predict the behavior of an engineered system are "idealizations of the processes they are taken to represent, and it is well recognized that the necessary simplifications and approximations can introduce error in the model." Engineers use professional judgment in addressing uncertainty (Vick 2002).
- Accidents are inherently unpredictable. Though systems can be put into place to reduce system failures, seemingly logical decisions about how to respond to a given situation can have unexpected consequences resulting from human error—for example, the January 2012 overtopping of the tailings dam at the Nixon Fork Mine near McGrath, Alaska (Box 8-1). Further, unforeseen events or events that are more extreme than anticipated can negate the apparent wisdom of prior decisions (Caldwell and Charlebois 2010).
- The ore deposit would be mined for decades, and wastes would require management for centuries or even in perpetuity. Engineered mine waste storage systems have only been in existence for about 50 years, so their long-term behavior is not known. The performance of modern technology in the construction of tailings dams is untested and unknown in the face of centuries of extreme events such as earthquakes and major storms.
- Human institutions change. Over the long time span of mining and post-mining care, generations of mine operators must exercise due diligence. Priorities are likely to change in the face of financial crises, changing markets for metals, new information about the resource, political priorities, or any number of currently unforeseeable changes in circumstance. The promises of today's mine developers may not be carried through by future generations of operators whose sole obligation is to the shareholders of their time (Blight 2010). Similarly, governments that are expected to assume responsibility when mining companies fail may not appropriately manage mine sites or the funds in performance bonds.

14.7 Summary of Risks in the Mine Scenarios

Even if the mining and mitigation practices described in the mine scenarios were performed perfectly, an operation of this size would inevitably destroy or degrade habitat of salmonids. The mine scenario footprints would eliminate, block, or dewater streams known to support spawning and rearing habitat for coho, Chinook, and sockeye salmon and Dolly Varden (Table 14-2). Wetlands would be filled or excavated in 4.5, 12, and 18 km^2 of the mine footprints in the Pebble 0.25, 2.0, and 6.5 scenarios, respectively; an additional 0.41, 0.93, and 1.8 km^2 of ponds and lakes would also be lost. Altered streamflows resulting from water use would significantly degrade additional stream reaches (Table 14-2) and an unquantifiable area of wetland habitat. Leachates and other wastewater would be collected and treated to meet standards, but leakage would be sufficient to cause direct toxic effects to fish in up to 57 km of streams and indirect effects due to loss of invertebrate food species in up to 82 km of streams (Table 14-2). In addition, the temperature and distribution of effluents could further degrade habitat. Streams between the transportation corridor and Iliamna Lake would receive silt and deicing chemicals, which would reduce habitat quality.

Table 14-2. Summary of estimated stream lengths potentially affected in the three mine size scenarios, assuming routine operations.

Effect	Stream Length Affected (km)		
	Pebble 0.25	Pebble 2.0	Pebble 6.5
Eliminated, blocked, or dewatered	38	89	151
Eliminated, blocked, or dewatered—anadromous	8	22	36
>20% flow alteration[a]	15	27	53
Direct toxicity to fish[a]	0	24	34–57
Direct toxicity to invertebrates[a]	21	40–62	60–82
Downstream of transportation corridor	272		

Notes:
[a] Stream reaches with streamflow alterations partially overlap those with toxicity.

This assessment considered failures of a tailings dam; product concentrate, return water, and diesel pipelines; roads and culverts; and water collection and treatment. Tailings dam failures are improbable in that they have a low rate of occurrence, but some sort of failure becomes likely in the extremely long-term. A tailings dam failure could destroy salmonid habitat in more than 30 km of the North Fork Koktuli River and associated wetlands for years to decades. Product concentrate and diesel pipeline failures near streams would be expected to occur during the life of a mine. Both would cause acute lethal effects on invertebrates and fish, and the concentrate could create highly toxic sediment. A truck wreck near a stream could introduce highly toxic chemicals causing acute lethality to fish and invertebrates. Culvert failures would be common, unless a more rigorous than usual maintenance program were maintained, and could block fish passage and degrade downstream habitat. Failures to collect and treat leachates and other wastewaters could cause releases ranging from short-term and innocuous to long-term and highly toxic to fish and invertebrates.

14.8 Summary of Cumulative Risks of Multiple Mines

To provide realism and detail, this assessment largely addresses the potential effects of a single mine, at three different sizes, on the Pebble deposit. However, the development of multiple mines of various sizes is plausible in the Nushagak and Kvichak River watersheds. Several known mineral deposits with potentially significant resources are located in the two watersheds, and active exploration is underway at a number of claim blocks. The construction of roads, pipelines, and other infrastructure for one mine would likely facilitate the development of additional mines. Thus, the development of multiple mines and their associated infrastructure may affect fish populations, wildlife, and Alaska Native villages distributed across these watersheds.

Outside of the Bristol Bay watershed, most ecosystems that support Pacific salmon have been modified by the cumulative effects of multiple land and water uses. Anadromous fish are particularly susceptible to regional-scale effects, because they require suitable habitat in spawning areas, rearing areas, and along migration corridors. Because Pacific salmon, Dolly Varden, and rainbow trout migrate among freshwater habitats seasonally or between life stages, loss or degradation of habitat in one location can diminish the ability of other locations to support these species. As a result of their particular susceptibility, anadromous salmonid fisheries have declined in most of their range due to the combined effects of habitat loss and degradation, pollution, and harvesting.

The Nushagak and Kvichak River watersheds are relatively undisturbed, and their ecosystems have not yet experienced these cumulative stresses associated with human activity. Bristol Bay salmon runs are resilient because the abundance, diversity, and quality of Bristol Bay habitats result in large and diverse salmon populations. Fluctuations in habitat availability or quality across the watersheds caused by natural processes typically result in temporary loss or reduction of a discrete portion of habitat, but these fluctuations are compensated for by Bristol Bay's diverse salmon populations. In contrast, the effects of mining may be long-lasting and extensive, eliminating habitat for extended periods and potentially killing or otherwise eliminating fish populations. Such effects may remove component populations permanently or for long periods of time, weakening the overall population's ability to resist and rebound from disturbance.

To examine the potential cumulative risks of multiple mines, we consider development of additional mines at the Pebble South/PEB, Big Chunk South, Big Chunk North, Groundhog, AUDN/Iliamna, and Humble prospects. The AUDN/Iliamna and Humble prospects are located approximately 90 and 135 km, respectively, southwest of the Pebble deposit. All of the other prospects are within 25 km of the Pebble deposit and may be of the same geological origin. Construction of mining infrastructure at the Pebble deposit would substantially reduce development costs for surrounding prospects and could facilitate creation of a mining district that could include these sites.

Impacts from the footprint of major mine components and associated accidents and failures would be similar to those projected in the mine scenarios. The footprints of the major mine components would eliminate substantial amounts of stream and wetland habitats, both directly and through dewatering. Total stream length eliminated by these components would range from 43 to 70 km, and wetland area lost would range from 7.9 to 27 km^2. Further habitat loss and degradation would result from flow alteration. Each additional mine would increase flow alteration from water removal and retention, increased impervious surface, and road crossings.

The consequences of leachate collection or treatment failure would depend on the chemical nature of the rock or tailings over which it flows. Because porphyry copper deposits tend to straddle the threshold between acid-generating and non-acid-generating, some of the waste rock and a portion of the tailings at any of these additional mines would be reasonably likely to be acid-generating. Each additional facility would increase the likelihood of collection and treatment failures, which would increase the frequency of discharge of untreated leachate or other wastewater in the Nushagak and Kvichak River watersheds, with each event resulting in an increment of impact. Longer roads and pipelines associated with additional mines, coupled with a greater number of stream crossings, would increase the frequency of events such as culvert failures, pipeline breaks, and truck accidents that would damage aquatic systems, incrementally decreasing habitat value over an extensive area. In the long-term, cessation of maintenance and treatment would likely result in the degradation of fisheries in waters downstream of each mine. Extreme natural events such as earthquakes and floods could cause failures of dams, roads, pipelines, or WWTPs at multiple mines.

Induced development is that which results from the introduction of industry, roads, and infrastructure. It is reasonably foreseeable that infrastructure from large-scale mining in the Nushagak and Kvichak River watersheds, particularly the transportation corridors, would induce further development in the region. Existing communities, the tourism industry, and the recreational housing market could benefit if large-scale mining expanded throughout the watersheds. Unmanaged access to currently roadless wilderness areas also could expand. Improved access would increase hunting and fishing pressure, as well as competition with existing subsistence users; increase damage from off-road vehicle, boat, and foot traffic in currently inaccessible areas; facilitate poaching, dumping, trespassing, and other activities; and lead to scattered development in the watersheds.