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An Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska

Executive Summary

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Tributary of Napotoli Creek, near the Humble claim Photo: Michael Wiedmer

Executive Summary

The Bristol Bay watershed in southwestern Alaska supports the largest sockeye salmon fishery in the world, is home to 25 Federally Recognized Tribal Governments, and contains large mineral resources. The potential for large-scale mining activities in the watershed has raised concerns about the impact of mining on the sustainability of Bristol Bay's world-class fisheries, and the future of Alaska Native tribes in the watershed who have maintained a salmon-based culture and subsistence-based lifestyle for at least 4,000 years. The U.S. Environmental Protection Agency (USEPA) launched this assessment to determine the significance of Bristol Bay's ecological resources and evaluate the potential impacts of large-scale mining on these resources. The USEPA will use the results of this assessment to inform the consideration of options consistent with its role under the Clean Water Act. The assessment is intended to provide a scientific and technical foundation for future decision making; the USEPA will not address use of its regulatory authority until the assessment becomes final and has made no judgment about whether to use that authority at this time.

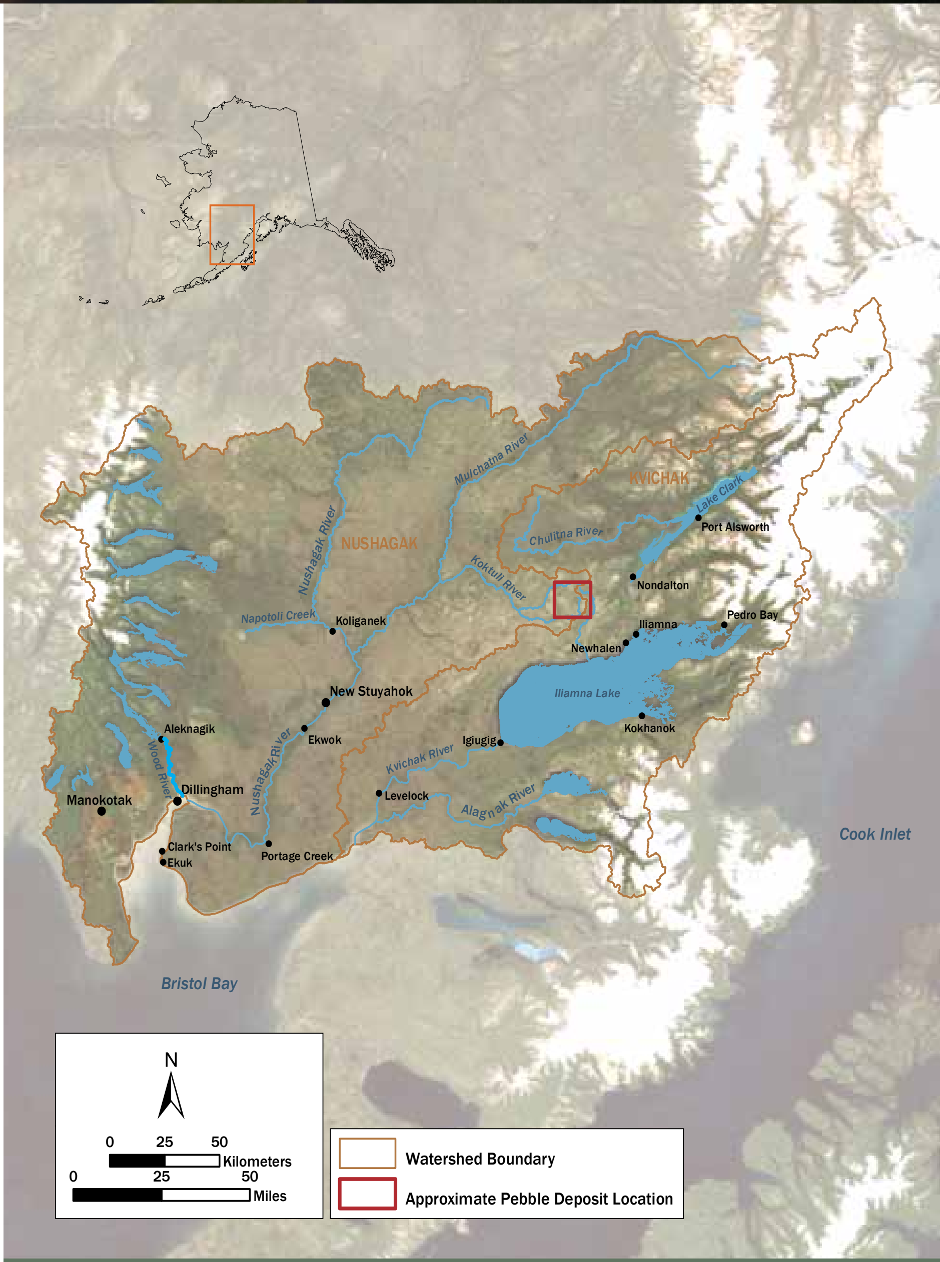
In addition to informing future USEPA actions, this report is of potential use to other federal and state government entities with an interest in mining in the Bristol Bay region. It is also of interest to both proponents and opponents of mining. By providing an unbiased assessment of potential risks, this assessment informs an active debate concerning the risks of mining development to the sustainability of the Bristol Bay salmon fishery.

The Lower Nushagak River between Portage Creek and Ekwok Photo: Michael Wiedmer (ADFG)

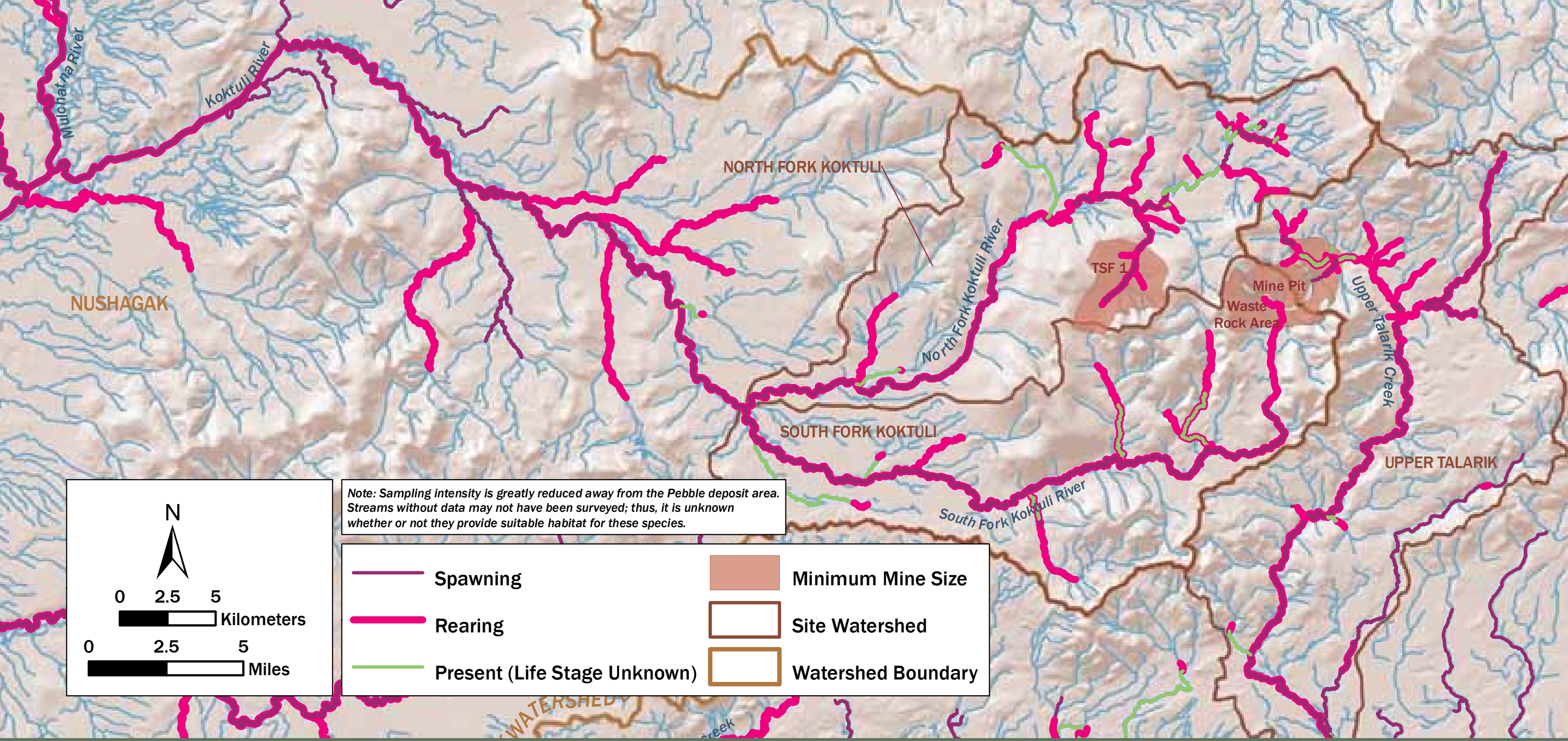
Scope of the Assessment

This assessment reviews, analyzes, and synthesizes available information on the potential impacts of large-scale mining development on Bristol Bay fisheries and subsequent effects on the wildlife and Alaska Native cultures of the region. The primary focus of the assessment is the quality, quantity, and genetic diversity of salmonid fish. Because wildlife and Alaska Native cultures in Bristol Bay are intimately connected and dependent upon fish, the quantity and diversity of wildlife and the culture and human welfare of indigenous peoples, as affected by changes in the fisheries are additional endpoints of the assessment.

The geographic scope of the assessment is the Nushagak River and Kvichak River watersheds. These are the largest of the Bristol Bay watershed's six major river basins and compose about 50% of the total watershed area. These two watersheds are also identified as mineral development areas by the State of Alaska. The Pebble deposit, the most likely site for near-term large-scale mining development in the region, is located at the intersection of the Nushagak River and Kvichak River



The Nushagak River and Kvichak River Watersheds of Bristol Bay

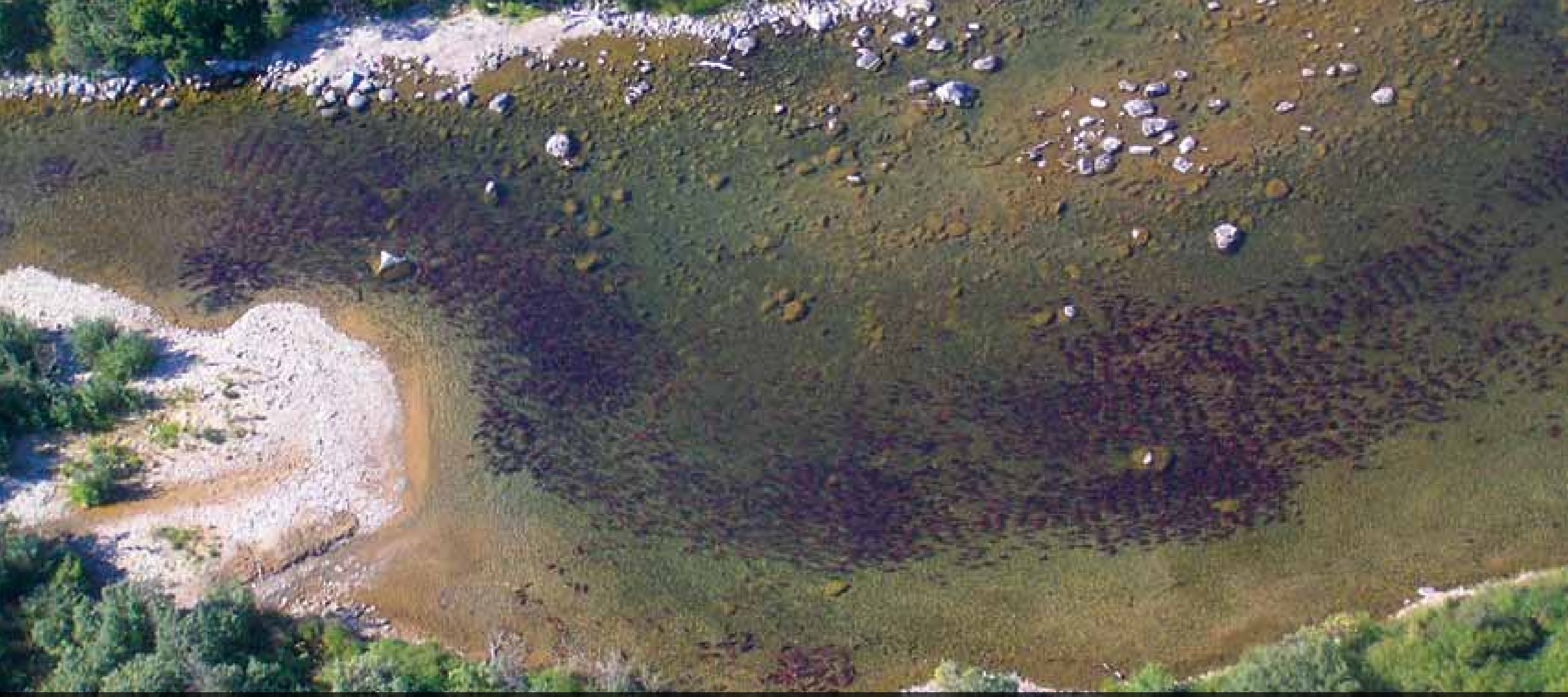


Reported Salmon (Sockeye, Chinook, Coho, Pink, and Chum Combined) Distribution in the North and South Fork Koktuli River and Upper Talarik Creek. Designation of species spawning, rearing, and presence is based on ADFG Draft 2012 Anadromous Waters Catalog (Johnson and Blanche pers. comm.). Spawning = spawning adults observed, rearing = juveniles observed, present = present, but life stage use not determined. Life stage-specific reach designations are likely underestimates, given the logistical constraints on the ability to accurately capture all streams that may support life stage use at various times of the year.

watersheds. The headwaters of three biologically productive tributaries originate in this region: the North Fork Koktuli River, located to the northwest of the Pebble deposit, which flows into the Nushagak River via the Mulchatna River; the South Fork Koktuli River, which drains the Pebble deposit area and converges with the North Fork west of the Pebble deposit; and Upper Talarik Creek, which drains the eastern portion of the Pebble deposit and flows into the Kvichak River via Iliamna Lake, the largest undeveloped lake in the United States.

The assessment addresses two general time periods for mine activities. The first is the development and operation phase, during which mine infrastructure is built and the mine is operated. This phase may last from 25 to 100 years or more. The second is the post-mining, or post-closure, phase, during which the site would be monitored and, as necessary, water treatment and other waste management activities continued and failures remediated. Because mining wastes would be altered by geologic processes but would not degrade, this period would continue for centuries and potentially "in perpetuity."

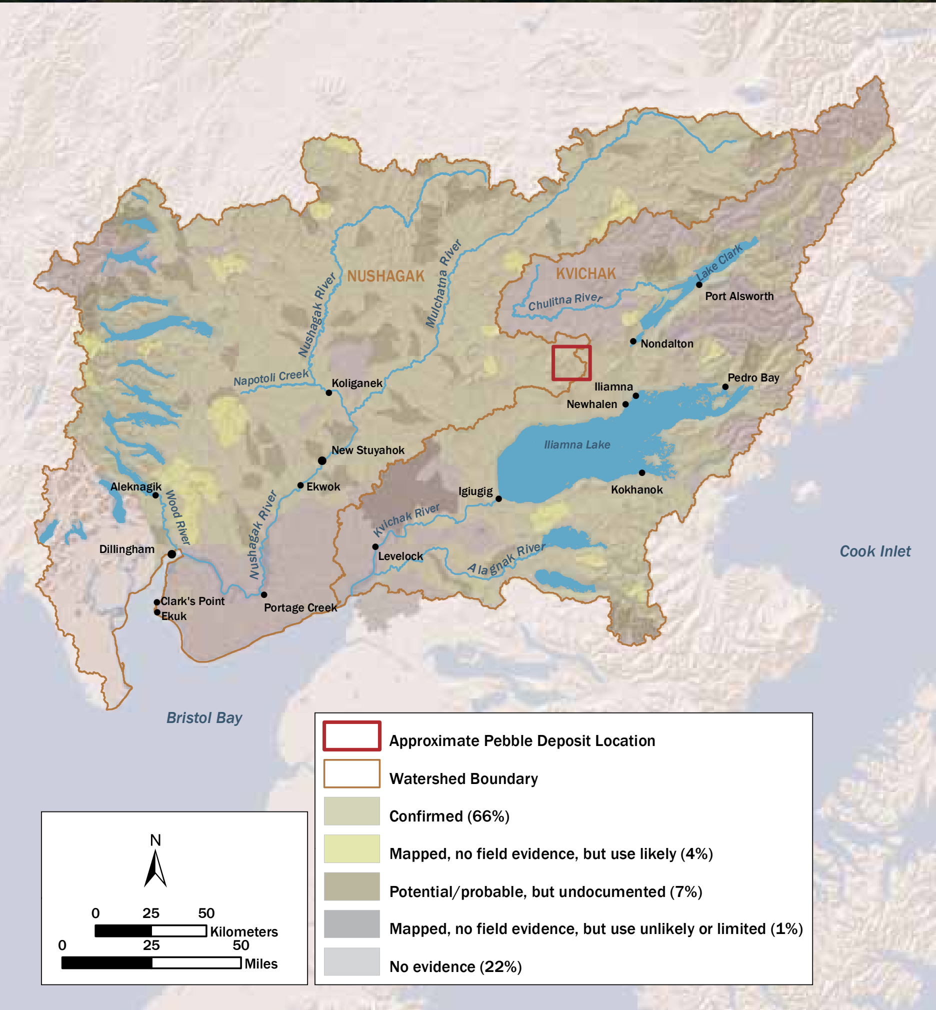
The assessment was conducted as an ecological risk assessment. We started with a thorough review of what is known about the Bristol Bay watershed fishery and wildlife and the Alaska Native cultures. We also reviewed information about copper mining and available information outlining proposed mining operations for the Pebble deposit that has been the focus of much exploratory study and has received much attention from various groups in and outside of Alaska. Using that information, we developed a set of conceptual models to show potential associations between the endpoints of interest—the salmon fishery and salmon populations—and the various types of environmental stressors that might reasonably be expected as a result of large-scale



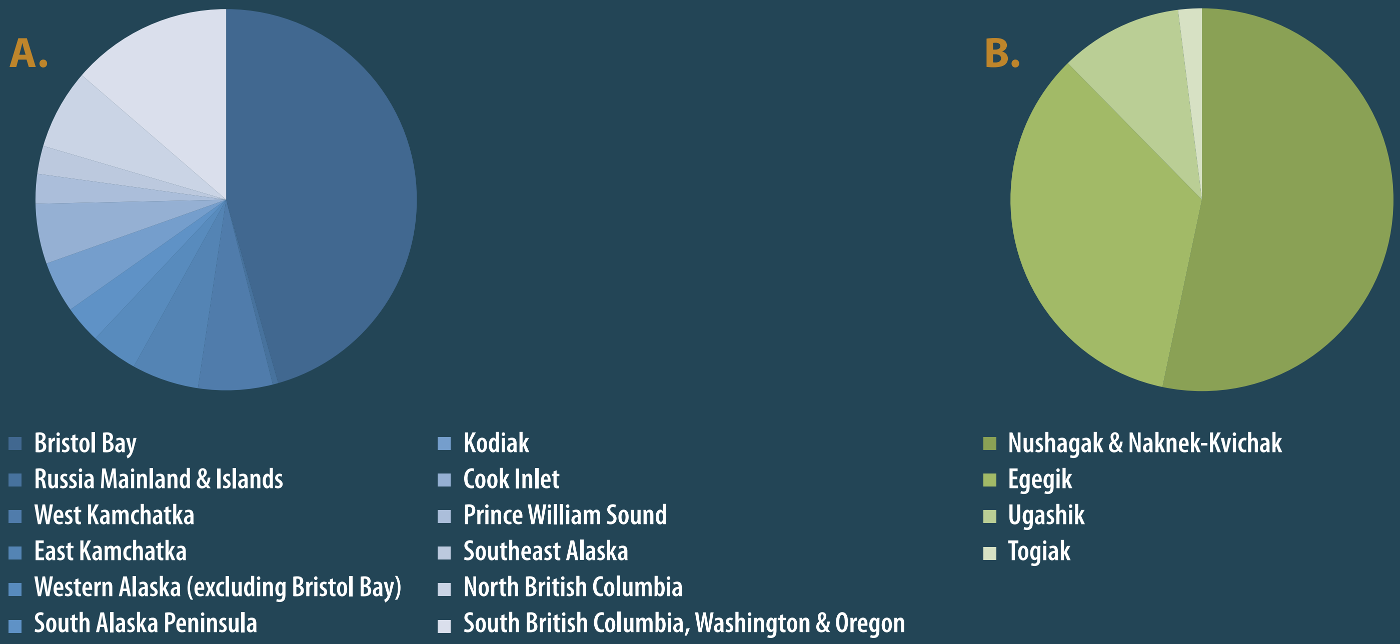
Sockeye salmon near Gibraltar Lake Photo: Thomas Quinn (University of Washington)

mining. Those conceptual models were refined through interactions with regional stakeholders. The assessment was then developed based upon the background characterization studies and the conceptual models.

This is not an in-depth assessment of a specific mine, but rather an examination of the impacts of mining activities at the scale and with the characteristics realistically foreseeable in the Bristol Bay region, given the nature of mineral deposits in the watershed and the requirements for successful mining development. Known information about the Pebble deposit is very relevant, because it is likely representative of any potential near-future mine development in the area. Thus, the assessment largely analyzes a mine scenario that reflects the expected characteristics of mining operations at the Pebble deposit. However, the analysis is intended to provide a baseline for understanding the potential impacts of mining development throughout the Nushagak River and Kvichak River watersheds. The potential mining of other existing copper deposits in the region would likely reflect the same type of mining activities and facilities analyzed for



Salmon-Producing Subwatersheds in the Nushagak River and Kvichak River Watersheds. A total of 568 subwatersheds (total area of 61,317 km^2) were assessed in the Nushagak River and Kvichak River watersheds. The percentage of this area in each category is shown in parentheses in the legend. Note that the southwestern portion of the Nushagak River watershed (i.e., the Nushagak Bay watershed) was not included in this analysis. Data from Demory et al. (1964), Nelson (1967), Salomone et al. (2009), Johnson and Blanche (2011), and ADFG (2012).



Average Annual Relative Abundance and Commercial Harvest of Wild Sockeye Salmon. A. Average annual relative abundance of wild sockeye salmon stocks in the North Pacific, 1956 to 2005; with the exception of Bristol Bay, stocks are ordered from west to east across the North Pacific, from Russia (Russia Mainland and Islands, West Kamchatka, East Kamchatka) to western North America (all other sites). B. Average annual relative commercial sockeye harvest in Bristol Bay watersheds, 1990 to 2009. Data from Ruggerone et al. (2010) and Salomone (pers. comm.).

the Pebble deposit scenario (open pit mining, waste rock piles, tailing storage facilities) and, therefore, would present potential risks similar to those outlined in this assessment.

Ecological Resources

The Bristol Bay watershed provides habitat for numerous animal species, including 35 fishes, more than 190 birds, and more than 40 terrestrial mammals. Many of these species are essential to the structure and function of the region's ecosystems and economies. Chief among these resources is a world-class commercial and sport fishery for Pacific salmon and other important resident fishes. The watershed supports production of all five species of Pacific salmon found in North America: sockeye (*Oncorhynchus nerka*), coho (*O. kisutch*), Chinook or king (*O. tshawytscha*), chum (*O. keta*), and pink (*O. gorbuscha*). Because no hatchery fish are raised or released in the watershed, Bristol Bay's salmon populations are entirely wild. These fish are anadromous—hatching and rearing in freshwater systems, migrating to the sea to grow to adult size, and returning to freshwater systems to spawn and die.

The most abundant salmon species in the watershed is sockeye salmon. The Bristol Bay watershed supports the largest sockeye salmon fishery in the world, with approximately 46% of the average global abundance of wild sockeye salmon. Between 1990 and 2010, the annual average inshore run of sockeye salmon in Bristol Bay was approximately 37.5 million fish. Annual commercial harvest of sockeye over this same period averaged 27.5 million. Approximately half of the Bristol Bay sockeye salmon production is from the Nushagak River and Kvichak River watersheds—the area of focus for this assessment.

In addition to sockeye salmon, Chinook salmon are also abundant. For example, Chinook returns to the Nushagak River

Sockeye salmon near Pedro Bay, Iliamna Lake Photo: Thomas Quinn (University of Washington)

are consistently greater than 100,000 fish per year and have exceeded 200,000 fish in 11 years between 1966 and 2010, frequently placing Nushagak River Chinook runs at or near the world's largest. This is noteworthy given the Nushagak River's small watershed area compared to other Chinook-producing rivers such as the Yukon River, which spans Alaska, and the Kuskokwim River in southwest Alaska, just north of Bristol Bay.

The Bristol Bay watershed also supports populations of resident fishes that typically remain within the watershed's freshwater habitats throughout their life cycles. The region contains highly productive waters for such sport and subsistence fish species as rainbow trout (*Oncorhynchus mykiss*), Dolly Varden (*Salvelinus malma*), Arctic char (*Salvelinus alpinus*), Arctic grayling (*Thymallus arcticus*), and lake trout (*Salvelinus namaycush*). These fish species occupy a variety of habitats within the watershed, from headwater streams to wetlands to large rivers and lakes. The Bristol Bay region is especially renowned for the abundance and size of its rainbow trout: between 2003 and 2007 an estimated 196,825 rainbow trout were caught in the Bristol Bay Sport Fish Management Area.

The exceptional quality of the Bristol Bay watershed's fish populations can be attributed to several factors, the most important of which is perhaps the watershed's high-quality, diverse aquatic habitats, which are untouched by human-engineered structures and flow management controls. Surface and subsurface waters are highly connected, enabling hydrologic and biochemical connectivity between wetlands, ponds, streams, and rivers, thus increasing the diversity and stability of habitats able to support fish. The high diversity of habitats, high quality of surface and subsurface waters, and relatively low development pressures all contribute to making Bristol Bay a highly productive system. This high diversity of habitats also has enabled the development of high genetic diversity of fish populations. This genetic diversity acts to reduce year-to-year variability in total production and increases the stability of the fishery.

The return of salmon from the Pacific Ocean brings nutrients into the watershed and fuels terrestrial and aquatic food webs. The condition of terrestrial ecosystems in Bristol Bay, therefore, is intimately linked to the condition of salmon populations. Unlike

Brown bear in the Kvichak River watershed Photo: USEPA

most terrestrial ecosystems, the Bristol Bay watershed has undergone little development and remains largely intact. Consequently, the watershed continues to support its historic complement of species, including large carnivores such as brown bears (*Ursus arctos*), bald eagles (*Haliaeetus leucocephalus*), and gray wolves (*Canis lupus*); ungulates such as moose (*Alces alces gigas*) and caribou (*Rangifer tarandus granti*); and numerous waterfowl species.

Wildlife populations tend to be relatively large in the region, due to the increased biological productivity associated with Pacific salmon runs. Brown bears are abundant in the Nushagak River and Kvichak River watersheds. Moose and caribou also are abundant, with populations especially high in the Nushagak River watershed where felt-leaf willow, a preferred plant species, is abundant. The Nushagak River and Kvichak River watersheds are used by caribou, primarily the Mulchatna caribou herd. This herd ranges widely through these watersheds, but also spends considerable time in other watersheds.

Indigenous Cultures

The Alaska Native cultures present in the Nushagak River and Kvichak River watersheds—the Yup'ik and Dena'ina—are two of the last intact, sustainable salmon-based cultures in the world. In contrast, other Pacific Northwest salmon-based cultures are severely threatened due to development, degraded natural resources, and declining salmon resources. Pacific salmon are no longer found in 40% of their historical breeding ranges in the western United States, and where populations remain, they tend to be significantly reduced or dominated by hatchery fish. Salmon are integral to the entire way of life in these cultures as subsistence food and as the foundation for their language, spirituality, and social structure. The cultures have a strong connection to the landscape and its resources. In the Bristol Bay watershed, this connection has been maintained for at least the past 4,000 years and is in part due to and responsible for the continued pristine condition of the region's landscape and biological resources. The respect and importance given salmon and other wildlife, along with the traditional knowledge of the environment, have produced a

Fishing boats at Naknek, Alaska Photo: USEPA

sustainable subsistence-based economy. This subsistence-based way of life is a key element of indigenous identity and it serves a wide range of economic, social, and cultural functions in Yup'ik and Dena'ina societies.

Fourteen of Bristol Bay's 25 Alaska Native villages and communities are within the Nushagak River and Kvichak River watersheds, with a total population of 4,337 in 2010. Thirteen of the 14 communities are Federally Recognized Tribal Governments. In the Bristol Bay region, salmon constitute approximately 52% of the subsistence harvest. Subsistence from all sources (fish, moose, and other wildlife) accounts for an average of 80% of protein consumed by area residents. The subsistence way of life in many Alaska Native villages is augmented with activities supporting cash economy transactions. Alaska Native villages, in partnership with Alaska Native corporations and other business interests, are considering a variety of economic development opportunities—mining included. Some Alaska Native villages have decided for themselves that large-scale hard rock mining is not the direction they would like to go, while a few others are seriously considering this opportunity. All are concerned with the long-term sustainability of their communities.

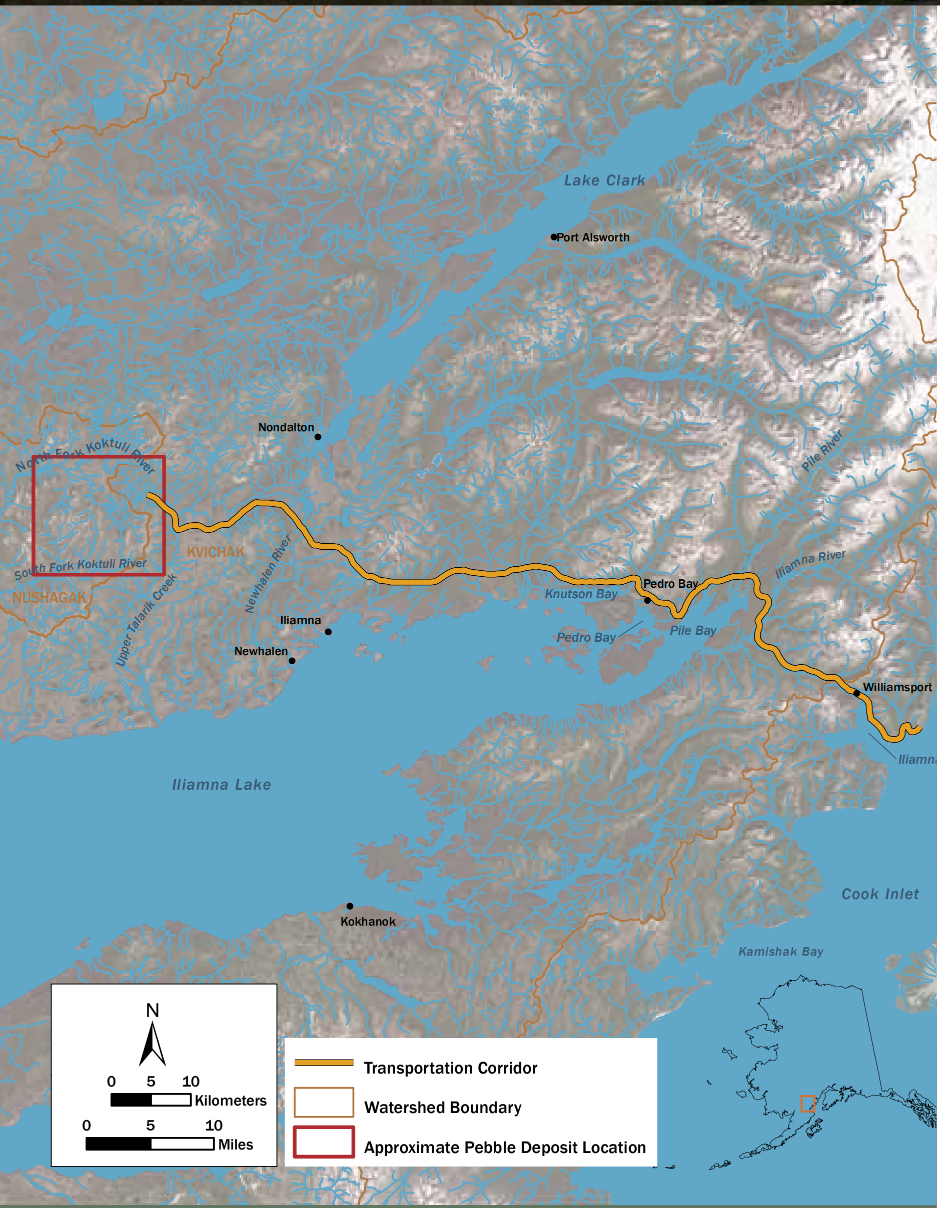
Economics Of Ecological Resources

The Bristol Bay watershed supports several economic sectors that are wilderness-compatible and sustainable: commercial, sport and subsistence fishing, sport and subsistence hunting, and non-consumptive recreation. Considering all these sectors, the ecological resources of the Bristol Bay watershed generated nearly $480 million (M) in direct economic expenditures and sales, in 2009, and provided employment for over 14,000 full- and part-time workers.

The Bristol Bay commercial salmon fishery generates the largest component of economic activity and was valued at approximately $300 M in 2009 (first wholesale value) and provided employment for over 11,500 full- and part-time workers at the peak of the season. These estimates do not include retail expenditures from national and international sales.

Based on 2009 data, the Bristol Bay sport-fishing industry supports approximately

Pebble deposit area Photo: Lorraine Edmond (USEPA)



Potential 139-kilometer (86-mile) Transportation Corridor Connecting the Pebble Deposit Area to Cook Inlet

29,000 sport-fishing trips, generates approximately \$60 M per year, and directly employs over 850 full- and part-time workers. The vast majority of this revenue is spent in the Bristol Bay region. Sport hunting—mostly of caribou, moose, and brown bear—generates more than \$8 M per year and employs over 130 full- and part-time workers. The scenic value of the watershed, measured in terms of wildlife viewing and tourism, is estimated to generate an additional \$100 M per year and supports nearly 1,700 full- and part-time workers. The subsistence harvest of fish also contributes to the region's economy when Alaskan households spend money on subsistence-related supplies. These contributions are estimated to be slightly over \$6 M per year.

Geological Resources

In addition to significant and valuable ecological resources, the Nushagak River and Kvichak River watersheds contain considerable mineral resources. The potential for large-scale mining development within the region is greatest for copper deposits and, to a lesser extent, for intrusion-related gold deposits. Because these deposits are

Mine pit at Fort Knox, Alaska Photo: Phil North (USEPA)

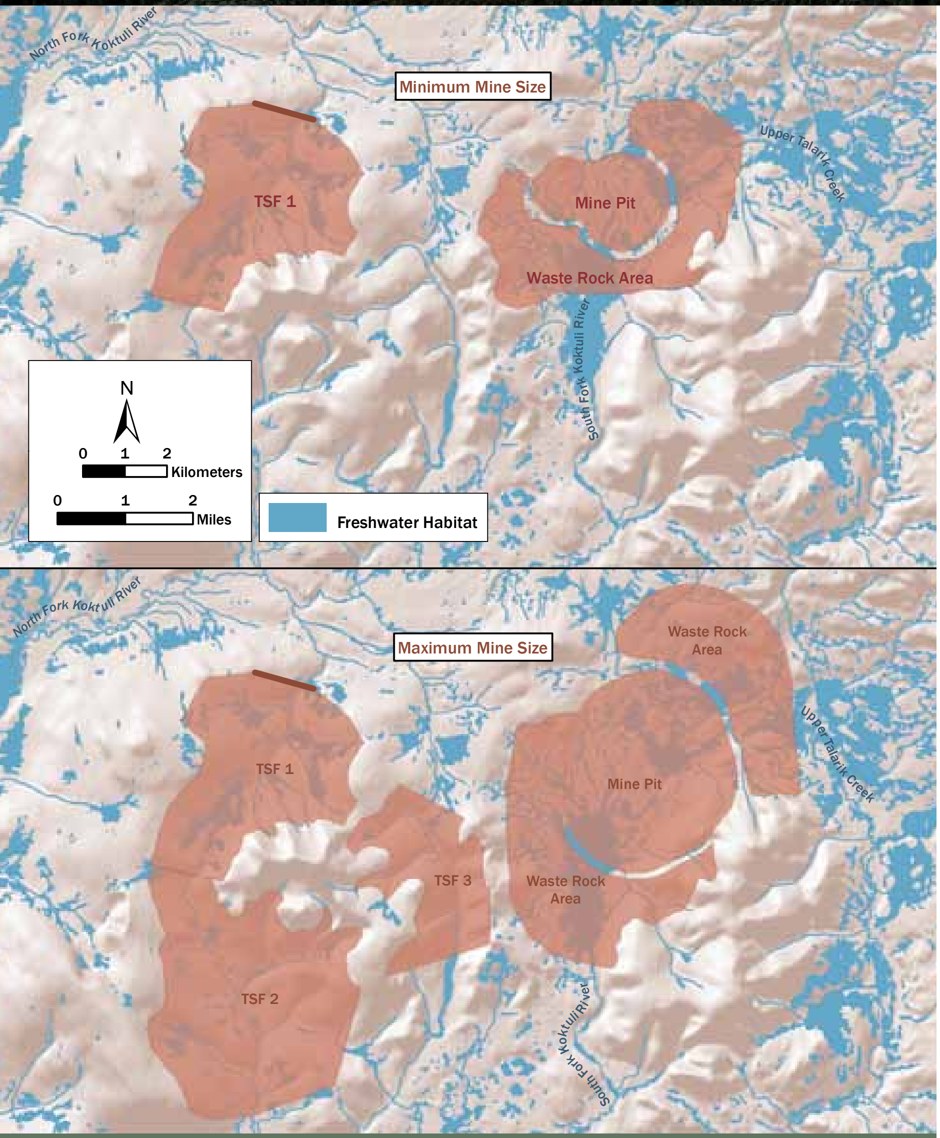
low-grade—meaning that they contain relatively small amounts of metals relative to the amount of ore—mining will be economic only if conducted over a large area, and a large amount of waste material will be produced as a result of mining and processing.

The largest known deposit and the deposit most explored to assess future mining potential is the Pebble deposit. If fully mined, the Pebble deposit could produce more than 11 billion metric tons (1 metric ton = 1,000 kg, approximately 2,200 pounds) of ore, which would make it the largest mine of its type in North America. In comparison, the largest existing copper mine in the United States is the Safford Mine in Arizona with 7.3 billion metric tons of ore. Although the Pebble deposit represents the most imminent and likely site of mine development, other mineral deposits with potentially significant resources exist within the Nushagak River and Kvichak River watersheds. Several specific claims have been filed, many near the Pebble deposit. Findings of this assessment concerning the potential impacts of large-scale mining are generally applicable to these other sites.

Mine Scenario

A detailed and final mine plan has not been made available for any of the copper deposits identified in the Bristol Bay watershed, nor is one strictly needed to conduct this assessment. To examine the mining-related stressors that could affect ecological resources in the watershed, we developed a hypothetical mine scenario, designed to be as realistic as possible. The mine scenario is based on mining of the Pebble deposit, because it is the best-characterized mineral resource and the most likely to be developed in the near term. Thus, the mine scenario draws on plans published by the Pebble Limited Partnership (PLP) and baseline data developed by PLP to characterize the likely mine site and surrounding environment. Details of a mining plan for the Pebble deposit or for other deposits in the watershed may differ from our mine scenario; however, our scenario reflects the general characteristics of mineral deposits in the watershed, contemporary mining technologies and best practices, the scale of mining activity required for economic development of the resource, and necessary development of infrastructure to support large-scale mining. Therefore, the USEPA concludes that the mine scenario represents the sort of development plan that can be

Landscape near the Pebble deposit location Photo: Joe Ebersole (USEPA)



Minimum and Maximum Mine Footprints in the Assessment Scenario. Individual mine components are the mine pit, waste rock piles, and one or more tailings storage facilities (TSFs). The dark bar at the north end of TSF 1 indicates the dam for which tailings dam failure is modeled.

anticipated for a copper deposit in the Bristol Bay watershed. Uncertainties associated with the mine scenario are discussed later in this executive summary.

The mine scenario includes minimum and maximum mine sizes, based on the amount of ore processed (2 billion metric tons vs. 6.5 billion metric tons), and approximate corresponding mine life spans of 25 to 78 years, respectively. Components of the minimum mine would include a 5.5 km^2 (1,358 acre) mine pit, a 14.9-km^2 (3,686-acre) tailings impoundment behind a 208 m-high (685-foot-high) earthen dam; a 13.3-km^2 (3,286-acre) waste rock pile; a 139-km (86-mile) road with four pipelines for product concentrate, return water, diesel, and natural gas; and facilities for ore processing and support services. The maximum size mine would include a much larger pit and waste rock pile, with a combined area of 38.4 km^2 (9,486 acres), potentially an underground mine, and three tailings impoundments, with a combined area of 43.7 km^2 (10,807 acres).

The first part of the assessment considers routine operation, which assumes that the mine would be designed using practices to minimize environmental impacts and that no significant human or engineering


Sockeye salmon near Pedro Bay, Iliamna Lake Photo: Thomas Quinn (University of Washington)

failures occur during or for centuries after operation. The second part of the assessment considers various failures that have occurred during the operation of other mines and have the potential to occur here.

The assessment does not consider all mining-related development. Although the mine scenario assumes development of a deep-water port on Cook Inlet to ship concentrated product elsewhere for smelting and refining, impacts of the development and operation of a deep-water port are not assessed. Additionally, the assessment does not evaluate the potential environmental impacts of one or more electricity-generating power plants that would need to be constructed to provide power at the mine site and the deep-water port facility. This assessment also does not consider potential impacts resulting from secondary development that is likely to accompany a large-scale mine development. Secondary development includes, but is not limited to, additional support services for mine employees and their families, increased recreational development due to increased access, development of vacation homes, and increased transportation infrastructure (i.e., airports, docks, and roads).

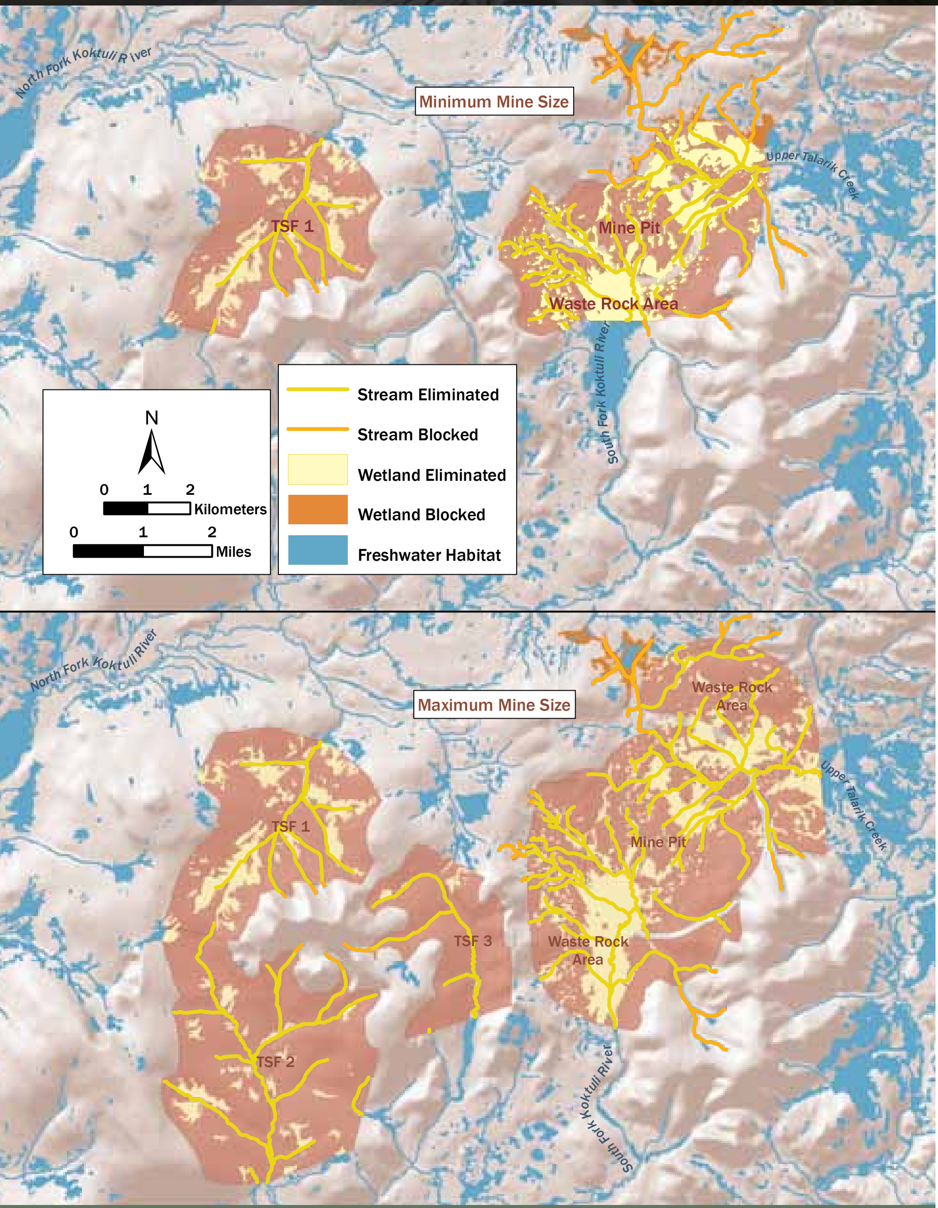
Overall Risks to Salmon and Other Fish

Based on the mine scenario, the assessment defines potential mining-related stressors that could affect the Bristol Bay watershed's fish and would consequently have impacts on wildlife and human welfare.

No Failure

No failure, or routine operation, is a mode of operation defined as using the highest design standards and day-to-day practices, with all equipment and management systems operated in accordance with applicable specifications and requirements. In the no failure mode of operation, we assume that best practical engineering and mitigation practices are in place and in optimal operating condition. We do not specify all of those mitigation practices, but rather, we assume that they would be in place and properly functioning. Analyzing routine operations is not meant to imply that a failure-free mining operation is likely; rather, it is meant to isolate the inevitable and foreseeable effects of mining from those that are unintended and thus more difficult to

Rainbow trout caught in American Creek, in the Kvichak River watershed Photo: USEPA



Streams and Wetlands Lost (Eliminated or Blocked) Under the Minimum and Maximum Mine Footprints

predict. With no failures, adverse effects outside the mine footprint are minimized by complete containment of waste rock and mine tailings, reliable collection of all water from the site, and effective treatment of effluents. Nonetheless, impacts on fish resulting from habitat loss and modification within and beyond the area of mining activity would result from six key direct and indirect mechanisms.

(1) Eliminated or blocked streams under the minimum and maximum mine footprints (i.e., the mine pit, waste rock piles, and tailings storage facilities) would result in the loss of 87.5 to 141.4 km (55 to 87 miles), respectively, of possible spawning or rearing habitats for coho salmon, Chinook salmon, sockeye salmon, rainbow trout, and Dolly Varden.

(2) Reduced flow resulting from water retention for use in mine operations, ore processing, transport, and other processes would reduce the amount and quality of fish habitat. Reductions in streamflow exceeding 20% would adversely affect habitat in


Lower Twin Lake in the Mulchatna River watershed Photo: Michael Wiedmer (USGS)

an additional 2 to 10 km (1.2 to 6.2 miles) of streams, reducing production of coho salmon, sockeye salmon, Chinook salmon, rainbow trout, and Dolly Varden. An unquantifiable area of riparian floodplain wetland habitat would either be lost or suffer substantial changes in hydrologic connectivity with streams due to reduced flow from the mine footprint.

(3) **Removal of 10.2 to 17.3 km² (2,512 to 4,286 acres) of wetlands** in the footprint of the mine would eliminate off-channel habitat for salmon and other fishes. Wetland loss would reduce availability and access to hydraulically and thermally diverse habitats that can provide enhanced foraging opportunities and important rearing habitats for juvenile salmon

(4) **Indirect effects of stream and wetland removal** would include reductions in the quality of downstream habitat for the same species listed above in the three headwater streams draining the mine site. Sources of these indirect effects would include the following:

- Reduced food resources would result from the loss of organic material and drifting invertebrates from the 87.5 to 141.4 km (55 to 87 miles) of streams and streamside wetlands lost to the mine footprint.

- The balance of surface water and groundwater inputs to downstream reaches would shift, potentially reducing winter fish habitat and making the streams less suitable for spawning and rearing.

- Water treatment and reduced passage through groundwater flowpaths could increase summer water temperatures and decrease winter water temperatures, making streams less suitable for salmon, trout, and char.

These indirect effects cannot be quantified but likely would diminish fish production downstream of the mine site.

(5) **Diminished habitat quality in streams below road crossings** would result primarily from altered flow, runoff of road salts, and

Groundwater upwelling near Kaskanak Creek in the Lower Talarik Basin Photo: Joe Ebersole (USEPA)

siltation of spawning habitat and reduced invertebrate prey. The road is adjacent to Iliamna Lake and crosses multiple tributary streams. These habitats are important spawning areas for sockeye salmon, putting sockeye particularly at risk to impacts from the road.

(6) **Inhibition of salmonid movement at road crossings** could result from culverts that may, over time, block or diminish use of the full stream length.

Failure

The assessment evaluates four failures that have occurred at other large-scale mining and related infrastructure projects and that could occur during mine operations or after mine closure: tailings dam failure, product concentrate or return water pipeline failure, water collection and treatment failures, and failures of roads and culverts. Risks associated with each of these failures are summarized in the following table.

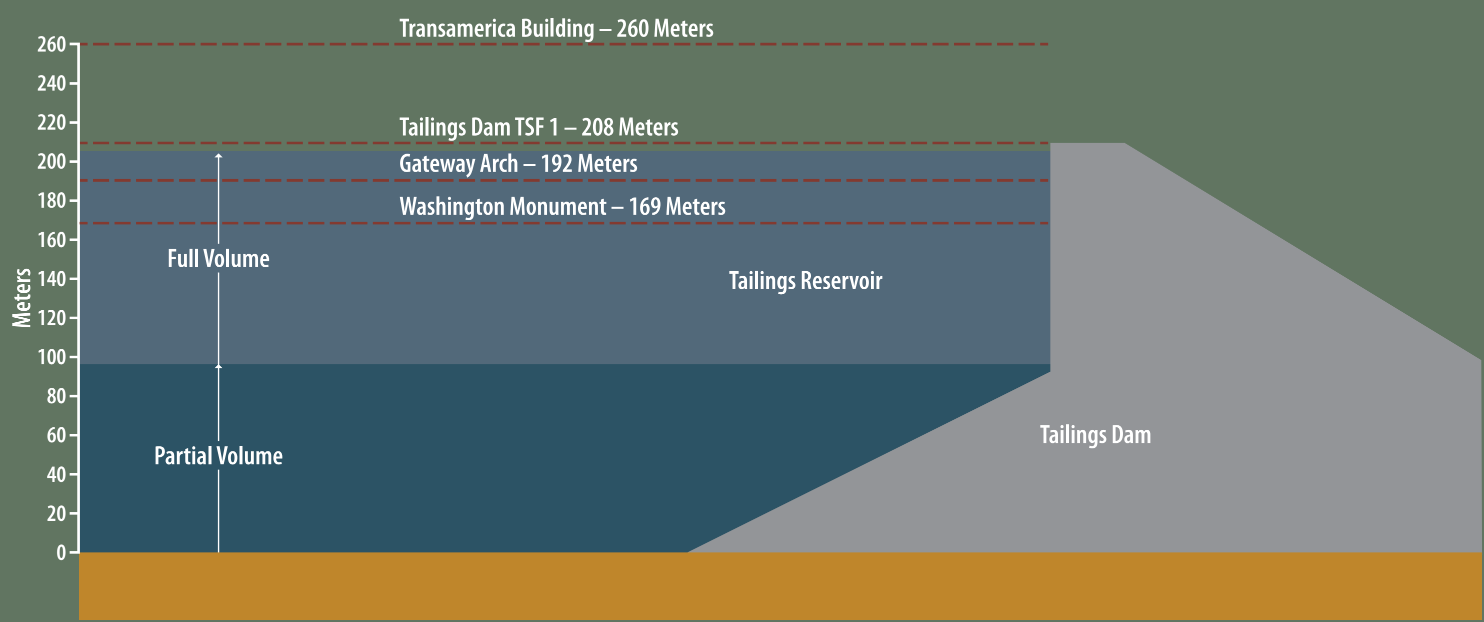
Tailings Dam Failure

Tailings are the waste materials produced during ore processing, which in our scenario would be stored in tailings storage facilities (TSFs) consisting of tailings dams and impoundments. The annual probability of failure for each tailings dam would be in the range of one-in-ten-thousand to one-in-a-million. The probability of one of several tailings dams failing increases with the number of dams. The minimum mine size outlined in the mine scenario includes one TSF with three dams; the maximum mine size includes three TSFs, with a total of eight dams. The TSFs and their component dams are likely to be in place for hundreds to thousands of years, long beyond the life of the mine. Although details for the actual design of mining operations at the Pebble deposit are unknown, available reports from the PLP suggest tailings dams as high as 208 m (685 feet) at TSF 1. At this height, the tailings dam would be higher than the St. Louis Gateway Arch and the Washington Monument. We evaluated two dam failures in this assessment: one when the TSF was partially full (partial-volume failure) and one when it was completely full (full-volume failure). In both cases we assumed a release of 20% of the tailings, a conservative estimate that is well within the range of historical tailings dam failures.

Summary of Probability and Consequences of Potential Failures under the Mine Scenario

Failure	Probability[a]	Consequences
Tailings dam	10^{-4} to 10^{-6} per dam-year = recurrence frequency of 10,000 to 1 million years[b]	More than 30 km of salmonid stream would be destroyed and more streams and rivers would have greatly degraded habitat for decades.
Product concentrate pipeline	10^{-3} per km-year = 98% chance per pipeline in 25 years	Most failures would occur between stream or wetland crossings and might have little effect on fish.
Concentrate spill into a stream	$2x10^{-2}$ per year = 1.5 stream-contaminating spills 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	3×10^{-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	Same as product concentrate pipeline	Fish and invertebrates would experience acute exposure to toxic water.
Culvert, operation	Low	Frequent inspections and regular maintenance would result in few impassable culverts.
Culvert, post-operation	3×10^{-1} to 6×10^{-1} per culvert-instantaneous = 4 to 10 culverts	In surveys of road culverts, roughly one-third to two-thirds are impassable to fish at any one time. This would result in 4 to 10 salmonid streams blocked.
Water collection and treatment, operation	High	Collection and treatment failures are highly likely to result in release of untreated leachates for hours to months.
Water collection and treatment, planned post-closure	High	Collection and treatment failures are highly likely to result in release of untreated leachates for days to months.
Water collection and treatment, premature post-closure or perpetuity	Certain	When water is no longer managed, untreated leachates would flow to the streams.

[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).



Height of the Partial-Volume and Full-Volume Dam at TSF 1, Relative to Common Landmarks

The range of estimated probabilities of dam failure is wide, reflecting the great uncertainty concerning such failures. The most straightforward method of estimating the annual probability of failure of a tailings dam is to use the historical failure rate of similar dams. Three reviews of tailings dam failures produced an average rate of approximately 1 failure per 2,000 dam years, or 5×10^{-4} failures per dam year. The argument against this approach is that it does not fully reflect current engineering practice. Some studies suggest that improved design, construction, and monitoring practices can reduce the failure rate by an order of magnitude or more, resulting in an estimated failure probability within our assumed range. The State of Alaska's guidelines suggest that an applicant follow accepted industry design practices such as those provided by the U.S. Army Corps of Engineers (USACE), Federal Energy Regulatory Commission (FERC), and other agencies. Both USACE and FERC require a minimum factor of safety of 1.5 against slope instability, for the loading condition corresponding to steady seepage from 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 for Category I Facilities (those designed, built, and operated with state-of-the-practice engineering) and 1 in 10,000 for Category II Facilities (those designed, built, and operated using standard engineering practice). This spans the failure frequency used in our failure assessment. The advantage of this approach is that it addresses current regulatory guidelines and engineering practices. The disadvantage is that we do not know whether standard practice or state-of-the practice dams will perform as expected, particularly given the large size of potential dams. In addition, slope instability is only one type of failure; other failure modes, such as overtopping during a flood, would increase overall failure rates.

Failure of the dam at TSF 1 would result in the release of a flood of tailings slurry into the North Fork Koktuli River, scouring the valley and depositing tailings several meters (yards) in depth over the entire floodplain of the river. The complete loss of suitable salmon habitat in the North Fork Koktuli River

Tributary of Napotoli Creek, near the Humble claim Photo: Michael Wiedmer

along at least 30 km (18.6 miles) of stream habitat—the spatial limit of the modeling conducted for this assessment—in the short term (fewer than 10 years) and the high likelihood of very low-quality spawning and rearing habitat in the long term (decades) would result in near-complete loss of mainstem North Fork Koktuli River fish populations. The North Fork Koktuli 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. The slurry flood would continue down the Koktuli River with similar effects, the extent of which cannot be estimated at this time due to model and data limitations.

The tailings dam failures evaluated here are predicted to have the following severe direct and indirect effects on aquatic resources, particularly salmonid fish.

(1) It is likely the the North Fork Koktuli River below the TSF 1 dam, and much of the Koktuli River, would not support salmonid fish in the short term (fewer than 10 years).

- Deposited tailings would degrade habitat quality for both fish and the invertebrates they eat. Based largely on their copper content, deposited tailings would be toxic to benthic macroinvertebrates, although existing data concerning toxicity to fish is less clear.
- Deposited tailings would continue to erode from the North Fork Koktuli and Koktuli River valleys.
- Suspension and redeposition of tailings would likely cause serious habitat degradation in the Koktuli River and downstream into the Mulchatna River.

(2) Those waters would provide very low-quality spawning and rearing habitat for a period of decades.

- Recovery of suitable substrates via mobilization and transport of tailings would take years to decades, and would affect much of the watershed downstream of a failed dam.

Knutson Creek draining into the Knutson Bay area of Iliamna Lake Photo: Keith Denton

- Ultimately, spring floods and stormflows would carry some proportion of the tailings into the Nushagak River.
- For some years, periods of high flow would be expected to suspend sufficient concentrations of tailings to cause avoidance, reduced growth and fecundity, and even death of fish.

(3) Near-complete loss of North Fork Koktuli River fish populations would likely result from these habitat losses.

- The Koktuli River watershed is an important producer of Chinook salmon. The Nushagak River watershed, of which the Koktuli River watershed is a part, is the largest producer of Chinook salmon in the Bristol Bay region, with annual runs averaging over 160,000 fish.
- The tailings spill would be expected to eliminate 28% of the Chinook salmon run in the Nushagak River due to loss of the Koktuli River watershed population; an additional 10 to 20% could be lost due to tailings deposited in the Mulchatna River and its tributaries.
- Sockeye are the most abundant salmon returning to the Nushagak River watershed, with annual runs averaging more than 1.3 million fish. The proportion of sockeye and other salmon species of Koktuli-Mulchatna origin is unknown.
- Similarly, populations of rainbow trout and Dolly Varden would be lost for years to decades. Quantitative estimates of the impacts on population sizes are not possible.

Effects would be qualitatively the same for both the partial-volume and full-volume dam failures, although effects from the full-volume failure would extend further and last longer. Failure of dams at the two additional TSFs under the maximum mine size (TSF 2 and

TSF 3) were not modeled, but would have similar effects in the South Fork Koktuli River and downstream. However, because their volumes would be smaller, effects would be less extensive.

Pipeline Failures

Under the mine scenario, the primary product of the mine would be a concentrate of copper and other metals that would be pumped in a pipeline to a shipping facility on Cook Inlet. Water carrying the sand-like concentrate would be returned to the mine site in a second pipeline. Based on the record of pipelines in general, and the world's largest metal concentrate pipeline in particular, one to two near-stream failures of each of these pipelines would be expected to occur over the life of the maximum mine (78 years). Failure of either the product or the return water pipelines would release water that is expected to be highly toxic, potentially killing fish and invertebrates in the affected stream over a relatively brief period. If concentrate spilled into a stream, it would settle and form bed sediment predicted to be highly toxic based on its high copper content and acidity. Unless the receiving stream was dredged, causing additional long-term damage, this sediment would persist for decades before ultimately being washed into Iliamna Lake. Potential concentrations in the lake could not be predicted, but near the pipeline route Iliamna Lake contains important beach spawning areas for sockeye salmon that could be exposed to a toxic spill. Sockeye also spawn in the lower reaches of streams which could be directly contaminated by a spill.

Water Collection and Treatment Failures

There is a long history of unplanned discharges of contaminated waters from mine sites into surface and ground waters. Water in contact with tailings or waste rock would leach copper and other metals. The failure of collection and treatment systems due to imperfect design or operation, or the failure to maintain and operate these systems in perpetuity, could result in contamination of one or more streams draining the site. Based on a review of historical and currently operating mines, some failure of the collection and treatment systems is likely during operation or post-closure periods. These failures could range from operational failures resulting in short-term releases of untreated leachates, to long-term failures to operate the collection and treatment system in perpetuity. Our evaluation looked at the realistic possibility of leachate escaping at the base of TSF 1. We also considered a failure to collect and treat leachate from waste rock piles around the mine pit.

Test leachates from the tailings and non-ore-bearing Tertiary waste rocks—those formed between approximately 65 million to 2.5 million years ago—are mildly toxic; they would require an approximately two-fold dilution to achieve water quality criteria for copper, but they are not expected to be toxic to salmonids. If Tertiary rock were to be used as planned for construction of mining infrastructure, leachate from these areas would need to be collected and treated to avoid toxic effects on benthic invertebrates. Our risk assessment did not evaluate this potential pathway in detail.

Pre-Tertiary waste rocks, which would be excavated to expose the ore body, are acid-forming with high copper concentrations in test leachates and would require 2,900 to 52,000-fold dilution to achieve water quality criteria. If leachate from a waste rock pile surrounding the mine pit was not collected, the 10.6 million m^3 (approximately 2.8 billion gallons) of leachate per year from the waste rock pile could constitute source water for Upper Talarik Creek, which flows to Iliamna Lake. The total flow of Upper Talarik Creek would provide only 18-fold dilution, so failure to prevent leachate releases could cause the entire creek and

Washed out culvert on Kenai Peninsula Photo: Robert Ruffner (Kenai Watershed Forum)

a potentially large mixing zone in the lake to become toxic to fish and the sensitive invertebrates upon which they feed. The significance of such an event to salmon is illustrated by the abundance of spawning salmon in Upper Talarik Creek. As many as 33,000 sockeye and 6,300 coho spawners have been counted in the creek on a single day; in 2008, 82,000 sockeye were counted in Upper Talarik Creek and one of its tributaries in a single day. The toxic event described could kill adult fish or the millions of eggs, larvae, and fry that they generate.

Road and Culvert Failures

Within the Kvichak River watershed, the transportation corridor would cross 34 streams and rivers supporting migrating and/or resident salmonids, including 17 streams designated as anadromous waters at the location of the crossing. The most likely serious failure associated with the transportation corridor would be blockage or failure of culverts. Culverts commonly become blocked by debris that may not stop water flow but would block fish passage. If these blockages occurred during adult salmon immigration or juvenile salmon outmigration and were not cleared for several days, production of a year-class (i.e., fish spawned in the same year) could be lost or diminished.

Culverts can also fail to convey water as a result of landslides or, more commonly, floods that wash out the culvert. In such failures, the stream could be temporarily impassible to fish until the culvert is repaired or until erosion reestablishes the channel. If the failure occurs during a critical period in salmon migration, the 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 silt, which could cause returning salmon to avoid a stream if they arrived during or immediately following the failure. More likely, deposition of silt would smother salmon eggs and larvae, if they were present, and would degrade the downstream habitat for salmonid fish and the invertebrates that they eat.

Extended blockage of fish passage at road crossings is unlikely during operation assuming best-case scenario daily inspection and maintenance.

Homes near Newhalen Photo: David Allnut (USEPA)

However, after mine operations cease, the road may be maintained less carefully or be transferred to a governmental entity. In that case, the proportion of culverts that are impassable would be expected to revert to levels found in published surveys of public roads (30 to 66%). Of the approximately 50 culverts that would be required, 17 would be on streams that are believed to support salmonids. Hence, over the long term, 4 to 10 streams would be expected to lose passage of salmon, rainbow trout, or Dolly Varden, and some proportion of those streams would have degraded downstream habitat resulting from the sedimentation from washout of the road.

Common Mode Failures

Multiple, simultaneous failures could occur as a result of a common event, such as the occurrence of a severe storm with heavy precipitation (particularly one that fell on spring snow cover) or a major earthquake. Such an event could cause one to three tailings dam failures that would spill tailings slurry into streams and rivers, road culvert washouts that would send sediments downstream and potentially block fish passage, and pipeline failures that would release product slurry, return water, or diesel fuel. The effects of each of these accidents individually would be the same as discussed previously, but their co-occurrence would cause cumulative effects on salmonid populations and make any mitigative response more difficult.

Over the perpetual timeframe that tailings, mine pit, and waste rock 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.

Overall Loss of Wetlands

Wetlands are a dominant feature of the landscape in the Pebble deposit area and throughout the Bristol Bay watershed, and are important habitats for salmon and other fish. Ponds and riparian wetlands provide spawning, rearing, and refuge habitat for both anadromous salmonids and resident fish species. Other wetlands moderate flows and water quality, and can influence downstream delivery of dissolved organic matter, particulate organic matter, and aquatic macroinvertebrates that supply food sources to fish. Under the mine scenario, wetlands would be filled or excavated in 10.2 km^2 (2,512 acres) and 17.3 km^2 (4,286 acres) of the minimum and maximum mine footprints, respectively. An additional 1.9 km^2 (481 acres) and 1.1 km^2 (267 acres) of riparian wetlands would be blocked by the minimum and maximum footprints, respectively, and would be lost or suffer substantial changes in hydrologic connectivity with streams as a result of reduced flow from the mine footprint. Another 0.18 km^2 (44 acres) 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 affect approximately 2.4 to 4.9 km^2 (593 to 1,211 acres) of wetlands. Finally, a tailings or product concentrate spill could damage wetlands and eliminate or degrade their capacity to support fish.

Fish-Mediated Risk to Wildlife

Although the effects of reduced salmon, trout, and char production on wildlife—the fish-mediated risk to wildlife—cannot be quantified given available data, some reduction in wildlife would be expected under the mine scenario. Changes in the occurrence and abundance of salmon have the potential to change animal behavior and reduce wildlife population abundances. Assuming no failures, routine operations would be expected to have local effects on brown bears, wolves, bald eagles, and other wildlife that consume salmon as a result of reduced salmon abundance from the loss and degradation of habitat in or immediately downstream of the mine footprint. Any of the accidents or failures evaluated would increase effects on salmon, which would proportionately reduce the abundance of their predators.

The abundance and production of wildlife also is enhanced by the marine 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 these nutrients on the landscape, thereby fertilizing the vegetation and increasing the abundance and production of moose, caribou, and other wildlife that depend on vegetation for food.

Fish-Mediated Risk to Indigenous Culture

Under routine operations with no major accidents or failures, the predicted loss and degradation of salmon, char, and trout habitat in North Fork Koktuli and South Fork Koktuli Rivers and Upper Talarik Creek is expected to have some impact on Alaska Native cultures of the Bristol Bay watershed. Fishing and hunting practices are expected to change in direct response to the stream, wetland, and terrestrial habitats lost due to the footprints of the mine site and the transportation corridor. Additionally, it is also possible that subsistence use of salmon resources could decrease based on the perception of reduced fish or water quality resulting from mining.

The potential for significant effects on indigenous cultures is much greater from a mine failure than from routine operations. As described above, failures could reduce or eliminate fish populations in affected areas, including areas significant distances downstream from the mine. Any loss of fish production from these potential failures would reduce the availability of those subsistence resources to local Alaska Native villages, and the reduction of food supply potentially would have negative consequences on human health if alternative food resources are not available. Salmon-based subsistence is integral to Alaska Native cultures. If salmon quality or quantity is adversely affected, the nutritional, social, and spiritual health of Alaska Natives and their culture will potentially decline.

Cumulative Risks

This assessment has focused on the potential effects of a single, hypothetical mine on salmon and other resources in the Nushagak and Kvichak River watersheds, including the cumulative effects of multiple stressors associated with that mine. However, the potential exists for development of multiple mines and associated infrastructure in these watersheds. Each potential mine poses risks similar to those identified for the mine scenario. Estimates of the loss of stream and wetland habitats would differ across different deposits based on the size and location of mining operations within the watersheds. Individually, each mine footprint would eliminate some amount of fish-supporting habitat and, should human or engineering failures occur, affect fish habitats beyond the mine footprint. Cumulatively, multiple mines have the potential to decrease the abundance and genetic diversity of fish populations and thereby increase their annual variability.

We considered development of mines at several sites in the Nushagak River watershed, including Big Chunk, Groundhog Mountain, and Humble claims. These sites were chosen, because all contain copper deposits that have generated exploratory interest. If all four mine sites were developed, the cumulative area covered by TSFs alone would be close to 73 km^2 (19,038 acres). Loss of stream habitats as a result of eliminated or blocked streams could reach 233 km (144 miles). The combined facilities would eliminate an estimated 34.6 km (21.5 miles) of documented salmon streams. The length of salmon stream affected is likely an underestimate, because most streams have not been sampled for the presence of salmon. Loss of these distinct streams would likely result in the loss of their associated salmon populations, reducing the genetic and life-history diversity generated through the existence of numerous distinct populations.

Summary Of Uncertainties In Mine Design And Operation

This assessment of a hypothetical mine scenario is generally applicable to the copper deposits in the Bristol Bay watershed and is based on specific characteristics of the Pebble deposit. The mine scenario does not represent the plans of any mining company; if the resource is mined in the future, actual events will undoubtedly deviate from this scenario. This is not a source of uncertainty, but rather an inherent aspect of a predictive assessment. Even an environmental assessment of a proposed plan by a mining company would be an assessment of a scenario that undoubtedly would differ from the ultimate development.

Multiple uncertainties are inherent in planning, designing, constructing, operating, and closing a mine.

- Mines are complex systems requiring skilled engineered design and operation. The uncertainties facing mining and geotechnical engineers include unknown geologic defects, uncertain values in geological properties, limited knowledge of mechanisms and processes, and human error in design and construction. 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 protect against system failures, seemingly logical decisions about how to respond to a given situation can have unexpected consequences resulting from human error (e.g., the January 2012 overflow of the tailings dam at the Nixon Fork

Salmon art on a building in Dillingham Photo: Alan Boraas (Kenai Peninsula College)

Mine near McGrath, Alaska). 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 the waste would require management for centuries or even in perpetuity. Engineered waste storage systems of mines have only been in existence for about 50 years. Their long-term behavior is not known. The response of our best technology in the construction of tailings dams is untested and unknown in the face of centuries of extreme events such as earthquakes and weather.
- Mine management or ownership may change over time. Over the long timespan (centuries) of mining and post-mining care, generations of mine operators must exercise due diligence. Priorities are likely to change in the face of financial circumstances, changing markets for metals, new information about the resource, political priorities, or any number of currently unforeseeable changes in circumstance.

Such uncertainties are inherent in any complex enterprise, particularly when they involve an incompletely characterized natural system. However, the large scales and long durations implied by the effort required to exploit this resource make these inherent uncertainties more prominent.

Summary of Uncertainties and Limitations in the Assessment

Significant uncertainties about and limitations of the estimated potential effects of the mine scenario, as judged by the assessment authors, include the following.

- Any mine plan submitted by a mining company may not exactly reflect the location and sizes of the mine pit, waste rock pile, and tailings storage facilities, and the location and length of the transportation corridor used in the scenario for this assessment. An actual mine plan may be smaller, larger, or laid out differently than the mine scenario considered here.
- The estimated annual probability of tailings dam failure is uncertain and based on both design goals and

Kvichak River below Iliamna Lake and Igiugig Photo: Joe Ebersole (USEPA)

historical experience. Actual failure rates could be higher or lower than the estimated probability.

- The proportion of the tailings that would spill in the event of a dam failure could be larger than the largest value modeled (20%).
- The long-term fate of the spilled tailings in the event of a dam failure could not be quantified. Analogous to other cases, it is likely that tailings would erode from the areas of initial deposition and move downstream over a period of more than a decade. However, the data needed to model that process and the resources needed to develop that model were not available.
- Consequences of the loss and degradation of habitat on fish populations could not be quantified because of the lack of quantitative information concerning salmon, char, and trout populations. The occurrence of salmonid species in rivers and major streams is known, but information on abundances, productivities, and limiting factors within each of the watersheds is not available. 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 are not available. 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. Further, salmon populations naturally vary in size because of a great many factors that vary among locations and years. Collecting sufficient data to establish reliable salmon population estimates takes many years. Estimated effects of mining on habitat become the available 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 composition of leachates from tailings

New Stuyahok Photo: David Allnut (USEPA)

impoundments, tailings deposited in streams and on their floodplains, and waste rocks in piles.

- The effects of tailings and product concentrate deposited in spawning and rearing habitat are uncertain. It is clear that they would have harmful physical and toxicological effects on salmonid larvae or sheltering juveniles, but the concentration in spawning gravels required to reduce salmonid reproductive success is unknown.
- The actual response of Alaska Native cultures to any impacts of the mine scenario is uncertain. Interviews with village elders and culture bearers, and other evidence suggest that responses would involve more than the need to compensate for lost food and would likely include some degree of cultural disruption. It is not possible to predict specific changes in demographics, cultural practices, or physical and mental health.

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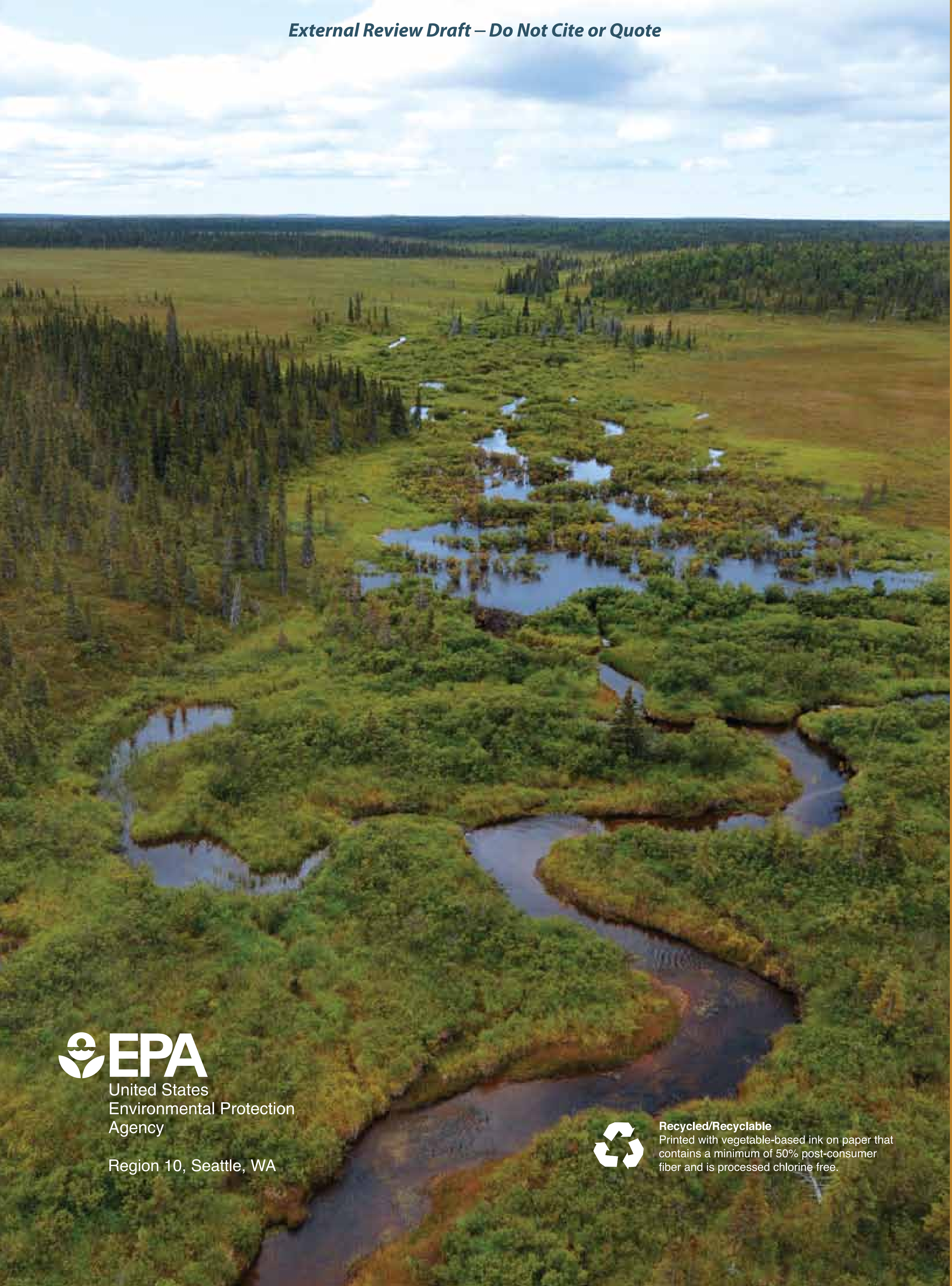
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