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

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Appendix J: Compensatory Mitigation and Large-Scale Hardrock Mining in the Bristol Bay Watershed

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Compensatory Mitigation and Large-Scale Hardrock Mining in the Bristol Bay Watershed

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This appendix provides an overview of Clean Water Act Section 404 compensatory mitigation requirements for unavoidable impacts to aquatic resources, and discusses an array of measures that various entities have proposed as having the potential to compensate for the unavoidable impacts to wetlands, streams, and fish identified in the Bristol Bay Assessment. Please note that any formal determinations regarding compensatory mitigation can only take place in the context of a regulatory action. The Bristol Bay Assessment is not a regulatory action, and thus a complete evaluation of compensatory mitigation is outside the scope of the assessment.

1. Overview of Clean Water Act Section 404 Compensatory Mitigation Requirements

The overall objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the nation's waters. To help achieve that objective, Section 404 of the Clean Water Act establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Section 404 requires a permit before dredged or fill material may be discharged into waters of the United States, unless the activity is exempt from Section 404 regulation (e.g. certain farming and forestry activities).

The U.S. Environmental Protection Agency (EPA) and the Department of the Army, operating through the Army Corps of Engineers (ACOE), share responsibilities for implementing the Section 404 program. Section 404(a) authorizes the ACOE to issue permits for the discharge of dredged or fill material into waters of the U.S. at specified disposal sites. Section 404(b) directs the ACOE to apply environmental criteria developed by EPA in making its permit decisions (these criteria are binding regulations known as the "Section 404(b)(1) Guidelines" (40 CFR Part 230)). Under EPA's Section 404(b)(1) Guidelines, no discharge of dredged or fill material may be permitted by the ACOE if: (1) a practicable alternative exists that is less damaging to the aquatic environment so long as that alternative does not have other significant adverse environmental consequences or (2) the nation's waters would be significantly degraded. Under the Guidelines, a project must incorporate all appropriate and practicable measures to first avoid impacts to wetlands, streams, and other aquatic resources and then minimize unavoidable impacts; after avoidance and minimization measures have been applied, the project must include appropriate and practicable compensatory mitigation for the remaining unavoidable impacts.

Compensatory mitigation refers to the restoration, establishment, enhancement, and/or preservation of wetlands, streams, or other aquatic resources conducted specifically for the purpose of offsetting authorized impacts to these resources (Hough and Robertson 2009). Compensatory mitigation regulations jointly promulgated by EPA and the ACOE (40 CFR §§ 230.91 - 230.98 and 33 CFR §§ 332.1 - 332.8) state that "the fundamental objective of compensatory mitigation is to offset environmental losses resulting from unavoidable impacts to waters of the United States authorized by [Clean Water Act Section 404 permits issued by the ACOE]" (40 CFR Part 230.93(a)(1)). Compensatory mitigation enters the analysis only after a proposed project has incorporated all appropriate and practicable means to avoid and minimize adverse impacts to aquatic resources (40 CFR Part 230.91(c)).

Section 404 permitting requirements for compensatory mitigation are based on what is "practicable and capable of compensating for the aquatic resource functions that will be lost as a result of the permitted activity" (40 CFR Part 230.93(a)(1)). In determining what type of compensatory mitigation will be "environmentally preferable," the ACOE "must assess the likelihood for ecological success and sustainability, the location of the compensation site relative to the impact site and their significance within the watershed, and the costs of the compensatory mitigation project"(40 CFR Part 230.93(a)(1)). Furthermore, compensatory mitigation requirements must be commensurate with the amount and type of impact associated with a particular Section 404 permit (40 CFR Part 230.93(a)(1)). The regulations recognize that there may be instances when the ACOE cannot issue a permit "because of the lack of appropriate and practicable compensatory mitigation options" (40 CFR Part 230.91(c)(3)).

1.1 Compensatory Mitigation Methods

Compensatory mitigation can occur through four methods: aquatic resource **restoration**, **establishment**, **enhancement**, or in certain circumstances, **preservation** (40 CFR Part 230.93(a)(2)).

- Restoration is the reestablishment or rehabilitation of a wetland, stream, or other aquatic resource with the goal of returning natural or historic functions and characteristics to a former or degraded aquatic resource. When it is an option, restoration is generally the preferred method, due in part to its higher likelihood of success as measured by gain in aquatic resource function, area, or both.
- Establishment, or creation, is the development of a wetland or other aquatic resource where one did not exist previously, with success measured as a net gain in both area and function of the aquatic resource.
- Enhancement includes activities conducted within existing aquatic resources that heighten, intensify, or improve one or more aquatic resource functions, without increasing the area of the aquatic resource. Examples include improved floodwater retention or wildlife habitat.
- Preservation is the permanent protection of aquatic resources and/or upland buffers or riparian areas through legal and physical mechanisms, such as conservation easements and title transfers. Because preservation does not replace lost aquatic resource area or functions, regulations limit its use to situations in which the resources to be preserved provide important functions for and contribute significantly to the ecological sustainability of the watershed,

and those resources are under threat of destruction or adverse modification (40 CFR Part 230.93(h)).

1.2 Compensatory Mitigation Mechanisms

There are three general mechanisms for achieving the four methods of compensatory mitigation (listed in order of preference as established in 40 CFR 230.93(b)): **mitigation banks**, **in-lieu fee programs**, and **permittee-responsible mitigation**.

- A mitigation bank is a site with restored, established, enhanced, or preserved aquatic resources, riparian areas and/or upland buffers that the ACOE has approved for use to compensate for losses from future permitted activities. The bank approval process establishes the number of available compensation credits, which permittees may purchase upon ACOE approval that the bank represents appropriate compensation. The bank sponsor is responsible for the success of these mitigation sites.
- For in-lieu fee mitigation, a permittee provides funds to an in-lieu fee program sponsor who conducts compensatory mitigation projects according to the compensation planning framework approved by ACOE. Typically specific compensatory mitigation projects are started only after pooling funds from multiple permittees. The in-lieu fee program sponsor is responsible for the success of these mitigation sites.
- In permittee-responsible mitigation, the permittee undertakes and bears full responsibility for the implementation and success of the mitigation. Mitigation may occur either at the site where the regulated activity caused the loss of aquatic resources (on-site) or at a different location (off-site), preferably within the same watershed.

Although it is the permit applicant's responsibility to propose an appropriate compensatory mitigation option, mitigation banks and in-lieu fee programs are the federal government's preferred forms of compensatory mitigation as they "usually involve consolidating compensatory mitigation projects where ecologically appropriate, consolidating resources, providing financial planning and scientific expertise (which often is not practical for permittee-responsible compensatory mitigation projects), reducing temporal losses of functions, and reducing uncertainty over project success" (40 CFR 230.93(a)(1); *see also* 40 CFR 230.93(b)).

1.3 Location, Type, and Amount of Compensation

Regulations regarding compensatory mitigation require the use of a watershed approach to "establish compensatory mitigation requirements in [Department of the Army] permits to the extent appropriate and practicable" (40 CFR 230.93(c)(1)). Under these regulations, the watershed approach to compensatory mitigation site selection and planning is an analytical process for making compensatory mitigation decisions that support the sustainability or improvement of aquatic resources in a watershed. It involves consideration of watershed needs and how locations and types of compensatory mitigation projects address those needs (40 CFR 230.92). The regulations specifically state that compensatory mitigation generally should occur within the same watershed as the impact site and in a location where it is most likely to successfully replace lost functions and services (40 CFR 230.93(b)(1)). The goal of this watershed approach is to "maintain and improve the quality and quantity of aquatic resources within watersheds through strategic selection of compensatory mitigation sites" (40 CFR 230.93(c)(1)).

The regulations emphasize using existing watershed plans to inform compensatory mitigation decisions, when such plans are determined to be appropriate for use in this context (40 CFR 230.93(c)(1)). Watershed plans that could support compensatory mitigation decision-making are typically:

> "…developed by federal, tribal, state, and/or local government agencies or appropriate non-governmental organizations, in consultation with relevant stakeholders, for the specific goal of aquatic resource restoration, establishment, enhancement and preservation. A watershed plan addresses aquatic resource conditions in the watershed, multiple stakeholder interests, and land uses. Watershed plans may also identify priority sites for aquatic resource restoration and protection" (40 CFR 230.92).

Where appropriate plans do not exist, the regulations describe the types of considerations and information that should be used to support a watershed approach to compensation decision-making. Central to the watershed approach is consideration of how the types and locations of potential compensatory mitigation projects would sustain aquatic resource functions in the watershed. To achieve that goal, the regulations emphasize that mitigation projects should, where practicable, replace the suite of functions typically provided by the affected aquatic resource, rather than focus on specific individual functions (40 CFR 230.93(c)(2)). For this purpose, "watershed" means an "area that drains to a common waterway, such as a stream, lake, estuary, wetland, or ultimately the ocean" (40 CFR 230.92). Although there is flexibility in defining geographic scale, the watershed "should not be larger than is appropriate to ensure that the aquatic resources provided through compensation activities will effectively compensate for adverse environmental impacts resulting from [permitted] activities" (40 CFR 230.93(c)(4)).

With regard to type, in-kind mitigation (i.e., involving resources similar to those being impacted) is generally preferable to out-of-kind mitigation, because it is most likely to compensate for functions lost at the impact site (40 CFR 230.93(e)(1)). Furthermore, the regulations recognize that, for difficult-to-replace resources such as bogs, fens, springs, and streams, in-kind "rehabilitation, enhancement, or preservation" should be the compensation of choice, given the greater likelihood of success of those types of mitigation (40 CFR 230.93(e)(3)).

The amount of compensatory mitigation required must be, to the extent practicable, "sufficient to replace lost aquatic resource functions" (40 CFR 230.93(f)(1)), as determined through the use of a functional or condition assessment. If an applicable assessment methodology is not available, the regulations require a minimum one-to-one acreage or linear foot compensation ratio (40 CFR 230.93(f)(1)). Certain circumstances require higher ratios, even in the absence of an assessment methodology (e.g., use of preservation, lower likelihood of success, differences in functionality between the impact site and compensation project, difficulty of restoring lost functions, and the distance between the impact and compensation sites) (40 CFR 230.93(f)(2)).

1.4 Compensatory Mitigation Guidance for Alaska

In addition to the federal regulations regarding compensatory mitigation, the agencies have also developed compensatory mitigation guidance applicable specifically to Alaska. In their 1994 Alaska Wetlands Initiative Summary Report, EPA and the Department of the Army concluded that it was not necessary to provide "broad exemptions" from mitigation sequencing in Alaska, given the "inherent flexibility provided by" the regulations and associated guidance. The agencies also recognized that "it may not always be practicable to provide compensatory mitigation through wetlands restoration or creation in areas where there is a high proportion of land which is wetlands. In cases where potential compensatory mitigation sites are not available due to the abundance of wetlands in a region and lack of enhancement or restoration sites, compensatory mitigation is not required under the [Section 404(b)(1)] Guidelines" (EPA et al., 1994). In promulgating the compensatory mitigation regulations in 2008, EPA and the ACOE specifically referenced the 1994 policy and reiterated the flexibility and discretion available to decision-makers (e.g., 40 CFR 230.91(a)(1), 40 CFR 230.93(a)(1)).

Although opportunities for wetland restoration and creation continue to be rather limited in Alaska, a number of other wetland compensatory mitigation options (e.g., mitigation banks, in-lieu fee programs) have become available since 1994. Moreover, it is important to note that the 1994 policy applies only to compensatory mitigation for impacts to wetlands and does not address compensatory mitigation for impacts to Alaska streams. Furthermore, subsequent guidance issued by the ACOE Alaska District in 2009 clarifies that fill placed in streams or in wetlands adjacent to anadromous fish streams in Alaska will require compensatory mitigation (ACOE 2009). A 2011 supplement to the Alaska District's 2009 guidance further recommends that projects in "difficult to replace" wetlands, fish-bearing waters, or wetlands within 500 feet of such waters will also likely require compensatory mitigation, as will "large scale projects with significant aquatic resource impacts," such as "mining development" (ACOE 2011).

The ACOE's 2009 Alaska guidance also provides sample compensatory mitigation ratios based on the type of mitigation and the ecological value of the impacted resource (high, moderate, or low). These guidelines include streams in the high quality category, indicating compensation ratios of 2:1 for restoration and/or enhancement and 3:1 for preservation (ACOE 2009).

2. Compensatory Mitigation Considerations for the Bristol Bay Assessment

2.1 Important Ecological Functions and Services Provided by Affected Streams and Wetlands

Bristol Bay's stream and wetland resources support a world-class commercial and sport fishery for Pacific salmon and other important fish. They have also supported a salmon-based culture and subsistence-based lifestyle for Alaska Natives in the watershed for at least 4,000 years. Bristol Bay's streams and wetlands support production of 35 species of fish including 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.

In the Bristol Bay region, hydrologically-diverse riverine and wetland landscapes provide a variety of salmon spawning and rearing habitats. Environmental conditions can be very different among habitats in close proximity, with ponds, lakes and streams expressing very different flow, temperature, and physical habitat characteristics at very fine spatial scales (see Chapter 7 of the assessment for additional discussion). Recent research has highlighted the potential for local adaptations and fine-scale population structuring in Bristol Bay and neighboring watersheds associated with this environmental template (Quinn et al. 2001, Olsen et al. 2003, Ramstad et al. 2010, Quinn et al. 2012). For example, sockeye salmon that use spring-fed ponds and streams located approximately 1 km apart exhibit differences in traits such as spawn timing, spawn site fidelity, and productivity consistent with discrete populations (Quinn et al. 2012). Bristol Bay's streams and wetlands support a diverse array of salmon populations that are unique to specific drainages within the Bay and this population diversity is key to the stability of the overall Bristol Bay salmon fishery (i.e., the portfolio effect) (Schindler et al. 2010).

As discussed in detail in the Bristol Bay Assessment (see Chapter 7), streams and wetlands that would be lost as a result of the mine footprints described in the assessment's scenarios provide important ecological functions. These headwater streams provide spawning habitat for coho and sockeye salmon and likely spawning habitat for anadromous and resident forms of Dolly Varden. Headwater streams and associated wetlands also provide rearing habitat for chum salmon, sockeye salmon, Chinook salmon, coho salmon, Dolly Varden, rainbow trout, Arctic grayling, slimy sculpin, northern pike, and ninespine stickleback (Johnson and Blanche 2012, ADFG 2012a). Headwater streams and associated wetlands are often exploited by fish for spawning and rearing because they can provide refuge from predators and competitors that are more abundant downstream (Quinn 2005). Off-channel wetlands with their unique low-velocity, depositional environments and variable thermal conditions provide additional options for juvenile salmon feeding and rearing. For example, ephemeral swamps provided important thermal and hydraulic refuge for coho salmon in a coastal British Columbia stream (Brown and Hartman 1988). Off-channel ponds provided highly productive foraging environments and enhanced overwinter growth of coho salmon in an interior British Columbia stream (Swales and Levings 1989).

It has long been recognized that in addition to providing habitat for stream fishes, headwater streams and wetlands serve an important role in the stream network by contributing nutrients, water, organic material, algae, bacteria and macroinvertebrates downstream, to higher order streams in the watershed (Vannote et al. 1980, Meyer et al. 2007). But only recently have specific subsidies from headwater systems been extensively quantified (Wipfli and Baxter 2010). The contributions of headwaters to downstream systems results from their high density in the dendritic stream network. Headwater streams also have high rates of instream nutrient processing and storage, thereby determining downstream water chemistry due to relatively large organic matter inputs, high retention capacity, high primary productively, bacteria-induced decomposition, and extensive hyporheic zone interactions (Richardson et al. 2005, Alexander et al. 2007, Meyer et al. 2007). Because of their crucial influence on downstream water flow, chemistry, and biota, impacts to headwaters reverberate throughout entire watersheds downstream (Freeman et al. 2007, Meyer et al. 2007).

The majority of streams directly in the footprint of the mine scenarios are classified as small headwater streams (less than 0.15 m^3/s mean annual streamflow) (see assessment Table 7-6). Because of their narrow width, headwater streams receive proportionally larger inputs of organic material than do larger stream channels (Vannote et al. 1980). This material is either used in the headwater environment (Tank et al. 2010) or transported downstream as a subsidy to larger streams in the network (Wipfli et al. 2007). Consumers in headwater stream food webs, such as invertebrates, juvenile salmon, and other fishes rely heavily on the terrestrial inputs that enter the stream (Doucett et al. 1996, Eberle and Stanford 2010, Dekar et al. 2012). Headwater streams also encompass the upper limits of anadromous fish distribution, and may receive none, or lower quantities of marine-derived nutrients (MDN) from spawning salmon relative to downstream portions of the river network, making terrestrial nutrient sources relatively more important (Wipfli and Baxter 2010).

Both invertebrates and detritus are exported from headwaters to downstream reaches and provide an important energy subsidy for juvenile salmonids (Wipfli and Gregovich 2002, Meyer et al. 2007). Headwater wetlands and associated wetland vegetation can also be important sources of dissolved and particulate organic matter, and macroinvertebrate diversity (King et al. 2012), contributing to the chemical, physical, and biological condition of downstream waters (Shaftel et al. 2011a, Shaftel et al. 2011b, Dekar et al. 2012, Walker et al. 2012). Thus, losses of headwater streams and wetlands due to the mine scenario footprints would not only eliminate important fish habitat but also reduce inputs of organic material, nutrients, water, primary producers, bacteria, and macroinvertebrates to reaches downstream of the mine scenario footprints.

2.2 Identifying the Appropriate Watershed Scale for Compensatory Mitigation

As previously noted, the regulations regarding compensatory mitigation specifically state that compensatory mitigation generally should occur within the same watershed as the impact site and in a location where it is most likely to successfully replace lost functions and services (40 CFR 230.93(b)(1)).

For the mine scenarios evaluated in the Bristol Bay Assessment, the lost functions and services occur in the watersheds that drain to the North Fork Koktuli (NFK) and South Fork Koktuli (SFK) Rivers and Upper Talarik Creek (UTC) (see Figure 1). Accordingly, the most appropriate geographic scale at which to compensate for any unavoidable impacts resulting from such a project would be within these same watersheds, as this location would offer the greatest likelihood that compensation measures would replace the "suite of functions typically provided by the affected aquatic resource" (40 CFR 230.93(c)(2), Yocom and Bernard 2013). An important consideration is that salmon populations in these watersheds may possess unique adaptations to local environmental conditions, as suggested by recent research in the region (Quinn et al. 2001, Olsen et al. 2003, Ramstad et al. 2010, Quinn et al. 2012). Accordingly, maintenance of local biocomplexity (i.e., salmon genetic, behavioral, and phenotypic variation) and the environmental template upon which biocomplexity develops will be important for sustaining resilience of these populations (Hilborn et al. 2003, Schindler et al. 2010). Thus, the most appropriate spatial scale and context for compensation would be within the local watersheds where impacts to salmon populations occur.

If there are no practicable or appropriate opportunities to provide compensation in these watersheds, it may be appropriate to explore options in adjoining watersheds. However, defining the watershed scale too broadly would likely fail to ensure that wetland, stream, and associated fish losses under the mine scenarios would be effectively offset, because compensation in a different watershed(s) would not address impacts to the portfolio effect from losses in the impacted watersheds. Similarly, compensation in different watersheds would not address impacts to the subsistence fishery where users depend on a specific temporal and spatial distribution of fish to ensure nutritional needs and cultural values are maintained (see Bristol Bay Assessment Chapter 12).

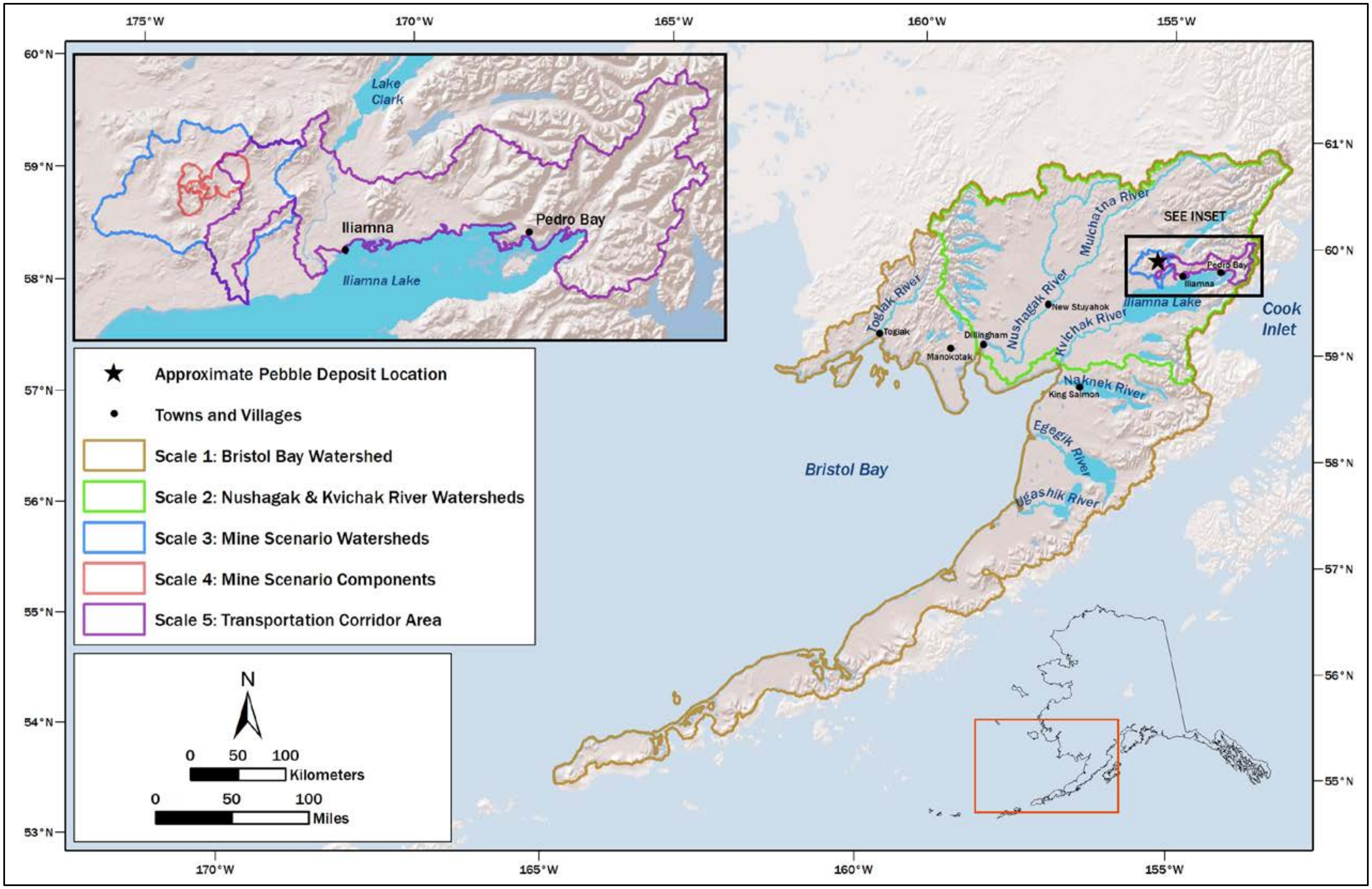

Figure 1. The boundaries of the Bristol Bay watershed (brown), the Nushagak and Kvichak River watersheds (green) and the North Fork Koktuli, South Fork Koktuli, and Upper Talarik Creek watersheds (blue).

3. Potential Compensatory Mitigation Measures in Bristol Bay

As discussed in Chapter 7 of the Bristol Bay Assessment, impact avoidance and minimization measures do not eliminate all of the footprint impacts associated with the mining scenarios. Reasons impact avoidance and minimization measures fail to eliminate these kinds of impacts include: the large extent and wide distribution of wetlands and streams in the watersheds, the fact that substantial infrastructure would need to be built to support porphyry copper mining in this largely undeveloped area and the fact that ore body location constrains siting options. The mine scenarios evaluated in the assessment identify that the mine footprints alone would result in the unavoidable loss (i.e., filling, blocking or otherwise eliminating) of hundreds to thousands of acres of high-functioning wetlands and tens of miles of salmon-supporting streams (see Figure 2).

The public and peer review comments on the draft Bristol Bay Assessment identified an array of compensation measures that some commenters believed could potentially offset these impacts to wetlands, streams, and fish. The following discussion considers the likely efficacy of the complete array of compensation measures proposed by commenters at offsetting potential adverse effects, organized in the order that the regulations prescribe for considering compensation mechanisms:

1) Mitigation bank credits;
2) In-lieu fee program credits; and
3) Variations of permittee-responsible mitigation.

3.1 Mitigation Bank Credits

There are currently no approved mitigation banks with service areas[1] that cover the impact site for the mine scenarios; thus, no mitigation bank credits are available. Should one or more bank sponsors pursue the establishment of mitigation bank sites to address the impacts associated with the mine scenarios, they would likely encounter the same challenges described below (Section 3.3).

[1] The service area is the watershed, ecoregion, physiographic province, and/or other geographic area within which the mitigation bank or in-lieu fee program is authorized to provide compensatory mitigation (40 CFR 230.98(d)(6)(ii)(A)).

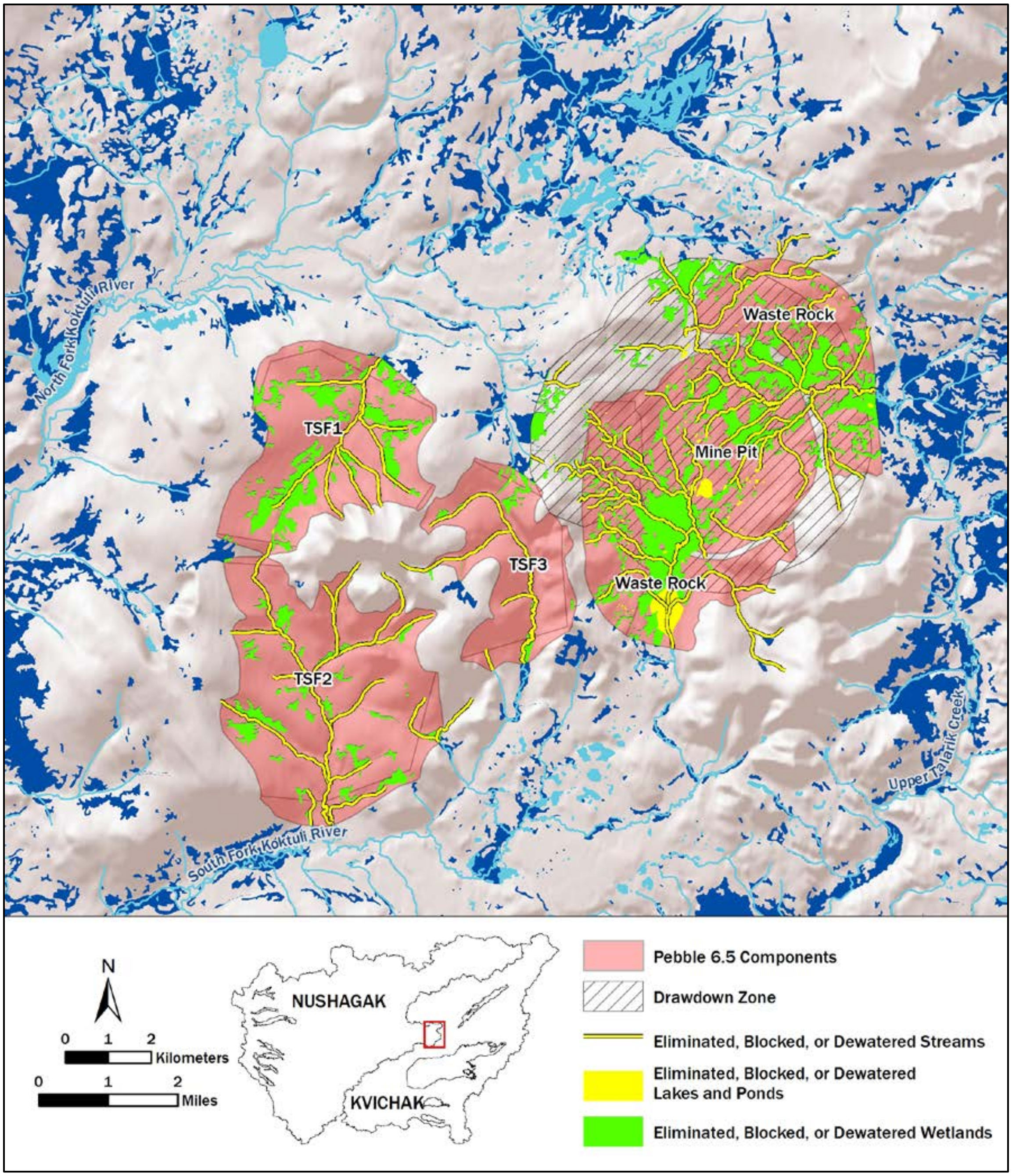

Figure 2. Streams, wetlands and other waters lost (eliminated, blocked, or dewatered) in the Pebble 6.5 scenario evaluated in the Bristol Bay Assessment.

3.2 In-Lieu Fee Program Credits

There is currently one in-lieu fee program approved to operate in the Bristol Bay watershed, which has been administered by The Conservation Fund (TCF) since 1994. The TCF program operates statewide, and the Bristol Bay watershed falls within one of its service areas. According to TCF, its compensation projects consist almost entirely of wetland preservation. To date, TCF has completed four wetland preservation projects in the Bristol Bay watershed, financed in part with in-lieu fee funds. Although the majority of in-lieu fees collected by the TCF program have been for relatively small impacts to aquatic resources, TCF has accepted in-lieu fees to compensate for a few projects with over 50 acres of impacts statewide. To date, the largest impact represented in the TCF program is the loss of 267 acres of wetlands associated with the development of the Point Thomson natural gas production/processing facilities on Alaska's Beaufort Sea coast. It is not clear if this program could effectively provide the magnitude of compensation necessary to address the loss of hundreds to thousands of acres of high functioning wetlands and tens of miles of salmon-supporting streams associated with the mine scenarios. In addition, it is likely that any in-lieu fee sponsor seeking to address the impacts associated with the mine scenarios would encounter the same challenges described below (Section 3.3).

3.3 Permittee-Responsible Compensatory Mitigation

Currently, there is no watershed plan for the NFK, SFK, or UTC, or other components of the Nushagak or Kvichak River drainages that could serve as a guide to permittee-responsible compensatory mitigation. In the absence of such a plan, the regulations call for the use of a watershed approach that considers information on watershed conditions and needs, including potential sites and priorities for restoration and preservation (40 CFR 230.93(c)). When a watershed approach is not practicable, the next option is to consider on-site (i.e., on the same site as the impacts or on adjoining land) and in-kind compensatory mitigation for project impacts, taking into account both practicability and compatibility with the proposed project (40 CFR 230.93(b)(5)). When such measures would be impracticable, incompatible, or inadequate, the last resort would be off-site and/or out-of-kind mitigation opportunities (40 CFR 230.93(b)(6)).

3.3.1 Opportunities within the NFK, SFK, and UTC Watersheds

In the context of the mine scenarios, the primary challenge to both a watershed approach and on-site compensatory mitigation is the absence of existing degraded resources within the NFK, SFK and UTC watersheds. Specifically, these three watersheds are largely unaltered by human activities; thus, opportunities for restoration or enhancement are very limited, and, as discussed below, likelihood of success appears to be very low.

Here we discuss specific suggestions for potential compensation measures within the NFK, SFK and UTC watersheds that were provided in the public and peer review comments on the Bristol Bay Assessment.

3.3.1.1 Increase Habitat Connectivity

Connectivity among aquatic habitats within stream networks is an important attribute influencing the ability of mobile aquatic taxa to utilize the diversity and extent of habitats within those networks. Within riverine floodplain systems, a complex array of habitats can develop that express varying degrees of surface and sub-surface water connectivity to main channels (Stanford and Ward 1993). In the study area, off-channel floodplain habitats can include side channels (both inlet and outlet connections to main channel), various types of single-connection habitats including alcoves and percolation channels, and pools and ponds with no surface connection to the main channel during certain flow conditions (PLP 2011 Appendix 15.1D). Beaver can be very important modifiers and creators of habitat in these off-channel systems (Pollock et al. 2003, Rosell et al. 2005). As a result of their morphology and variable hydrology, the degree of surface-water connectivity and the ability of fish to move among floodplain habitats changes with surface water levels. Connectivity for fish movement at larger spatial scales within watersheds is influenced by barriers to longitudinal movements and migrations. Examples include dams and waterfalls.

Efforts to manage or enhance connectivity within aquatic systems have primarily focused on watersheds altered by human activities, where land uses and water utilization have lead to aquatic habitat fragmentation. Specific activities to increase habitat connectivity within human-dominated stream-wetland systems may include: 1) improving access around real or perceived barriers to migration (including dams constructed by humans or beaver); 2) removing or retrofitting of road culverts; and 3) excavating and engineering of channels to connect isolated wetlands and ponds to main channels. Within watersheds minimally impacted by human activity, efforts may include creation of passage around barrier waterfalls to expand the availability of habitat for species like Pacific salmon. Human-created dams do not offer any opportunities for habitat improvement or expansion in the Nushagak or Kvichak River watersheds because they are absent, so they are not discussed further. Since road stream crossing retrofits presently offer no opportunities for habitat improvement or expansion within the NFK, SFK, and UTC watersheds, but exist elsewhere in the larger Nushagak and Kvichak River watersheds, they are discussed in Section 3.3.2.3. Here, we focus on beaver dam removal and engineered connections to variably-connected floodplain habitats, and habitats upstream of barrier waterfalls. For each of these measures, the potential applicability, suitability, and effectiveness as mitigation tools within the study area watersheds are addressed.

3.3.1.1.1 Remove Beaver Dams

Two commenters suggested the removal of beaver dams as a potential compensation measure. Presumably, the rationale for this recommendation is that beaver dams can block fish passage, limiting fish access to otherwise suitable habitat, thus, the removal of beaver dams could increase the amount of available fish habitat. This rationale is based upon early research that led to the common fish management practice of removing beaver dams to protect certain fish populations like trout (Sayler 1934, Reid 1952, *in* Pollock et al. 2004). However, more recent research has documented numerous benefits of beaver ponds to fish populations and habitat (Murphy et al. 1989, Pollock et al. 2003). For example, Bustard and Narver (1975) found that a series of beaver ponds on Vancouver Island had a survival rate for overwintering juvenile coho salmon that was twice as high as the 35% estimated for the entire stream. Pollock et al. (2004) estimated a 61% reduction in summer habitat capacity relative to historical levels, for coho salmon in one Washington watershed, largely due to loss of beaver ponds.

Kemp et al. (2012) recently published a definitive review of the effects of beaver in stream systems, indicating that they have a positive impact on sockeye, coho, and Chinook salmon as well as Dolly Varden, rainbow trout, and steelhead. Using meta-analysis and weight-of-evidence methodology, the review showed that most (71.4%) negative effects cited, such as low dissolved oxygen and impediment to fish movement, lack supportive data and are speculative in nature, whereas the majority (51.1%) of positive impacts cited are quantitative in nature and well-supported by data (Kemp et al. 2012). In addition to increased invertebrate (i.e., food) production and habitat heterogeneity, the study cited the importance of beaver ponds as rearing habitat due to the increased cover and protection that higher levels of woody material and overall structural diversity provide. Other studies have identified beaver ponds as excellent salmon rearing habitat because they have high macrophyte cover, low flow velocity, and increased temperatures, and they trap organic materials and nutrients (Nickelson et al. 1992, Collen and Gibson 2001, Lang et al. 2006). DeVries et al (2012) describe a stream restoration approach that attempts to mimic and facilitate beaver dam creation and the numerous positive benefits for stream habitat and riparian enhancement. Studies in Oregon have shown that salmon abundance is positively related to pool size, especially during low flow conditions (Reeves et al. 2011), and beaver ponds provide particularly large pools. During winter, beaver ponds typically retain liquid water below the frozen surface, providing refugia for species that overwinter in streams and off-channel habitats (Nickelson et al. 1992, Cunjak 1996).

Beaver dams generally do not constitute significant barriers to salmonid migration even though their semi-permeability may temporarily limit fish movement during periods of low stream flow (Rupp 1954, Gard 1961, Bryant 1984, Pollock et al. 2003). Even when beaver dams impede fish movements, the effects are typically temporary, with higher flows from storm events ultimately overtopping them or blowing them out (Leidholt-Bruner et al. 1992, Kemp et al. 2012). Even the temporary effect may be limited, when seasonal rainfall is at least average (Snodgrass and Meffe 1998, Kemp et al. 2012). Adding to the body of evidence, Pacific salmon and other migratory fish species commonly occur above beaver dams, including above beaver dams in the study area (PLP 2011; Appendix 15.1D). One study in southeast Alaska documented coho salmon upstream of all surveyed beaver dams, including one that was two meters high; in fact, the survey recorded highest coho densities in streams with beaver (Bryant 1984). Other surveys have documented both adult and juvenile sockeye salmon, steelhead, cutthroat, and char upstream of beaver dams (Bryant 1984, Swales et al. 1988, Murphy et al. 1989, Pollock et al. 2003).

Beavers preferentially colonize headwater streams, such as those found near the Pebble deposit, because of their shallow depths and narrow widths (Collen and Gibson 2001, Pollock et al. 2003). An October 2005 aerial survey of active beaver dams in the mine scenarios area mapped a total of 113 active beaver colonies (PLP 2011). The Pebble Limited Partnership's (PLP) Environmental Baseline Document (EBD) highlights the significant role that beaver ponds are currently providing for Pacific salmon in this area when it states:

> "[W]hile beaver ponds were relatively scarce in the mainstem UT [UTC], the off-channel habitat study revealed a preponderance of beaver ponds in the off-channel habitats. As in the SFK watershed, beaver ponds accounted for more than 90 percent of the off-channel habitat surveyed. Beaver ponds in the UT provided habitat for adult spawning and juvenile overwintering for Pacific salmon. The water temperature in beaver ponds in the UT was slightly warmer than in other habitat types and thus, beaver ponds may represent a more productive habitat as compared to other mainstem channel habitat types" (PLP 2011).

The current body of literature describing the effects of beaver dams on salmonid species reports more positive associations between beaver dam activity and salmonids than negative associations (Kemp et al. 2012). Hence, removal of beaver dams as a means of compensatory mitigation could lead to a net negative impact on salmonid abundance, growth, and productivity. Moreover, since the mine scenario would eliminate or block several streams with active beaver colonies in the headwaters of the SFK and UTC, the benefits provided by those habitats would be part of the suite of functions that compensatory mitigation should aim to offset.

3.3.1.1.2 Connect Off-channel Habitats and Habitat Above Impassible Waterfalls

Off-channel habitats can provide important low-velocity rearing habitats for juvenile salmon and other native fishes. Floodplain-complex habitats including beaver ponds, side channels, oxbow channels, and alcoves can contribute significantly to juvenile salmonid rearing capacity (e.g., Beechie et al. 1994). Such habitats are a common feature of unmodified alluvial river corridors. These habitats may express varying degrees of surface-water connectivity to main channels that in unmodified rivers is dependent upon streamflow stage and natural channel dynamics. Off-channel habitats may become isolated from the main channel during certain streamflow conditions due to channel migration or avulsion, and in highly dynamic channels, connectivity may change frequently during bed-mobilizing events (Stanford and Ward 1993). This shifting mosaic of depositional and erosional habitats within the floodplain creates a diverse hydraulic and geomorphic setting, contributing to biocomplexity (Amoros and Bornette 2002). In river systems modified by human activity, isolation or elimination of off-channel habitats has had severe impacts on salmon productivity (e.g., Beechie et al. 1994), and re-connection and re-creation of off-channel habitats are now common tools for increasing juvenile salmonid habitat capacity in those systems (Morley et al. 2005, Roni et al. 2006).

Waterfalls or high-gradient stream reaches can prevent mobile fish species from accessing upstream habitats, due to velocity barriers or drops that exceed passage capabilities of fish (Reiser et al. 2006). Waters upstream of barriers may be devoid of all fish life, or may contain resident fish species including genetically-distinct populations (e.g., Whiteley et al. 2010). Engineered passageways for fish around waterfalls have been used to create access to upstream lakes or stream systems for fish such as salmon. However, the response of resident fish species to barrier removal and the colonization success of species from downstream habitats may be difficult to predict (Kiffney et al. 2009). Salmon population responses to a fishway in southeast Alaska depended on the species, and the ecological effects of fish passage on the upstream lake system and watershed are not fully understood (Bryant et al. 1999). Burger et al. (2000) provide a well-documented history of colonization of sockeye salmon in Frazer Lake, Alaska above a historically-impassible waterfall following passage installation and planting of salmon eggs, fry, and adults above the barrier. Their study documents how differing donor populations, each with different life-history characteristics, contributed differently toward the establishment of populations in the newly accessible habitats (Burger et al. 2000). This study highlights the importance of genetics and life history adaptations of source populations to colonization success.

Creating connectivity between parts of the river network that are naturally disconnected can have adverse ecological effects, including impacts to resident vertebrate and invertebrate communities, as well as disruptions to ecosystem processes. Introduction of fish to fish-less areas can lead to altered predator-prey interactions, food web changes, changes in algal production, nutrient cycling and meta-population dynamics of other vertebrate species (see Section 3.3.2.5). For example, previous studies on the introduction of trout species to montane, wilderness lakes have shown that introducing fish to fish-less lakes can have substantial impacts to nutrient cycles (Knapp et al. 2001). The risk of disruption to the functions of naturally fish-less aquatic ecosystems should be fully evaluated before these approaches are used for the sole purpose of creating new fish habitat area.

Rosenfeld and co-authors (Rosenfeld et al. 2008, Rosenfeld et al. 2009) conducted a variety of experiments and monitoring activities within a re-connected river meander in coastal British Columbia to explore the relationship of salmon productivity to habitat features. Their work highlights the importance of habitat configuration. In their study, spacing of pools (foraging habitats for fish) and riffles (source areas for invertebrate prey) was an important factor influencing growth rates of juvenile coho salmon. Given the high diversity of channel conditions within floodplain habitats in the project area (PLP 2011), it is likely that fish responses to increased connectivity would be highly variable.

Rosenfeld et al. (2008) point out the importance of considering the full suite of factors that influence habitat capacity and productivity when designing restoration or enhancement projects. For instance, 'optimising' habitat structure for one species may adversely impact species with differing habitat preferences, as demonstrated by Morley et al. (2005) who found differential responses of juvenile steelhead and juvenile coho salmon to conditions in constructed and natural off-channel habitats. Predator-prey relationships also need to be considered. Increased connectivity of off-channel habitats has been proposed as a strategy for enhancing northern pike production in northern Canada (Cott, 2004). How increased connectivity in the project area would influence trophic relationships among northern pike and salmon, trout and char is unknown, although introduced northern pike in other areas of Alaska have the potential to reduce local abundances of salmonids via predation (Sepulveda et al. 2013). Bryant et al. (1999) in their study of the effects of improved passage at a waterfall concluded that the effects on food webs, trophic relationships, and genetics among resident and newly-colonizing species were largely unknown. Rosenfeld and co-authors (2009) emphasize the high degree of uncertainty associated with channel design for enhanced fish productivity, stating:

> "…despite the enormous quantity of research on stream rearing salmonids and their habitat associations, stream ecologists still lack a definitive understanding of the relationship between channel structure, prey production and habitat capacity for drift-feeding fishes" (Rosenfeld et al. 2009, page 581).

Several commenters proposed that enhanced or increased connectivity of off-channel habitats or habitats above waterfalls could provide fish access to habitat currently underutilized or inaccessible. This comment presumes that currently disconnected habitats would provide suitable mitigation sites. Based on the above, there are multiple criteria that would have to be met, and numerous assumptions that would have to be validated in order for these sites to qualify as valid mitigation sites. For such measures to succeed, the following conditions would need to be considered:

a. Are currently inaccessible habitats suitable for salmon and other target fish species?

b. Does improved access to habitat address a currently limiting factor or condition?

c. Can the habitat be effectively connected in a way that enhances productivity?

d. Will enhanced connectivity be sustainable over the long term (e.g., be maintained despite sediment dynamics or channel adjustments)?

e. If enhanced connectivity is not self-sustainable, can a feasible monitoring and maintenance plan ensure continued connectivity and effectiveness?

f. What is the risk that changes to the hydrology, chemistry, temperature and morphology of the habitat complex associated with the construction of hydrologic connectivity will fundamentally alter the habitat suitability of the site such that it is no longer addressing a habitat need?

g. Would predators/competitors present within the existing disconnected habitat overwhelm the benefit to target species?

h. Are fish populations present in isolated habitats (e.g., above impassible waterfalls) genetically distinct or otherwise of special value, and potentially lost if connections to downstream fish populations are enabled?

i. How would potential adverse ecosystem changes in fish-less isolated habitats (e.g., above impassible waterfalls) due to fish introductions be evaluated and addressed?

Given the above considerations and examples of the challenges of connectivity management, use of fishways at waterfalls and engineered connections to off-channel habitats have many unanswered questions for the project area streams and wetlands. Such approaches would be effectively an "adaptive management experiment" (Rosenfeld et al. 2008); requiring careful monitoring and evaluation of alterations within an experimental context.

3.3.1.2 Increase Habitat Quality

Addition of large structural elements such as wood and boulders to streams has been a common stream habitat rehabilitation approach in locations where stream habitats have been extensively simplified by mining, logging and associated timber transportation, or other disturbances (Roni et al. 2008). The goals of large structure additions are typically to create increased hydraulic and structural complexity and improve local-scale habitat conditions for fish in streams that are otherwise lacking in rearing or spawning microhabitats. Properly engineered structural additions to channels can increase hydraulic diversity, habitat complexity, and retention of substrates and organic materials in channels, but benefits for aquatic life have been difficult to quantify (see review by Palmer et al. 2010). The paucity of demonstrated beneficial biotic responses to stream structural enhancements is at odds with perceptions by managers whose evaluations tend to be overtly positive – but usually based on qualitative opinion rather than scientific observation (Jähnig et al. 2011). In addition, improperly sited or engineered structural additions can fail to achieve desired effects or have adverse, unanticipated consequences (e.g., via structural failure or scour and fill of sensitive non-target habitats (Frissell and Nawa 1992)), highlighting the need for appropriate design.

Commenters proposed that quality of stream habitats in the project area could be enhanced by increasing habitat complexity through the addition of boulders or large wood to existing off-channel habitats. Off-channel habitats can provide important low-velocity rearing habitats for juvenile salmon and other native fishes. Floodplain-complex habitats including beaver ponds, side channels, oxbow channels, and alcoves provide hydraulic diversity that can be important for fish in variable flows (Amoros and Bornette 2002, Rosenfeld et al. 2008). Beaver are a major player in the creation and maintenance of these habitats in the study area (PLP 2011, Appendix 15.1D), as has been noted elsewhere (Pollock et al. 2003, Rosell et al. 2005). Off-channel habitats also provide important foraging environments, and can be thermally-diverse, offering opportunities for thermoregulation or enhanced bioenergetic efficiency (Giannico and Hinch 2003). Off-channel habitats are relatively frequent and locally-abundant in area streams and rivers, particularly in lower-gradient, unconstrained valley settings and at tributary confluences (e.g., PLP 2011 Figure 15.1-15, cover photo of this assessment). PLP's EBD, Appendix 15.1D (PLP 2011) contains an assessment of the natural fluvial processes creating and maintaining off-channel habitats, and their quality and quantity and function in the study area, including mechanisms of connectivity to the mainstem channels. This background information provides very useful information for evaluating the potential effectiveness of off-channel habitat modification.

Commenters proposed that off-channel habitats could also be improved by engineered modifications to the depth, shoreline development ratio, and configuration of off-channel habitats to create better overwintering habitat for juvenile salmon. The degree to which existing habitats could be enhanced to improve survival of juvenile salmon as proposed by commenters will be dependent upon several considerations, including an evaluation of factors known to influence the utilization, survival, and growth within these habitats. These considerations are discussed below.

Off-channel habitats surveyed by PLP and other investigators reveal that patterns of occupancy and density are high but variable among off-channel habitats (PLP 2011, Appendix 15.1D). Some of the highest densities observed were within off-channel habitats such as side channels and alcoves, but even some 'isolated' pools held fish (PLP 2011, Appendix 15.1D). This variability could reflect variation in suitability, access, or other characteristics of individual off-channel habitats. Juvenile salmonids require a diverse suite of resources to meet habitat requirements – cover and visual isolation provided by habitat complexity is one such resource, but other critical resources include food, space, and suitable temperatures and water chemistry (Quinn 2005). Habitat configuration within constructed side-channel habitats can also strongly influence density, size and growth of juvenile salmonids (Rosenfeld and Raeburn 2009). Giannico and Hinch (2003) in experimental treatments in side channels in British Columbia, found that wood additions were beneficial to coho salmon growth and survival in surface-water fed side channels, but not in groundwater-fed channels. They attributed this effect to differences in foraging strategy and bioenergetics of the juvenile coho salmon overwintering in the channels. Additions of wood had no effect, or even possibly a detrimental effect, on coho salmon survival in groundwater-fed side channels. These findings highlight the importance of understanding the ecology, bioenergetics, and behavior of the species and life histories present within habitats that may be quite diverse with regard to hydrology and geomorphology.

It is not clear from current data that adding complexity would address any limiting factor within existing off-channel habitats, or that additions of boulders and wood would enhance salmonid abundance or survival. Placement of structures (e.g., boulders, large wood) within stream channels should also be guided by careful consideration of potential adverse consequences, including unanticipated shifts in hydraulic conditions that lead to bank erosion or loss of other desirable habitat features. Sustainability of off-channel habitat modifications is also in question. As stated in the EBD, off-channel habitats are a product of a dynamic floodplain environment and "..are continually being created and destroyed" (PLP 2011; Appendix 15.1D; page 2). Maintenance of engineered structures or altered morphologies of such habitats over the long term would be a challenging task. Observations from the EBD suggest that beaver are already providing desired complexity; to quote, "..habitat mapping from this off-channel study shows that the beaver ponds contain extensive and diverse habitats and dominate the active valley floor." And, "…these off-channel habitats provide a critical habitat component of freshwater rearing of coho salmon, and to a lesser extent, other anadromous and resident species." (PLP 2011, Appendix 15.1D page 14).

3.3.1.3 Increase Habitat Quantity

The creation of spawning channels and off-channel habitats has been proposed as a means to compensate for lost salmon spawning and rearing areas. The intent of a constructed spawning channel is to simulate a natural salmon stream by regulating flow, gravel size, and spawner density (Hilborn 1992). Off-channel habitats may be enlarged or modified to alter habitat conditions and capacities for rearing juvenile salmonids. Examples include the many spawning channels (Bonnell 1991) and off-channel habitats (Cooperman 2006) enhanced or created in British Columbia and off-channel ponds rehabilitated by the City of Seattle (Hall and Wissmar 2004).

Off-channel spawning and rearing habitats can be advantageous to salmon populations by providing diverse hydraulic and habitat characteristics. Redds constructed in these habitats may be less susceptible to scour compared to main channel habitats due to flow stability provided by their hyporheic or groundwater sources (Hall and Wissmar 2004). Moderated thermal regimes can provide benefits for growth and survival for overwintering juveniles (Giannico and Hinch 2003). Morley et al. (2005) compared 11 constructed off-channel habitats to naturally-occurring paired reference side channels and found that both natural and constructed off-channel habitats supported high densities of juvenile salmonids in both winter and summer. Although numerous studies have documented short-term or localized benefits of constructed off-channel habitats, ascertaining population-level effects is much more difficult. Any additional fry produced by spawning channels (if successful) would require additional suitable habitat for juvenile rearing and subsequent life stages in order to have a net positive effect on populations. Hilborn (1992) indicates that success, measured by increased production of adult fish from such channels, is unpredictable and generally unmonitored. A notable exception is the study by Sheng et al. (1990), which documented 2- to 8-fold increases in recruitment of coho spawner production from groundwater-fed off-channel habitats. Sheng et al. (1990) stated that effectiveness would be greatest in systems which currently lack adequate overwinter refuges. As with any rehabilitation strategy, population responses will be dependent upon whether factors actually limiting production are addressed. As stated elsewhere in this assessment, additional research and monitoring is required to quantify factors currently limiting production within project area watersheds.

Replacing destroyed salmon habitats with new constructed channels is not a simple task. Factors for consideration in designing and implementing off-channel habitat development are outlined in Lister and Finnigan (1997), and include evaluation of species and life stages present, current habitat conditions, and factors limiting capacity or productivity (Roni et al. 2008). Research indicates that channels fed by hyporheic flow or groundwater may be most effective for creating suitable spawning and rearing habitats (Lister and Finnigan 1997). Near-stream excavation and compaction associated with channel construction can alter groundwater flowpaths, so designing projects to protect current function and groundwater connectivity is very important.

Numerous researchers have emphasized that replacing lost habitats is not merely a process of providing habitat structure (Lake et al. 2007). Effective replacement of function also requires establishment of appropriate food web structure and productivity to support the food supply for fish – in essence, an entire ecosystem, including all full suite of organisms such as bacteria, algae, and invertebrates – needs to be in place in order for a constructed channel to begin to perform some of the same functions of a destroyed stream (Palmer et al. 2010). Quigley and Harper (2006b), in a review of stream rehabilitation projects, concluded “the ability to replicate ecosystem function is clearly limited.”

There is some history of using constructed spawning channels to mitigate for the impacts of various development projects on fish, based on the premise that they would provide additional spawning habitat and produce more fry, which would presumably result in more adult fish returning (Hilborn 1992). Off-channel rearing habitats have also been used to create additional overwintering habitats in Pacific Northwest rivers (Roni et al. 2006), and spawning channels have also been shown to provide suitable overwintering habitats for juvenile coho salmon (Sheng et al. 1990). However, there are very few studies regarding the efficacy of such channels at enhancing adult salmon recruitment in the published literature. Constructed spawning channels, particularly those dependent upon surface flow, may also require annual maintenance and cleaning (Hilborn 1992), and salmon using them can be prone to disease outbreaks (Mulcahy et al. 1982). The need for frequent maintenance would be contrary to the regulations' intent that compensatory mitigation projects be self-sustaining (40 CFR 230.97(b)). Off-channel habitats to mainstems are also extremely difficult to engineer in a way that can self-sustain in the face of a dynamic fluvial environment. Alluvial channels frequently shift (Amoros and Bornette 2002), and beaver are highly effective ecosystem engineers whose activities are constantly re-arranging floodplain channels and creating new dams (Pollock et al. 2003) - including within engineered channels and culverts (Cooperman 2006).

In light of their uncertain track record, it does not appear that constructed spawning channels and engineered connections of off-channel habitats would provide reliable and sustainable fish habitat in the Bristol Bay region.

3.3.1.4 Manage Water Quantity

Two commenters suggested a variety of techniques to manipulate water quantities within the NFK, SFK and UTC watersheds to improve fish productivity. Possible techniques for accomplishing this include: flow management, flow augmentation, and flow pump-back.

3.3.1.4.1 Direct Excess On-site Water

Commenters suggested that fish habitat productivity could be improved through careful water management at the mine scenario site, including the storage and strategic delivery of excess water to streams and aquifers to maintain or enhance flow and/or thermal regimes in the receiving streams. Delivering such flows via groundwater (i.e., by using wastewater treatment plant (WWTP) discharges to "recharge and surcharge groundwater aquifers") was identified as a preferred approach; commenters argued doing so would both render the measure less prone to operational anomalies at the WWTP and better mimic current natural flow patterns, thereby attenuating potential adverse effects related to discharge volume and temperature. Ideally, flow, temperature, and habitat modeling would inform the design and operation of flow management to optimize species and habitat benefits by, for example providing water at specific times to locations where low flow currently limits fish productivity.

Manipulation of surface flows at another mine in Alaska—Red Dog, in the northwest part of the state—has resulted in an increase in fish (Arctic grayling and Dolly Varden) use of the downstream creek (Scannell 2005, Ott 2004). The circumstances at Red Dog, however, differ from those in the NFK, SFK, and UTC area. As described in Scannell (2005), the near complete absence of fish in Red Dog Creek prior to implementation of the water management techniques was the direct result of water quality, not quantity, as the stream periodically experienced toxic levels of metals that occurred naturally as it flowed through and downslope of the exposed ore body. Furthermore, the Red Dog water management system primarily involves point-to-point diversion or transfer of surface, rather than groundwater, both around the ore body and from tributaries upstream of the mine. We have been unable to locate any documentation of successful attempts to manage flow volume or temperature from mine sites (or other industrial developments), via groundwater, for the benefit of fish and/or fish habitat.

Given that most streams in the area support multiple salmonid species and life stages, with differing habitat needs at different times, designing and managing a water delivery system to overcome limiting factors for one or more species without adversely impacting others would be a significant challenge. Given the complexity of the surface-groundwater connectivity in the area, ensuring that discharges to groundwater actually reached the target habitat at the intended time would, perhaps, be the most difficult task. Quigley and Harper (2006b), in a review of stream rehabilitation projects, concluded “the ability to replicate ecosystem function is clearly limited.”

This challenge could potentially be easier to overcome where habitat limitations occurred only as a result of mine development, assuming pre-project modeling and verification accurately identified groundwater flow paths to those areas. It is important to note, however, that even if such actions appeared to be feasible, they likely would be required to avoid or minimize the adverse impacts of flow reduction due to mine development, rather than to compensate for unavoidable habitat losses.

If it were an overall enhancement to pre-existing habitat, using WWTP discharges to groundwater to address natural limitation factors could be a form of compensatory mitigation. For example, PLP (2011) points out that productivity may be limited by the existence of “losing” reaches along the SFK mainstem and intermittent or ephemeral tributaries to both the SFK and NFK. Altering the natural flow regimes at such sites, however, could have unintended consequences on the local ecosystem and species assemblages (Poff et al. 1997). Moreover, “enhancing” these habitats through a WWTP-sourced groundwater flow delivery system would be even more challenging than managing flow to avoid or minimize impacts to already productive habitat, because it would require “improving” the natural flow delivery system that currently results in the periodic drying/low flows. We have not located any documented successful application of this technique, making it a highly experimental approach to enhancing fish productivity, particularly in a natural stream system. Highly experimental and unpredictable activities are generally discouraged as compensatory mitigation (40 CFR 230.93(a)(1); *see also* 73 FR 19633). The regulations also strongly discourage compensatory mitigation projects that require the long-term use of active engineering features (40 CFR 230.97(b)).

3.3.1.4.2 Augment Flows

Another means suggested for maintaining or increasing habitat productivity downstream of the mine site is to increase flow volume into certain streams by creating new sources of surface flow and/or groundwater recharge, specifically, from impoundments and/or ice fields. We are unaware of any documented successful efforts to create impoundments or ice fields for the benefit of salmonids. As described in the previous section, actions to maintain or reestablish pre-mine flow in streams likely would be required as avoidance or minimization measures, and would not constitute compensatory mitigation for unavoidable impacts.

Only if it were an overall enhancement to existing habitat would creating impoundments and/or ice fields have the potential for offsetting unavoidable adverse impacts. Thus, the objective would be to target stream reaches where flow-habitat modeling indicated opportunities for enhancement.

PLP's EBD notes that a portion of the SFK mainstem, as well as some Koktuli River tributaries, exhibit either intermittent or ephemeral flow that appears to be a limiting factor for salmonid productivity (PLP 2011). However, two of the tributaries are in the uppermost reaches of the SFK and would be eliminated by the mine scenarios.

Although there are potential locations for impoundments to manage flow in the stream reaches identified as having "sub-optimal" flow, logistical and environmental issues decrease the likely efficacy and sustainability of such an approach. Manipulating streamflows in particular watersheds would require diverting water from other basins or capturing water during peak flows for subsequent release at other times, with the concomitant engineering, construction, and maintenance challenges. Doing so would create additional adverse impacts from the construction of infrastructure and would be subject to modeling and perpetual management sufficient to ensure that water withdrawals from the "donor" watershed or from other times of the year would not adversely impact fish habitat and populations in its downstream waters. These concerns are in addition to those commonly associated with impoundments, such as alteration of flow, thermal, and sediment transport regimes.

Creating ice fields to increase the total volume of water available to a stream would also require water diversion, with the same challenges and concerns related to building and maintaining system infrastructure and reducing water volumes in the source watershed.

Using ice fields to change the timing of water availability would encounter issues related to managing the melt to produce stream flow at the intended time (i.e., late summer or late winter low-flow periods). Moreover, since aquatic organisms supported by a particular water body typically have evolved specific life history, behavioral, and morphological traits consistent with the characteristics of that water body's natural flow regime, local populations are inherently vulnerable to flow modification (Lytle and Poff 2004). Any use of ice fields would face the potentially substantial challenges of the effects of climate change on ice production and preservation. Besides requiring active management in perpetuity, ice field creation for flow augmentation would be decidedly experimental, with high uncertainty regarding the likelihood of success. Flow augmentation techniques would also be inconsistent with the regulation's provision that "[c]ompensatory mitigation projects shall be designed, to the maximum extent practicable, to be self-sustaining once performance standards have been achieved. This includes minimization of active engineering features…" (40 CFR 230.97(b)).

3.3.1.4.3 Pump Water Upstream

Another option suggested for making flow in some stream reaches more persistent is to pump groundwater or surface water from a down-gradient site upstream to either a direct release point or a recharge area. This technique has been used for fish habitat restoration at sites in the continental U.S. (e.g., the Umatilla River, OR (Bronson and Duke 2005), the Lower Owens River, CA (LADWP 2013), and Muddy Creek, CO (AECOM et al. 2010 and GrandRiver Consulting 2008)), although we are unaware of any documentation addressing its efficacy in increasing salmonid productivity. As with flow management and augmentation, using this technique to offset flow reductions from mine operations would not be compensatory mitigation, limiting its potential use as such to reaches that already have sub-optimal flow. One such stream is NFK 1.190.10, a tributary that enters NFK 1.190 downstream of the tailings storage facility location. Flow modeling, however, indicates that mine development would diminish flow in that stream even further (see Figures 7-15 through 7-17 of the assessment).

For the periodically intermittent or ephemeral reaches identified in the EBD, potential source sites presumably would be in or along the lower reaches of the NFK or SFK, downstream of the mine, waste rock, and tailings storage facilities. Flow modeling indicates that the NFK would experience a decrease in flow under the Pebble 6.5 scenario (see Figure 7-17 of the assessment), increasing the possibility that withdrawing additional water from the system to pump back upstream either would not be possible or would have adverse downstream impacts. Extensive modeling would be necessary to assess downstream effects in either watershed.

Even with sufficient downstream water, this technique would require substantial disturbance associated with the construction of tens of kilometers of water pipeline, power infrastructure, and access, along with maintenance of those facilities in perpetuity. It would also entail active management to ensure that releases occur at appropriate times, to increase the persistence of flow in target streams without otherwise adversely impacting their hydrographs or habitat. Such management would be another aspect of the approach that would be perpetual. In total, this technique would involve a great deal of uncertainty with regard to both efficacy and sustainability, making it a questionable mechanism for providing compensatory mitigation. This technique would also be inconsistent with the regulation's provision that "[c]ompensatory mitigation projects shall be designed, to the maximum extent practicable, to be self-sustaining once performance standards have been achieved. This includes minimization of active engineering features (e.g., pumps) and appropriate siting to ensure that natural hydrology and landscape context will support long-term sustainability" (40 CFR 230.97(b)).

3.3.1.5 Manipulate Water Quality

Two commenters suggested that alteration of stream water chemistry would improve fish production in the NFK, SFK and UTC. They suggest increasing two groups of water chemistry parameters: basic parameters such as alkalinity, hardness, and total dissolved solids, and nutrients such as nitrogen (N) and phosphorous (P). This argument suggests that low concentrations of basic parameters and/or nutrients limit the production of algae, which limits aquatic macroinvertebrate production and habitat complexity. This in turn can reduce overall fish production, reduce individual fish growth rates, or result in fish movements away from low production areas.

3.3.1.5.1 Increase Levels of Alkalinity, Hardness, and Total Dissolved Solids

Commenters propose that altering stream water chemistry to increase levels of alkalinity, hardness, and total dissolved solids would improve the buffering capacity, primary productivity, secondary productivity, and reduce the potential toxicity of metals at waters downstream of these altered locations. Commenters suggest two mechanisms to achieve these improvements: 1) the addition of limestone in some form at "appropriate" locations or 2) the discharge of higher alkalinity water into fish-producing streams through a water management program. Commenters argue that current levels of alkalinity, hardness, and total dissolved solids in the NFK, SFK and UTC are suboptimal for fish production and could be manipulated to improve fish production. However, the majority of the literature relating to alkalinity and limestone management, including every published study cited by commenters, evaluates these approaches in streams and lakes in northern Europe, eastern U.S., or eastern Canada whose fisheries have been heavily impacted by acid mine drainage, acid deposition or other mechanisms of acidification and even in these degraded water bodies, alkalinity/limestone treatment results were variable (Gunn and Keller 1984, Hasselrot and Hultberg 1984, Rosseland and Skogheim 1984, Zurbuch 1984, Gagen et al. 1989, Lacroix 1992, Clayton et al. 1998, McClurg et al. 2007). It is not clear from any of the published studies cited by commenters what effect the addition of limestome or higher alkalinity water would have on the kinds of unaltered stream systems and fishery resources found in the Bristol Bay region of Alaska.

Alkalinity has two potential roles. First, it is a measure of the ability of water to neutralize acids. If the intent is to neutralize acid rock drainage from the potential mine, that use constitutes impact minimization or remediation, not compensation. Second, alkalinity is primarily due to carbonate and bicarbonate, which is the source of carbon used by aquatic algae so increasing alkalinity is potentially fertilization. However, given that the streams at the site are relatively shallow and rapidly flowing, it is very unlikely that they are carbon limited. Therefore, it is unlikely that increasing alkalinity would increase algal production unless it is neutralizing acids from a mine.

Similar considerations apply to increasing hardness. Aqueous hardness is due to calcium and magnesium, which reduce the toxicity of divalent metals such as copper by competing for uptake sites. Increasing hardness would be a potential means of remediating the effects of high metal levels drainage from mine waste leachate into streams. Alternatively, calcium and magnesium are nutrient elements and hypothetically could be limiting production. However, the commenters produce no evidence that such limitations are occurring, and it is less credible than the potential N and P limitations discussed in the next section.

Manipulating water chemistry could have a deleterious effect on salmon populations. A key characteristic of Pacific salmon is their homing migrations from oceanic feeding grounds, through diverse habitats, to their natal river to spawn. Homing is generally precise and has resulted in reproductively isolated spawning populations with specialized adaptations for their natal habitat. (Wisby and Hasler 1954, Hasler and Scholz 1983, Quinn and Dittman 1992, Dittman et al. 1995, Dittman and Quinn 1996). Olfactory systems of salmon are acutely sensitive to changes in water chemistry (McIntyre et al. 2012). Physiological and behavioral experiments demonstrate that calcium is an important odorant enabling salmon to recognize individual waters and that sockeye salmon olfactory systems are acutely sensitive to calcium ions (Bodznik 1978). This would suggest that manipulating stream chemistry through the addition of limestone or higher alkalinity water could impede salmon from recognizing and homing to their natal streams. Some commenters who raised concerns about manipulating stream chemistry through these approaches point out that homing failure could reduce productivity if salmon die without spawning or stray to non-natal habitats to which they are poorly adapted and experience higher mortality.

We are not aware of any published studies describing projects where the chemistry of unaltered/un-degraded salmon streams in Alaska or elsewhere has been manipulated through the addition of limestone or higher alkalinity water to achieve improvements in buffering capacity against natural acidity, increase primary or secondary productivity, or reduce toxicity to naturally occurring metals. Rather, the scientific literature suggests that such chemical alterations could result in deleterious effects on salmon in unaltered/un-degraded stream systems. Manipulating stream chemistry in the NFK, SFK and UTC through the addition of limestone or higher alkalinity water would be a challenging and difficult experiment with an unknown outcome.

3.3.1.5.2 Increase Levels of Nitrogen and/or Phosphorus

The same two commenters suggest altering stream water chemistry to increase levels of N and P where they are individually or co-limiting. They provide four categories of considerations for determining how to increase stream or lake nutrients:

1) The spatial and temporal distribution of the limiting nutrients,
2) The timing and duration of nutrient application(s),
3) The desired concentrations of each nutrient and the ratio between N and P for each application location, and
4) The need for detailed pre-project information including the biological species composition of the waterbody and a low level nutrient analysis.

The commenters make a few general recommendations about how to consider these factors when developing mitigation in the NFK, SFK and UTC. They suggest that the spatial distribution could focus on existing or newly created side channels, sloughs, beaver ponds, alcoves, or, if necessary, the main channels at 10 km intervals. They suggest several possible temporal distribution options; of adding the nutrients only during the growing season, potentially earlier, or all winter in open water locations where biological production continues year round. They further indicate that the key considerations are access cost and maintenance requirements. The commenters note several types of nutrient delivery methods: liquid fertilizer, slow-release fertilizer, and nutrient analogs (which are essentially slow-release pellets of processed fish).

As support for their conclusion that lake and stream fertilization represent "demonstrably successful mitigation techniques" for the NFK, SFK and UTC, the commenters cite a number of papers summarizing experiments and case studies, as well as references to several management programs in the U.S., Canada, and northern Europe. These studies have examined the use of increased levels of N and P, or fish carcasses, to improve ecosystem productivity and/or fish production.

The two commenters argue that current levels of N and P in the NFK, SFK and UTC are suboptimal for fish production stating that benefits of fertilizing oligotrophic waters to stimulate fish production have been demonstrated in many venues. Although numerous studies show an effect at one or more trophic levels in response to fertilization, these studies are insufficient for drawing conclusions regarding the long-term effectiveness of nutrient application to streams in the NFK, SFK and UTC watersheds because they lack scientific controls or have not been replicated, do not account for potential confounding factors, were conducted in very different ecosystems, and/or only evaluated short-term effects. These differences are pointed out in the following paragraphs.

Commenters provided examples of experiments and studies aimed at increasing primary productivity and theoretically salmon productivity. These studies assume that nutrients are the limiting factor preventing increased salmon productivity, but that is not necessarily the case. Paleolimnetic studies in Alaska indicate nutrient inputs are not always tied to higher primary productivity or salmon productivity (Chen et al 2011). Wipfli and Baxter (2010) found that most fish consume food from external or very distant sources, including from marine systems borne by adult salmon, from fishless headwaters that transport prey to downstream fish, and from riparian vegetation and associated habitats. An increase in food via nutrients may not overcome other limiting factors such as habitat availability or interspecies competition.

Most studies on stream and lake fertilization to increase productivity are short-term in duration and conducted in ecosystems with important differences from Bristol Bay (e.g. Perrin et al. 1987, Raastad et al. 1993, Wipfli et al. 1998, Slaney et al. 2003). For example, studies conducted at the Keogh and Salmon Rivers (Ward et al. 2003, Slaney et al. 2003) examined the effect of nutrient supplement in the form of salmon carcasses and inorganic N and P, respectively, in two coastal river systems for a period of three years. A spike in productivity has been seen in a number of these studies, but long term studies call into question whether the trend will be sustained over longer periods as is described in the following two long-term studies.

Results from the longest running study on stream fertilization raise concerns about using fertilization other than as an interim restorative measure. Slavik et al (2004) found that persistent increased levels of N and P can result in dramatic ecosystem shifts. This long term ecological research on the North Slope of Alaska examined the effect of P input into P-limited streams, finding an increase in production for some species at all trophic levels over the first few years. However, starting at seven or eight years, nutrient enrichment caused a dramatic rise in moss (photos A and B) that changed ecosystem structure. Despite higher insect biomass in the fertilized area during this period, the growth of fish was no longer significantly greater than in the reference area (Slavik et al. 2004). The resulting decrease in fish productivity was thought to result from the effects of moss on preferred insect prey. Following cessation of nutrient enrichment, it took eight years of recovery to approach reference levels, after storms had scoured most remnant moss in the recovering reach. These results demonstrate that even at low concentrations, sustained nutrient enrichment can have “dramatic and persistent consequences” (Benstead et al. 2007).

Photos showing the difference in bottom coverage between the diatom state (Photo A, left) and the fertilized moss state (Photo B, right). Used with permission (Slavik et al.).

In another study, long-term nutrient enrichment produced an unanticipated trophic decoupling whereby enrichment continued to stimulate primary consumer production without a similar increase in predator fish. The majority of the increased ecosystem productivity was confined to lower trophic levels because the long-term enrichment primarily stimulated primary consumers that were relatively resistant to predation. Based on these results, the authors concluded that "even in ecosystems where energy flow is predicted to be relatively efficient, nutrient enrichment may still increase the production of non-target taxa (e.g. predator or grazer resistant prey), decrease the production of higher trophic levels, or lead to unintended consequences that may compromise the productivity of freshwater ecosystems" (Davis et al. 2010 p 124).

These unanticipated results raise important questions about the potential consequences of long-term nutrient supplementations. They also underscore the unpredictability of nutrient additions on the food web, and the greater likelihood of unintended consequences as the effects ripple through complex interactions between species. These implications are especially relevant considerations for potential long-term mitigation that would be necessary in the NFK, SFK and UTC. If long-term nutrient addition were to cause an ecosystem shift at lower trophic levels in the NFK, SFK and UTC, effects on higher trophic levels including the productivity of salmon and other target fish species are unknown.

Studies examining the relationship between salmon carcasses and productivity at various trophic levels are another active area of investigation. Some research provides evidence that carcasses are superior to inorganic nutrient amendments for sustaining and restoring stream productivity, including fish production, potentially because inorganic nutrients lack biochemicals and macromolecules that are utilized directly by consumers (Wipfli et al. 2010, Martin et al. 2010, Heintz et al. 2010). Others have found the effects of carcasses can be transient, localized, and variable with no increase in fish growth (Cram et al. 2011). Few studies have documented the long-term impacts of carcass addition, and there are many remaining gaps in understanding the efficacy of this method of potentially improving salmon productivity. In addition, a number of authors express concern about the potential for the spread of toxins and pathogens when carcasses are used as the supplemental nutrient source (Compton et al. 2006).

Setting aside questions of scientific efficacy and applicability, there are numerous practical challenges inherent in nutrient addition as a potential mitigation method. Conducting a long-term management protocol in remote waterways subject to extreme weather changes necessarily requires careful monitoring of water chemistry and precise application of nutrients, which calls into question the sustainability of altering stream water chemistry to improve the fish production.

Authors of many of these studies state that the application of their results are relevant and appropriate for salmonid restoration in streams or lakes with depressed numbers (Larkin and Slaney 2011). The authors do not describe their results as informing methods to manipulate existing unaltered wild systems to further augment salmon production. Although the commenters draw heavily from Ashley and Stockner (2003), the authors of that study actually state:

> "The goal of stream and lake enrichment is to rebuild salmonid escapement to historical levels via temporary supplementations of limiting nutrients using organic and/or inorganic formulations. Stream and lake enrichment should not be used as a 'techno-fix' to perpetuate the existing mismanagement of salmonids when there is any possibility of re-establishing self-sustaining wild populations through harvest reductions and restoration of salmonid habitat. Therefore, fertilization should be viewed as an interim restorative measure that is most effective if all components of ecosystem recovery and key external factors (e.g. overfishing) are cooperatively achieved and coordinated. This paper reviews some of the technical and more applied aspects of stream, river, and lake enrichment as currently practiced in British Columbia and elsewhere. As a caveat, the discussion assumes that salmonid stock status of candidate lakes and streams has been quantified and classified as significantly depressed and that additional limiting factors (e.g. habitat/water quality and quantity) have been addressed and/or incorporated into an integrated basin or lake restoration plan." (Ashley and Stockner 2003 p. 246)

There are still many gaps in understanding the role of nutrients in fish productivity, so there is a great deal we do not know about whether nutrient addition can be a successful method to increase fish productivity. At this time there are no scientific studies showing how an increase in nutrients resulting in increase salmon productivity can be reliably achieved on a long-term basis in the NFK, SFK and UTC watersheds or the larger Bristol Bay ecosystem without risk to the region's existing robust populations. Just as for the addition of non-nutrients such as limestone, manipulating stream chemistry in this largely unaltered ecosystem through the addition of N and P would be a challenging and difficult experiment with many negative outcomes possible.

3.3.1.6 Preserve Aquatic Resources

As described above, preservation as compensatory mitigation for the mine scenarios would require a site that is very large, performs similarly important aquatic functions, and is under threat of destruction or adverse modification. No commenters identified specific potential preservation sites, either within these watersheds or elsewhere in Bristol Bay. One challenge in identifying appropriate preservation sites is the high percentage of state and federal land ownership in the area. Public lands can provide mitigation, but only if the mitigating measure—in this case, preservation—is "over and above [that] provided by public programs already planned or in place" (40 CFR 230.93(a)(3)). Further, the aquatic functions of any preservation site downstream from the proposed mine scenarios would be subject to degradation from the direct, secondary, and cumulative effects of the mine itself. These factors could limit most properties of adequate area and similar aquatic function from serving as acceptable mitigation sites. Moreover, there is no precedent for such a preservation-dominated compensation approach in the context of this type and magnitude of ecological loss.

3.3.2 Other Opportunities within the Nushagak and Kvichak River Watersheds

As noted above, if practicable or appropriate opportunities to provide compensation within the NFK, SFK or UTC watersheds are non-existent or limited, it may be appropriate to explore options in adjoining watersheds. For example, there are a few scattered degraded sites in more distant portions of the Nushagak and Kvichak River watersheds that could potentially benefit from restoration or enhancement.

Here we discuss specific suggestions for other potential compensation measures within the Nushagak and Kvichak River watersheds that were provided in the public and peer review comments on the Bristol Bay Assessment.

3.3.2.1 Remediate Old Mine Sites

The U.S. Geologic Survey (USGS) identifies four small mine sites within the Nushagak and Kvichak River watersheds: Red Top (in the Wood River drainage), Bonanza Creek (a Mulchatna River tributary), Synneva or Scynneva Creek (a Bonanza Creek tributary), and Portage Creek (in the Lake Clark drainage) (USGS 2008, 2012). These sites could provide opportunities for performing ecological restoration or enhancement. However, due to their relatively small size and distant location, it is unlikely that these sites could provide sufficient restored or enhanced acreage or ecological function to offset what would be lost under the assessment mine scenarios. Further, some mitigation measures have already occurred at these mines; for example, there have been some remediation activities at Red Top mine, although traces of mercury and diesel-range organics remain in soils (BLM 2000). Resolution of liability and contamination issues at these old mines would be necessary before they could serve as compensatory mitigation sites for other projects.

3.3.2.2 Remove Roads

Another potential type of restoration within the Nushagak and Kvichak River watersheds is the removal of existing or abandoned roads. As described in detail in Appendix G of the assessment, roads have persistent, multifaceted impacts on ecosystems and can strongly affect water quality and fish habitat. Common long-term impacts from roads include: 1) permanent loss of natural habitat; 2) increased surface runoff and reduced groundwater flow; 3) channelization or structural simplification of streams and hydrologic connectivity; 4) persistent changes in the chemical composition of water and soil 5) disruption of movements of animals, including fishes and other freshwater species; 6) aerial transport of pollutants via road dust; and 7) disruption of near-surface groundwater processes, including interception or re-routing of hyporheic flows, and conversion of subsurface slope groundwater to surface flows (Darnell et al. 1976, Trombulak and Frissell 2000, Forman 2004). Road removal, thus, could facilitate not only the reestablishment of former wetlands and stream channels, but also the enhancement of nearby aquatic resources currently degraded by the road(s).

Commenters did not offer specific suggestions for potential road removal sites. As Appendix G of the assessment highlights, the Nushagak and Kvichak River watersheds are almost entirely roadless areas (see Figure 1 of Appendix G). Further, it is unlikely that local communities would support removal of any segments of the few existing roads in the watersheds. Thus, it would appear there are very few, if any, viable opportunities to provide environmental benefits through road removal.

3.3.2.3 Retrofit Road Stream Crossings

Another potential type of enhancement within the Nushagak and Kvichak River watersheds is to retrofit existing road stream crossings to improve fish passage through these man-made features. Stream crossings can adversely impact spawning, rearing (Sheer and Steel 2006, Davis and Davis 2011), and refuge habitats (Price et al. 2010), as well as reduce genetic diversity (Wofford et al. 2005, Neville et al. 2009). These changes can in turn reduce long-term sustainability of salmon populations (Hilborn et al. 2003, Schindler et al. 2010). Blockage or inhibition of fish passage is a well-documented problem commonly associated with declines in salmon and other fish populations in many regions of the U.S. (Nehlsen et al. 1991, Bates et al. 2003), including Alaska (ADFG 2012b).

Removing and replacing crossings that serve as barriers to fishes could improve fish passage and re-open currently inaccessible habitat. However, as noted in Section 3.3.2.2, the Nushagak and Kvichak River watersheds are almost entirely roadless areas, and thus offer few, if any, viable opportunities to provide the extent of environmental benefits necessary to offset the magnitude of impacts associated with the mine scenarios and associated development. Further, prior to concluding that any effort to retrofit existing stream crossings would be appropriate compensatory mitigation, it would first be necessary to determine that no other party has responsibility for the maintenance of fish passage at those stream crossings (e.g., through the terms or conditions of a Section 404 permit that authorized the crossing).

3.3.2.4 Construct Hatcheries

One commenter referenced the potential use of hatcheries as a compensation measure. Such a proposal could be very problematic, particularly in the context of Bristol Bay, where the current salmon population is entirely wild. There are several concerns over the introduction of hatchery-produced salmon to the Bristol Bay watershed, best expressed by the National Oceanic and Atmospheric Administration's Northwest Fisheries Science Center:

> "Over the past several decades, wild salmon populations have declined dramatically, despite, and perhaps sometimes because of, the contribution of hatcheries. Many salmon stocks in Washington and Oregon are now listed as either threatened or endangered under the U.S. Endangered Species Act. With this decline has come an increased focus on the preservation of indigenous wild salmon stocks.
>
> Hatcheries have the potential to assist in the conservation of wild stocks, but they also pose some risks. At this time, scientists still have many questions about the extent to which hatchery programs enhance or threaten the survival of wild populations. Additional research and investigation is needed." (NOAA 2012)

Many of the potential risks associated with fish hatcheries concern reductions in fitness, growth, health, and productivity that result from decreases in genetic diversity when hatchery-reared stocks hybridize with wild salmon populations. Hatchery-raised salmon have lower genetic diversity than wild salmon (Christie et al. 2011, Yu et al. 2012). Consequently, when hatchery-raised salmon hybridize with wild salmon, the result can be a more genetically homogenous population, leading to decreases in genetic fitness (Waples 1991). In some cases, wild populations can become genetically swamped by hatchery stocks. Zhivitovsky et al. (2012) found evidence of such swamping in a wild chum salmon population in Kurilskiy Bay, Russia during a two-year period of high rates of escaped hatchery fish. This genetic homogenization is of concern because hatchery-raised fish stocks are considered less genetically "fit" and therefore could increase the risk of collapse of salmon fisheries. This concern is supported by Araki et al. (2008), a review of 14 studies which suggests that nonlocal hatchery stocks reproduce very poorly in the wild. The authors of this review also found that wild stocks reproduce better than both hatchery stocks and wild, local fish spawned and reared in hatcheries.

Hatchery fish can also compete directly for food and resources with wild salmon populations in both freshwater and marine environments (Rand et al. 2012a). Ruggerone et al. (2012) examined the effect that Asian hatchery chum salmon have had on wild chum salmon in Norton Sound, Alaska since the early 1980s. They found that an increase in adult hatchery chum salmon abundance from 10 million to 80 million adult fish led to a 72% reduction in the abundance of the wild chum salmon population. They also found smaller adult length-at-age, delayed age-at-maturation, and reduced productivity were all associated with greater production of Asian hatchery chum since 1965 (Ruggerone et al. 2012). In addition to this competition for resources, hatchery-raised subyearling salmon can also prey upon wild subyearling salmon, which tend to be smaller in size (Naman and Sharpe 2012).

Despite extensive efforts to restore federally listed Pacific Northwest salmon populations, they remain imperiled, and hatchery fish stocks may be a contributing stressor (Kostow 2009). Given the exceptional productivity of the wild Bristol Bay salmon population, hatcheries would appear to pose greater ecological risks than benefits to this unique and valuable wild salmon population.

3.3.2.5 Stock Fish

Since many of the fish used in fish stocking originate in hatcheries, fish stocking raises many of the same concerns as hatcheries and thus would also be a problematic form of compensatory mitigation for the Bristol Bay region. Although stocking has been a common practice in other regions, even in previously fishless habitats (e.g., Red Dog Mine, Alaska), a large body of literature describes widespread adverse impacts of such management decisions. Fish stocking throughout western North America and worldwide has impacted other fish (Knapp et al. 2001, Townsend 2003), nutrient cycling (Schindler et al. 2001, Eby et al. 2006, Johnson et al. 2010), primary production (Townsend 2003, Cucherousset and Olden 2011), aquatic macroinvertebrates (Dunham et al. 2004, Pope et al. 2009 Cucherousset and Olden 2011), amphibians (Pilliod and Peterson 2001, Finlay and Vredenberg 2007), and terrestrial species (Epanchin et al. 2010). Although fish stocking has provided limited benefits in certain circumstances, it would appear from the growing body of literature that the ecological costs of fish stocking far outweigh any potential benefits.

3.4 Other Suggested Compensation Measures

Comments also included suggestions that compensatory mitigation for impacts to fish and other aquatic resources could take the form of making payments to organizations that support salmon sustainability or investing in various public education, outreach, or research activities designed to promote salmon sustainability. Although these kinds of initiatives can provide benefits in other contexts, compensatory mitigation for impacts authorized under Section 404 of the Clean Water Act can only be provided through purchasing credits from an approved mitigation bank or in-lieu fee program or conducting permittee-responsible compensatory mitigation projects (40 CFR 230.92). One commenter also suggested reducing commercial fishery harvests to compensate for fish losses due to large-scale mining; however, such a measure would also be inconsistent with the definition of compensatory mitigation (40 CFR 230.92).

4. Effectiveness of Compensation Measures at Offsetting Impacts to Salmonids

In North America, 73% of fish extinctions are linked to habitat alterations (Miller et al. 1989). Although extensive efforts have been undertaken to create or improve salmon habitat and prevent losses to fisheries, the current status of U.S. salmon is a sobering testament to the billions spent on mitigation efforts given that all U.S. Atlantic salmon populations are endangered (NOAA 2013), 40% of Pacific salmon in the Lower 48 are extirpated from historic habitats (NRC 1996), and one third of remaining populations are threatened or endangered with extinction (Nehlsen et al. 1991, Slaney et al. 1996, Gustafson et al. 2007). Approximately one third of sockeye salmon population diversity is considered endangered or extinct (Rand et al. 2012b), and Bristol Bay sockeye salmon likely represent the most abundant diverse sockeye salmon populations left in the U.S.

Since 1990, a billion dollars has been spent annually in the U.S. on stream and watershed restoration (Bernhardt et al. 2005) and more than 60% of the projects completed during this period were associated with salmon and trout habitat restoration efforts in the Pacific Northwest and California (Katz et al. 2007). Despite the proliferation of projects and the significant funds being expended on these efforts, debate continues over the effectiveness of various fish habitat restoration techniques and the cumulative impact of multiple, poorly coordinated restoration actions at a watershed or regional scale (Reeves et al. 1991, Chapman 1996, Roni et al. 2002, Kondolf et al. 2008). Further, independent evaluations of the effectiveness of fish habitat compensation projects are rare (Harper and Quigley 2005b, Quigley and Harper 2006a, Quigley and Harper 2006b), and consequently the long-term success rates and efficacy of such projects are not well known (DFO 1997, Lister and Bengeyfield 1998, Lange et al. 2001, Quigley and Harper 2006a). A recent study by Roni et al. (2010) clearly questions the efficacy of mitigation to specifically offset salmon losses.

The most comprehensive investigation, to date, of the efficacy of fish habitat mitigation measures was conducted by the Department of Fisheries and Oceans, Environment Canada (Harper and Quigley 2005a, Harper and Quigley 2005b, Quigley and Harper 2006a, Quigley and Harper 2006b). Quigley and Harper (2006a) showed that 67% of compensation projects resulted in net losses to fish habitat and only 2% resulted in no net loss, whereas only 31% achieved a net gain in habitat area. Quigley and Harper (2006a) concluded that habitat compensation in Canada was, at best, only slowing the rate of fish habitat loss. Quigley and Harper (2006b) showed that 63% of projects resulted in net losses to aquatic habitat productivity and only 25% achieved no net loss, whereas only 12% provided net gains in aquatic habitat productivity. Quigley and Harper (2006b) concluded “the ability to replicate ecosystem function is clearly limited.”

Quigley and Harper (2006b) highlight the need for improvements in compensation science as well as institutional approaches such as better project planning, monitoring, and maintenance. However, they also recognize that, based on decades of experience in wetland replacement projects, simply achieving compliance with all regulatory requirements does not ensure that ecological functions are replaced (NRC 2001, Sudol and Ambrose 2002, Ambrose and Lee 2006, Kihslinger 2008). Although there are clearly opportunities to improve the performance of fish habitat compensation projects, Quigley and Harper (2006b) caution:

> “it is important to acknowledge that it is simply not possible to compensate for some habitats. Therefore, the option to compensate for HADDs [*harmful alteration, disruption or destruction to fish habitat*] may not be viable for some development proposals demanding careful exploration of alternative options including redesign, relocation, or rejection.”

5. Conclusions

There are significant challenges regarding the potential efficacy, applicability and sustainability of compensation measures proposed by commenters for use in the Bristol Bay region, raising questions as to whether sufficient compensation measures exist that could address impacts of the type and magnitude described in the Bristol Bay Assessment. The mine scenarios evaluated in the assessment show that the mine footprint alone would result in the loss (i.e., filling, blocking or otherwise eliminating) of hundreds to thousands of acres of high-functioning wetlands and tens of miles of salmon-supporting streams. In addition to these direct losses, these mine scenarios would also result in extensive adverse secondary and cumulative impacts to wetlands, streams, and fish that would have to be addressed. Such extensive habitat losses and degradation could also result in the loss of unique salmon populations, eroding the genetic diversity essential to the stability of the overall Bristol Bay salmon fishery.

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