Failure to Address Cumulative and Long-Term Effects of Bioaccumulation and Biomagnification of Contaminants, including Trace Metals and Hydrocarbons, in the Pebble Project DEIS (February 2019)

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1. Introduction

This report concerns the failure of the Pebble Project DEIS to address the environmental effects of bioaccumulation, biomagnification, and biotransport of several persistent pollutants that are highly likely, in fact virtually certain, to enter the aquatic ecosystems of Bristol Bay as a consequence of the project. These processes operate to cause persistent pollutants released over long periods of time, resulting in potentially large biological and toxicological effects. Moreover, biotransport of bioaccumulated toxins will predictably cause any such effects to extend over large areas of the region, far beyond the localized source of the pollutants. Such impacts may be far more extreme in their ecological effect in relatively pristine ecosystems that have been little exposed to these classes of pollutants in their ecological and evolutionary history, compared to the same level of exposure in ecosystems with previous and industrial influence, where biota have already been shaped by exposure to such toxins and by the ecological consequences of longstanding bioaccumulation and biomagnification of more persistent pollutants.

In preparation of this comment I read sections of the Pebble Project DEIS and supporting record pertinent to mine and road-related contaminants entering surface waters.

2. Definitions:

- ***Bioaccumulation*** is the gradual accumulation of substances in an organism. Bioaccumulation of pollutants can occur from water, from suspended particles, from sediments and through food chains. The rate at which accumulation occurs in an organism depends not only on the availability of the pollutant but on a range of biological, chemical and environmental factors. The ultimate level of bioaccumulation is governed by the ability of the organism to excrete the pollutant or, alternatively, store it. This latter often leads to the attainment of very high concentrations and sometimes no equilibrium level is ever reached. (Bryan and Darricot 1979).

- ***Biomagnification***, also known as **bioamplification**, is the process whereby certain substances such as persistent organic pollutants or heavy metals enter aquatic ecosystems and then move up the food chain in progressively greater concentrations as they are incorporated into the diet of aquatic organisms such as zooplankton and benthic macroinvertebrates, which in turn are eaten by fish, which then may be eaten by bigger fish, large birds, animals, or humans. The substances become increasingly concentrated in tissues or internal organs as they move up the food chain.

- ***Biotransport*** here refers to the movement of pollutants from one locale to another via the migration or dispersal of animals that have bioaccumulated body burdens of those pollutants, most importantly via dietary consumption.

3. Scope of the Problem

The scientific literature on the subject of bioaccumulation, biomagnification, and biotransport of trace metals and other persistent contaminants in freshwater ecosystems is extensive and has been rapidly growing in the past 20 years. Nevertheless, a search of the term "bioaccumulation" in the literature cited in the Pebble Project DEIS and supporting documents at the Pebble Project EIS website online turned up just a single citation: Mann et a. 2011, cited in the DEIS Chapter 4.27. The relevant section (DEIS 4.27. 122-125) is intended to relate only to the metals originating from potential accidental spills of concentrate and other materials at the mine site or in transport. This text acknowledges that metals originating from such spills can bioaccumulate and could adversely affect wildlife, particularly birds and mammals that consume contaminated fish. Interestingly, the DEIS (4.25.125) even states that "Loss of prey (primarily salmonid species) may indirectly impact marine mammals."

However, in obvious conflict with the above-cited DEIS text, the adjacent discussion of fish merely assumes that fish, including salmonid species, and aquatic invertebrates will not be affected at all. The latter conclusion—sprinkled in various forms in several places in Chapter 4.27 is based on four premises that are either ill-documented or undocumented in the DEIS, and in my opinion are largely unfounded: 1) that only discharges of metals that exceed government-permitted concentrations need to be considered as having harmful effects; 2) that spilled or discharged metals will for the most part not be bioavailable, being tied up by unspecified binding processes neither described in the DEIS nor measured in the field; 3) that 7-day tests of acute toxicity in a handful of lab experiments are an effective measure of toxicity as it will be expressed in a multitude of circumstances in in a large range of species in the field; and 4) that any possible sublethal effect could only be expressed within "a few miles" of the point of origin, invoking unspecified general dilution processes. In fact the immediately preceding section of the DEIS on wildlife effects includes a fragmented, speculative, and largely undocumented discussion of dilution, but this discussion is not brought forward in the Fish section, and the discussion of dilution fails to consider that bioaccumulation can occur even given trace increases in accumulation-prone contaminants, especially it they are released over a prolonged period of time. (The dilution argument in Chapter 4.27 is essentially an inversion of the undocumented assumption #1 stated above, that below some stated threshold, no effect will occur.) This section of Chapter 4.27 on fish and aquatic life simply does not in fact address bioaccumulation of trace metals and its potential cumulative of and long-term effects

Metals like mercury, cadmium and selenium, and certain persistent hydrocarbons such as polycyclic aromatic hydrocarbons (PAHs) (Albers 1996, Grung et al. 2016), are acquired and stored within tissues by plants and other organisms to concentrations well beyond the ambient environmental concentration, then can be passed to herbivores (D'Adamo et al. 1997, Henley et al. 2000) and subsequently to carnivores (Tillit et al. 1992) in food webs via dietary intake (Fisher 1995).

Persistent hydrocarbons, pollutants that will certainly originate from transport operations, are not considered at all in the DEIS, for aquatic life, fish or wildlife, as far as I can discern. And even though the text in 4.27 pertaining to potential toxicity of spills also applies to discharges of metals and hydrocarbons from ongoing, non--accidental (non-"spill") sources at the mine site and transportation corridor (see Frissell and O'Neal Road Dust report, and Frissell comments on Road Runoff), these effects of bioaccumulation and biotransport are not mentioned in those pertinent sections of the DEIS. For example, bioaccumulation, biomagnification, and biotransport of contaminants including metals and hydrocarbons should be explicitly considered in Chapters 4.23 (environmental consequences for Wildlife Values) and 4.24 (environmental consequences for Fish Values), but are not.

Bioaccumulation, biomagnification, and biotransport of persistent contaminants in my opinion constitutes the most pressing family of likely adverse cumulative environmental effects of the proposed Pebble Project, short of catastrophic failure of mine site infrastructure. Fundamentally this is so because the release of even low levels of persistent contaminants over long periods of time into an ecosystem that has previously has been only minimally affected by such industrial pollutants, can result in long-term build-up of large and potentially irreversible biological effects. Novel pollutants mobilized by such industrial development do not simple vanish—they enter the ecosystem, and those that are prone to bioaccumulation become a dynamic and biologically active component of the ecosystem they enter. Yet despite widespread recognition of these concerns in the scientific literature, they are virtually ignored in the key portions of the DEIS concerning impacts on fish and wildlife, and cumulative effects of the project.

It is important to note that the contaminants of concern are not restricted to accidental spills or discharge exceedances. Rather they are inimical (delivered via dust and runoff) to the disturbances and operations associated with the mine site and transportation system. It is also important to recognize these contaminants can cause the effects considered here even when discharges remain at trace quantities below applicable water quality standards and typical permitted conditions.

I will discuss in my comments below some of what the scientific literature illuminates about environmental risks from bioaccumulated metals or hydrocarbons, especially in freshwater ecosystems, and why it is critical that the DEIS include a credible and informed assessment of the risks.

4. The EPA's Bristol Bay Watershed Assessment

The Bristol Bay Watershed Assessment (hereafter BBWA, EPA 2014) raised the issue of bioaccumulation of mining-related contaminants, and discussed the importance of analysis to account for potential environmental cumulative effects, particularly of metals. For example, selenium bioaccumulation and biomagnification risks were discussed on BBWA (Vol. 1) p. 8-31 and 12-6, mercury bioaccumulation on BBWA p. 8-51, modeling methods to address key components and processes of metals bioaccumulation in stream food webs on BBWA (Vol. 1) p. 9-36, 9-40, 9-43-44. Vulnerability of long-lived northern pike to bioaccumulation of mercury was discussed in BBWA Vol. 2 (Appendix B) p.6, and lake trout at BBWA Vol. 2 (Appendix B) p. 38. Given the recognition of the potential importance of bioaccumulation in the BBWA, it seems inexplicable that the subject has been grossly neglected in the DEIS.

5. Acute Toxicity vs. Bioaccumulation

Bioaccumulation occurs precisely because the metals or persistent organics accumulated by one species of organism, or a set of species across one trophic level, are not acutely toxic to those species. But organisms that feed upon them, or feed at higher trophic levels in the food web, acquire concentrations via diet may be chronically or acutely affected by the same contaminants (Buchwalter et al 2017, Poteat and Buchwalter 2013, Fisher 1995). Such a disparity can result from two different factors: 1) difference species have different physiological mechanisms for processing and detoxification, hence different sensitivities and tolerances to the contaminants, and 2) species at higher trophic levels can accumulate and be exposed to greater, and toxic, concentrations by consuming contaminated prey (Rainbow 2002, Luoma and Rainbow 2005, Poteat and Buchwalter 2013). For example, copper seldom bioaccumulates to a larger degree in freshwater food webs, because it is so broadly toxic to most plants and animals (Luoma and Rainbow 2005). By contrast, lead, mercury, selenium, and many persistent organic compounds are toxic at higher concentrations, and therefore animals lower in the food chain can consume and bioaccumulate them without suffering immediate acute mortality (though sublethal effects sometimes occur).

6. Mercury Risks

Mercury Sources from Pebble Project include:

- Chronic discharge from the mine site treatment system.
- Alteration of drainage patterns and hydrologic regime by roads and road crossings causing mobilization of atmospheric–source or geologic-source mercury in wetlands and connected surface waters.
- Roadway deicing salts mobilizing atmospheric–source or natural geologic-source mercury from roadside soils into runoff.
- Chronic leaking, spills, and fugitive dust on vehicles from mine concentrate in transport (Frissell and O'Neal 2019)
- Possible native Hg sources in road construction materials.
- Possible trace sources from motor vehicle wear, and in vehicle fuels and exhaust emissions (Ozaki et al. 2004, Frissell and O'Neal 2019).
- Possible bulk transmission in the case of failure of mine site treatment systems and waste storage infrastructure.

These sources are nowhere identified and accounted for in the DEIS in such a way that the net cumulative effects of mercury pollution from the project can be recognized, assessed, or minimized.

Even in the absence of industrial point sources of mercury or environmental alterations that mobilize mercury, diffuse pollution (likely primarily atmospheric deposition, although biotransport by migratory species may also play a role) has resulted in mercury concentrations in arctic marine mammals exceeding government health guidelines for human consumption (Wagemann et al. 1996). Top-level predators may be exposed to and bioaccumulate contaminants differently depending on the specific food resources they exploit (Atwell et al. 1998, Das et al. 2003, Loseto et al. 2008), and relatively small increases in Hg contamination, for example, lower in the food chain can lead to relatively large increases in mercury tissue burdens in top-level predators, especially older animals (i.e., biomagnification) (Das et al. 2003).

7. Microbial and Environmental Roles in Mercury methylation

The majority of mercury production occurring in aquatic systems is via biotic mechanisms, namely, bacterial methylation, and numerous classes of microbes have been identified as playing a principal role in methylation (Gilmour et al. 2013, Paranjape and Hall 2017). The physicochemical conditions within wetlands influence the degree of methylmercury mobilization (Poulin et al. 2019). Therefore the activity of these microbes in the mobilization of methylmercury can be influenced by changes in wetlands, streams, and lakes that affect the nature of organic carbon pools and in particular by sulfate concentrations. At present the DEIS fails to adequately address mercury methylation and the fate and effects of mercury in wetlands, streams and lakes that will be influenced by mercury discharged from the mine site and potentially released from the road system. A cursory , undocumented, and unqualified claim in the DEIS that mercury entering surface waters will become biologically unavailable stands in complete ignorance of the extreme variability of chemical environments that exist in wetlands, streams, rivers, lakes, and estuaries, as a consequence of seasonal changes in water flow, temperature and biotic activity, sediment storage, and sediment transport (Mason et al. 2000, Gray et al. 2004, Bradley et al. 2011).

Methylation tends to be enhanced by increased sulfate concentrations, as shown experimentally by Coleman Wasick (2012). Increased sulfate concentrations can be expected if the Pebble project is built and operated, with sulfate originating from mine waste discharge, mine site dust, and road runoff and dust contaminated by hauled concentrate from spills and leakage. Even in the absence of mining sources road runoff itself can contain elevated concentrations of sulfate anions compared to rainfall and non-road surface runoff (Polkowska et al. 2007).

The characteristics of organic matter can also influence mercury methylation. Graham et al. (2013) found that high molecular weight/highly aromatic dissolved organic matter isolates and/or those with high sulfur content were particularly effective at enhancing Hg methylation. Alteration of the dissolved organic carbon pool is likely to occur along the Pebble transportation corridor and at the mine site by at least three means: 1) construction and operation of the road system altering the hydrology of wetlands and streams, 2) chemical alteration by road runoff and constituents of road dust, and 3) physical and chemical alteration of the organic pool and associated microbial communities by earlier snowmelt along roads (Walker and Everett 1987). Finally, road de-icing salts can increase bioavailability and mobilization of Hg and other heavy metals in roadside soils (Feick et al. 1972, Zehetner et al. 2009, Schuler and Relyea 2018).

An important cumulative effect of the proposed Pebble project transportation system on mercury mobilization and associated contamination of aquatic ecosystems appears to be entirely overlooked in the DEIS. Upland soils serve as sinks for mercury from geologic sources and accumulated from global atmospheric deposition (e.g., Driscoll et al. 1998), and wetlands act as sources of methylmercury (St. Louis et al. 1996), in large part due to the fluctuating geochemical environment with changing soil saturation as surface and groundwater levels change seasonally. Hence, it is not surprising that soil disturbance and alteration of surface and groundwater flows in soil and wetlands by road construction and maintenance can lead to mobilization of methylmercury (Porvari et al. 1997, Munthe and Hultburg 2004) and to greater bioaccumulation of mercury in aquatic periphyton (Desrosiers et al. 2006) fishes (Garcia and Carignan 2000) in downstream lakes. Roads unavoidably alter the flow paths of surface and subsurface water, especially in relatively wet environments such as those affected by the proposed Pebble project. By way of ponding and diversion of both surface and subsurface flows, roads commonly disrupt and change the hydroregime of adjacent wetlands (Adamus 2014). The effects of the proposed actions on mobilization of mercury in soil storage are ignored entirely in the DEIS, but they could be very significant.

The proximity of the proposed Pebble mine and its transportation system footprint to extensive water bodies indicates that a high fraction of mercury mobilized by soil and water disturbance would be likely to enter streams, rivers, lakes, and ultimately, the Bristol Bay ecosystem downstream of Iliamna Lake. Road effects on soil disturbance and mercury mobilization can be minimized by locating roads far from wetlands, streams and lakeshores, to reduce hydrologic alterations, and by minimizing the foot print of soil disturbance (Hsu0Kim et al. 2018). However, because the DEIS fails to recognize mercury mobilization along the road and pipeline corridors as an effect of the project, no measures are identified to minimize or avoid this impact.

It is critical to account for *all* sources of mercury mobilization by the proposed project, because mercury is highly prone to bioaccumulation and biomagnification in aquatic ecosystems.

8. Selenium Risks

Selenium on one hand is an essential micronutrient for numerous physiological processes. Selenium also plays a key role in the biological process that allows fish, amphibians, birds, and mammals to sequester mercury to reduce the toxicity of high body burdens of mercury (Peterson et al. 2009, Clark 1987). On the other hand, when acquired at very high concentrations through diet, Selenium is recognized as having toxic effects, especially evident as lethal effects on embryos in fish and birds. Selenium bioaccumulates and is commonly observed to biomagnify upward from the base of the food web, with increasing concentrations in animal tissues at higher trophic levels (Luoma and Presser 2009, 2018). Although adult fish, birds and mammals are relatively tolerant of dietary selenium intake, and can benefit from it, bioaccumulated selenium is passed on to their offspring (Janz 2011, Romero et al. 2016). At elevated selenium concentrations, embryos are likely to develop lethal developmental abnormalities. However concentrations at which selenium exerts toxic effects are variable and species-specific (Chapman et al. 2009). Under certain conditions selenium can bioaccumulate to toxic concentrations in organisms lower in the food web, such as stream mayflies (Conley et al. 2009).

The principle known sources of selenium from the proposed project would be discharge from the mine site treatment system (Zamzow et al. 2019a), untreated runoff and contaminated groundwater from construction sites, pads and waste materials (Maest 2019), and fugitive dust originating from the mine site (Zamzow 2019b). Baseline selenium is low in the environment at Pebble. The Pebble EIS comment document of Zamzow et al. (2019a) on the Pebble Project DEIS identifies reasons to expect that treatment will be less effective than claimed in the DEIS, hence direct selenium discharges to streams are likely to be far greater than disclosed in the DEIS. Morever, the DEIS fails to account for the likely bulk release of selenium into the aquatic environment in the case that mine site waste infrastructure or the proposed concentrate slurry pipeline fail (Maest 2019).

The DEIS (4.27.124) recognizes that "Selenium poisoning may persist for several generations and can be passed from parents to offspring through their eggs (Mann et al. 2011 in Sánchez-Bayo et al. 2011). Therefore, the potential duration of impacts may extend beyond the initial period of exposure to elevated levels of selenium."

However, this disclosure in the DEIS is restricted to birds, and fails to disclose that the same considerations of selenium bioaccumulation apply to fish and mammals, which also can pass bioaccumulated selenium to their offspring (see citations above, and in Sobelwski et al. 2019 comment on selenium in this DEIS).

Salmon that acquire selenium near and downstream of the mine site will go out to sea, but upon return may have higher loads of selenium than those that remained unexposed in the juvenile life stages. When they return en masse to specific reaches on specific streams, and carcasses would likely pass the selenium into sediment-associated biomass and the water column where eggs, fry, and juvenile fish could be exposed – and pass selenium further up the food chain to those that prey on them. Salmon carcasses will also be consumed and pass selenium to a wide range of scavengers. Because the source of the selenium is a treatment plant at the mine site that would need to operate in perpetuity, the source would never be eliminated, hence the processes of bioaccumulation and biotransport of selenium to areas beyond the immediate mine site appears likely to cumulatively increase both in terms of geographic distribution and body tissue concentration. The potential cumulative impacts of selenium release over the two to eight decade life of the mine, and in subsequently in perpetuity, need to be considered and fully assessed in the EIS.

Selenium is known to bioaccumulate in amphibians (Ohlendorf et al. 1998). Therefore Selenium discharges should be considered to pose a risk to wood frogs in the study area, especially considering their close ties to freshwater habitats. Wood frogs are also vulnerable to mercury, PAHs, and other toxins.

9. Persistent Organic Pollutants: Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are aromatic hydrocarbons with two or more fused carbon rings that have hydrogen or an alkyl group attached to each carbon (Albers 1996. Incardona et al. 2004)). PAH's form a large group of chemical variants, of variable toxicity, but many of if not most are not only persistent in the environment and in organism tissues, but depending on the pathway of exposure, can be toxic to fishes at very low concentrations (LeBihanic et al. 2014). Most PAHs are formed by thermal decomposition (pyrolysis) and subsequent recombination (pyrosynthesis) of organic molecules, and many of the PAH's of concern as bioaccumulating pollutants originate from partial combustion of petroleum products (Albers 1996). PAHs and a host of other hydrocarbons originate from motor vehicle exhaust, lubricants, tire wear (Day et al. 1993, Gualieri et al. 2005), and chronic leakage or spills of petroleum fuels. PAHs enter waterways primary by way of aqueous runoff and transport of contaminated sediments from roads and vehicle and machinery pads (Frissell 2019), as well as aerial transport attached to dust particles (Frissell and O'Neal 2019, Zamzow et al. 2009). Even as other forms of persistent organic pollutants have declined in arctic ecosystems since about 1985, concentrations of PAHs have increased 10- to 30-fold in invertebrates and fish, and PAH's now dominate the organic pollutant load in arctic organisms (De Laender et al. 2011).

Albers (1996) summarizes the origin and date of hydrocarbons that enter aquatic ecosystems: Microbes in the water metabolize the light and structurally simple hydrocarbons and non-hydrocarbons, while heavier compounds are more resistant to microbial degradation and can eventually move into bottom sediments. Hydrocarbons also adhere to particles (detritus, clay, microbes, phytoplankton) in the water and settle to the bottom, where a variety of microbes metabolize the lighter and structurally simple compounds. Phytoplankton and aquatic macrophytes can absorb and accumulate hydrocarbons directly from water. Mammals, birds, fish, and many invertebrates ingest such hydrocarbons and metabolize and excrete some ingested during feeding, grooming, and respiration, but more complex and persistent forms are stored and not quickly metabolized. Accumulation of hydrocarbons is usually inversely related to the ability of the organism to metabolize them once ingested or absorbed (Albers 1996).

Unmetabolized PAHs can have toxic effects, but a major concern in animals is that reactive metabolites of PAHs can bind to cellular proteins and DNA, resulting in biochemical disruptions and cell damage, mutations, developmental malformations, tumors, and cancer (Albers 1996). Although fish can metabolize some if not all PAHs (D'Adamo et al. 1997), nevertheless known sublethal toxic effects on fishes begin at concentrations of less than 0.5 ppm and include changes in heart and respiratory rates, gill structural damage, enlarged liver, reduced growth, fin erosion, corticosteriod stress response, immunosuppression, impaired reproduction, increased external and decreased internal parasite burdens, behavioral responses, and a variety of biochemical, blood, and cellular changes (Albers 1996). Even when adult fishes may survive exposure to bioaccumulated hydrocarbon toxins and their breakdown products, these may be highly toxic to larval fishes even in trace amounts (Incardona et al. 2004).

Even localized sources of persistent hydrocarbons can measurably contaminate large ecosystems, such as freshwater lakes and rivers (e.g., Grung et al. 2016), and the effects of seasonally intermittent exposures can be seen in migratory fishes, including salmon. Rice et al. (2008) measured increases on concentration of PAHs in surface waters of Auke Lake, AK, associated with discharges from seasonal use of motorized watercraft. They warned that PAH concentrations observed could pose a risk to migrating salmon that inhabit the lake during recreational boating season. PAHs in road runoff and dust deposition from proposed Pebble mine road system pose similar or greater health risks to fish in the Kvichak River system and Iliamna Lake, because of their chemical persistence, their tendency of to bioaccumulate in food webs, their inherent toxicity, and fact that the discharges that will occur over a sustained period of many decades, during all seasons of the year.

10. Physical transport of Metals and Hydrocarbons

Contrary to vague assertions in the DEIS, long-distance transport of contaminants originating at the proposed Pebble Mine site and transportation corridor and entering freshwater is extremely likely, by way of both biological and physical processes. Sediment-bound metals and PAHs bound to organic matter can be physically transported many kilometers downriver, deposited and accumulate in pools, estuaries, floodplain wetlands, and lakeshores (Pratt & Lottermoser 2007). The DEIS is grossly inadequate in its treatment of physical transport of contaminants, relying on unsupported, ridiculously simplified, and in my opinion, indefensible assumptions about the dynamics of potential storage and mobilization conditions od persistent pollutants in the affected aquatic environments.

Once deposited, and depending on physical conditions at the site of deposition and over time, these contaminants can be mobilized into water or into the food web in downstream riverine, lake, and estuarine environments and food webs. Biotransport of trace metals is considered below.

11. Food Webs in Bristol Bay Region are Complex and Relatively Pristine

Most research ecotoxic effects and bioaccumulation of contaminants has been conducted in highly altered ecosystems subject to relatively high concentrations of pollutants. Extensive impact to such ecosystems from multiple sources commonly leads to simplified food web, commonly with loss or depletion of long-lived species, top carnivores, and migratory species—i.e., those that play the largest roles in bioaccumulation and biotransport of contaminants. In the case of the Bristol Bay ecosystems potentially affected by the Pebble Project, concentrations of pollutants considered at a regional scale might be low, but they will extend over a significantly large area (particularly in the Kvichak River-Iliamna Lake system). And the ecosystems affected are relatively pristine, with large natural populations of diverse, long-loved top carnivores (aquatic, terrestrial, and avian), and a host of species that are highly mobile or migratory (including Pacific salmon). This biotic richness embodies complex food webs comprised of many levels of animal predation; the range of fish species and sizes alone in Iliamna Lake (Table 1) supports a food web of up to four trophic levels: small fish feeding on larval or post-emergent fish (themselves feeding on zooplankton), medium-sized fish feeding on small fish, and large fish (e.g., lake trout and northern pike) feeding on medium and small–sized fish. Beyond that, Iliamna seals feed especially heavily on large fish, and large and medium fish are also the principle prey of larger avian and terrestrial predators, such as eagles, ospreys, and bears.

As with trace metals, the number of functional trophic levels in a food web is a consistent predictor of the concentration of persistent hydrobcarbons and other contaminants prone to bioaccumulation (Bentzen et al. 1996, Watras and Bloom 1998, Gantner et al. 2009. In other words, food webs with a large biomass of top carnivores are more prone to biomagnification, because accumulation of persistent contaminants acquired primary through ingestion is compounded at each trophic level. Iliamna Lake is therefore of particular concern, as trace pollutants entering the Kvichak River and its tributaries from the Pebble Project mine site and transportation corridor will reach the lake, whether by physical or biological transport.

Studies of Pacific salmon have well established their role in bioaccumulation and biotransport of persistent organic pollutants into food webs in freshwater spawning areas (Gregory-Eaves et al. 2006, Gerig et al. 2015), including in Alaska, where Ewald et al. (1998) found that organic pollutants accumulated by the salmon during their ocean life stage were not eliminated during migration, but were transported to the spawning lakes and accumulated in the freshwater food web there, doubling the detectable load of persistent organic pollutants detected in resident arctic grayling. They concluded that biotransport of PCB and DDT by salmon played a far greater role in the Copper River system than regional atmospheric deposition. Persistent organic contaminants are partitioned in differing and complex ways within the bodies of organisms. Eggs of salmon naturalized in Great Lakes waters carried higher concentrations of some persistent organic pollutants and lower concentrations of others compared to body tissues (Gerig et al. 2015).

Predacious fish generally accumulate higher body burdens of Hg and other bioaccumulated contaminants than to herbivorous fish of the same size or age (Simeneau et al. 2005). The growth rate of predaceous fishes can influence their body burden of bioaccumulated contaminants, with slower-growing fishes acquiring higher metal concentrations (Simeneau et al. 2005). In larger rivers and lakes, large-bodied long-lived, and slow-growing fish species such as lake trout and northern pike prey heavily on other fishes, hence are prone to accumulating the highest levels of contamination (Bentzen et al. 1996, Power et al. 2002, Stafford et al. 2004). These large-bodied fishes in turn are frequently targeted for consumption by predacious birds and mammals, including bears, lake seals, marine mammals, and humans.

Fish and birds that acquire contaminants—particularly by feeding in fish in polluted source areas—can and often do transport bioaccumulated contaminants widely to other regions and ecosystems when they migrate. Salmon and migratory birds are obvious vectors of long-distance transport of selenium from food webs in the immediate area the proposed Pebble mine site to other water bodies in the region, thus likely secondarily contaminating the food web in lake, rivers, and marine waters (Bard 1999, Baker et al., 2009).

Trophic calculations based on caloric content and population vital rates indicate that roughly 50 percent of total life cycle sockeye salmon production in a typical lake-rearing population is entrained in food webs via predation of juvenile sockeye salmon by other animals (fuiish, birds, and mammals) (C.A.S. Hall, Professor Emeritus, Environmental Sciences and Forestry, Syracuse University, personal communication). The majority of that predation occurs in freshwater, estuarine, or nearshore habitats. Hence contaminants acquired by fish feeding on invertebrates exposed in the vicinity of mine site discharges and streams affected by roads and road runoff can be mobilized rapidly into the food web, bioaccumulated, and biotransported as the exposed fish migrate and are consumed

Table 1. From Hauser et al. (2008)

Table 1. Family and species names of the fishes inhabiting the Kvichak River drainage (described in Bond & Becker, 1963) that are possible prey items for Iliamna Lake harbor seals

Family	Species
Petromyzontidae	Pacific lamprey (*Lampetra tridentatata*)
	Arctic lamprey (*Lampetra japonica*)
Salmonidae	Lake trout (*Salvelinus namaycush*)
	Arctic Char (*Salvelinus alpinus*)
	Dolly Varden (*Salvelinus malma*)
	Rainbow trout (*Oncorhynchus mykiss*)
	Pink salmon (*Oncorhynchus gorbuscha*)
	Coho salmon (*Oncorhynchus kisutch*)
	Chinook salmon (*Oncorhynchus tshawytscha*)
	Sockeye salmon (*Oncorhynchus nerka*)
	Chum salmon (*Oncorhynchus keta*)
Coregonidae	Round whitefish (*Prosopium cylindraceum*)
	Pygmy whitefish (*Prosopium coulteri*)
	Humpback whitefish (*Coregonus pidschian*)
	Least cisco (*Coregonus sardinella*)
	Arctic cisco (*Coregonus autumnalis*)
Osmeridae	Eulachon (*Thaleichthys pacificus*)
	Arctic smelt (*Osmerus eperlanus*)
	Pond smelt (*Hypomerus olidus*)
Gasterosteidae	Threespine stickleback (*Gasterosteus aculeatus*)
	Ninespine stickleback (*Pungitius pungitius*)
Catostomidae	Longnose sucker (*Catostomus catostomus*)
Gadidae	Burbot (*Lota lota*)
Cottidae	Slimy sculpin (*Cottus cognatus*)
	Coastrange sculpin (*Cottus aleuticus*)
Umbridae	Alaska blackfish (*Dallia pectoralis*)
Esocidae	Northern pike (*Esox lucius*)

by predators, themselves often mobile species such as eagles grizzly bears, river otters, and a host of other species (Wren et al. 1983, Willson et al. 1998).

Salmon that take their accumulated body burdens to sea will contribute to the contamination of estuarine and marine food webs. But Chinook, chum, coho, and sockeye salmon originating in the waters upstream of Iliamna Lake will certainly carry some level of persistent contaminants back with them when they home to natal spawning streams and freshwater rearing habitats. Although during rapid marine growth—given lower food web exposures—the per-individual tissue concentration of accumulated contaminants might decline, nevertheless the returning body burden of contaminantswould still be potentially higher than prior to mine development. Moreover, it is more likely that additional contaminants acquired in the marine food web would add additional burdens of persistent organic pollutants (Ewald et al. 1998) and possibly metals. Hence some portion of the returning residual contaminants would be circulated back into streams and rivers (Ewald et al. 1998, Gregory-Eaves 2006), and adjacent terrestrial ecosystems via predation, egg deposition, and carcass decomposition (Willson e al. 1998). Sockeye returning to and spawning within the Iliamna Lake system could contribute recycling of some magnitude of their body burden of persistent contaminants acquired prior to ocean life, even as marine-derived nutrients are recycled (Kline et al. 1993). Body burdens of contaminants in returning salmon would add to the continuing influx of contaminants from the mine source, road dust, road runoff, and spills. Bioaccumulated contaminants can remain in biotic food webs rather than returning to bio-unavailable forms of storage in the ecosystem; most mercury bioaccumulated by top predator fishes in freshwater food webs appears to remain biotically demethylated and sequestered, rather than returning to sediments (Watras et al. 1998).

Iliamna Lake seals feed on a wide variety of fishes including petromyzontids, osmerids, cottids, coregonids, and gasterosterids, as well as salmonids (Hauser et al. 2008), especially including adult sockeye salmon in the season when they are abundant (July and August). Methylmercury accumulation renders rapidly-growing juvenile seals more vulnerable to infections, diseases and decreases immune response (Lalancette et al. 2003). Nonanadromous salmonids also occur in the lake, including Arctic char and Dolly Varden. Rainbow trout migrate between streams and rivers and Iliamna Lake to exploit the productive benthic invertebrate community as forage, while also consuming large quantities of sockeye salmon eggs; after feeding and growing in the lake, they are exposed to high levels of predation by seals and grizzly bears when at large size they migrate back to natal spawning area (Arostegui and Quinn 2018). Artic char in Iliamna Lake feed heavily on other fishes, as well as sockeye salmon eggs (Denton et a. 2010, Woods et al, 2013, Arostegui and Quinn 2018), hence the char, also potential forage for seals, might express higher biomagnification of contaminants.

Residents of indigenous communities have traditionally hunted, and continue to hunt liamna Lake seals for food and other needs (Kugo 2014, Burns et al. 2016). For this reason, potential future bioaccumulation of Se, Hg, PAHs, or other mining-associated contaminants in the lake's food web poses a potentially elevated health risk to native people.

12. Marine Food Webs

Marine mammals are embedded at or near the top of food webs in Bristol Bay that include an abundance of salmon originating from the river and lake systems affected by the Pebble Mine proposal. Against a background of already-measurable bioaccumulation of metals and industrial hydrocarbons originating from globally distributed atmospheric sources (McKinney et al. 2012, Becker 2000), industrial developments including mines, roads and pipelines bring additional regional sources of persistent toxins to arctic ecosystems. Industrial contamination originating from the mine and transportation system—especially that involving persistent contaminants prone to bioaccumulation and biomagnification—could have disproportionate effects on species like beluga whales, which show physiological evidence of having high toxic sensitivity to polycyclic aromatic hydrocarbons (Wilson et al. 2005).

13. Sensitivity of fish and wildlife in pristine ecosystems to novel industrial toxins

While the literature on bioaccumulation of toxins often focuses on higher trophic levels (in part because upper-level animals are more often exploited as food for humans), it is important to recognize that bioaccumulation of contaminants can have biological impacts at the lowest levels of the food web as well. For example, Weisse (1991) found that contaminants have disproportionately large impacts on autotrophic picoplankton, a group of organisms that normally plays a dominant role in carbon production at the base of freshwater and marine food webs. The overall ecological effects of major shifts or losses in production at the base of aquatic food webs are highly uncertain, but potentially could reverberate to the higher trophic levels where salmon and other fishes reside. Desrosiers et al. (2006) reported that increased methylmercury concentration in periphyton in lakes following catchment disturbance by logging was accompanied by reduced periphyton biomass. Metals contamination affects some species of stream macroinvertebrates that are important as prey for larger species (Kiffney 1996, Richardson and Kiffney 2009). The resulting shifts in predation pressure among invertebrates could reduce availability of species such as certain active and free-swimming mayflies that serve as important prey for salmonid fishes. These are just a few of the reasons why scientists continue to advocate for alternative, ecologically-informed bases for establishing water quality regulatory standards (Buchwalter et al. 2017, Poteat and Buchwalter 2013)

The apparent high sensitivity of beluga whales to even small concentrations of PAHs (Wilson et al. 2005) exemplifies a potentially critical evolutionary principle that is fundamental to ecotoxicological assessment: organisms inhabiting ecosystems previously unexposed to novel industrial-origin contaminants may be highly inherently sensitive to and harmed by even very low concentrations of these contaminants. By comparison, animals, plants, and microbes from parts of the world where they have a multigenerational evolutionary history of exposure to specific industrial chemicals may be genetically selected for resistance and show few or no apparent physiological, immune, or external stress responses tor relatively high concentrations (Benton and Guttman 1992). Importantly, bioassays for toxicity relied on by government agencies to set water quality and other environmental standards rely on test organisms that commonly have a long history of exposure to the toxins they are bioassaying--hence these organisms have likely evolved reduced sensitivity, and higher tolerance to many of the substances they are commonly exposed to in laboratory tests, especially compared to counterparts in natural environments with a very limited history of industrial pollution (Nunes et al. 2006). The important point here is that biota in the Bristol Bay ecosystem are likely to me more sensitive to novel industrial toxins than standard toxicity tests might suggest.

14. Multiple Stressor Effects

Introduction of several major categories of novel industrial toxins to an ecosystem with complex, multi-level food webs and extremely limited prior exposure to the pollutants in question likely represents a worst cast scenario in terms of the potential for ecotoxic effects on ecosystems and fish and wildlife populations. There is strong experimental evidence, for example. That some animals are relatively tolerant of diesel fuel and of metal contamination when exposed separately, but they exhibit high mortality when exposed to diesel and metal contamination simultaneously (Beyrem et al. 2006). At a genetic level, empirical evidence is accumulating that exposure to a toxin reduces the resilience of populations, and increases vulnerability to other toxins—and to other environmental stressors generally—because the initial toxic exposure narrows genetic diversity of the population (e.g., Benton and Guttman 1992, Krane et al. 1999, Belfiore and Anderson 2001). Brady (2013) found that wood frogs, rather than adapting to the chemical and other stressors affecting roadside populations, instead showed evidence of genetic maladaptation that reduced survival and increased the incidence of developmental malformations in roadside populations. The result is that each toxic substance a population is exposed to can incrementally diminish its adaptive capacity to cope with environmental challenges from other causes—including other toxins, normative environmental fluctuations, habitat alteration, fishery harvest, disease, and climate change. By introducing or increasing several categories of industrial-origin toxins, the Pebble mine and transportation system proposed in the DEIS threaten exactly these kinds of cumulatively-acting impacts to the Bristol Bay ecosystem

15. Cumulative Impact Interactions with Anticipated Climate change

Climate change is expected to manifest itself strongly within the next few decades in the Bristol Bay region (Wobus et al. 2016) (and likely already has begun to do so). Climate change will exert alterations in the pattern of weather events and extremes, climatic trend, vegetation change, hydrologic alterations, and ecosystem biological and trophic changes (Schindler et al. 2008). These are certain to interact with and influence the various mechanisms considered in this document—that is, the pathways by which metals and PAHs are mobilized and become entrained and magnified in food webs. These changes must be considered in the DEIS when addressing impacts on water and biota and possible means of reducing, minimizing, or mitigating them. For example, the following hypotheses (initially informed in part by the analysis of Wobus et al. 2016) warrant close examination and analysis in the DEIS:

- Increased frequency of freeze-thaw processes and loss of permafrost with climate change could result in greater propensity for mobilization of mercury from soils into surface waters and their biota.
- Increased rain-on snow runoff and more precipitation as rain rather than snow is likely to increase aqueous runoff and sediment transport from polluted road surfaces into surface waters.
- Increased incidence and temporal juxtaposition on of freezing and thawing during the cold season is likely to increase the need for application of deicing agents to keep road surfaces operable.
- Increased duration and frequency of dry weather in summer and winter seasons is certain to increase the incidence and magnitude of dust generation and dispersal from the mine site and roads.
- Increased freeze-thaw episodes and more rainfall as precipitation is certain to increase the need for grading, recontouring, culvert and bridge maintenance and reconstruction work on roads; each such event raises the risk that mercury and other accumulated mining-related pollutants are mobilized from roads and soils adjacent to wetlands and streams.
- Increased hydrologic variability overall will increase the likelihood of overwhelming the design criteria applied in stream crossings, resulting in washouts, possible accidents, spills, and pipeline ruptures, and the need for ongoing reconstruction work.
- Increased hydrologic variability will alter the physical transport of persistent pollutants, and increasing the likelihood of fluctuating redox and wetting conditions that spur methylation and mobilization of mercury from storage in sediments and streamside and floodplain soils.
- Reduced life history complexity of sockeye salmon (especially reduced variance in age at return, or number of year classes contributing to a return year, Cline et al. 2019), partly a result of climate change, likely increases the vulnerability of sockeye salmon populations to spills or catastrophic failures associated with mining.

16. Recommendations:

- A revised or supplemental DEIS must explicitly consider the potential for bioaccumulation, biomagnification, and biotransport away from the immediate source areas of metals and polycyclic aromatic hydrocarbons other persistent organic pollutants that will be discharged or delivered in nonpoint runoff and fugitive dust, and are likely to increase in the environment of Bristol Bay as a consequence of construction and operation of the mine and its transportation system.

- The potential for bioaccumulation and biotransport of pollutants emanating from the project must be assessed even if those pollutants are discharged below extant point source discharge standards, or as nonpoint sources. Such an analysis and its conclusions are potentially critical to understanding the long term and cumulative effects of the proposal.

- Analysis of bioaccumulation potential is feasible by adapting a general biodynamic modeling approach *sensu* Luoma and Rainbow (2005) to the known organization of biological communities of the receiving waters and downstream affected waters of Bristol Bay.

- Cumulative effects of discharges and environmental alterations proposed in the project, accidental leaks, spills, and failures that are certain to occur in a project of this magnitude and duration—taken together with climate trends that are expected to occur over the time frame the project exists—must be identified, anticipated, and addressed, and effective measures identified to avoid or minimize them.

17. Concluding Statement

The failure of the DEIS to acknowledge or address in any way the risks and potential effects of bioaccumulation and biotransport of contaminants in the receiving waters and the rivers, lakes, and marine water of Bristol Bay renders the DEIS fatally incomplete, and unreliable as a basis for making an informed decision, and grossly inadequate for ensuring that effective avoidance and mitigation actions for the project are properly identified. The DEIS in my opinion is fatally flawed and fundamentally misleading in its lack of disclosure about likely the scope, magnitude, and duration of harmful environmental effects of the proposed project.

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