ENVIRONMENTAL IMPACTS OF THE PEBBLE MINE

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EXECUTIVE SUMMARY

Development of the Pebble mine could potentially have severe impacts on the environment, human health, and the world’s most productive wild salmon fishery in Alaska. The project is proposed to extract gold, copper, and molybdenum from one of the largest sulphide deposits in the world. This study is conducted to evaluate the levels of risk that the mining operations in the area pose to the environment. This is done through identification of various contaminants of concern (COCs) associated with the Pebble Mine and their impacts on the aquatic life and human health. Arsenic, cyanide, and acid mine drainage (AMD) are potentially the most hazardous of all COCs. A brief economical risk evaluation of the project is followed by biological risk assessment to wild salmons and other species in the area. It is then examined how construction activities could potentially disrupt aquatic and terrestrial ecosystems. An evaluative comparison of economical benefits of the $500 billion Pebble project over $6 billion fishing industry in the region is investigated. With the preliminary knowledge presented throughout the report, from an environmental perspective, the levels of risk and their associated uncertainty are such that an informed decision cannot be made until the results of an in depth study that precisely evaluates impacts of mining activities on aquatic life and ecosystems, is released. At this point in time, based on the information available, the mine proposes a unique threat to the environment.
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1. INTRODUCTION

Gold mining is one of the areas in industry that has been controversial because of its repetitive negative records. The Pebble Mine in Alaska has also led to widespread debates between environmentalists, mining companies, and the public. In this study we aim to evaluate potential risks that the project could pose to the environment, humans, and the fishing industry in Alaska. A brief introduction of Bristol Bay area and the Pebble project is followed by an assessment of risks that contaminants of concern (COCs) could potentially pose to the environment and human health. Next, various risks associated with the project are discussed, and the conclusion is preceded by a short history of gold mining in different parts of the world, and an economical evaluation of gold mining and fishing industry.

1.1 BRISTOL BAY

Bristol Bay is located in southwestern Alaska in the eastern arm of the Bering Sea. Bristol Bay is known for its strong runs of salmon, including the world’s largest run of Sockeye salmon. It is home to the world’s most valuable wild salmon and its natural reproductive cycle that contributes to more than $400 million annually to Alaska’s economy. The commercial fishery in the region harvests about 17 million Sockeye salmon per year. Region’s reputation for healthy habitat, fresh wilderness setting, and pure clean water is deriving most of Bristol Bay’s wild salmon and trout economic value (RRC: NDM’s Proposed Pebble Mine Plans, 2010). This area also supports widely known sport fisheries for salmon and other habitant species. The subsistence fishery would be severely impacted by the Pebble Mine (Hauser, 2007). The bay also produces strong runs of chum, silver and king salmon. The population of Bristol Bay is composed of 66% percent Alaska natives (Alaska Government, 2001). The Alaskan native population of Bristol Bay includes the Yup’ik Eskimos, Deneina, Athabascans, Aluets and Alutiiqs, which have lived in this area for thousands of years and continue to depend on the bay as a renewable resource for subsistence and life. The diet of salmon for Alaskan natives is, on average, 20%. Economically the salmon fisheries account for 88% of the economic base (Alaska Government, 2001). There are many fresh water lakes and rivers that support the salmon runs, including Iliamna Lake, a critical habitat for millions of Salmon that spawn every year.

1.2 THE MINE

The proposed site for the Pebble Mine in Bristol Bay contains large amounts of gold, copper and molybdenum, as well as significant amounts of silver, rhenium and palladium (Pebble Partnership). The amount of raw minerals found makes Pebble Mine one of the largest deposits of copper and gold in North America. Its location would be on the headwaters of the Kvichak and Nushagak Rivers. Kvichak River empties into Lake Iliamna and the Nushagak River empties into Nushagak Bay. The
mine will be owned by two companies which make up the Pebble Partnership: Northern Dynasty and Anglo American. The mine is currently in the pre-permitting, advanced exploration state. The partnership aims to have a preliminary development plan by the end of this year (Northern Dynasty Minerals Ltd, ND). The mine’s design is both open pit and underground, and is split into two parts: Pebble West and Pebble East. Pebble East, the larger of the two mines could be up to two miles wide, several thousand feet deep and generate 2.5 billion tons of waste rock material (The Economist, 2007). Pebble East would be mined through underground methods (block caving), involving a 9 mile long road stretching along lake Iliamna (Pebble Partnership).
2. CONTAMINANTS OF CONCERN (COCs)

This section discusses the contaminants that are of concern as a result of Pebble mining operations. The choice of the contaminants was based on the historical documentations of gold mining by-products and tailings in different parts of the world. For each COC its association with mining activities is primarily discussed, followed by assessing its potential impacts and damages to the environment and human health. Since there are many factors driving the potential hazards of COCs, previous mining operations can only be used as a measure for comparison. It is therefore implausible to accurately assess the potential risk that each contaminant poses. For quantitative measures of the Pebble mine resources refer to the Appendix. A. Canadian Environmental Water Quality Guidelines for the protection of aquatic life in freshwater and marine ecosystems for the COCs are available in Appendix. B.

2.1 ARSENIC

Arsenic is a natural common element that could be found in soil, air, and water and is one of the most toxic elements encountered in the environment. It is the 20th most abundant element in earth’s crust, 14th in seawater, and 12th in the human body (Straskraba & Moran, 2006). It is a significant component of sulphide deposits and is a commonly encountered element with gold ores and is often a by-product of tailings from gold mining operations.

Mining operations in sulphide deposits can enhance the oxidation mechanism of the minerals containing arsenic. Weathering of gold is often known to lead to an increased acidity of surrounding water, liberation of metal traces, and thus mobilizing arsenic. Consequently high concentrations of arsenic in acidic waters are often related to open pit and underground gold mining. In these environments an increase in the amount of water pH can reduce the amount of dissolved arsenic. The dissolved arsenic will rapidly settle and accumulate at the bottom of ponds or streams. For this reason arsenic in tailings and mine wastes tend not to migrate for great distance. Cyanide leaching can also lead to mobilization of arsenic, although the environment acidity is low.

Since the water from abandoned mine can discharge to surface waters, elevated concentrations of arsenic in water can pose potential risks to the environment. Arsenic intoxication is very rare and only a few cases of arsenic poisoning have been reported in places such as Nova Scotia (1977) and Chile (1976). Arsenic concentration of 0.05 mg/lit in drinking water is considered hazardous to human health. This value is adapted by WHO and EPA (Straskraba & Moran, 2006).

High concentrations of arsenic in surface and ground water are often found in many gold mining operations. Hydrologic study of background arsenic concentrations in surface and ground water for some selected locations of gold mining projects in western USA are presented in Table.1 (Straskraba & Moran, 2006).
Elevated concentrations of arsenic in Colorado are results of widespread gold mining operations at the end of 1800s that discharged acidic water from tailings to local water resources. This caused great concern for human health and lead to considerations for a permanent treatment plant for the discharged water. In these areas, mining companies interested for developing new mines are held responsible for the cleanup of past pollutions.

Arsenic has a strong coherence with gold. Table 2 demonstrates occurrence of arsenic in nature, comparing gold deposits with other natural sources (Straskraba & Moran, 2006).

In regions with sulphide deposits, average content of arsenic in surface water is often less than 20 µg/lit, whereas for normal surface water i.e. away from mineralized areas, arsenic concentration in surface water can be as low as 2 µg/lit. In western USA, range of maximum concentration of arsenic in ground water is 0.13 – 48.0 mg/lit; that is nearly three orders of magnitudes more than surface water. Concentration of arsenic in soil is naturally around 5 – 14 mg/kg, but can be much higher in mining sites (Straskraba & Moran, 2006).

Health Canada and International Agency for Research on Cancer both consider arsenic as a carcinogenic contaminant. A newly set guideline for water content of arsenic by Health Canada is at 0.01 mg/lit, based on lifetime exposure of human to arsenic from drinking water (FNEHIN-Arsenic, 2008). EPA has set the values in Table 3 for standard guidelines (CSP, 2006).

Table 1: Arsenic concentrations at gold mining projects in western US

<table>
<thead>
<tr>
<th>Location</th>
<th>Maximal Arsenic Concentration (mg/lit)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface Water</td>
</tr>
<tr>
<td>South Alaska</td>
<td>0.011</td>
</tr>
<tr>
<td>South Dakota</td>
<td>0.446</td>
</tr>
<tr>
<td>Central Colorado</td>
<td>26.0</td>
</tr>
</tbody>
</table>

Table 2: Natural concentrations of arsenic

<table>
<thead>
<tr>
<th>Source</th>
<th>Concentrations (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Igneous &amp; Sedimentary Rocks</td>
<td>1.0 – 2.1</td>
</tr>
<tr>
<td>Shales</td>
<td>12.0</td>
</tr>
<tr>
<td>Gold Deposits</td>
<td>&lt;5000</td>
</tr>
</tbody>
</table>

Table 3: EPA standards for drinking water and aquatic life

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Drinking Water Standard (mg/lit)</th>
<th>Aquatic Life Standards Surface Water (mg/lit)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute</td>
<td>Chronic</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.05</td>
<td>0.36</td>
</tr>
</tbody>
</table>
High levels of arsenic can cause serious damage to human health. Damage to different parts of the body is illustrated in Figure 1.

![Dangers of arsenic poisoning](http://rydberg.biology.colostate.edu/Phytoremediation/2010/Ana%20Koduah.pptx)

Figure 1 Damage to human health caused by arsenic

Arsenic in fish is of a form that does not pose any risk to human health. The main exposure path to arsenic is through ingestion and drinking water. Arsenic in drinking water is tasteless and odourless. Once in body, it is distributed by the bloodstream but mostly excreted through urine. Inhalation or dermal contact of arsenic does not pose risk to human health (FNEHIN-Arsenic, 2008).

There are many possible mechanisms for reducing arsenic content of water, generally categorized in two groups: passive and active approaches. As for passive approach, soils are capable of attenuating arsenic content of mine tailings. This is done through four natural mechanisms:

- Ion exchange
- Sorption
- Precipitation
- Biodegradation

Among different types of soils, clay, owing to its capacity of cation exchange, has the highest attenuation capability. Allowing the tailings to percolate to wetlands can also lead to lowering the

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1 [http://rydberg.biology.colostate.edu/Phytoremediation/2010/Ana%20Koduah.pptx](http://rydberg.biology.colostate.edu/Phytoremediation/2010/Ana%20Koduah.pptx)
concentration of arsenic through chemical reactions; but it is restricted by the area available, quality of soil, and the length of growing season.

Active water treatment for arsenic removal involves:

- Chemical precipitation
- Sorption
- Reverse osmosis

Chemical precipitation usually includes the application of iron isotopes with high removal rates efficiency. Activated carbon absorption has also indicated satisfactory results, but has been competitive with chemical precipitation in terms of cost effectiveness. Reverse osmosis is also not cost effective for large volumes of water, but is suitable for treating of contaminated drinking water in small towns located near the mining sites. Overall active methods are more effective and thus favoured over the passive approaches, although they are invariably more expensive.

Two major tailings dam failures occurred in 2000 in Romania. As a result, rivers which were tributaries of River Tisa (one of the main rivers in eastern and central Europe with an approximate length of 900 km) were contaminated with arsenic and other heavy metals. The contamination was transported downstream to River Danube in Hungary, Serbia, and Bulgaria. The arsenic spill caused severe pollution and had significant environmental impacts (Bird, et al., 2003).

There has not been much study on the effect of high arsenic concentration in water streams on aquatic life.

2.2 CYANIDE

The process of excavating gold from ores with cyanide was devolved in Scotland in 1887 (Eisler & Wiemeyer, 2004). Heap leaching, the process of obtaining gold from low grade ore, was not proposed in the US until 1969 (Eisler & Wiemeyer, 2004). Currently heap leaching of gold with cyanide is used at 90% of mines in Canada (Eisler & Wiemeyer, 2004). Heap leaching involves taking heaps of ore and leaching them with a diluted cyanide solution. The solution percolates and is recovered so the gold can be recovered through precipitation (Eisler & Wiemeyer, 2004).

Cyanide is a non carcinogenic substance that can be lethal to humans and animals/fish with the right dose (Eisler & Wiemeyer, 2004). Cyanide is readily absorbed through ingestion, skin contact, and inhalation. Cyanide is an asphyxiant; it disrupts the body’s ability to deliver oxygen and can lead to brain damage or death. Cyanide usually does not persist in the environment in high quantities since it breaks down rapidly. Therefore, it does not biomagnify up the food chain and does not persist in surface waters (Eisler & Wiemeyer, 2004).
The advantage of using cyanide is that it does not accumulate in surrounding ecosystems. If it escapes from the tailing ponds, high concentrations will disperse rapidly. Cyanide, however, does have direct effects on ecosystem services. Numerous accidental spills have resulted in massive kills of fishes, amphibians, aquatic insects, and aquatic vegetation. The trouble with testing the effects of cyanide on ecosystems is that it does not have environmental persistence; periodic testing of cyanide is unsatisfactory for asserting potential hazards. A similar case is made for cyanide in the atmosphere (Eisler & Wiemeyer, 2004). There has been some testing under controlled conditions where fishes are the most sensitive aquatic organisms, with deaths from salmon starting at as little as 20 µg/lit (Eisler & Wiemeyer, 2004).

Disposing of cyanide has improved with technology. The use of a natural reaction with ore, soil, clay, and microorganisms has been advanced as a mechanism for returning a site to a safe condition. Though under certain alkaline conditions, cyanide can persist for at least a century. The treatment of sludge with these methods has shown to work in a waste water treatment plant in Fairbanks Alaska (Eisler & Wiemeyer, 2004).

2.3 ACID MINE DRAINAGE (AMD)

Acid mine drainage is known to be mining industry’s greatest threat to the environment, with potential impacts on water streams and aquatic life. It severely degrades water quality and makes it almost unusable.

Exposure of sulphide minerals in large quantities to water and air during mining operation produces sulphuric acid. The acid is able to dissolve hazardous metals such as copper, arsenic, and mercury when they come in contact with it and if remained uncontrolled may runoff to ponds and rivers or percolates into groundwater streams. Once in water, contaminated streams can travel far from where they were originally polluted. This threat is associated with both open pit and underground excavations.

Although no direct hazard is posed to public health by sulphuric acid, but soluble metals in it can threat human health by contaminating drinking water, as well as killing wildlife and fish. Dissolved metals are easily absorbed by fish and human body and can be bioaccumulated in food chain. Discharge of AMD into a water stream can cause high acidic environment in which no plants or fish has a likely chance of survival.

Sulphuric acid can also be suspended in air but is removed after rainfall. AMD has 20 to 300 times more acidity than acid rain (FNEHIN-AMD, 2008).

AMD is of great concern particularly because it can cause damage to the environment long after the mining operations have ended and tailings dams decommissioned. If contamination occurs, the problem becomes intergenerational and water treatment has to go possibly for centuries. One
example of the ongoing threat of AMD is Johannesburg in South Africa which is facing an environmental catastrophe due AMD spill after 120 years that gold mining operations have ended in the region (Naido, 2009).

A study in 2006 indicated that metallic sulphide mines are very likely to develop pollution problems because of their poor environmental records. The analysis illustrated that for sulphide deposits close to groundwater, as it is at the Pebble Mine, there is a high level of probability that the quality of water exceed safe levels as a result of acid discharge (Hauser, 2007).

Direct exposure to AMD could potentially result in:

- Severe irritation and skin burn
- Lung damage
- Eye damage and blindness

Long-term exposure to intermediate concentrations can cause:

- Dermatitis
- Erosion of teeth

Acid sulphuric is unlikely to accumulate in body since it is excreted in urine, but long time exposure of miners to elevated levels of AMD can have carcinogenic effects on them (FNEHIN-AMD, 2008).

Even with the existing technology, neutralising contaminated water streams from AMD has not proven to be cost-effective and sustainable.

### 2.4 Mercury

Mercury is not attached to gold but is commonly found with its deposits with concentrations as high as 100 mg/kg. For those gold mines containing mercury, it is often released during the cyanide extraction. The gold bearing rock which has been crushed by cyanide is spread over by liquid mercury to remove the gold. The mercury then evaporates, leaving the gold. The gold mining operations therefore play a major role as being a significant source of mercury pollution. Mercury is no longer mined as a primary mineral.

Once released to the air, mercury will eventually fall back to the land and water streams. It is then consumed by bacteria and is converted to “methylmercury”, a type of mercury that can be easily absorbed by fish, animals, and plants. Methylmercury is concentrated in food chain through bioaccumulation, building up in older and larger fish and animals. Since it is not mobilized well, it cannot be removed from body.
At mining sites workers could inhale vapour mercury or absorb it through dermal contact. But the most common exposure path for the general public is by consumption of contaminated fish. In Alaska mercury has been found in every type fish (Breithaupt, 2009).

Because of salmon position in food chain, it is naturally exposed to lower contents of mercury. In other words, biomagnification of mercury for salmon is such that under normal concentrations of mercury in aquatic environments, there is no threat for humans by consuming salmon².

Adverse health effects of mercury on human include mental retardation and damage to nervous system. The extent of damage from mercury to human body is highly dependent on dosage and timing of exposure (ACAT, 2009). It is generally recommended that child bearing women, pregnant women, and children under twelve years of age carefully watch their mercury consumption.

According to CSP report, maximum allowable concentration of mercury in freshwater is 1.4 µg/lit. Toxicity threshold for fish content of mercury is 1.0 mg/kg (wet weight) (CSP, 2006).

Mercury use in extraction of gold deposits is becoming an abolished practice in the US. Therefore the future pollutions of mercury will be mainly a result of natural concentrations of mercury in ore deposits.

There are various mercury pollution control strategies that are employed with regards to the phase of mercury and the extraction method. The most commonly used processes in Alaska are (Breithaupt, 2009):

- Fabric filter
- Carbon adsorption filter
- Wet scrubber

These are mostly applicable for removal of vapour mercury from air, though each employs a different technical approach for the job.

Treatment technologies for low concentrations of mercury in water i.e. up to 10 µg/lit include:

- Filtration
- Lime softening
- Reverse osmosis

Lime softening is a water treatment method that removes ions in the water through chemical reaction by utilization of calcium hydroxide. Filtration of water includes various methods; reverse osmosis can be considered as a filtering technique as well.

² For instance it is recommended that swordfish should not be consumed more than once a week, whereas there is no such recommendation for salmon (Charbonneau. G, Mercury in Fish Fact Sheet, FNEHIN, 2010).
2.5 COPPER

Copper is an essential element for human health, though elevated levels of copper in body can be hazardous. Naturally, copper is found with gold and molybdenum deposits, as well as having association with nickel and zinc.

Main problem with copper extraction is the AMD that can run off from mining site and cause damage to aquatic life. Smelting operations of copper can also result in degradation of water resources quality and affect reproductive adult fish populations. Recently a whole run of salmon was nearly wiped out in the Tsolum River on Vancouver Island due to copper contamination (FNEHIN-Copper, 2008).

There is a lack of reliable data to accurately predict how elevated concentrations of copper can impact salmons and their living environment. Bioavailability and toxicity of copper is hard to measure because it is directly affected by levels of water pH, calcium, and zinc in the water stream. However it is clear that zinc—which is available at the Pebble—will increase the toxicity of copper and severely affect the aquatic environment. Increased copper content can (Woody, 2010):

- Reduce fish survival ability by reducing olfactory
- Kill salmon food organisms (e.g. zooplankton)
- Reduce survival and growth of fish

Roch and McCarter (1984) exposed Chinook salmon eggs to varying degree of zinc, copper, and cadmium concentrations in order to assess the survival, growth, and hepatic metallothionein occurrence in fish population. The salmons were residents of Campbell River in BC and were exposed to high levels of heavy metals as a result of mining operations in the region. Resident salmons were safe if concentrations were not to exceed 50 µg, 2.5ug, and 0.5 µg per litre for zinc, copper, and cadmium, respectively (Roch & McCarter, 1984).

Copper in air is deposited into soil by rainfall, which then attaches strongly to organic minerals and materials that can be harmful to soil organisms.

EPA drinking water standard for copper is 1.3 µg/lit (CSP, 2006). High levels of copper (more than 15 mg/day) can damage human health by causing (FNEHIN-Copper, 2008):

- Skin allergies
- Nausea
- Diarrhoea
- Jaundice

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3 When salmon is attacked by a predator, the wounded fish sends an alarming scent that can be detected by other fishes downstream of the river
Acute copper poisoning is rare in humans and is often a result of ingestion of copper salts. Long-time exposure to copper can cause kidney and liver damage that could be caused through inhalation of copper containing dust or dermal contact during mining operations. Historically there have been a vast number of mortalities among the copper smelter workers as a result of cancer caused by exposure to copper. These workers were exposed to the contaminant for more than a decade. However Health Canada does not consider copper a carcinogen (Lightfoot, Pacey, & Darling, 2010).

2.6 MOLYBDENUM

Molybdenum has been proven to be an essential and beneficial element for aquatic organisms, with an optimum concentration of 25 µg/lit in water (CCME, 1999). Molybdenum is not poisonous on its own, but rather can cause damage when it interacts with copper (Eisler R., 1989). This element mostly settles in soil and usually has lower concentration in aquatic environments than in terrestrial ecosystems.

Citing different previous studies, both CCME (1999) and Eisler R. (1989) suggested that molybdenum does not bioaccumulate in fish.

In BC, the only province where molybdenum mining has been in operation in Canada, molybdenum concentrations of surface water never exceeded 57 µg/lit, compared to an average value 70 µg/lit of molybdenum concentration where industrial activities operate. The level of molybdenum in freshwaters in Canada can reach 500 µg/lit. The interim water quality guideline for molybdenum for the protection of freshwater life is 73 µg/lit (CCME, 1999).

Generally freshwater fishes are extremely resistant to molybdenum. Most of adverse impacts of molybdenum on aquatic organisms appear when its concentration in water exceeds 50 mg/lit; however, as the only exception in the literature, eggs of rainbow trout have shown to be vulnerable to molybdenum concentrations as low as 0.8 mg/lit. This suggests that further research should be focused on the impacts of molybdenum concentration on early stages of life (Eisler R., 1989).

2.7 DISCUSSION ON COCs

Arsenic, cyanide, and AMD are the more concerning of the contaminants mentioned above. As it was discussed, employing mercury in leaching is being abolished, copper often runs off to the environment as a solution in AMD, and molybdenum has been insignificant in terms of impacting aquatic environments. For the former three, exposure pathways for both human and ecological receptors were introduced and the toxicity of each was briefly examined.
The Canadian Water Quality Guidelines (Appendix. B) do not suggest any value of sulphuric acid concentrations for protecting aquatic life; this is reasonable since the toxicity of the contaminant strongly depends on its solutions. For instance in the case of AMD at the Pebble mine, trace metals are the main source of toxicity.

The most recent updated guidelines on cyanide concentrations trace back to a 1991 Health Canada document. In this report a maximum acceptable concentration of 200 µg/lit for free cyanide in drinking water was set. The document does not enclose the method for calculating this value, nor for the guideline value for protection of aquatic life (HealthCanada, 1991).

CCME water quality standard of arsenic concentration for the protection of freshwater life is 5 µg/lit. This value is derived by multiplying safety factor of 0.1 by the fourteen days exposure of half maximal effective concentration (14-d EC50) of 50 µg/lit for the most sensitive organism to arsenic (the alga S. Obliquus) (CCME, 1999).

CCME water quality standard of arsenic concentration for the protection of estuarine and marine life is 12.5 µg/lit. Multiplying the same safety factor as for freshwater life by the lowest observed effect concentration (LOEC) of 125 µg/lit for the most sensitive organism to arsenic (the diatom S. Costatum) would yield this value (CCME, 1999).
3. ADDITIONAL RISKS

3.1 ECONOMICAL RISKS

Economics creates environmental risk because of the unpredictability of the prices for resources in the market. The risk of an ‘event’ occurring that could create a hazard to humans or damage natural resources is correlated with the price of resources (Finnie, Stuart, Gibson, & Zabriskie, 2006). This is because mining companies are more likely to absorb environmental costs when the price of resources is high. The harm to humans or natural resources could happen during the mine’s production period or after it has been abandoned. Remediation can only occur if the mining firm still exists and is financially viable.

Mining firms are responsible for natural resource damages that could harm human health or the environment (Finnie, Stuart, Gibson, & Zabriskie, 2006). Valuing the risk is difficult. This may be the reason why, in the United States, there are no set guidelines for financial reporting and accounting surrounding environmental risks (Finnie, Stuart, Gibson, & Zabriskie, 2006). For example, if a company’s action resulted in one dead pelican, how much would replacing that pelican be worth? The answer to that question is extremely difficult as there is no market value for pelicans. Expanding this problem to an ecosystem or to the loss of a human life, the estimation of either’s financial worth is nearly impossible. This is the reason why there is no financial reporting of environmental risk in the US. It is because accounting for contingencies only needs to occur if it is estimable (Finnie, Stuart, Gibson, & Zabriskie, 2006). Therefore, public scrutiny provides the incentive for environmental safety not presentably possible through policy.

There are more than 80 abandoned sites on the United States National Priorities List (EPA, 2004). For many of the sites, the parties responsible either do not exist or are not financially viable. The cost of remediation is now the responsibility of the taxpayers. The cost according to the EPA is between 32 and 72 billion dollars (EPA, 2004). For mining firms currently in operation, they have the ability to declare bankruptcy to avoid confronting high environmental costs. The high environmental costs would come from the Compensation and Liability Act, which requires restoration of damages to resources and includes the diminished value of a local industry (like a fishing industry). The performance of many mines in the past that avoided environmental remediation should not be an indicator of how a specific mining firm will act now. Knowing how the firms can defer costs to taxpayers if the operation proves not to be as profitable as projected is an important risk factor to the people of Bristol Bay and to the local ecosystem.
3.2 ECOLOGICAL RISKS

Building a mine alters the landscape and in any environment can produce unintended damage to ecological systems. Ecological systems such as the hydrology and the nutrient cycles are complex and have to be studied in situ to be fully understood. Though the broad idea is well understood, the characteristics are specific to each environment. It is impossible to say without a complete ecological study what kind of effects could occur from the construction of the mine: a small leakage of contaminants, a large leakage, or mine abandonment. An example of a compounding ecological effect that could occur is how salmon affect nutrient levels in aquatic and terrestrial ecosystems. There is an increase in nutrient rich plant life existing around lakes because there are salmon, and in particular Sockeye salmon, runs (Bilby, Beach, Fransen, & Walter, 2003). Therefore, a decrease in salmon will decrease the biodiversity of riparian plant life. How salmon give nutrients to terrestrial plant life is due to the fact that salmon are on a low trophic level and are food for bears and wolves. Once consumed their carcasses are left for plants to use as nutrients. An additional effect is the diet changes of both bears and wolves because of the change in the population of salmon – which can have a whole range of other effects on other prey of those species.

3.3 RISK TO SALMON

Salmon plays an important role in ecosystem services, as mentioned in the previous paragraph. In this paragraph the risk to salmon will be overviewed. Before mentioning the risks, it is important to understand the salmon life cycle. Every year pacific salmons migrate upstream to spawn at their birth place. To get to the exact spot the salmons use their sense of smell that is imprinted in their memory (Wisby & Hasler, 1954). Salmons that are in the same spawning area or watershed have similar traits. There are many watersheds of salmon in the Bristol Bay area. In order to keep the population sustainable, many watersheds of salmon are necessary to keep up high levels of genetic biodiversity (Ramstad, Woody, & Sage, 2004). The risk of a cyanide spill to salmon has been outlined in the cyanide section. As mentioned, fish are the most sensitive aquatic organisms to cyanide in the aquatic ecosystems. The cyanide concentrations and risk to fish are listed below:

Fish Hazard:  10 µg/lit irreversibly impair the swimming ability of salmon  
50 µg/lit to 200 µg/lit were fatal to sensitive fish species  
> 200 µg/lit rapidly lethal to most species.  
(Eisler & Wiemeyer, 2004)

Another risk to salmon is from copper which can get into waterways from copper mining or from AMD. The effect of copper to salmon is that it impairs fish olfaction (sense of smell). The salmons’ sense of smell is an important part of their lifecycle. It enables salmon to mate, find food, avoid predators and find their way back to spawning sites (Tierney, 2010). This will reduce the ability of survival for the salmon, as mentioned before (Baldwin, Sandahl, Labenia, & Scholz, 2003).
3.4 RISKS ASSOCIATED WITH CONSTRUCTION AND STRUCTURAL FAILURE

The effects on the environment due to construction projects will include:

- Long-term, multi-year losses of fish production and stream productivity
- Deterioration and interference with juvenile or adult fish migration between important habitats by bridges and culverts in the access road
- Smothering fish food organisms and incubating fish eggs by dust and silt from the road during the life of the project or leakage from the slurry line
- Compacting the soil and altering the movement of groundwater which could disrupt beach spawning by Sockeye salmon in Iliamna Lake by the weight of the roadbed and traffic

The combined project footprint of nearly 1000 square miles that includes all the major components, will directly impact the aquatic and terrestrial habitat through (Hauser, 2007):

- Various storage dams as deep as 700 feet with a total area of about 12 square miles allocated to contain 2.5 billion tonnes of waste
- Dewatering of nearly 60 lineal miles of main stem as well as their associated tributaries and wetlands
- 104 miles of access road from Pebble site to Cook Inlet
- Port facilities on Cook Inlet
- Slurry and returned recycled water pipelines parallel with the access road

Most of the manmade structures mentioned above will become permanent features of the land.

As part of the project, five incredibly large earthen dams that would contain the waste from the mining process, or in other words be toxic waste storage sites, will be constructed. Not only would the dams divert large amounts of water needed by fish, but they would forever sit on one of the world's most earthquake-prone areas (Chambers, 2007). In the case of a large earthquake, there is a high risk of failure for tailing dams. Release of a large amount of tailings could cause catastrophic and long-term environmental damage with high cleanup costs. The probability of such failure is very low, but should it occur, the consequences are disastrous.

Although the dams are expected to withstand earthquakes with a maximal magnitude of 7.8 (Bluemink, 2006), it is the cumulative effect of various small or medium scale earthquakes and storms over years that is of concern. Dams and other facilities can be constructed with a design to withstand a certain-sized earthquake or storm event, but the cumulative effects can cause cracks that can in turn lead to stress and failure of structure.

Water streams and drainages close to the mining site, as well as tributary streams and associated wetlands that are important for the health of the stream flow systems and the fish habitants, will be dewatered for mining operations and filling the tailing ponds. Moreover, groundwater connected to
these streams will be pumped for mine operations and thus will alter the groundwater movement and recharge of the stream flow (Hauser, 2007).

Nearly 120 streams that support fish habitats will be crossed by the access road and the power transmission corridor. Construction of road, as well as installation of bridges and culverts for power transmission, can lead to siltation (pollution of water by terrestrial rocky materials) that could potentially disturb fish food organism and incubating eggs and alevins.

The roadbed will compact the underlying subsurface and could deteriorate groundwater quality and prevent its movement, and alter the underground water drainage patterns over time. Since the road passes near the Knudson Bay which is home to up one million Sockeye salmon beach-spawning area, altering groundwater movement could cause mortality of incubating eggs and alevins. Annual maintenance of the road will produce vehicle waste and road treatment chemicals that could diffuse into water streams and impact aquatic ecosystems.

At Pebble East and as a result of block caving, it is possible that subsidence occur. Subsidence at the surface can cause percolation of water to the underground mine from above that can come in contact with the broken rock beneath the mined areas. The rock in the deposit will be mineralized and could lead to AMD and decomposition of the sulphide minerals. If a flow path exists from the mine to ground, migration of toxicants off the mine site can become a long term issue (Hauser, 2007).

Fine materials produced by the construction activities will frequently enter the streams and if the amount of siltation caused is large, effects in the downstream of these streams might reach Iliamna Lake. This could potentially decrease survival rate of eggs spawned by nearly one million Sockeye salmons. The mining activities and road usage will also produce dust from ground rock for years that could drift onto the surrounding lands and waters and have cumulative impacts. The dust may contain toxic materials or materials which may become toxic in water. Accumulation of fine materials over the years causes diminishing of food production and fish egg hatching rates.

A pipeline will transport the ore liquid slurry from the mine site to a port facility. After years of operation, pipelines will become susceptible of corroding and breakage. A break in the pipelines will have the potential of releasing the slurry contents from the pipeline into streams and impact the aquatic habitats. Pipeline contents will include heavy metal sulphide concentrates, dissolved heavy metal ions, and processing chemicals. The risk associated with this problem can be minimized by using valves along the pipeline (Hauser, 2007).
4. MINES

4.1 MINING DISASTERS

Environmental disasters caused by mining occur throughout the world. They happen in both first world and developing countries. In the case of gold mining, environmental contamination does not happen at higher rates in developing countries than in first world countries (Koop & Tole, 2008). During this study the scale of contamination was not taken into account. Regardless, what the study suggests is that there is either no difference in the safety regulations between developing countries and first world countries, or the increased regulations have not improved the probability of an environmental event from occurring.

With environmental contamination and gold mining, an example that is commonly referenced is the event that took place in Baia Mare, Romania. It is an example of improper design by the mining firm including the lack of foresight with regards to historical flood levels.

The mining disaster in Baia Mare, Romania, dumped mud wastewater and cyanide into the Sasar River. The Baia Mare disaster happened on January 30th 2000 because of an opening in a dam encircling a tailings pond (Lucas, 2001). The disaster occurred at 22:00, when a 25 metre long section of the retaining wall collapsed (Lucas, 2001). The retaining wall opening let out 10 000 cubic metres of slurry, which included 50-100 tons of cyanide and unspecified amounts of heavy metals (Cunningham, 2003). The sludge initially flowed into the Sasar River, then the Somas River, the Tisza, the Danube River (Europe’s second largest river), and finally into the Black Sea. Traveling through these rivers the plume was 60-70 meters long (Cunningham, 2003).

 Shortly after the disaster the damage was assessed by Romanian, Hungarian, and Yugoslav authorities. The damage was assessed by multiple governments because the river systems flowed into more than one country. Testing by Romanian, Hungarian, and Yugoslav authorities gave results that were not in sync with each other. Unfortunately, these are the only results that were taken immediately after the spill. A UN team was brought in to investigate the spill three weeks after the disaster. The UN tests were completed comparing contamination to the Danube and the Rhine rivers: a low water quality standard. The results of the assessment showed that the water quality was highly unacceptable. There were high levels of copper and zinc evident; levels were variable dependent on who measured it. UN tests showed that concentration levels were 88 times higher than the .01 milligram per litre permissible according to Romanian standards. Tests on the Danube were measured at 0.0058 mg/L (UNEP, March 2000). The UN report concluded that there was not a dramatic increase in water contamination close to the mining accident.
Though, many of the findings on certain rivers were complicated because of years of contamination. Local residents had named the Sasar River the Dead River well before the accident occurred. Fortunately, there were no reported human deaths because of this disaster.

It is difficult to predict the long term damages of the spill; even harder because of the contamination to the rivers in close proximity from so many different sources. For example, a dam overflowed within a year of Baia Mare in a nearby facility in Baia Borsa releasing 20 000 tons of tailing sludge containing heavy metals (Lucas, 2001). It is estimated that 80% of all fish in the Tisza River died because of this disaster.

4.2 GOOD MINING

The accident at Baia Mare is not an isolated incident. Cyanide leakage and spills have occurred in many other countries around the world. This does not mean that mining has to have severe effects on the environment. There are mines that have managed to stay out of the news, which also makes finding public information about these companies from primary sources extremely hard to find. A quick example is the Ontario Giant Gold Mine that is currently in the remediation process, as the mine closed in 2006 (Canada, 2007). Another is the Red Dog Mine, not a gold mine, but an exemplary case of how a firm can have a positive effect on the environment. Before the Red Dog Mine began operations, the river was naturally acidic and could not support a diverse aquatic ecosystem. Currently there is a diverse aquatic ecosystem because the firm, through their mining process, have de-acidified the water (EPA, 2006).
5. Fish vs. Mining

The pebble mine is unique from other mines in two ways 1) the size of the mine and 2) the risk to the sustainability of the fish industry. Besides these reasons, there is no difference between this mine and any other mine. The only reason not to construct this mine is the increased risk due to the size of the mine and the risk to the fishing industry in Bristol Bay. As has been mentioned, the fishing industry has managed to stay sustainable for the last 120 years (Verner, 2008). To further emphasize the importance of the fishing industry to the area, Bristol Bay has the largest Sockeye salmon run in the world and is one of the largest salmon runs in the world. Therefore, the decision to build the mine or not is framed as salmon versus mining.

The mining industry has predicted that that there is $500 billion in revenue in 2008 market prices of ore that exists where the Pebble mine will be built (Verner, 2008). In contrast, the fishing industry has revenue of $108 million per year. The mine is projected to run between 30 and 60 years, therefore, economically the difference between the two industries is $500 billion versus $3.2 billion to $6.4 billion. Obviously there is a large economic incentive to the community to want this mine built. Even so, a survey in the community has concluded that the majority of residents are against the construction of Pebble (Verner, 2008). The reason for this in an economic perspective is that the resident’s value of their land exceeds the difference between the values of the two industries. In this economical assessment, it is assumed that the industry will die because of the construction of the mine. This is obviously not the case and there isn’t a 100% chance that the mine will evoke damage on the fishing industry. What the exact risk levels are is impossible to know, but estimates of what they could be are currently being calculated. It is impossible to make an educated point of view on the mines worth to the community without knowing the risk to the fishing industry.
6. Conclusion

The Pebble Gold Mine could bring a large amount of economic activity to the Bristol Bay area and the surrounding communities. Pebble Mine brings in a 500 billion dollar opportunity for the residents of Bristol Bay. Even still, the census from local residents is that Pebble Mine is not welcomed here. A quote from an interview illustrates the local perceptive of Pebble Mine: “fish is my gold, we have it all our life, generation from generation. Gold right now you see it, you won’t have it... the money ... so long. It will be all gone but our subsistent way of life will still be here” (Resident, 2010). The reason for the resistance to Pebble is because of the assumption that during its operation or afterwards, the fishing industry and the waterways of Bristol Bay will be affected. This assumption is not incorrect, but since the risk is unknown at this time it can be assumed to be anything, including a 100% chance of failure. An in depth study of how the mine could affect the ecosystem and what the exact risks are needs to be presented to the public and the scientific community.

Currently, Anglo American and Northern Dynasty have invested an estimated 300 million dollars to evaluate the risks and effects that the mine could have on the environment. James Wyatt-Tilby, the head of media at Anglo Media, has been quoted in regards to environmental impacts of the mine as saying: 1) the intent always is to put the area back the way it was and 2) if the mine cannot be developed safely, it will not be built (Wyatt-Tilby, 2010). Whether this is what will happen or not, there is no way to know. There is also no way to know if it is even possible to put the area back the way it was found. Also, what does Wyatt-Tilby assume is a safe risk? Without the background knowledge the report will show about the area, it is impossible to make an educated decision on how this mine should be built or whether it should be built at all.

With all the risks and economic advantages, there is still one issue that has not being discussed. There is a demand for copper, gold, and molybdenum all over the world, including Canada and the United States. Consumers demand these minerals. Industry demands these minerals – including the green energy industry. This is a great opportunity for Bristol Bay; this is also an opportunity to mine valuable minerals for use in industry in North America and around the world. Therefore, the only reason this should not be built is if the Pebble Mine brings a unique danger to the environment.

Here are the questions that need to be answered:

(1) Is the danger to the Sockeye salmon greater than other ecological dangers the mining industry could cause in other parts of the world?

(2) How valuable is the largest Sockeye salmon run?

(3) Is it worth more than the estimated $500 billion in revenue?
All three questions are extremely hard to answer. The last two can be addressed because the majority of local residents do think that the salmon is worth more than the revenue the mine will bring to the community, since the inhabitants of Bristol Bay have the most to lose or gain from the mine. Their opinion on whether the mine should be built is an economic assessment of how much the salmon are worth.

Therefore, from the preliminary knowledge that is known about the risk of the Pebble mine to the environment, the authors of this report agree with the local residents. At this point in time, with the knowledge that has been presented, the mine proposes a unique threat to the environment. Without a full risk assessment to educate in this decision, the authors are hesitant to agree to permit the mine being built if they were put in place of the decision makers in the Alaskan government.
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UNEP. (March 2000). *Cyanide at Baia Mare Romania*. Environmental Report, UNEP / OCHA.


Wyatt-Tilby, J. (2010, November). The battle for King Salmon. (N. Rankin, Interviewer) BBC.
### Measured Mineral Resources

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### Inferred Mineral Resources

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Notes:

1 The estimate was prepared for the Pebble Partnership. David Gaunt, P.Geo., a qualified person as defined under 43-101 who is not independent of Northern Dynasty, is responsible for the estimate.

2 Copper equivalent calculations used metal prices of US$1.85/lb for copper, US$902/oz for gold and US$12.50/lb for molybdenum, and metallurgical recoveries of 85% for copper 69.6% for gold, and 77.8% for molybdenum in the Pebble West area and 89.3% for copper, 76.8% for gold, 83.7% for molybdenum in the Pebble East area. Revenue is calculated for each metal based on grades, recoveries and selected metal prices: accumulated revenues are then divided by the revenue at 1% copper. Recoveries for gold and molybdenum are normalized to the copper recovery as show below: CuEQ (Pebble West) = Cu % + (Au g/t x 69.6%/85% x 29.00/40.79) + (Mo % x 77.8%/85% x 275.58/40.79) CuEq (Pebble East) = Cu% + (Au g/t x 76.8%/89.3% x 29.00/40.79) + (Mo % x 83.7%/89.3% x 275.58/40.79).

3 By prescribed definition, “Mineral Resources” do not have demonstrated economic viability. An Inferred Mineral Resource is that part of a mineral resource for which quantity and grade can be estimated on the basis of geological evidence and limited sampling and reasonably assumed, but not verified, geological and grade continuity. The mineral resources fall within a volume or shell defined by long-term metal price estimates of US$2.50/lb for copper, US$900/oz for gold and US$25/lb for molybdenum.

4 For bulk underground mining, cut-offs such as 0.60% CuEQ, are typically used for porphyry deposit bulk underground mining operations at copper porphyry deposits located around the world. A 0.30% CuEQ cut-off is considered to be comparable to that used for porphyry deposit open pit mining operations in the Americas. All mineral resource estimates, cut-offs and metallurgical recoveries are subject to a feasibility study.

Source: Northern Dynasty Minerals Ltd.
## B. CCME Water Quality Guidelines

### Canadian Environmental Quality Guidelines Summary Table

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<th>Marine Concentration (µg/L)</th>
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<sup>a</sup>The CWQG is a minimum of 2 µg/L regardless of water hardness

Source: CCME Canadian Environmental Quality Guidelines
(http://st-ts.ccme.ca/?chems=9,71,73,131,133,138&chapters=1)