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Pebble Mine: Hydrogeology and Geochemistry Issues

Abstract

This report addresses more than a dozen environmental issues arising from the hydrological and geochemical conditions at the proposed Pebble Mine, which would develop a metallic sulfide deposit in the Bristol Bay drainages of Southwest Alaska. These drainages produce a major portion of the world's sockeye salmon supply, important subsistence use, and recreation. The hydrological and geochemical issues fall into two groups. The first is "substantive" issues – e.g. (a) acid mine drainage from unprocessed waste and host rock, mine or pit walls, tailings, tailings storage facilities, and dust; (b) pollution from chemicals used in processing ore, (c) pollution from fuels, oils, greases and antifreeze; (d) pollution from residues of explosives; (e) chemical and bacteriological pollution from sewerage treatment facilities; (f) pollution from herbicides, pesticides and road deicing compounds; etc. The second group is "procedural" issues. They result from (a) inadequate data (or decisions not to release all data) particularly on matters related to hydrology and chemical compositions of rock, potential ore, waste rock, tailings, etc; (b) inadequate sampling techniques, and inadequate protocols for preserving field samples or gathering field or lab data; etc. The procedural issues weave throughout the substantive issues and undermine the ability of the public and their agencies to understand the potential, significant environmental impacts, particularly to water and fish, which will result from Pebble Mine. This report concludes that significant impacts to some of the world's most important fisheries are likely.

1.0 Introduction

This report provides a brief summary of the primary technical, environmental issues related to the hydrogeology and water quality impacts at metal mines. Such issues routinely create the most contentious disputes and often result in the greatest long-term costs and impacts to the general public. That is:

- Will the mining operations alter the chemical composition of the local surface and ground waters?
- With respect to the Pebble Project, will such “contamination” result in negative impacts, either short-term or long-term to the quality to the local water resources and especially to the fisheries of the Bristol Bay region?
- Will water levels (either surface or ground water) be impacted in the area?

This report is intended to express viewpoints and perspectives that are not discussed, or are inadequately discussed by the Northern Dynasty Mines, Inc. (NDM). This report is an attempt to illuminate some of the issues and viewpoints that NDM and their consultants have failed to emphasize.

The opinions presented here are neither pro- nor anti-mining. I have often worked for clients with both orientations. This report is not intended to tell the citizens or public officials what to do. Rather, it is intended to provide technical assistance so that informed decisions can be made and to constructively influence the public review *process*. **The ultimate choices, however, must be made by the citizens and their elected representatives. They are the ones who will be personally impacted and may ultimately be financially responsible.**

These opinions were developed after reviewing all relevant portions of the NDM water, water quality, geology and geochemical reports available at http://www.dnr.state.ak.us/mlw/mining/largemine/pebble/env_baseline_studies.htm#2004_reports , together with NDM information presented on their website: <http://www.ndmpebblemine.com/pages/PebbleFacts.php>. In addition, I also reviewed reports related to the site geology and geochemistry available on the Canadian Securities Administration, available at <http://www.sedar.com/> .

One dilemma for the public is that mining companies, NDM included, routinely claim that they can operate a modern metal mine without environmental impacts. *This is simply false*. It is inevitable that an operation of this magnitude will have some negative impacts on, as a minimum, the water quality of the surrounding surface and ground waters. I have never seen a comparable metal mine operated, long-term, that has not produced such negative impacts.

Although environmental aspects of modern metal-mines have improved, *qualitatively*, compared to similar operations of 20 to 30+ years ago, claims of “improved technology” have been made every decade for much of the last century----and there are still significant environmental problems. One should note that most modern, open-pit base and precious metal mines are now, however,

constructed on a scale unheard of less than 30 years ago. Pits at some sites are many hundreds of feet, up to 2000+ feet deep, and may be 1 to 2 miles across. Hence the potential *quantities* of wastes produced and magnitude of the potential impacts are generally *much greater* than in past decades.

Background

Because the proposed Pebble Mine is currently only in the exploration phase, much of the detailed, technical information on the full extent of mining, proposed extraction processes, specific facilities locations, etc. has not been made public.

Nevertheless, we know the following:

- The proposed Pebble Mine would excavate a metallic sulfide porphyry deposit. Cu-Mo-Au (copper, molybdenum, gold) and some accessory Ag (silver) would be the main products. Similar porphyry copper deposits around the world sometimes extract additional metal products such as selenium, mercury, and uranium.
- The Pebble deposit is presently being explored by NDM, a Canadian-based corporation that has never operated a mine, in partnership with Anglo American plc, a U.K.-based corporation which is one of the largest mining and natural resource groups in the world. Almost 20% of the NDM portion of the Pebble shares are held by Rio Tinto, another of the largest mining companies in the world, based in the U.K. and Australia.
- The overall project area footprint is at least 28 square miles / 18,237 acres, of State land, and possibly much more.
- Pebble will probably employ *both open pit and underground operations*.
- NDM claims that it has identified as much as 8.2 billion tons of ore. If processed at about 200,000 tons per day, the life of the mine could exceed 100 years.
- Over 99% of the ore will become waste, which will remain on site forever.
- NDM has proposed dams for tailings impoundments that have dam heights (max.) of 700—740 feet (Facility A), and 450 feet (Facility G);
- The estimated open pit depth is 1,700 feet at Pebble West.
- Global climate changes must be considered when developing appropriate, conservative assumptions and related predictions concerning flooding, recharge, sizing of diversion structures, etc. for facilities that must last forever.
- The Pebble Mine would be upgradient of the world's largest wild, sockeye salmon fishery.

2.0 Environmental “Process” Issues

NDM has released dozens of partial documents to the public and regulators, many of which are available at:

http://www.dnr.state.ak.us/mlw/mining/largemine/pebble/env_baseline_studies.htm#2004_reports

However, some of the most important documents contain only old or incomplete data, which have not been updated for several years. These data need to be revised and made public much more rapidly or there will be no reasonable opportunity for the public or regulators to provide a thorough review during the formal permitting stages. Given the large number of NDM contractors, it is often impossible to determine whose opinions are represented in the reports.

The data are not organized in a manner that promotes review by either the public or the regulators. For example:

- surface water flow data* should be organized by monitoring station and date, and then integrated with the related *water quality data*.
- water quality data need to be organized in tabular form so that all data from any one monitoring station can be readily compared by date. Such tables should present dissolved [filtered] and total [unfiltered] water quality data side by side for comparisons by date.
- water quality data needs to be statistically-summarized for all monitoring stations to show: n (sample size); min (minimum value); max (maximum value); median; mean.
- these statistical data need to be compiled to generate ranges of “baseline” water quality, bottom sediment chemical analyses, aquatic biota data, etc. Such statistical data would allow the public to know what the surface and ground water quality was prior to commencement of the Pebble operations. In addition, these data need to include the earlier Cominco data in the tabular summaries. Such data provide even earlier baseline data, prior to the extensive NDM exploration activities---all of which can influence baseline.

All data are presently collected by representatives of NDM. The same will be true if the Pebble operation receives permit approval; monitoring data will be collected by the mine operator. Some mechanisms need to be incorporated which allow for “independent” oversight of the sampling, data handling, etc. Several project aspects would benefit from the involvement of independent parties.

--The latest (2004) Ground Water Draft Baseline Progress Report contains significant problems with some well completions and evidence that at least one well has been contaminated by cement grout entering the screened interval. Unfortunately, neither the report authors nor the regulators have commented on these problems.

--Sampling and sample handling: some of the surface water samples were filtered and preserved between 8 and 12 hours after sample collection. Such procedures are inadequate to prevent many chemical constituents from coming out of solution, thereby yielding lower reported lab concentrations.

Some of the well completion and sampling / sample handling inadequacies described above have already generated unreliable data.

3.0 Contaminant Sources at Mine / Mineral Processing Sites

Active metal-mine operations routinely release chemicals into the surrounding environment from two general sources---the natural, mineralized rock, and the massive quantities of chemicals that are added and utilized throughout the mining and mineral processing activities. The various mineral processing techniques (both physical and chemical) greatly increase the *rates* at which many chemical constituents are released from the mineralized rock.

Natural Rock. Mineralized rock containing high mineral content is called ore. Such ore is mined from either open pits or underground excavations using explosives and transported for processing using huge trucks or conveyer belts. Much of the rock removed from an open pit contains metal concentrations that are too low to be economically processed. This material, waste rock, is often discarded in huge piles, somewhere near the pit perimeter. Thus, mineralized rock is exposed to air and water in numerous mining locations: open pit walls, underground workings, waste rock piles, exposed tailings, and road cuts. Chemical reactions of the rock with air, water and bacteria often create acidic waters (pH often between 3 and 5, sometimes lower) which mobilize high / elevated concentrations of the minerals in the rock, including numerous metals and metal-like constituents which may be toxic to humans and aquatic life---especially fish. Waste rock accumulations are often the largest source of acidic and other drainages. These acidic waters may be called acid rock drainage (ARD).

Once acid rock drainage develops, it is often a truly long-term problem. Davis, et. al.(2000), report evidence that acid conditions have existed for thousands of years in the Rio Tinto region of southern Spain, the source of the corporate name of the Rio Tinto Group.

Process Chemicals. At mines similar to the proposed Pebble operation, the ore is shipped to a mill where process chemicals (reagents-- see discussion below) are added to the ore to extract the metals. These chemicals are mixed with the crushed ore and water in various complex stages to extract the desired metals and the resulting waste called tailings are discharged to a tailings impoundment. [In historical mining jargon, the ore entering a mill was often referred to as "heads", and the wastes exiting the mill were called "tails".] Such tailings discharges are often alkaline, having an initial pH between about 9.5 and 12.0, and are approximately 50% liquid and 50% solid particles. As the tailings age, and the solids react with the liquids and air, the liquid pH may over many years become acidic. Because of the massive quantities of ore that will be processed, huge amounts of process chemicals will ultimately be used.

NDM has not made public the precise mineral processing techniques it plans to employ. Nevertheless, NDM began Feasibility Studies and conducted preliminary bench scale tests (NDM, June 2005) that chemically process rock representative of future ore. In these tests, three types of Pebble tailings were generated, the combined Scavenger and Bulk Cleaner Tailings and two forms of Pyrite tailings---non-acidic and acidic. These tests indicated that the median pHs of the tailings samples were 8.2, 7.3, and 3.5 respectively (see discussion below). Note that the tailings actually produced at Pebble might, in fact, have different pH characteristics.

Fuels / Oils and Greases / Antifreeze. Such modern operations are highly mechanized utilizing trucks and equipment that require the use of immense quantities of fuels [diesel, gasoline, kerosene], oils and greases and anti-freeze compounds [see discussion below], all of which are stored and used onsite. These organic compounds frequently leak from their storage containers or are spilled during normal usage or in accidents. All may be highly toxic to aquatic organisms.

Explosives. Constructing underground mine workings, open pits, roads, etc. requires tremendous quantities of blasting compounds. When exploded, they leave soluble residues (nitrate, ammonia) on the rock surfaces, which wash off into the environment after rainstorms. One of these residues, ammonia, is roughly as toxic to fish as free cyanide.

Water Treatment, Sewage Facilities, Laboratories. All similar mines must operate facilities for their workers, which includes constructing camps with water treatment and sewage facilities, and they maintain laboratory facilities. All such functions utilize chemicals and often release chemical and bacteriologic wastes into the environment.

Miscellaneous Operations. Depending on the physical environment, many mines utilize significant quantities of herbicides, pesticides, and road deicing compounds---all of which can be toxic to organisms.

Modern mine operations attempt to collect and contain as many of the chemical wastes described above as possible. Frequently, the tailings impoundment receives mixtures of these wastes. Hence, the solid-liquid mix included in such an impoundment is essentially a “chemical soup” containing literally hundreds of different inorganic and organic chemical compounds.

Mining-related Geochemical Processes

Mining and mineral processes of blasting, crushing and grinding convert the rock from a solid (sometimes fractured solid) into smaller particles which have much greater surface area. The chemical and bacteriologic reactions between the rock minerals, water and air occur predominantly at these mineral surface areas.

Hence, numerous chemical reactions tend to occur at greater rates when smaller rock particles have been created.

In general, higher concentrations of soluble chemical constituents will be released from such finer-grained materials into local waters than would be released from the original, unbroken rock---regardless of the pH of the waters. The concentrations of many chemical constituents [metals, metalloids, non-metals, etc] will increase greatly when in contact with acidic, low pH waters. Similarly, the concentrations of some chemical constituents, especially those that form negatively-charged anions in "normal" waters [i.e. aluminum, arsenic, antimony, selenium, manganese, molybdenum, vanadium, uranium, chromium, nickel, etc.], will increase as the pH rises above about 8.5. Even when the waters reacting with the geologic materials are of nearly-neutral pH, concentrations of soluble constituents will increase when smaller rock particles are produced.

While NDM has failed to make public much of the detailed geochemical information necessary to evaluate all water quality-related environmental impacts, it is common for such mineralized igneous rocks having sulfide concentrations of 5% or more and quite low alkalinity concentrations to yield much waste rock that releases discharges / effluents that are often acidic, containing elevated concentrations of numerous chemical constituents---many of which are toxic to forms of aquatic life, especially cold-water fishes.

Likewise, rock with such general chemical characteristics tends also to yield tailings that can release toxic effluents, which may initially have near-neutral or elevated pH, but which can become acid over the long-term. It must be recalled that the waste rock and tailings will remain on the Pebble site *forever*.

NDM has stated that contamination will be avoided because most of the waste rock and all of the tailings will be stored under water, in perpetuity. Firstly, NDM has stated that they have as much as 8.2 billion tons of ore to be processed. However, it appears they presently have storage capacity for only 2.5 billion tons of tailings and potentially acid generating waste rock. Secondly, it is not possible to guarantee that such wastes will remain contained and saturated *forever*, especially in an area with such significant seismic activity. One need only observe Alaskan roads created on steep hillsides to note that sediments tend to be "in motion" in such areas, every season. Thirdly, storing mine wastes under water will merely slow the chemical reaction rates. It will not *stop* them. Contaminants will continue to be released into the local ground and surface waters, simply at reduced rates---assuming the wastes remain inundated and contained.

Portions of the pit walls will be exposed above the highest water level. Long-term, these walls are likely to release significant concentrations of metals / metalloids, and nonmetals such as sulfate. Nitrate and ammonia, largely as

explosive residues, will also be released from the surfaces of the pit walls, both during operations and post-closure.

Much of the Pebble rock will be sulfide-rich material. Additional evidence of the pervasive impacts associated with mining sulfide ores can be found by reading Todd and Struhsacker (1997). This study was commissioned by the mining industry in an attempt to favorably influence mining legislation in the State of Wisconsin (U.S.A.). It was intended to show "...that a mining operation has operated in a sulfide ore body in the United States and Canada for at least 10 years without polluting groundwater or surface water from acid drainage at the tailings site or at the mine site or from release of heavy metals." It was also intended to show "...that a mining operation that operated in a sulfide ore body in the United States or Canada has been closed for at least 10 years without polluting groundwater or surface water from acid drainage at the tailings site or at the mine site or from the release of heavy metals."

Data from hundreds of mine sites from the U.S. and Canada were investigated. **A careful reading of the details in this paper shows that the authors were unable to locate any sites that totally complied with the criteria at the time the paper was published.**

It is possible that a few closed sulfide-rich metal mines, worldwide, might comply with these "long-term" criteria since the Todd, et. al. study was conducted. I am not aware of any. However, the more important point is that, when a statistically-significant population of such mines was examined, the majority created long-term acid rock drainage problems.

4.0 Inadequacies of Hydrological / Hydrogeological Data

What are the amounts of water available in the Pebble project area---both surface and ground water?

Surface Water. At present, the only publicly-available surface water data are the limited data presented in the Draft Environmental Baseline Studies, 2004 Progress Reports, Chapter 4, Surface Water Hydrogeology (NDM 2005a). These studies were conducted in two parts: the Mine Area, and the Road / Port Area. Little or no surface water data were available for the Road / Port area prior to the 2004 studies.

The immediate Pebble Mine study area is drained by several rivers with significant flow (the North and South Forks of the Koktuli River, Upper Talarik Creek and their tributaries). NDM is also monitoring stations within the Kaskanak / Kvichak drainage because of possible impacts from inter-basin transfers of water from the South Fork of the Koktuli River. The project area watersheds are enormous, encompassing 361 square miles, and long-term mean annual precipitation is estimated to be 34.1 inches, of which about 30 percent falls as snow (NDM, 2005a).

NDM's consultants began collecting baseline surface water data in 2004. NDM (2005a) states that hydrologic data were also collected by Cominco between 1991 and 1993, but these data have not been shown or integrated into the NDM hydrologic studies. It will be important to have these Cominco baseline data integrated into future NDM baseline reports.

Prior to the initiation of the 2004 activities, very little surface water hydrologic information existed for the site---with the exception of the Cominco data that was not shown in NDM (2005a). NDM (2005a) reports that only one operational stream flow gage existed within the entire project area [Iliamna River], and it had only 9 years of flow records as of the time the 2005 report was prepared. Almost no *historical* stream flow data has been made public for the rest of the site as of 2005. No additional site surface water flow data have been released to the present time.

Detailed surface water flow data, measured over many years, are fundamental to designing basic site features such as roads, culverts, overpasses, tailings impoundments, waste facilities, storm run-off structures, etc.

The project area has experienced severe flooding in recent years (see NDM 2005a, Fig. 4-31) and flows in some major rivers have overtopped existing bridges (i.e. the Iliamna River bridge). The presently-available flow data seem inadequate to reliably predict maximum flood events on the major site drainages.

Maps presented in NDM (2005a) fail to show the locations of future mine and mineral processing features. Hence, it is not possible to determine whether monitoring locations are adequate in number or are correctly located.

In future surface water reports, it will be important to integrate the stream flow and water quality data to develop baseline calculations for both sediment and chemical constituent *loads* throughout the site. In addition, it will be imperative to characterize and describe areas of surface water-ground water interactions.

These preliminary baseline hydrology studies indicate that ground water inflows provide significant contributions to the surface water flows in some areas. In addition, they suggest that some sections of the South Fork of the Koktuli River are losing reaches and surface channels may be dry in late summer. Such observations need to be verified over several years, especially in areas where mining-related activities might have impacts.

The preliminary NDM surface and ground water reports, while incomplete, describe a typical mountain ground water system with permeable alluvium and shallow bedrock, both of which are in hydrogeologic connection with the rivers. They indicate that the shallow, weathered bedrock is permeable, and transmits ground water to the local streams in some locations, causing local stream flow to increase. These data are not sufficiently detailed to reveal whether these stream

reaches continue to receive ground water inflows after high flow conditions cease. The NDM data also indicate that other portions of the bedrock are fractured, and transmit varying amounts of water although permeability seems to generally decrease with depth. There are also indications that some ground water is artesian and flows under natural pressure to the land surface. The presence of significant dissolved oxygen concentrations in most of the NDM wells is further evidence that shallow ground water flow rates are relatively high in many zones.

These observations indicate quite clearly that effluents from future mine facilities [i.e. waste rock piles, tailings, ore stockpiles, fuel and explosive storage areas, etc.] will have obvious pathways for movement of contaminants toward the local rivers and ground waters.

Because almost no historical (pre-2004) surface water flow data was available for the road / Port area, NDM's predictions of the magnitude of flood flows in these downstream / coastal areas should be assumed to be subject to considerable uncertainty.

Ground Water. At least four different consulting firms performed field work (2004) and contributed to the preparation of the NDM Baseline Ground Water Hydrogeology Progress Report (NDM, 2005b). As with the surface water hydrology baseline report, no maps show the locations of specific, proposed mine / process facilities relative to the ground water monitoring installations. Thus, it is impossible to know if these newly-installed wells and piezometers are adequate to monitor future activities.

NDM (2005b, pg. 5-3) mentions the existence of previous baseline studies, presumably conducted by Cominco. However, no results from such previous hydrogeological studies are described in the NDM report. If such studies exist, the results should be integrated with the recent NDM studies.

These NDM preliminary hydrogeology studies showed that bedrock was water-bearing, especially in shallower zones and where fractured. They also showed that the unconsolidated overlying sediments (fluvial, glacial, lake-deposits) were also generally water-bearing and permeable. Ground waters recharge local surface waters, and ground water flow is believed to cross the surface water divide between the South Fork Koktuli River valley and the Upper Talarik Creek.

While the 2004 studies were quite preliminary, they indicate that effluents from future waste rock, tailings, and other facilities have significant potential ground water pathways that would allow migration of contaminants towards local rivers.

Future ground water studies will need to define the quantities of water that will be pumped from the open pit and from any other workings that might be constructed. In addition, it will be important to define the extent (radius, depth) of

the drawdown from pit dewatering and whether the drawdown will intersect any of the nearby surface waters. At similar mines, dewatering of the open pits and or underground workings often drops the local water table, often inducing leakage from nearby rivers or lakes. This can reduce stream recharge or reduce actual stream flows, impacting both the flow rates and the river quality. Obviously future NDM studies will need to quantify such ground water-surface water interactions.

NDM states that a lake will form in the mined-out pit once dewatering pumps are turned off. While predictions of future pit or drainage water quality are notoriously imprecise (see discussion below), it will be important to anticipate the quality of the pit lake waters. Given that the ground water sampling studies (NDM, 2005c) consistently measured high dissolved oxygen (D.O.) concentrations in most of the site wells, it is likely that oxidation of the sulfide ores is capable of proceeding in the pit walls and even in the boreholes. Also, given that the shallow bedrock is permeable, pit lake water eventually will tend to migrate towards the local rivers.

It would have been much more informative if the ground water hydrogeology studies had been integrated with the ground water chemistry discussions. Such integration would have indicated, for example, that at least one of the monitoring wells (MW-5) constructed in 2004 had obviously been contaminated, probably by the cement-grout mixture entering the screened interval. [As indicated by "impacted" pH, alkalinity, hardness, TDS, low D.O., calcium, sodium.] As a result, the water quality data from this well is totally unrepresentative. Such problems would have been readily detected if the hydrogeology studies had also included water quality data that combined both the field and the lab determinations of temperature, pH, S.C. and turbidity.

The present ground water data in NDM (2005b) are far too limited in time, areal coverage and depth to answer many of the important questions regarding ground water flow directions, ground water-surface water interactions, future ground water chemistry, and to develop a reliable water balance.

Water Balance / Future Water Treatment. NDM has publicly stated that the Pebble Mine will be a *zero-discharge facility* and thus will not require any discharge permits. At present, the public has not been shown a detailed water balance to substantiate such claims. It is imperative that NDM use measured precipitation and evapotranspiration data from specific site areas [such as the tailings impoundment, pit, etc.] to verify that the mine will not be a net precipitation area.

Depending on the actual site water balance, NDM may be able to avoid any permitted, point-source discharges while the facilities are being operated. However, once the mill ceases to operate, and the recycling of water stops, will there be a need to discharge excess tailings water to the environment? Given the geochemistry of the ores and wastes, it is probable that some form of active water treatment will be required, possibly during operation, and probably

following closure. Depending on the actual water balance, it is possible that leachates from the tailings and waste rock might need to be collected and treated prior to release for many years post-closure, possibly in perpetuity.

Future NDM reports should also discuss the financial / economic aspects of water use. For example, what will be the volumes and the prices paid by NDM for the numerous sources of water utilized in the Pebble Project?

5.0 Geochemistry

What are the representative chemical compositions of the ore, the waste rock and the tailings?

NDM has released only partial geochemical data. They are inadequate to provide detailed answers to questions about the chemical composition of ore, waste rock and tailings. NDM has released the Draft Environmental Baseline Studies, 2004 Progress Reports, Chapter 8, (NDM, June 2005) but this is composed of data from rock samples collected between 1988 and 2003. While NDM has obviously been conducting additional drilling, none of the more recent environmentally-relevant geochemical data from 2004 to the present are available to the public.

NDM (June 2005) and Rebagliati and Payne (2005) present considerable site geologic data, but fail to present representative summaries of the whole rock geochemical compositions of the ore, waste rock and tailings. Table 3 (NDM, June 2005) presents only rock concentrations for As, Cu, Mo, and Zn, but the reader has no way of knowing if these samples represent typical ore, etc. The public and regulators need to see much more complete whole rock chemical analyses in order to determine whether the scope of the environmental monitoring is adequate. Such data should include: aluminum, antimony, arsenic, barium, cadmium, copper, chromium, cobalt, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, tin, titanium, tungsten, vanadium, zinc, calcium, magnesium, sodium and potassium, boron, phosphorus, silica, natural radioactive constituents (uranium, thorium, potassium-40, gross alpha and beta, in general), rare earth elements, etc.

Schrader (2001), presents limited whole rock and trace element analyses of Pebble rocks [see table 4, pg. 50], which are much more extensive than those presented in NDM (June 2005). Nevertheless, these results are also far too limited to determine the representative trace / minor element concentrations of Pebble ores, waste rock, and tailings. The Schrader thesis fails to present data for several of the more environmentally-sensitive constituents such as Cd, Mo, Se, Hg. Comparable ore bodies, worldwide, frequently release these constituents into the environment [air, soils, waters, stream sediments].

NDM (June 2005) presents preliminary geochemical testing data which indicate that much of the site rock has geochemically-significant concentrations of sulfide-sulfur. The authors state: "Sulfur concentrations in the pre-Tertiary rock types

(i.e. much of the ore and non-overburden waste) are typically between 1 and 5 percent sulfur up to maximum concentrations near 9 percent.” Clearly rock containing sulfide contents this high will generate acid rock drainage when exposed to air, water and bacteria.

What is the realistic probability that acid rock drainage will be generated in the wastes and pit walls? What other types of chemical effluents may be released?

As stated above, NDM (June 2005) documents that much of the site rock has sulfide-sulfur concentrations between 1 and 5%, sometimes up to 9% or greater. Significant volumes of rock containing 1% – 5% sulfur-as-sulfides **clearly suggest a concern for the development of acid mine drainage** at the Pebble site. At the Zortman-Landusky Mine, Montana, it was found that waste rock having as little as 0.2 % sulfide was capable of generating net acid (U.S. BLM, 1995).

Chapter 8 of the 2004 Progress Reports (NDM June 2005) presents some preliminary discussion of the tests that have and will be conducted to determine whether Pebble wastes will release acid and other contaminants. The data made public to date are quite incomplete, but they clearly show that much of the ore and waste rock contains elevated sulfide concentrations that will generate net acidity in the long-term. In addition, these data (Table 3, for example) show that these rocks contain elevated concentrations of, as a minimum, arsenic (up to 1013 ppm), copper (up to 0.6%), molybdenum (several samples contained between 100 and 240 ppm), and zinc (up to 113 ppm). NDM (and Cominco previously) has obviously been analyzing the Pebble rocks for a much more extensive list of trace and minor constituents, as they make clear in section 8.6.1.2 Element Scans of 2004 Core, but these data have not been released to the public. Nevertheless, the data they have released, plus the historical environmental record from similar copper mines, clearly suggest that much of ore and waste rock will release trace and minor constituents into the environment.

All operators of comparable mines are faced with a similar dilemma--- demonstrating that the ore and wastes (waste rock, tailings) release acceptably-low concentrations of contaminants. Hence they routinely conduct geochemical tests to demonstrate the extent to which these rocks will release various constituents. Chapter 8 of NDM (June 2005) discusses several such tests, for example, leach tests called shake flask tests, and kinetic tests. However, Chapter 8 fails to describe the detailed testing procedures, and provides no actual data for either type of test. It is of concern that the reader is not told the length of time that shake flask samples were in contact with the various liquids, or whether leached samples were filtered or preserved prior to analysis. No details were provided on the specific constituents that were leached from the rock samples and their concentrations. In addition, no details were provided on the time duration of the proposed kinetic tests, or whether leachate subsamples would be filtered or preserved prior to analysis. All such tests have their strengths

and weaknesses, but as a minimum, the public and reviewing agencies need to have the specific procedures described and be shown the data.

Geochemical Test Limitations. Price (1997) describes the most common geochemical tests used in predicting acid formation and contaminant liberation from mining-related rocks and wastes. These normally include short-term, *static tests*, like the acid-base-accounting (ABA) tests which generated the rock sulfide concentrations described in Chapter 8 (NDM, June 2005), and various leach tests, such as the shake flask tests mentioned above. Secondly, they include some form of kinetic tests, such as the humidity tests described in Chapter 8. The latter involve the reaction of rock samples with water and air through long-periods of time in an attempt to simulate long-term chemical reactions that will take place at the mine site. The presently available NDM data discusses some aspects of such tests, but have not reported the actual test details or results. Hence, in anticipation that the public will be allowed to see such test details, it seems useful to discuss some of the more common limitations these tests.

When attempting to predict whether geologic materials will become acid, it is important to reliably determine the quantities of both the acid-producing and neutralizing minerals, such as calcium carbonate, present in the various geologic materials. Most of the acid comes from the breakdown of iron sulfides. Various geologic materials may also contain carbonate minerals (and others) which decompose, releasing basic constituents, such as bicarbonate and carbonate, that tend to neutralize, or buffer, the available acidity. The simplest such tests are static tests, sometimes called acid-base-accounting (ABA) tests, which determine the potential acidity (AP) and the potential neutralizing content (NP) of the rocks. Static tests simply measure these potential quantities, but do not consider the rates at which they are mobilized.

Frequently, static data from many tests (often hundreds) are summarized by rock type as *average* values. Average data on waste rock neutralizing potential (NP) versus the **average** acid-producing potential (AP) [the NP / AP], often fails to accurately predict real world acid rock drainage problems. This is partly because the migrating water must actually come in contact with and chemically-react with these AP- and NP-producing mineral grains. Often they do so selectively, in a manner that does not reflect the average geochemical composition. More importantly, there is an inherent time-related bias in this type of geochemical testing, and static tests do not consider the effects of TIME (Morin & Hutt, 1994). The NP-producing minerals generally react more rapidly than do the AP-producing minerals, so that over the long-term, the NP will be depleted, and, if sufficient AP minerals are present, the waters will become acid.

These general conclusions about static geochemical tests are corroborated by many other researchers, including Kim Lapakko of the Minnesota (U.S.A.) Department of Natural Resources, one of the foremost experts on geochemical testing of mine ores and wastes (see, for example, Lapakko 2003).

Kinetic tests attempt to simulate the effects of weathering through time. For example, selected waste rock samples are reacted with air and water for extended periods of time, and leachate samples are collected weekly and analyzed. Such tests are subject to NUMEROUS sources of significant error, but if conducted scrupulously, they can be useful for predicting whether acid rock drainage will develop--- at least qualitatively.

One of the largest sources of kinetic testing error results from running the tests for an inadequate period of time. Chapter 8 states that Pebble kinetic tests will follow a modified ASTM (American Society for Testing and Materials) procedure (ASTM, 2000) having a test duration of twenty weeks. However, essentially all geochemists experienced in such testing agree that *much longer* time periods are required to adequately predict whether acid rock drainage will develop, long-term. A few examples of quotes from internationally-recognized experts should make this point obvious:

Lapakko (2003): "One major concern regarding the ASTM D5744-96 method is that it recommends a minimum test duration of 20 weeks. However, the method also states in Note 12 (ASTM 2000, pg. 265) that additional testing may be required to demonstrate the complete weathering characteristics of mine-waste samples (e.g., as much as 60 to 120 weeks were required for some samples). If only a 20-week test duration is used, this is clearly too short to allow for potential drainage acidification from mine-waste samples in general." *That is a polite way of saying that the official guidance on test duration is ridiculous. In fact, Lapakko's laboratory has conducted numerous kinetic tests having durations of many years where the chemistry has continued to change.*

- Morin and Hutt (1977): "The duration of humidity cell test(s) is usually at least 40 weeks, or until the rates of sulphate generation and metal leaching have stabilized at relatively constant rates for at least five weeks. Experience has shown that stabilization can take over 60 weeks, and significant changes may take place even after several years."
- Price (1997) states that stabilization of kinetic / humidity cell tests often requires at least 40 weeks, can sometimes take over 60 weeks, and may even require several years (pg. 100).
- Robertson and Ferguson (1995), on the research staff of Canadian mining company Placer Dome stated the following: "Kinetic testing methodology prescribes that tests should last a minimum of 20 weeks, although Placer believes that this time frame is inadequate for reliable results unless the samples are extremely high in sulphur content, low in buffering capacity, and/or potentially highly reactive. On sites which warrant this type of testing the company typically runs samples for two to three years, allowing

for a more complete assessment of slower or marginally reactive materials.”

As stated above, NDM (June 2005) does not present any actual data from Pebble kinetic tests. Future Pebble reports should also show statistical tabulations of the actual static test data, and define which rock categories are considered ore, and various categories of waste rock.

The NDM public reports fail to present criteria for defining and segregating the supposedly non-acid-generating rock (NAG) from other categories of acid-generating or potentially-acid-generating rock (PAG). Such distinctions will be extremely important because so much of the NAG material will be needed for dam construction, and there will be a tendency to overestimate the amount of NAG material because: (1) NAG material will be needed for construction; and, (2) most of the PAG material will go to the tailings facility, and decrease the amount of tailings that can be stored there. Even when the NAG and PAG materials have been adequately defined, it is often difficult to actually separate them given that waste is defined on the basis of tests from small samples of large amounts of material and the waste segregation is physically performed with massive, often imprecise, mechanical equipment.

Tailings Composition / Leachates. The specific mineral processing procedures to be used at Pebble have not been made public at this time. Thus, the precise chemical composition of the tailings is undefined. However, bench-scale laboratory tests have been conducted on potential ores, resulting in partial analyses of three categories of tailings (see NDM June 2005, 8-9 through 8-13).

1. Scavenger Tails---produced by rougher flotation followed by scavenger flotation.
2. Bulk Cleaner Tails—produced by cleaner flotation followed by scavenger flotation.
3. Pyrite Tails—Produced by copper sulfide flotation and cleaning.

The first two tailings categories will be combined and are expected to be low in sulfide, but NDM provides no sulfide analyses to support this. They state on pg. 8-12 that these scavenger / bulk cleaner tails will have an NP / AP ratio of about 3.7, indicating they expect these tails to contain 3.7 times as much neutralizing material as acid-producing material. Thus, NDM does not expect these tailings to generate net acid. However, as stated above, it is common for the neutralizing minerals to react more rapidly than the acid-producing minerals so that, after decades, it is possible that the buffering capacity may be depleted and the tailings might generate net acid. This is especially likely in the decades after active tailings production ceases. Nevertheless, such tailings can release contaminated leachates, even if acid pHs do not develop.

It seems undeniable that the pyrite tails will generate acid and elevated contaminant concentrations in the long-term.

Table 7 [Process Water Chemistry from Bench-Scale Testing], pg. 8-13 of NDM (June 2005) shows the anticipated chemistry of the three categories of tailings. It states that these are “selected results”, so we do not know if other samples have been analyzed, but not shown. It is clear that many important chemical constituents commonly found in such tailings have been determined (see pg 8-9, section 8.5.7) but are not reported in Table 7, such as mercury, nickel, chromium, lead, sulfide, nitrate, ammonia, chloride, cyanide forms, organic compounds, uranium and other radioactive constituents, etc.

The Scavenger / Bulk Cleaner Tails waters had significant concentrations of sulfate, hardness, antimony, arsenic, copper, manganese, molybdenum, and selenium. The median pH of these tails is reported to be 8.15, but the number (n) of measurements is not reported.

Pyrite Tails (*non-acidic*) waters had elevated concentrations of sulfate, hardness, antimony, arsenic, copper, manganese, molybdenum, and zinc, with a median pH of 7.3. Again the number (n) of measurements was undefined. *The report presents no explanation for the circum-neutral pH of these Pyrite tails. Does it mean they were processed differently or that the contact time between solids and liquids were different than for the other Pyrite Tails?*

Pyrite Tails (*acidic*) waters had elevated concentrations of sulfate, hardness, antimony, copper, manganese, molybdenum, selenium, zinc, and the median pH was 3.48. Again the number (n) of measurements was undefined, *and unlike the other Tails statistics, no maximum values were provided for the acidic Pyrite Tails.* Future reports should show complete statistical summaries of all such data, including the n, min.—max. range, median, etc. Otherwise the usefulness of such data cannot be determined.

The NDM report does not state the amount of time the rock solids had been in contact with the chemical reagents prior to being analyzed. Longer contact time may generate higher concentrations of some constituents. Also, it does not state if tails water samples were preserved prior to analysis. If samples were not preserved, determined concentrations would likely be unreasonably low. On page 8-9 it states, however, that samples were filtered prior to analysis. Filtration (depending on the filter pore diameter) would also remove suspended / colloidal particles, also lowering measured concentrations. Unfiltered and preserved samples would generate much more representative, conservative results. Actual tailings leachates that might seep into the local ground and surface waters would likely contain constituents mostly in dissolved form, but there is considerable evidence in the literature that some percentage of such contaminants may migrate in colloidal form, even in ground waters (McCarthy, et. al. 1989; Ramsey, et. al. 2000).

Thus, the public has not been shown truly representative details on the expected chemical composition of the tailings waters. Decades of actual experience with tailings waters at copper mines indicates that the waters often have chemical compositions that may be toxic to cold water organisms, especially trout and salmon. It is interesting to note that on page 8-9 of Chapter 8 (NDM, June 2005), it states: "One bioassay has been performed on a solution sample." Unfortunately, NDM has not presented any data or discussion of the bioassay results in this report, or anywhere else to my knowledge.

6.0 Processing Reagents

NDM has not yet released information on the specific processing steps or chemicals that will be used at the Pebble mill. Nevertheless, many of the following chemical reagents are commonly used in processing similar ores: lime, sodium isopropyl xanthate (such as commercial product SF-113), dithiophosphate and thionocarbamate, [such as in Aeropromotor AC 6682], methyl isobutyl carbinol (MIBC), and polypropylene glycol methyl ether (Dowfroth 250). Portions of these reagents are recycled, but significant percentages will be discharged with the tailings and some portion will seep through the bottom of the largely unlined impoundment into the local ground waters.

Many of these flotation compounds, such as the xanthates, are toxic to plants and aquatic organisms as a minimum (Australian Government Publishing Service, 1995), but little or no detailed toxicity information is publicly available, and regulators do not require that their concentrations be monitored.

Given the significant gold and silver concentrations in the Pebble ores (cite), it is possible that sodium cyanide will also be used in the Pebble processing.

Much of the following reagent discussion is taken directly from Ayers, et. al., 2002, pg. 15-16.

"The specific processes appropriate for beneficiation of copper ores are dependent on the combination of minerals in the ores. Individual mining companies have developed a variety of proprietary processes to recover various by-products or co-products. The main technique for concentration of sulfide ores is froth flotation, sometimes preceded by gravity separation.

Organic wetting agents, known as collectors, permit air bubbles to adhere preferentially to some minerals (in finely divided suspensions) carrying them to the surface in froth. Collectors for sulfide minerals are usually xanthates or other chain hydrocarbons. Frothers in sulfide flotation are usually alcohols, pine oil or ring-carbon molecules like cresylic acid.

Flotation agents used depend on the specific copper minerals in the ore (*Table 2.2*). According to one source, sodium mono-sulfide is used as a precipitation agent for the oxides (azurite, cuprite and malachite). None is needed for the sulfides (bornite, chalcocite, chalcopyrite). Sodium silicate is used as a

dispersant for all copper minerals, sulfide and oxide. Sodium cyanide is a depressant for the sulfides; quebracho for azurite and cuprite, tannic acid for malachite. Sulfide minerals require no activator; polysulfide for the oxides. Alkyl or alkyl aryl xanthate aerofloats are collecting agents for the sulfides and azurite; fatty acids are added in the case of oxides. Pine oil is used as a frother in all cases, with vapor oil and cresylic acid added in the case of the oxides. Lime is a pH regulator and pyrite depressant for the sulfides; sodium carbonate for the oxides.”

Table 1 presents a summary of the typical flotation reagents and the quantities used at various non-ferrous metal mills. This table is taken from Ayers, et. al. (2002), Table 2.2. The proposed Pebble project is presently expected to process up to 8.2 Billion tons of ore. [At 200,000 tons of ore per day, or 73,000,000 tons per year (NDM – presentation by Robert Dickinson to AMEX, Apr07)].

Table 1. Typical Flotation Reagent Consumption, from Ayers, et. al. (2002).

Table 2.2: Typical flotation reagent consumption in non-ferrous metal mills (g/t ore)

	Pb-Zn (sulfides) Les Malines France	Pb-Zn (oxide + sulfides) Zellidja Morocco	Cu-Pb-Zn Brunswick Mining & Smelting Canada	Ni (sulfide) Falconbridge Canada	Cu (sulfide) Lornex Canada	Au cyanidation + CIF Homestake USA	Cu-Zn (pyrite) Pyhasalai Finland
Acids H ₂ SO ₄				500 - 600			5000 ^(b)
Alkalis:							
Lime	1000		2500	225 - 400	1100	1200	3150
Sodium carbonate		550	3300				
Sodium hydroxide		246					
Modifier							
Copper sulfate	200	120	815	35 - 60			330
Sodium cyanide	10	13				550	28
Zinc sulfate	60	91					1450
Sodium sulfate		2800					
Sodium silicate		2700					
Sulfur dioxide			700				
Starch			100				
Collectors							
x-Amylxanthate	45	130	270	60 - 85	35		220
x-Isopropylxanthate					30		
x-Ethylxanthate	5	20					
Diesel oil		69					
Amine		250					
R-242 ^(a)		60					
Frothers							
Dowfroth 250				20 - 25	14		
Hexylic acid	40						
Pine oil					20		
HBTA frother		85					
Carbon						30	

Source: [UNEP/IEPAC 1991, Table 8b]

a. R242 = Aniline dicresyl dithiophosphate plus thiocarbonilide

b. Sulfuric acid is used for pyrite recovery

Assuming that the three copper mills in Table 1 also processed 73 M tons of ore per year, the reagent quantities shown in Table 2 would be representative of the reagent quantities that might be used at the future Pebble mill. For example, at these processing rates, the Finnish site would have used 116,677 tons per year

of zinc sulfate. While NDM has not stated what they believe to be the expected life of the Pebble Mine, it could easily exceed 100 years given the 8.2 Billion tons of ore described on their website (What is the Pebble Project?, <http://www.ndmpebblemine.com/pages/Publications.php>, June 15, 2007). In such a case, truly enormous quantities of the processing reagents would be used and disposed of in the tailings impoundment.

Table 2. Typical Copper Flotation Reagent Consumption (tons / year).

	Cu-Pb-Zn Brunswick Mining & Smelting Canada	Cu (sulfide) Lornex Canada	Cu-Zn (pyrite) Pyhasalai Finland
Acids H ₂ SO ₄			402,336
Alkalis:			
Lime	201,168	88,514	253,472
Sodium carbonate	265,542		
Sodium hydroxide			
Modifier			
Copper sulfate	65,580		26,554
Sodium cyanide			2253
Zinc sulfate			116,677
Sodium sulfate			
Sodium silicate			
Sulfur dioxide	56,327		
Starch	8046		
Collectors			
x-Amyl xanthate	21,726	2816	17,702
x-Isopropyl xanthate		2414	
x-Ethyl xanthate			
Diesel oil			
Amine			
R-242 ^(a)			
Frothers			
Dowfroth 250		1126	
Hexylic acid			
Pine oil		1609	
HBTA frother			
Carbon			

Modified from Ayers, et. al. (2002).

7.0 Water Quality

What are the pre-operational, baseline environmental conditions?

Developing statistically-reliable baseline data, especially water quality data, is one of the most crucial requirements for evaluating potential environmental impacts from a proposed mining project. Nevertheless, baseline water quality data are often inadequate for such purposes, even at modern mines.

In order to demonstrate that water quality has or has not been impacted by any of the project-related activities, it is necessary to have detailed baseline water quality data—collected prior to the onset of any operational activities.

Unlike many mine sites, the proposed Pebble project is in a largely pristine, unimpacted region. The limited *mine site* baseline water quality data presented in the Draft Environmental Baseline Studies, 2004 Progress Reports, (NDM, June 2005,

http://www.dnr.state.ak.us/mlw/mining/largemine/pebble/env_baseline_studies.htm#2004_reports) show that most of the ground water samples collected by NDM's contractors had Total Dissolved Solids (TDS) concentrations less than 100 mg/L and Specific Conductance (SC) measurements of less than 100 micromhos / cm, and minor and trace constituent concentrations were consistently low or non-detectable. The surface water data also had TDS and SC values that were generally below 100 mg/L and 100 μ mhos / cm.

While these baseline water quality data are far too limited to evaluate statistically, it is obvious that most of the preoperational site surface and ground waters are extremely dilute, clean and uncontaminated.

Baseline surface water quality data for the *Road / Port area* are presented in NDM (2005 c) and samples were often collected near road corridors. Not surprisingly, these samples had higher concentrations of dissolved and total constituents than did the mine site samples. However, it is unlikely that these higher concentrations, sometimes described as “naturally occurring exceedances” (see pg. 6-48, Table 6-29) are actually representative of the natural, unimpacted water quality. It is more likely that these elevated concentrations result from road runoff which normally includes all manner of inorganic and organic compounds.

Monitoring locations [surface and ground water] need to be stable for decades so that changes through time can be noted. The present Baseline reports do not include maps showing proposed locations of future mine facilities relative to the baseline monitoring sites. Hence, it is often difficult to tell if adequate baseline monitoring is being conducted.

As with the geochemical data discussed above, NDM has presented some limited baseline data in the Draft Environmental Baseline Studies, 2004 Progress Reports, Chpts. 4, 5, 6, 7 (NDM, June 2005, available at:

http://www.dnr.state.ak.us/mlw/mining/largemine/pebble/env_baseline_studies.htm#2004_reports)

The most recent surface water baseline data are from 2004. In addition, NDM states that baseline data collected by Cominco during various periods during 1991—1993 will be integrated in the future. Thus, no recent surface water flow data are available for the years since 2004.

Water quality data should include quantitative, statistically-reliable summaries of water quality and quantity, aquatic biology, soils chemistry, bottom sediment chemistry, etc. Analytical results from a few individual samples are of little or no value when it comes to demonstrating, in the future, that changes in water quality have occurred.

Baseline chemical data from soils, river bottom sediment chemistry, waste rock, tailings, and waters in areas near (and down-gradient from) the proposed mining and processing facilities need to be collected. Such samples need to be analyzed for a broad range of inorganic and organic compounds. Such analyses should include, as a minimum: field and lab pH, specific conductance, water temperature, together with total determinations (and in some cases dissolved determinations) of: aluminum, antimony, arsenic, barium, cadmium, copper, chromium, cobalt, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, zinc, calcium, magnesium, sodium and potassium, sulfate, nitrate, ammonia, boron, phosphorus, fluoride, chloride, and natural radioactive constituents (uranium, thorium, potassium-40, gross alpha and beta, in general), cyanide and related breakdown compounds (metal-cyanide complexes, cyanate, thiocyanate, organic carbon, oils and greases, together with a comprehensive scan for organic compounds.

All water quality sample preparation (filtration, preservation, etc.) should be done immediately following collection in the field. *The 2004 NDM surface water samples were collected and held for between 8 and 12 hours prior to filtration and preservation. Such procedures are inadequate to prevent many chemical constituents from coming out of solution, thereby yielding lower reported lab concentrations.*

When attempting to detect the possible migration of mine-related leachates, sulfate is often the best “tracer”. It appears that sulfate is missing from the 2004 analyses.

Geochemical / Water Quality Predictions

The mining industry (and other industries) routinely presents computer-generated predictions of future mine water quality and quantity in EIAs to promote the sense that they can “predict the future”. Unfortunately, such predictions are notoriously inaccurate and imprecise, as has been verified in recent studies by Kuipers and Maest (2006), and also summarized in Septoff (2006).

The Kuipers and Maest (2006) study investigated the track record of predicting pre-mining environmental water quality impacts at mining sites versus actual impacts years later. The authors of this study concluded:

- 100 percent of mines predicted compliance with water quality standards before operations began (assuming pre-operations water quality was in compliance).
- 76 percent of mines studied in detail (25 mines) exceeded water quality standards due to mining activity.
- Mitigation measures predicted to prevent water quality exceedances failed at 64 percent of the mines studied in detail.
- 85% of the mines near surface water with elevated potential for acid drainage or contaminant leaching exceeded water quality standards.
- 93% of the mines near groundwater with elevated potential for acid drainage or contaminant leaching exceeded water quality standards.
- Of the sites that did develop acid drainage, 89% had predicted low acid drainage potential initially or had no information on acid drainage potential.

Such “predictive” models are often created by consultants for mine operators to demonstrate that water quality impacts will be minimal and that permits should be given. In addition, these models are often used in justifying optimistic assumptions when making financial assurance calculations. The use of such flawed models has led regulatory agencies to frequently underestimate the dollar amounts of financial bonds they require from mining companies (Kuipers, 2000). Thus, the long-term costs of remediating unforeseen water quality impacts have often been paid by the taxpayers, not the operators. In addition, such model results have often not been suitable to define the realistic future financial liabilities for investors.

Acid rock drainage and related water quality and river sediment contamination are likely long-term impacts that will occur at the Pebble site, post-closure. Many of these water-quality-related impacts may not become obvious until long after the operation has been closed.

8.0 Potential Impacts to Aquatic Life

As described above, mine / mineral processing wastes can release very complex combinations of inorganic and organic compounds. The chemical constituents released from tailings but also waste rock, etc. are mixed together much like a chemical soup. The individual chemical constituents can be toxic to biologic organisms, especially fish, if present in concentrations toxic to any of the life forms of these organisms. In addition, such waste mixtures often can generate additive / synergistic effects to aquatic organisms that are much more complex than the effects due to any one component.

Table 3 includes some examples of actual constituent concentrations from waters at three copper mine sites: Kennecott Utah Copper (KUC), Utah; the Globe-Miami area, Arizona; and the Southern Peru Copper Corp. (SPCC), Peru.

These data are included merely for comparative purposes, and to give some indication of the concentrations sometimes released into the environment via water pathways. Their inclusion is not intended to imply that the future Pebble waste waters will have these concentrations. All of the examples in Table 3 had unlined tailings impoundments, or in the SPCC example, no tailings impoundment.

Table 3. Waste-Impacted Water Quality: Three Copper Sites
[µg/ L, unless otherwise noted; D= dissolved]

Constituent	KUC: ground waters downgradient of waste rock	KUC: ground waters near tailings	KUC: tailings waters	Globe-Miami wells	SPCC Tailings Waters
Arsenic	4 to 200	87.0 to 281.0	3,100 to 13,000	190 to 2,500	5 to 162
Cadmium	70 to 380			100 to 1,000	0.5 to 6.4
Chromium	---		19,200 to 39,400		5 to 46
Copper	112,000—128,000	40.0	227,000 to 456,000	18,000 to 150,000	5 to 11,300
Nickel	20,000—22,200			870 to 3,000	5 to 46.0
Selenium	70 to 170	5,000 to 10,000			13 to 33.0
Silver	30				3 to 23.0
Lead			3,400 to 9,800		2 to 243.0
Aluminum (D)				16,000 to 230,000	
Cobalt (D)				1,600 to 10,000	
Iron (D)				130,000 to 2,710,000	30 to 144,000
Manganese (D)				42,000 to 670,000	1.0 to 4,120
Molybdenum					279 to 826.0
Zinc (D)				2,900 to 24,000	28 to 1,010
Sulfate (mg/L)				7,000 to 9,000	231 to 1930
Chloride(mg/L)				220 to 440	49 to 115
Ammonia					2,000 to 9,000

These examples include only a few of the chemical constituents actually present in the site waters; many constituents were not determined or the data were not made public. The KUC data come from USEPA (1994) and represent 1) ground waters down-gradient of waste rock piles, 2) ground waters near the tailings, and

3) tailings waters. The Globe-Miami data come from USGS (1990), and represent ground waters contaminated by waste rock drainage and possible tailings effluents that have migrated into the local ground waters. The SPCC data are from Woodward Clyde (1994) and are tailings waters. The pHs of the examples in Table 3 were approximately: KUC tailings waters—7.0 to 9.0; KUC ground waters down-gradient of waste rock—6.0 to 7.0; Globe-Miami wells---3.7 to 6.0; SPCC tailings waters—9.9 to 11.4.

Some of the individual contaminants of concern at metal mine sites and the lower concentrations at which they are considered toxic to fish species are presented in Table 4. These criteria are generally *aquatic life criteria* taken from US EPA (2006) or from ADEC, 2003. In addition, some of the criteria below may be drinking water standards or criteria.

Table 4. Water Quality Criteria

<u>Constituent</u>	<u>Lowest Water Criterion (µg/ L)</u>
Al	87.0
Sb	5.6
As	10.0
Cd	0.1
Cr	24.0
Cu	2.7
Pb	0.54
Hg	0.05
Mo	10.0
Ni	16.0
Se	4.6
Ag	0.32
Tl	0.24
V	100
Zn	36.0
pH	6.5—9.0
CN (free CN)	5.2
NH3 (as N)	2.0--325 (acute); 32—49 (chronic)

<u>Constituent</u>	<u>Drinking Water Criterion</u>
Fe	300
Mn	50.0
U	30.0
SO4	250,000
NO3 (as N)	10,000

Note that µg / L (micrograms per liter) corresponds to parts per *billion*. Thus, toxic responses develop in cold-water aquatic organisms, especially trout and salmon, at very low concentrations. Many of the concentrations shown in Table 3, and

those in waste effluents at other copper sites far exceed the criteria shown in Table 4.

Most comparable copper operations are located in environments that are remote and away from sensitive fisheries—frequently in deserts. The environmental impacts from many of these sites go undetected or unreported. In the proposed Pebble Mine region, the existing salmon presently thrive in surface waters (baseline) that are comparable to the purity of nearly-distilled waters. Such pure and dilute waters are easily contaminated because the addition of even relatively small quantities of acidic, metal-laden waters may significantly alter the original chemistry. [They have little original buffering capacity.]

Mine effluents that enter nearby surface waters, either as point or non-point sources tend to react chemically with the river waters generating chemical reactions that cause insoluble substances to form, which then settle to the bottom of the rivers. These solid, chemical precipitates are predominantly composed of aluminum, iron and manganese compounds, together with very high concentrations of other metals and metalloids. Aquatic bottom-dwelling organisms ingest such bottom particles. These contaminated benthic organisms are then consumed by fishes, resulting in potentially toxic diets for the fish.

Even where active water treatment systems have been installed (e.g. Red Dog, Alaska, etc.), the mixture of liquid and solid effluents often have elevated concentrations of dissolved solids combined with numerous toxic trace constituents. These solids settle to the river bottom and may also be toxic to benthic organisms.

Numerous mine operations (including all of the earth moving and road construction) cause an increase in the physical sediment load released into local surface waters. Such physical sediments can be toxic to benthic organisms and various stages of fish by simply burying their habitat and, or sometimes smothering the immature stages.

The criteria listed in Table 4 generally refer to dissolved constituent concentrations, those determined by analyzing filtered (0.45 micrometer-filtered) samples. However, it is often important to evaluate the potential toxicity from unfiltered samples. Fish and other organisms do not live in and consume filtered water.

Note that the section above does not discuss organic constituents that might be released from the tailings impoundment or other facilities (i.e. oils, greases, etc.) into local waters and which may be toxic to aquatic organisms. Many of these organic compounds are known to be toxic to aquatic organisms, but frequently inadequate toxicity research has been conducted thus no formal criteria are available in the literature.

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Even when a mine is well run, it is unavoidable that chemical contaminants will be released into the nearby environment. I know of no comparable, large-scale copper-molybdenum-gold ore body that has been mined without release of significant concentrations of contaminants into the nearby surface and or ground waters, over the long-term. In addition, it is unlikely that a similar copper-molybdenum-gold mine has ever been operated in an area with such a valuable and potentially-vulnerable fishery---anywhere in the world.

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Experience

Dr. Robert Moran has more than thirty-five years of domestic and international experience in conducting and managing water quality, geochemical and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, NGO's, law firms, and governmental agencies at all levels. Much of his technical expertise involves the quality and geochemistry of natural and contaminated waters and sediments as related to mining, nuclear fuel cycle sites, industrial development, geothermal resources, hazardous wastes, and water supply development. In addition, Dr. Moran has significant experience in the application of remote sensing to natural resource issues, development of resource policy, and litigation support. He has often taught courses to technical and general audiences, and has given expert testimony on numerous occasions. Countries worked in include: Australia, Greece, Mali, Senegal, Guinea, Gambia, Ghana, South Africa, Iraqi Kurdistan, Oman, Pakistan, Kazakhstan, Kyrgyzstan, Argentina, Chile, El Salvador, Guatemala, Honduras, Mexico, Peru, Canada, Great Britain, Romania, United States.

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