

A Review of PLP Environmental Baseline Documents: Water Quality



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EXECUTIVE SUMMARY

**Table ES.1. Review of Pebble Limited Partnership’s Environmental Baseline Document (EBD):
Water Quality Characterization**

Basic issue	What are the characteristics of surface water and groundwater in areas that could be impacted by mining?
Approach, data quality, and intended uses	<p>The intended use of the data is to determine the variability of naturally occurring constituents in surface water and groundwater, including waters that could receive or supply mine water. This will inform future discharge permit limits. The data was also to inform fish habitat and groundwater flow studies.</p> <p>Water sampling methods were acceptable, with the exception of a poor choice in surface water sampling equipment in 2004. Laboratory analytical results were of high quality. Sediment contamination, with co-incident high metal concentrations, occurred in several groundwater samples.</p> <p>Non-representative surface water and groundwater data were retained in both, and data interpretation in the EBD implies water quality is poorer than data support. Removal of non-representative data was inconsistent and did not follow standard protocols. Poor protocol for treatment of outliers allowed inclusion of anomalously high and low concentrations of analytes in surface and groundwater. Methods for determining when sample concentrations exceeded water quality standards for hardness-based metals were not clear and failed to follow repeatable methods. These issues affect the reliability of data that could be used for site-specific criteria.</p>
Primary data gaps	<p>No final water quality data set after quality control analysis is provided. This hampers interpretation and review.</p> <p>No reference sites outside of potentially impacted areas were defined for long term monitoring of surface water or groundwater. Groundwater monitoring was less extensive than surface water, and no monitoring wells were installed in key upwelling areas where contaminants could be transported to streams during or after mine development. The characterization of deep groundwater – which informs the quality of operational water – is limited to one deep bore hole at a single point in time. No analysis for fuel hydrocarbons was conducted along the proposed transportation route.</p>
Principal findings and recommendations	<p>Waters are of high quality, with the exception of tributaries and some wells directly on the deposit. Surface waters are highly susceptible to degradation; low alkalinity, low hardness, and low concentrations of dissolved organic carbon provide little ability to buffer or mitigate potential aquatic life toxicity resulting from an increase in metals or a decrease in pH. Most trace metals were rarely, if ever, detected. Metal concentrations increased briefly during spring snow melt.</p> <p>To characterize the natural waters in order to support discharge permit limits and determine potential risks, a final data set needs to be presented and clear interpretive graphs developed from it. There is no consolidation of fish habitat and water chemistry studies to determine where baseline water quality supports or impedes fish populations. Data interpretation should be reviewed closely with respect to water quality criteria calculation and potential contaminants of concern.</p>

INTRODUCTION

The Bristol Bay region in Southwestern Alaska supports wild stocks of anadromous and resident fish important for subsistence and market economies in the Bristol Bay region (Dann et al 2009; Ruggerone 2010; Minard et al 1998; Knapp 2004; Fall et al 2006). Pristine, intact watersheds provide water of exceptionally high quality for fish and aquatic insects. Large scale development will necessarily--by design and accident--impact waters (Maest et al 2005). A reliable baseline is the foundation for understanding the potential resiliency of the system and determining water quality discharge permit limits.

The Pebble Limited Partnership (PLP) has conducted water quality characterization studies as required prior to development of a copper ore body hosted in sulfide rock. The purpose of this review is to summarize baseline water quality data in the EBD and evaluate the study approach, repeatability of methods in data collection and analysis, data interpretation, data gaps, and the degree to which conclusions are supported.

The primary EBD documents examined were Chapter 9 “Water Quality: Bristol Bay Drainages” and relevant sections of Appendix A (Quality Assurance/Quality Control), Appendix E (Consolidated Study Plan), Appendix F (Field Sampling Plans) and Appendix G (Quality Assurance Project Plans). Due to the limited time and length of this review, independent interpretive graphs (e.g. upstream-downstream analyte comparisons) were not developed.

CRITERIA FOR EVALUATION

A water quality characterization program encompasses site selection, methods for sample collection, frequency of primary sample collection, extent of constituent analysis, and quality control measures. Standard guidance can be found in the USGS Water Quality Field Manual (USGS, various dates) and Contract Lab Program Functional Guidelines (USEPA 2004). There are no standards for data interpretation, but guidance can be found in Data Quality Assessment (USEPA 2006), EPA’s Sourcebook for Industry in the Northwest and Alaska (USEPA 2003), and Study and Interpretation of Chemical Characteristics of Natural Water (Hem 1985).

The EBD water quality site and methods selections relied on the USGS Field Manual (PLP 2011a, Section 6.1.2.2) and data validation relied on Contract Lab guidelines (PLP 2011b, Section A.1.4). Groundwater data interpretation (PLP 2011c, Section 9.2.4.4) relied on Statistical Methods for Groundwater Monitoring (Gibbons 1994), graphic interpretations (Piper 1944), and EPA Guidance for Data Quality Assessment (USEPA 2000). The surface water section does not define methods for data interpretation, which appeared to rely heavily on visual assessment of graphs and professional judgment (PLP 2011c, Section 9.1).

EBD WATER QUALITY CHARACTERIZATION METHODS

Site selection

Surface water sites were selected in order to establish baseline water quality, document chemistry in waters that could receive or supply mine water, and inform fish habitat studies (PLP 2011a, Section 6.1.2.2). The EBD describes water sampling from April 2004-December 2008 within the drainages of the North Fork Kaktuli River (NK), South Fork Kaktuli River (SK), and Upper Talarik Creek (UT), and one

surface water site each on the Kaktuli (KR) and Kaskanak Creek (KC) (Figure 1). Data collected in the Chulitna River watershed north of mining claims were not presented.¹ In 2005, surface water sites were added to SK to characterize groundwater upwelling areas (PLP 2011a, Section 6.1.2.3). Groundwater well locations were selected to characterize baseline water quality and inform flow studies (PLP 2011a, Section 6.1.3). Wells on SK extend approximately 10 miles downgradient of the ore deposit, wells on the NK are within a proposed tailings storage area (Wardrop 2011), and wells on the UT are adjacent to the deposit in an area likely to be dewatered. Deep groundwater, which represents the water likely to be encountered during mining operations and informs potential water treatment methods, was collected from a single 4,000 foot drill hole at Pebble East in 2008 (PLP 2011c, Section 9.2.5.8).

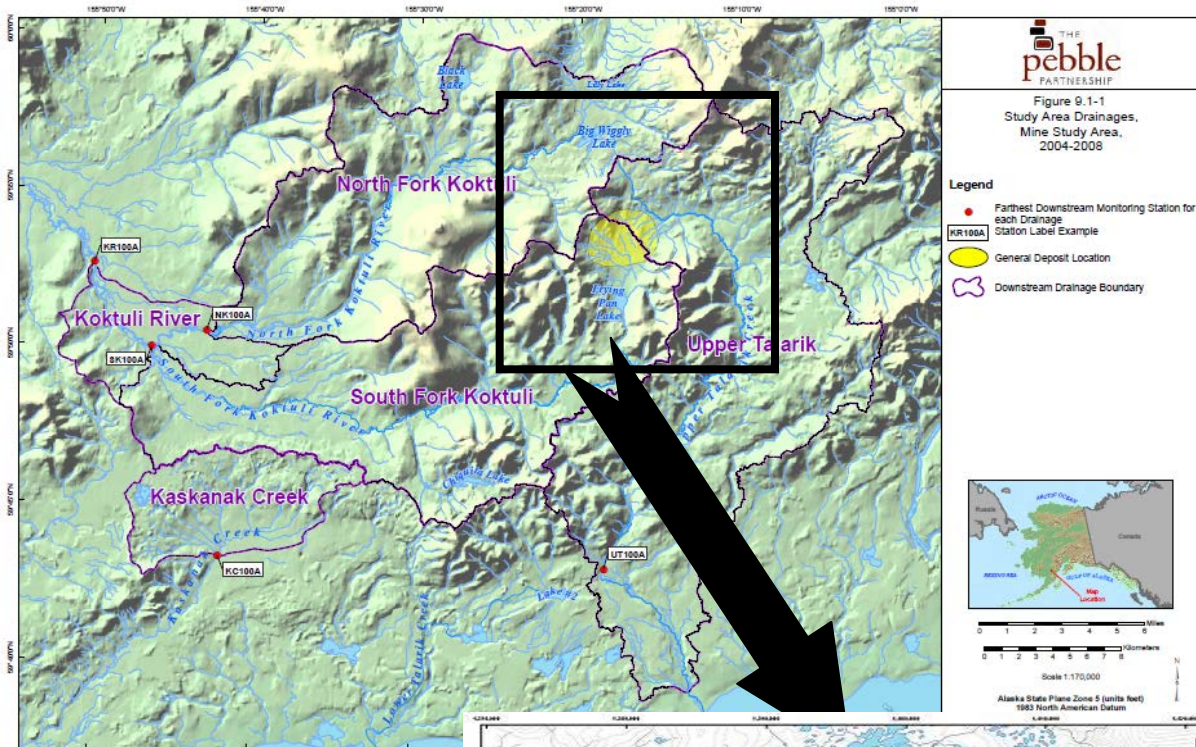


Figure 1. Watersheds in the Pebble region. The major drainages and the downstream extent of surface water sampling are shown. The outlined area is shown in Figure 2 with monitoring well locations.

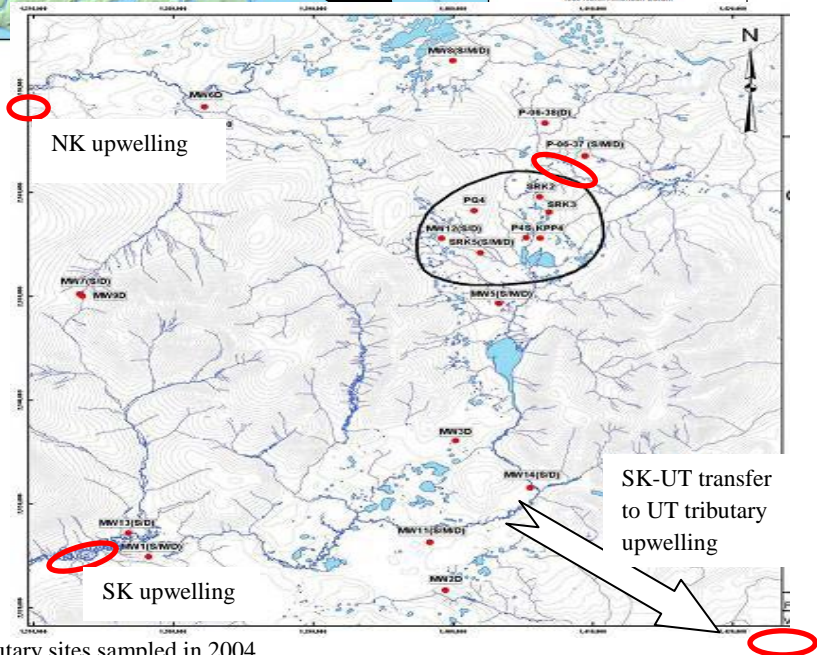


Figure 2. Upwelling areas. Significant upwelling areas are noted in heavy red circles (added to the published EBD figure); note that some lay outside the map. Red dots indicate monitoring wells (EBD Figure 9.2-1). No monitoring wells are located downgradient of upwelling areas in the NK, SK, and UT (where SK groundwater transfers to the UT). Information is from EBD Chapter 7, Figure 7.2-5 and section 7.2.7.2.

¹ PLP 2008 contains data for two Chulitna tributary sites sampled in 2004.

Water sampling

Surface water sampling methods were chosen to characterize the natural trends and statistical variation of constituents, particularly during changing flows and seasons, while groundwater sampling was conducted to characterize the geochemical character of groundwater and inform groundwater flow studies (PLP 2011a, Section 6.1.2 and Section 6.1.3).

Stream and groundwater sample collection methods were clearly described and repeatable (PLP 2011a, Section 6.1). Field data for surface water was collected using YSI 556 meters, which is standard equipment (PLP 2011d, Section 7.2), and in-flow cells for groundwater (PLP 2011a, Section 6.1.3).

Water samples for laboratory analysis were collected following USGS techniques (PLP 2011a, Section 6.1.2.2; USGS various dates). Samples were flown to a primary laboratory in Anchorage within 24 hours of sample collection, using standard chain of custody protocols (PLP 2011b, Section 1.1.2). Stream water samples were obtained monthly with depth-integrated composite sampling equipment to collect a representative cross-section of the stream (PLP 2011d, Section 6.1) and groundwater was sampled quarterly using peristaltic pumps. To capture dissolved constituents, an in-line filter was utilized at groundwater sites (PLP 2011a, Section 6.1.3); surface water samples were filtered in the field or at base camp within 12 hours of collection (PLP 2011d, Section 6.1; PLP 2011a, Section 6.1.2.2; PLP 2011b, Section 3.1.1). Analytical data was provided for major ions, minor and trace elements, nutrients, dissolved organic carbon (DOC) and cyanides. The analytical methods were sufficiently sensitive (e.g. ICP-MS for metals), and full quality control analysis was conducted (PLP 2011b, Section A.1.2).

Data validation

The purpose of data validation is to determine the completeness and usability of the data (PLP 2011b, Section A.1.4). EBD data validation followed EPA contract laboratory guidelines (USEPA 2004) and quality assurance/quality control (QA/QC) procedures. The process determined whether data was representative of natural waters through indicators such as completeness, precision, accuracy, representativeness, cation-anion balance, and a comparison of total versus dissolved element concentrations.

Data Interpretation

Validated data underwent interpretation to determine what the data said and whether it fulfilled intended uses. Treatment of non-detects and outliers were part of this process (PLP 2011c, Section 9.0.6). The EBD classified constituents for data interpretation based on the information the group of constituents could provide. The classifications included trace elements to characterize constituents associated with toxicity, organics to document naturally occurring concentrations prior to mine development, and DOC for information on potential mitigation of trace element toxicity (PLP 2011c, Section 9.0.6).

Eleven trace elements were selected for surface water data interpretation (aluminum, arsenic, barium, iron, cadmium, copper, lead, manganese, molybdenum, nickel, zinc), and an additional eight parameters were added for groundwater data interpretation (antimony, beryllium, chromium, mercury, selenium, silver, thallium, vanadium) (PLP 2011c, Section 9.0.6). In addition to baseline characterization of trace metals, data interpretation included comparing results of trace elements to water quality criteria (PLP 2011c, Section 9.0.7). This will provide information for water discharge permits.

DISCUSSION

Water was collected using commonly accepted methods, but not all aspects of data validation followed standard methods, while data quality assessment and interpretation methods were inconsistent and difficult to follow.

Summary of water quality studies and intended use

Studies intended to determine the chemistry of surface waters and groundwater, determine constituent variability with stream flows and seasons, and inform fish habitat and groundwater flow studies. The completeness and usability of the data was compromised by inconsistent and non-standard methods of data interpretation that impaired the determination of stream and groundwater chemistry, while limited placement of groundwater wells impaired the ability to fully provide chemical data to inform flow studies, and fish habitat and water chemistry data sets were disconnected.

EBD data indicate that waters were of exceptionally high quality in the three main stream systems; higher groundwater input in the UT provided slightly higher alkalinity and cations (PLP 2011c, Appendix 9.1B). All streams had little sediment, low temperatures,² and high dissolved oxygen, important conditions for salmon spawning and egg incubation (Groot and Margolis 1991). Metal concentrations were often below detection limit, and generally only exceeded water quality criteria for a brief period during snowmelt or rain (PLP 2011c, Appendix 9.1B). Waters were primarily calcium bicarbonate, but hardness was low and alkalinity often near or below the recommended Alaska standards of 20 mg/L. DOC was also low; subarctic rivers may have an average DOC near 19 mg/L (Hem 1985) while the highest concentrations near Pebble streams were below 8 mg/L. Low organic matter, hardness, and alkalinity indicate there is little in natural waters to bind trace metals and mitigate toxicity to aquatic life.

Evaluation of Site Selection

The sampling program intended to characterize waters that could receive or supply mine water (PLP 2011a, Section 6.1.2). Gaining and losing reaches where surface water and groundwater exchange should be characterized, as they represent potential contaminant pathways. Losing and gaining reaches were identified (PLP 2011h, Section 7.2); surface water sites were located in gaining reaches, but no groundwater wells were located near the SK-UT transfer area or other gaining reaches (Figure 2).

Groundwater monitoring wells ranged from tens to a few hundred feet deep, and only a single deep well (4,000') with sampling at a single period of time provides information on deep groundwater (PLP 2011c, Section 9.2.5.8). This deep groundwater represents water likely to be encountered during mining operations (Wardrop 2011) and informs potential water treatment.

Site selection data gaps

- groundwater wells on the NK are limited to a single valley, and on the UT limited to headwaters
- deep groundwater sampling is limited to one well
- no monitoring wells downstream of gaining (upwelling) areas
- no surface water or groundwater reference sites were identified or sampled

² For example, median temperatures at SK main stem sites were 2°C, 3°C, 7°C, 5°C, 2°C, 3°C from downstream to upstream; temperatures could reach over 15 °C in July, and reached 20 °C at SK100F below Frying Pan Lake twice, in July 2004 and July 2005. In the Upper Talarik main stem, individual measurements were all below 12 °C except one sample at UT100B at 15°C in August 2005 and two samples at UT100D near 13°C.

Evaluation of Sampling

This section reviews sampling methods and quality control procedures. Field data was acceptable, with the exception that the data on stream temperatures did not match in presented tables (PLP 2011c, Appendix 9.1B). Stream sampling methodology diverged from USGS protocol in 2004 when inappropriate sampling equipment with potential for metals contamination was utilized (Lane et al 2003; PLP 2011a, Section 6.1.2.3; PLP 2011c Section 9.1.5.3). In groundwater, high total suspended solids (TSS) with associated metals indicated a problem with groundwater sampling methodology. High TSS occurs from erosion and is not representative of ambient groundwater (PLP 2011c, Section 9.2.5.4).

To determine the aqueous concentration of constituents, water is filtered to remove particles. USGS field-filtering protocols were followed for groundwater sampling, but it is unclear if they were followed for surface water sampling³ and hundreds of samples were rejected when dissolved metals values in surface water exceeded those for total metals. Filters were replaced but issues remained (PLP 2011b, Section 3.1.1). Equipment blanks (EB) (laboratory-grade water passed through sampling equipment) would have shown contributions from the filter; although samples were collected (PLP 2011d, Section 6.5) results were not reported (PLP 2011c, Section 9.0.6.2). The EBD fails to address numerous occurrences of dissolved major cation concentrations exceeding total (PLP 2011b, Section 2.1.8). Calcium and magnesium cations determine hardness and thus water quality criteria for hardness-dependent metals.⁴

Organics sampling⁵ was limited, and results were scattered between chapters or not presented.⁶ One site in each of the main stems SK, NK, and UT was sampled in August and October 2004, and in July 2005, and may have been conducted in 2007.⁷ Analysis of diesel range and residual range organics (DRO/RRO) in ponds and small lakes was limited to sediment (PLP 2011e, Section 10.2.7.3; PLP 2011d and f) while Iliamna Lake water was analyzed for volatile and semi-volatile organics (VOC, SVOC) (PLP 2011g).

Methods data gaps and issues

- no analysis for DRO/RRO or GRO in water along the proposed transportation route⁸
- no analysis for organic compounds in tributaries, small lakes or pond water
- improper stream sampling equipment in 2004
- high suspended solids and associated metals in groundwater samples
- equipment blank results are missing
- data results for organic compounds analyzed in mine area streams are missing

Evaluation of data validation

Methods of assessing precision and representativeness are questionable (PLP 2011b, Section A.2.1) and laboratories did not meet all acceptable standards for accuracy.

³ Appendix E Section 6.1.2.2 says samples were filtered in the field or placed on ice and filtered within 12 hours; Appendix A Section 3.1.1 implies that field filtering did not occur.

⁴ E.g. at surface water site UT146A Ca, Mg, K, and Na dissolved concentrations exceeded total by 33%, 30%, 15%, and 19%.

⁵ DRO/RRO, gasoline range organics (GRO), VOC's, SVOC's, polychlorinated biphenyls (PCB's) and pesticides

⁶ Transportation corridor organics results were presented in Chapter 9 Appendix 9.3F; for the mine site, Chapter 9 Appendix 9.1B is referenced but no organics data was found. Organics data for sediment is in Chapter 10.

⁷ Chapter 9 Section 9.1.5.3 and Section 9.1.8.1 (page 9.-19) conflict. Table 1-5 in the 2007 QAPP (Appendix G) suggests sampling for organics in 2007 was only done in Iliamna Lake and stream sediments.

⁸ Petroleum hydrocarbons are on the analyte list in Section 9.3.5.3, however DRO/RRO and GRO do not appear to have been in the list of analytes in Appendix G, Table 1-6 nor on the table of results (Chapter 9 Appendix 9.3F)

Accuracy (bias, or ability to “hit the target”) is a measure of the agreement of a known value with the laboratory-measured value as “percent recovered”. It is assessed by adding a known quantity of analyte to laboratory water (laboratory control samples (LCS)) and field samples (matrix spikes – MS) or by submitting quality control samples prepared by a company independent of the laboratory (performance evaluation (PE)) and determining whether the lab measures the amount accurately. Although LCS and MS were within the acceptable performance ranges (PLP 2011b, Section A.2.2.1), PE sample results indicated the primary lab did not accurately measure alkalinity, fluoride, sulfate, total cyanide, nitrate, and phosphorous (PLP 2011b, Table A-5a). Both the primary and secondary labs were out of acceptable range for weak-acid dissociable (WAD) cyanide measurements, and this may have affected data interpretation. There were no significant issues with the accuracy of metal measurements (PLP 2011b, Table A-5a).

Precision (reproducibility, or ability to “hit the same spot repeatedly) is assessed by the relative percent difference (RPD) in concentrations of primary and replicate samples. Laboratory precision may have been calculated from LCS (PLP 2011b, Sections A.2.1.1 and A.2.2.2, Tables A-7 and A-11), which is not the correct method. Field and laboratory precision were calculated from field duplicates (PLP 2011b, Section A.2.2.1 and Table A-7), which is a correct method. RPDs of 35% are acceptable for field precision (USEPA 2004). Although tables imply several samples were out of range,⁹ we do not know how widely precision for analyte sets varied.

Cation-anion balance is the calculation of total cations (iron, aluminum, cadmium, calcium, magnesium, manganese, potassium, sodium, zinc, and acidity) and total anions (bicarbonate alkalinity, chloride, fluoride, nitrate, sulfate) from filtered samples using standard methods (Clesceri et al 1998). Imbalance could indicate an issue in accuracy or precision. The EBD states that 99% of the “sample collection points” met criteria (PLP 2011b, Section A.2.2.1), but there is no detailed discussion.

Representativeness assesses the degree to which measured data reflects actual concentrations (PLP 2011b, Glossary). It is unclear if PLP assessed this through field blanks (PLP 2011b, Section A.2.2.1), which would be appropriate, or through PE samples and field replicates (PLP 2011b, Section A.2.1.3), which would not be. Assessment should include equipment blanks; these were collected, but results were not provided (PLP 2011d, Section 6.5).

Completeness is a quantitative and qualitative measurement of the percent of field samples submitted for analysis that are not rejected. Data sets were determined to be 98% complete. The primary reason for rejection was dissolved (filtered) metals in higher concentration than total (unfiltered) (PLP 2011c, Section 9.0.6). Dissolved concentrations must be equal to or less than total concentrations, and if not, samples may not be representative. The “completeness” section does not discuss the many examples of dissolved cations in higher concentration than total cations.

Issues with data validation

- the data validation report was not included in the EBD
- some data validation methods may have been inappropriate

⁹ Elements were analyzed as n-pairs (the primary-duplicate pairs for the site). The number of pairs ranged from around 100 to over 700, depending on how many samples were submitted for analysis and how many were not rejected.

Evaluation of data interpretation

Data interpretation suffered from lack of clarity and transparency and utilization of non-standard and non-repeatable methods.

pH and alkalinity

EBD data indicates clean water consistently across the watersheds, but the interpretation and wording suggests lower quality. For example, in discussing the North Fork Koktuli:

“The pH was out of the most stringent criteria range at seven locations. The locations ...with concentrations out ofrange were NK119A (25 of 79) and NK100B (17 of 79).....indicating locations with acidic water occur in the North Fork Koktuli River throughout the year. Alkalinity was below the most stringent minimum value in many samples from multiple locations.” (PLP 2011c, Section 9.1.8.1)

Table 9.1-10 indicates that pH exceeded chronic aquatic life criteria (pH below 6.5; ADEC 2006) in 79 of 240 samples, and exceeded drinking water criteria (pH below 6.0) in 30 of 240 samples. However:

- At surface water station NK119A, the mean pH is 6.54 and the median is 6.6 (n=52); at NK100A, the mean and median pH (n=46) is 6.75 and 6.7 respectively, above water quality standards. The lowest pH at both sites was pH 5, but such low values occurred rarely and are representative of pH commonly observed when organic acids flush into streams (PLP 2011c, Appendix 9.1B).
- At surface water station NK119A, alkalinity is low, with the mean and median near 11 mg/L; at surface water station NK100A the mean and median alkalinity were 24 mg/L. Although samples are reported to exceed aquatic life criteria (90% of samples at NK119A and 23% of samples at NK100A), in Alaska an alkalinity of 20 mg/L or higher, or natural background values, meet water quality standards. On that basis, no samples exceed criteria (PLP 2011c, Appendix 9.1B).

Rather than indicating water quality is poor, the pH and alkalinity values suggest that water quality is extremely good, and can be easily impacted. Development of a sulfide ore body presents the risk of acid rock drainage from sulfide oxidation (Hem 1985). Most waters in the area, particularly along the SK and NK, have a pH of 5 to 7.5. Organic material may cause pH to drop as low as pH 4.5, but acid rock drainage can cause pH to drop far below this range (Hem 1985). Sulfate, pH and alkalinity concentrations suggest water characteristics reflect organic material input (generally humic and tannic acids from plant material), but references to “acidic water”, while technically correct, provides the incorrect impression that highly acidic conditions exist extensively in natural waters.

Treatment of non-detects

EBD data also indicates water quality is similar across all watersheds, with the exception of higher alkalinity and hardness in the UT, but from the EBD interpretation: *“it is clear that each of the major river systems has significantly different constituent background concentrations”* (PLP 2011c, Section 9.1.8.5). The tests supporting the conclusion removed non-detects prior to analysis: *“For the Kruskal-Wallis and Mann Whitney statistical tests, which were used to distinguish differences in surface-water concentrations between watersheds, only detected concentrations and J-qualified results were included to avoid skewing the datasets based on multiple non-detect values”* (PLP 2011c, Section 9.0.6.3). This method biases the data high, resulting in an erroneous conclusion.

Outliers

Prior to data analysis, PLP removed some data points that did not appear to be representative of ambient water quality as part of “data reduction” (PLP 2011c, Section 9.0.6.6). Goals of outlier exclusion and inclusion were unclear.

*“the statistical **normal distribution** function was used to determine the **98 percent confidence interval** of each parameter-station combination. One percent of the data were statistically lower than the lower limit and one percent of the data were statistically higher than the upper limit.These limits statistically included 98 percent of all data and were plotted on the time series as horizontal lines for reference....The confidence test could not be used without professional judgment because the data sets were often **not normally distributed** and because the frequency of detection was commonly less than 50 percent for trace metals”* (emphasis added)

There are three statements within the quoted section that are problematic.

1. Measurements in the natural world often do not follow normal distribution patterns (USEPA 2006); e.g. for surface water chemistry, seasonal variations are expected.
2. A confidence interval is an estimate of a population parameter, such as the true mean concentration. Using a confidence interval to trim the top and bottom one percent is neither logical nor statistically defensible (personal communication with Joel Reynolds, biostatistician with Anchorage office of the US Fish and Wildlife Service). If, instead, they were attempting to reach a confidence limit for a tolerance interval – an interval that would contain a specific portion of the sample observations to get a good idea of the range of possible future sample observations – then they used the wrong formula (Reynolds and Braman 2009).
3. While there is no specified protocol, mean determination for water chemistry data with skewed distributions and analytes below detection limit are thoroughly discussed in the literature (USEPA 2006; Singh et al 2006).

A second round of outlier analysis was conducted after the “final” data sets (PLP 2011c, Appendices 9.1B and 9.2B) were uploaded. The method used was a visual inspection of time-series plots (PLP 2011c, Section 9.0.6.6). Protocols for additional outlier analysis and exclusion or inclusion of data in the database were unclear. Some outliers were identified and removed, some identified and used in interpretive material (time series plots, ratios of measured concentration to water quality criteria, etc., PLP 2011c, Appendices 9.1D and 9.2C) and some data points were not identified as outliers at all.

Issues with assessment of surface water outlier analysis

The issues were compounded by the protocol for treatment of high and low data points in surface water:

“Surface water chemistry was expected to have high variability corresponding with seasonal flow rates and temperature, and other environmental influences. Therefore, no outliers were flagged for having high or low concentrations.” (PLP 2011c, Section 9.0.6.6)

The assumption that surface water data lacks high or low concentration outliers due to natural variability is flawed and is entirely contrary to EPA protocol (USEPA 2003 Section 6.2). Outliers that cannot be explained should be flagged; they may or may not be within the range of natural variation as determined through multiple years of sampling and assessment of upstream and downstream sites under different flows.

Anomalously high concentrations of single or multiple elements, many of which could affect site means and medians, are retained in the EBD. An example is hardness at NK119A or copper at surface water site UT100C2 (Figure 3). At UT100C2, a concentration of 16 ug/L total copper is retained in the database (and interpretive material), although copper concentrations do not exceed 1.5 ug/L for any other date at this site, or adjacent sites. Many similar examples exist in the data sets. Because these data are not considered “outliers”, they appear in surface water box-and-whisker interpretive plots (PLP 2011c, Appendix 9.1G) as extremes of natural variation rather than non-representative data.¹⁰

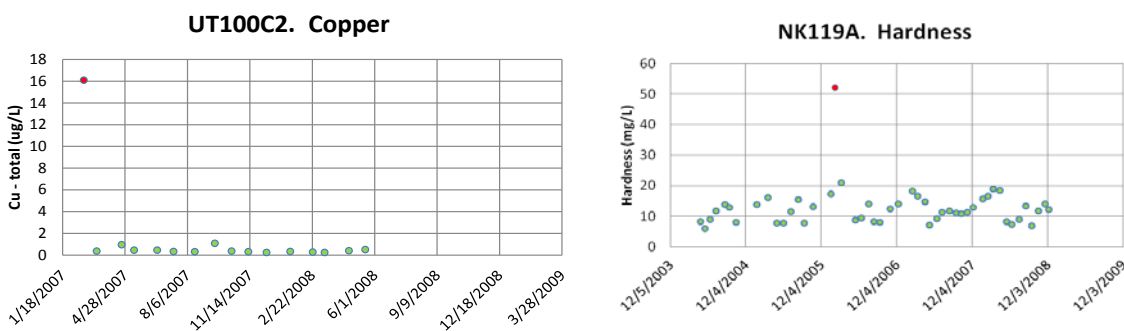


Figure 1. Single point anomalies, surface water. At stream site UT100C2 on Upper Talarik Creek, the first sample is notably higher than later samples; at stream site NK119A in the North Fork Kaktuli valley that could be used to store mine tailings, a single high concentration for hardness occurs. There are many similar examples throughout the EBD. Retention could skew analyte means and medians for the site.

A separate issue revolves around whether all monthly sampling was included in data sets. The stream in one section of the SK, between SK100D upstream and SK100B downstream, goes dry in some months of some years, although it runs all year in other years. The EBD implies few fish make it past this section to Frying Pan Lake or other streams closer to the deposit (public presentations by R2 consultants, Nondalton and Dillingham, AK 2012). For SK100C, near the SK losing reach, 2008 data was reported only for May; for SK100D, no data was reported after May 2008 (PLP 2011c, Appendix 9.1B). Late April to mid-May are consistently the months with the highest metals concentrations and excluding data from other months could bias the mean high for the site, potentially suggesting that both high copper and dry months prevent salmon from reaching waters closer to proposed development.

Issues with assessment of groundwater outliers

Several non-representative data points and trends were retained,¹¹ and some data identified as outliers were used in interpretations. In addition to single point anomalies (Figure 4), there was a bias towards higher metal concentrations by retention of data from samples with high TSS and data from wells that were not fully equilibrated after well development. There are many examples of wells with elevated TSS,¹² often resulting in high metals concentrations in the final data set.¹³ Some of these data were removed, but some were not (Figure 5).¹⁴

¹⁰ “All data points flagged as outliers were excluded from the plots, statistics, and interpretation” (Chapter 9 Section 9.0.6.6)

¹¹ E.g. Chapter 9 Section 9.2.5.7 discusses groundwater data that should not be used in ambient water characterization

¹² Monitoring wells MW-5S, MW-11SS, MW-12S, MW-13D are a few; see data sets in Chapter 9 Appendix 9.2B

¹³ e.g. at MW-13D, the first four samples had high TSS, with the first sample TSS at 63 mg/L and metals quite elevated

¹⁴ For the example of MW-13D, in “ratio to water quality standards” (Chapter 9 Appendix 9.2D) all data for August 2005 was removed except chromium, despite the high chromium concentration; data for dates after August 2005 were kept and used in the “ratio” analysis.

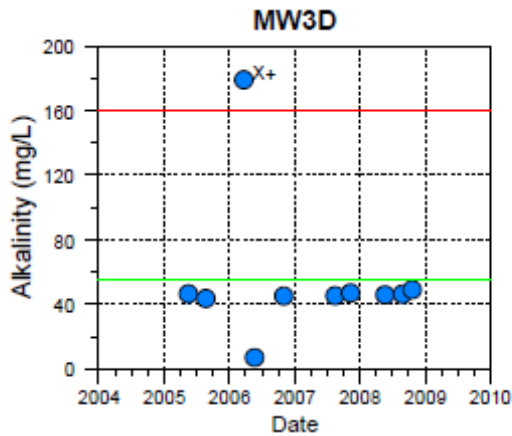
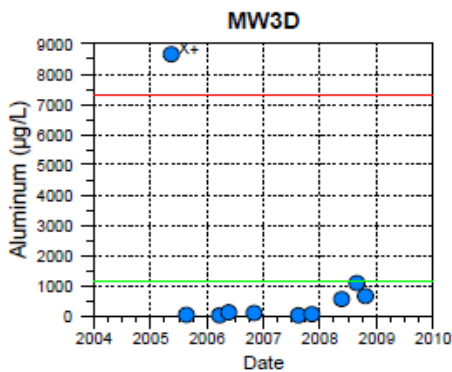


Figure 2. Single point anomaly, groundwater. The anomalously high alkalinity point is removed, but the anomalously low alkalinity point is not. The red line represents the upper 98% confidence limit; the green line is the mean. The lower confidence limit is not shown. Groundwater well MW-3D is located about one mile south of Frying Pan Lake. Appendix 9.2C-2



Sample Date	Aluminum (ug/L)	TSS (mg/L)
05/16/05	8650	15.1
08/22/05	28.7	0.075
03/24/06	12.7	0.147
05/23/06	112	2.20
11/02/06	85.4	2.70
05/09/07		
05/10/07		
08/16/07		
08/17/07	17.1	0.150
11/11/07	47.0	2.10
03/22/08		
05/22/08	555	43.4
08/27/08	1090	74.5
10/21/08	653	39.9

Figure 3. TSS and elevated aluminum in groundwater. Groundwater is expected to have consistent water quality and low TSS. Right: Elevated TSS (highlighted) and aluminum (red font). Left: The first data point was removed (symbol X+) but the last three were not. The high concentrations on the y-axis make it difficult to observe the later trend. Water quality standards for aluminum are 87 ug/L at 25 mg/L hardness. The red line represents the upper 98% confidence limit; the green line is the mean; lower confidence limit is not shown. Groundwater well MW-3D is one mile downstream of Frying Pan Lake.

Another example of retention of non-representative data is shown in Figure 6. Some results appeared to be a mix of equilibration effects and TSS (Figure 7). Trends that did not characterize natural groundwater were noted in the EBD:

“non-normal behavior was often due to concentrations that trended downward ...[due to]..equilibration of the well chemistry to ambient groundwater conditions, a process that [could] take more than a year. Therefore, all data were visually inspected in the time series plots and professional judgment was used to identify outliers.”(PLP 2011c, Section 9.0.6.6)

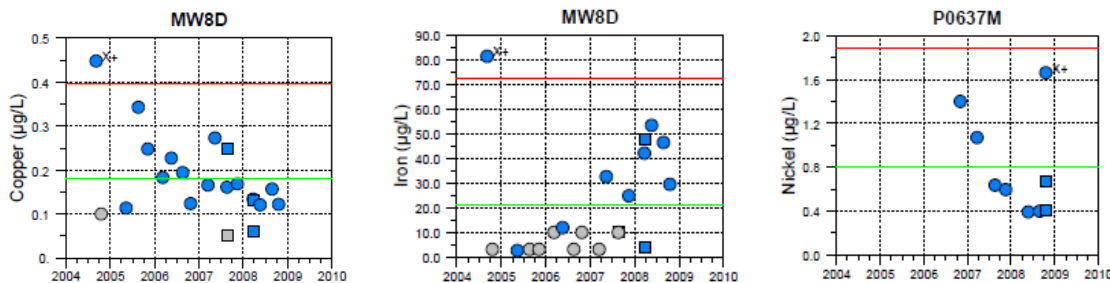
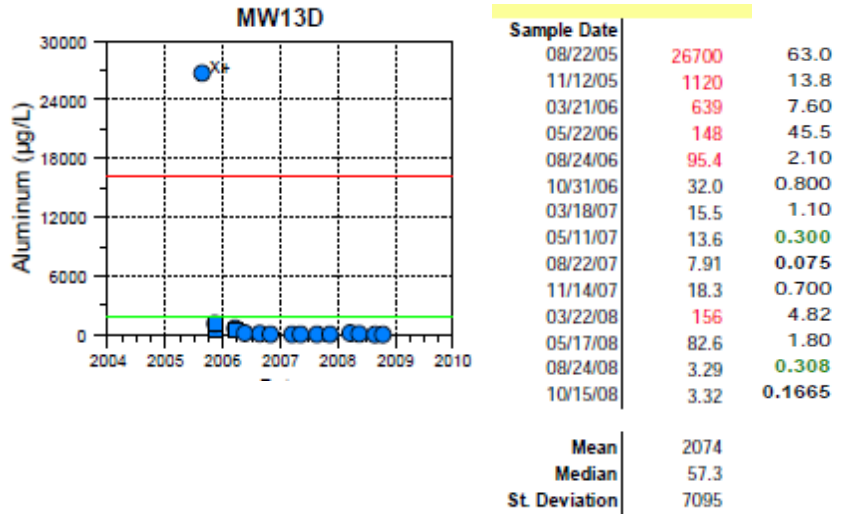


Figure 4. Trends in monitoring wells. Data points above the upper 98% confidence limit have been removed; data points between the mean and upper confidence limit are retained, although they may not be representative of natural water chemistry. Not all trends are due to equilibration (center graph). At well P06-37M, an outlier below the 98% confidence limit was removed, but most points in the trend were retained. Many other examples appear in Appendix 9.2C. Retaining the data points could bias concentrations high. Plots depict dissolved concentrations. The red line represents the upper 98% confidence limit; the green line is the mean. The lower confidence limit is not shown.

Figure 5. Equilibration and TSS in groundwater. Left: The plot shows outliers removed for total aluminum in the well (Appendix 9.2C). Only the first sample is identified as an outlier, indicated by the symbol “X+”. Right: The data source Appendix 9.2B. The first 3-5 samples are likely not representative of natural waters. The y-axis scale on the plot only allows very high concentrations (over 3,000 ug/L) to be clearly observed, therefore the declining concentration trend in values is not seen on the plot. MW-13D is the well located furthest downstream on SK, about 10 miles from the deposit (Figure 9.2-1).



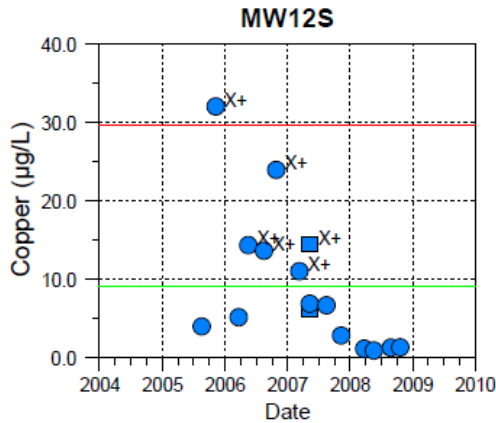
Copper

Development of a copper mine presents a risk of releasing copper into groundwater and/or surface water (directly and through upwelling). Copper has critical impacts on the salmon olfactory system and lateral line (Sandahl et al 2007; Hecht et al 2007). Given the potential for contaminant transport through groundwater-surface water exchange (Woody and Higman, 2011), and impact of small increases in copper concentrations on salmon, baseline characterization needs to accurately assess natural copper concentrations. Retention of non-representative data, methods for interpreting when and if metal concentrations exceed water quality standards, and wording in the EBD often imply metal concentrations are higher than actual measured data indicates. Directly on the deposit, two small streams have high copper (maximums near 15 ug/L), but most streams generally have low copper (maximums < 3 ug/L), even near the deposit. Groundwater from at least two wells directly on the deposit have high copper and low alkalinity, other wells on the deposit have relatively good quality water.

In Alaska, groundwater is important to salmon egg incubation and survival, and needs to meet surface water quality standards (ADEC 2006). The EBD suggests five wells always, or often, exceed water quality standards.¹⁵ However, a review of the data in PLP 2011c Appendix 9.2B indicates copper concentrations are not representative of ambient water in well MW-12S (Figure 8), and possibly in three other wells due to the presence of suspended sediment from well development. While TSS is discussed relative to trace metals (PLP 2011c, Section 9.2.5.4), data not removed as outliers are used in some interpretive material (e.g. total copper in MW12S was retained for PLP 2011c Appendix 9.2D comparing measured concentrations to water quality criteria, but it was not shown in box-and-whisker plot figures).

The data sets for fish habitat, fish presence, and water quality are disconnected so that it is not possible to determine how, or if, water chemistry informs fish habitat studies. Information, particularly on copper concentrations, should be correlated with known fish habitat and spawning information to determine if, and where, baseline water quality inhibits fish presence.

¹⁵ Chapter 9 Section 9.2.5.4 identifies wells MW-12S, SRK5D, MW-01M, P-06-38M, and PQ4 as having 56% - 100% of samples exceeding copper standards, based on 25 mg/L hardness.



Total Suspended Solids	Copper ⁽⁴⁾	
	Total	Dissolved
mg/L	µg/L	µg/L
2.40	3.94	1.43
41.8	32	1.54
13.5	5.12	0.383
15.1	14.3	0.975
10.7	13.6	1.12
10.7	23.9	0.716
10.7	11.0	0.771
2.80	6.87	0.260
3.70	6.64	0.220
2.70	2.79	0.367
1.17	1.12	0.624
0.400	0.877	0.590
1.27	1.24	0.764
0.619	1.27	0.648

Figure 7. TSS and copper concentrations. Data are from monitoring well MW-12S on the deposit. Right: Elevated copper (and other metals, not shown) is associated with elevated TSS not representative of groundwater (Appendix 9.2B). Left: Most of the elevated copper is identified as outliers (symbol X+, Appendix 9.2C-2), but there does not appear to be a final data set with an updated mean concentration.

In the examples below, data from monitoring well KP-P4 on the deposit (Figure 9) is not described as unusual in the Temporal Trends results section (PLP 2011c, Section 9.2.5.7). Similarly, total and dissolved copper concentrations at well SRK-5M on the deposit are < 1.5 ug/L in all samples with the exception of a single anomalous total and dissolved copper concentration near 1,000 ug/L, which was not flagged. In addition to strongly skewing the mean, only the anomalous dissolved data was removed when evaluating whether measured groundwater concentrations exceeded water quality standards. The total copper values were retained (PLP 2011c, Appendix 9.2D), while both total and dissolved copper values were used to create box-and-whisker plots (Figure 10). This calls into question the assumption that groundwater on the deposit is poor; in fact, several wells show good groundwater quality with neutral pH and metals within water quality criteria.

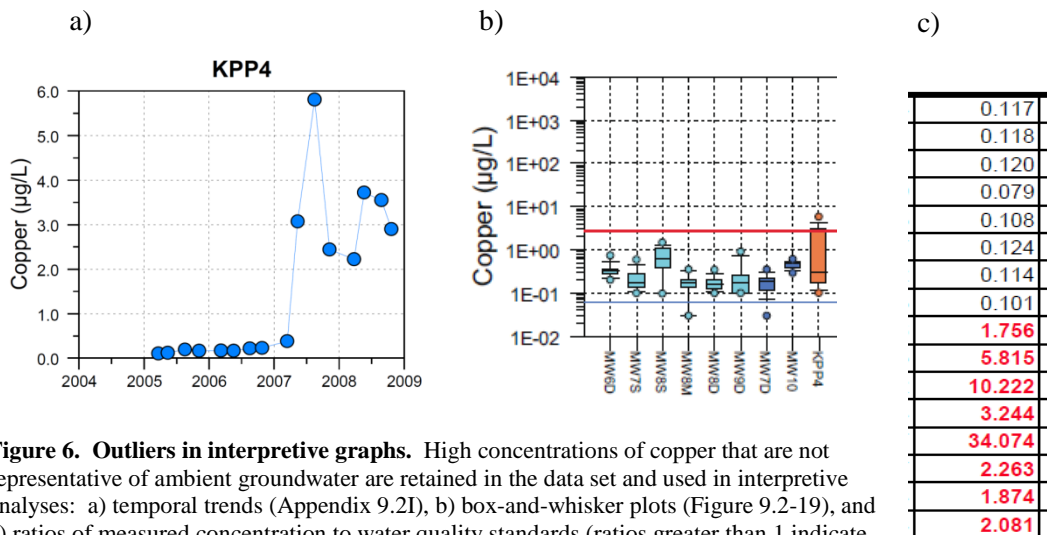


Figure 6. Outliers in interpretive graphs. High concentrations of copper that are not representative of ambient groundwater are retained in the data set and used in interpretive analyses: a) temporal trends (Appendix 9.2I), b) box-and-whisker plots (Figure 9.2-19), and c) ratios of measured concentration to water quality standards (ratios greater than 1 indicate exceedence of water quality standards (Appendix 9.2B)). Monitoring well MW-01M has a similar increasing trend in copper concentrations. Trends for other elements were not examined in this review.

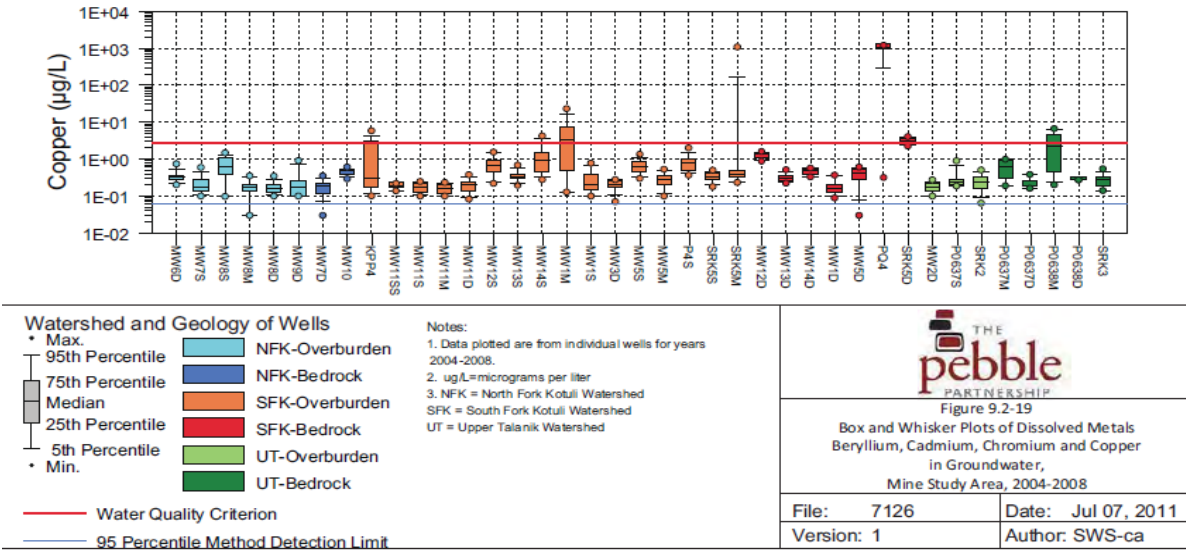


Figure 10. Retained non-representative data affects interpretation of groundwater quality. In this figure from the EBD, non-representative dissolved copper data is plotted with representative data for SRK-5M in box-and-whisker plots, although it was removed from the analysis of “ratio of measured concentrations to water quality standards”. No box-and-whisker plots were developed for total metal concentrations.

Cyanide

Cyanide concentrations were reported to exceed water quality standards at several sites, including two groundwater sites. These are likely false positives. Cyanide is produced naturally by plants or deposited from fires, but cyanide is not present in natural groundwater (personal communication, Dr. Glenn Miller, University of Nevada Reno).

Surface water cyanide concentrations reported are also questionable. In the North Fork Kottuli, “*The samples where WAD cyanide concentrations were naturally above the most stringent maximum criteria were at locations NK100A, NK100AI, and NK100C.*” (PLP 2011c, Section 9.1.8.1). WAD cyanide concentrations in water samples exceeded criteria once or twice at each location, but all samples had total cyanide less than WAD, and most total cyanide was below detection limits. Therefore, it is likely that the WAD analysis was in error. As discussed under “Accuracy”, the primary and secondary labs were out of acceptable performance range for WAD cyanide indicating that concentrations may tend to be low or high, depending on the lab.

Hardness and water quality standards

The EBD reports that total and dissolved copper commonly exceeded standards. Alaska water quality criteria for some metals depend on the hardness of the water (ADEC 2008), but the EBD did not discuss its method for calculating hardness-based criteria and there was no apparent consistent utilization of daily hardness, site mean or median hardness, or watershed mean or median hardness. For example, at the UT, the EBD reports that total copper concentrations exceeded chronic water quality criteria in 35 of 486 samples and that dissolved copper exceeded chronic values in 9 of 350 samples. Virtually all reported exceedences (32 of 35 total copper samples; 8 of 9 dissolved copper samples) occurred at the surface water site UT146A, the closest site to the deposit. Based on hardness on the day of sampling and on mean site hardness, zero to three samples would exceed for dissolved copper (Table 1). Alaska water quality criteria are based on the dissolved concentrations of hardness-dependent metals, and for waters for

which the hardness is less than 25 mg/L, criteria should be calculated using the ambient hardness of the surface water (ADEC 2008). The pattern was repeated in the North Fork Koktuli and South Fork Koktuli (Table 2);¹⁶ many reported exceedences of copper criteria are not supported by data.

Table 1. Copper water quality criteria in the Upper Talarik. Dissolved copper concentrations listed in the EBD as exceeding water quality criteria (Appendix 9.1B) is shown in the first column, with measured ambient hardness in column 2. Median hardness at the site and hardness measured on the day of sample collection, as reported in the EBD, were used in this review to calculate the hardness-based chronic aquatic life criteria (CCC) for copper (columns 3 and 4). Measured copper concentrations are compared to calculated CCC in columns 5 and 6. Zero to three of the 9 reported exceedences are valid. The mean hardness for site UT119B is 15.8 ug/L; for site UT146A is 37 ug/L. At UT146A, exceedences occurred in April, May, or June 2004-2008.

Site	Measured copper concentration (ug/L)	Measured ambient hardness concentration (mg/L as CaCO ₃)	CCC, based on sample hardness (ug/L Cu)	CCC, based on site mean hardness	Exceed based on sample hardness?	Exceed based on mean site hardness?
UT119B	1.26	32	3.4	1.85	No	No
UT146A	1.90	21.5	2.4	3.84	No	
	1.96	34.4	3.6		No	
	2.02	15.8	1.85		Yes	
	1.94	27.8	3.00		No	
	2.32	15.5	1.82		Yes	
	2.21	23.3	2.58		No	
	2.14	15.8	1.85		Yes	
	2.26	27.5	2.97		No	

Table 2. Copper exceedences on a watershed basis. Using mean site copper concentrations and mean hardness values, only a single site within all three watersheds had dissolved copper concentrations exceeding water quality standards. Data source, PLP 2008.

Watershed	No. Sites with Dissolved Cu and Hardness	No. Exceeding Dissolved CCC Value	% Exceeding Dissolved CCC Value
South Fork Koktuli	23	1	4%
North Fork Koktuli	12	0	0%
Upper Talarik	22	0	0%

Issues with data interpretation

- high and low analyte concentrations were inappropriately retained
- seasonal variation in streams was not captured
- stream water quality data from 2008 at the SK may be missing

¹⁶ When EBD data indicating the number of individual samples exceeding dissolved copper criteria is compared to 2004-2007 data with copper criteria calculated using measured hardness, there appear to be at least 50% fewer exceedences than are indicated by the EBD. Individual sample data from the EBD was not used for the calculation due to lack of time; table 2 and the discussed calculation are provided to make the point that metal exceedences are likely over-indicated and not supported by data.

CONCLUSIONS

The general quality of the water in the three main river systems is exceptionally good and indicates water will not easily buffer acid or metal input. Groundwater quality is also high, except in some wells in the immediate vicinity of the deposit.

Groundwater monitoring should be extended spatially (in groundwater upwelling locations and in deep groundwater) and temporally (to capture a longer time period after well development effects have subsided). Analysis of organic compounds also needs to be more extensive spatially and across different types of water bodies. No reference sites have been identified for long term monitoring. Characterization does not distinguish between natural organic acidity and acidity from acid rock drainage, nor does it accurately capture the range of seasonal variation in stream analyte concentrations.

A complete, QC'd database, with explanations of flagged data points, is not provided. Non-representative data is retained and affects interpretation of baseline water quality. Data interpretation in the EBD erroneously implies that surface water and groundwater exceed criteria for metals and cyanide more often than the data would support, and erroneously suggests waters outside a pH of 6.5-8 or below 20 mg/L alkalinity negatively impact fish. Metal concentrations, including copper, in streams and groundwater are low across the region with few exceptions. Copper concentrations in some tributaries on the deposit exceed hardness-based water quality standards. A synthesis of surface water quality copper concentrations with identified habitat and distribution of resident and anadromous fish would clearly show whether natural copper concentrations affect the ability of fish to utilize habitat, and if so, to what extent.

Interpretive material developed from a clear, final data set is needed to accomplish the stated goals of the water quality study.

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