Technical Memorandum

Date: October 24, 2014

To: [redacted]

From: [redacted]

SO #: F1700-110406

PO #: FP9CA-15-0003

RE: Mount Polley – Biological effects of metals on salmonids and freshwater foodwebs of the Quesnel system following Mount Polley Mine tailings pond breach

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This memorandum reviews water and sediment quality data collected by BC Ministry of Environment (MOE) and provided to Azimuth by DFO up to and including water sampling conducted on September 4, 2014. Based on the review, we identify Contaminants of Potential Concern (COPCs; those parameters exceeding relevant water quality guidelines for protection of aquatic life) and evaluate a short list of key COPCs. Finally, we make recommendations for further evaluation of potential adverse impacts on aquatic life.

Importantly, this memorandum is based on a limited set of information, and any conclusions that are drawn should be considered tentative. We understand that additional relevant studies have been undertaken or are in progress. Broader consideration of other information would be appropriate for drawing firmer conclusions and making recommendations for future monitoring.

USE AND LIMITATIONS OF THIS REPORT

This report has been prepared by Azimuth Consulting Group Partnership ("Azimuth"), based partly on data provided by the Ministry of Environment (MOE), for the use of the Department of Fisheries and Oceans (DFO; the "Client"). The Client has been party to the development of the scope of work for the subject project and understands its limitations.

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In addition, the conclusions and recommendations of this report are based upon applicable legislation existing at the time the report was drafted. Changes to legislation, such as an alteration in acceptable limits of contamination, may alter conclusions and recommendations.

This report is time-sensitive and pertains to a specific site and a specific scope of work. It is not applicable to any other site, development or remediation other than that to which it specifically refers. Any change in the site, remediation or proposed development may necessitate supplementary investigation and assessment.

EXECUTIVE SUMMARY

On August 4th, 2014, the tailings pond dam at Mount Polley Mine site in central British Columbia partially breached releasing 25 million cubic meters of water and tailings sediment into the receiving environment, including Polley Lake and known salmon bearing systems; Hazeltine Creek and Quesnel Lake. In light of concerns surrounding the nature of the slurry material and possible environmental impacts, the BC Ministry of Environment (MOE) began environmental sampling. This report reviews water and sediment quality data provided to Fisheries and Oceans Canada by MOE, covering samples collected in Quesnel Lake up to and including September 4, 2014. Our analysis is limited to the water and sediment chemistry data provided and does not consider any additional limnological, chemical (water, sediment or fish), biological, or toxicological data collected by Imperial Metals or others.

Key conclusions are as follows:

- Approximately 15 metals or other parameters have been measured in Quesnel Lake at concentrations exceeding water quality guidelines for protection of aquatic life. In many cases, 'total' metals concentrations surpass guidelines but are nevertheless unlikely to cause significant adverse effects because (a) most exceedances are dominated by particle-bound metals which are less biologically available thereby limiting direct toxicity, and (b) most guidelines are derived in a conservative manner so that they can be generically applied.
- In addition to the effects of the suspended sediment itself, the parameters that have highest potential to pose direct or indirect effects on fish are copper and to a lesser extent aluminum. While other parameters may also warrant more detailed assessment to determine the likelihood of adverse effects, effort should probably be focused primarily on suspended sediment, turbidity, aluminum (dissolved) and copper (total and dissolved).
- Concentrations of key parameters of concern in water are strongly associated with suspended sediments (i.e., the tailings plume).
- Concentrations of suspended sediments (and therefore key parameters of concern) appear to have decreased over time in surface water (i.e., top 5 m) consistent with the expectation that heavier material will sink. Water quality in surface water samples from the latest sampling event (September 4, 2014) is highly unlikely to affect aquatic life. However, concentrations in deeper waters (i.e., > 5 m) are of concern in some areas of Quesnel Lake and the implications of fall turnover need to be considered.

There are many potential mechanisms by which the suspended sediment and associated parameters of concern could impact fish and fish habitat. Based on the information reviewed for this memo, it is not possible to identify their relative importance. Direct toxicity to rearing fry and returning adults may be limited to the extent that fish avoid the turbid water, or if most fish are found in other areas of the lake. Of note, a detailed 1982 study of juvenile sockeye in Quesnel Lake during a dominant cycle year

showed that in late summer and fall the densities of fish were low in the areas around and downstream of Hazeltine Creek. However, clarification of fish movements and behavior in the lake, and their likely response if they encounter turbid water, is very important for understanding potential direct impacts. This memo is based on a limited dataset; as more water quality data and fish distribution data became available they should be reviewed to evaluate plume behavior and transport relative to fish habitat use.

A workshop-based process with relevant DFO and external experts would be appropriate for focusing further work on mechanisms that have the highest potential to cause unacceptable impacts related to DFO's mandate. On October 6-7 2014 scientists met to discuss findings to-date and information needs, which laid the groundwork for such a workshop.

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1. INTRODUCTION

1.1. Background

On August 4th, 2014, the tailings pond dam at Mount Polley Mine site in central British Columbia partially breached releasing 25 million cubic meters of water and tailings sediment into the receiving environment, including Polley Lake and known salmon bearing systems; Hazeltine Creek and Quesnel Lake. The tailings pond covered four square km and a substantial amount of tailings material left the impoundment and entered the downstream environment. The tailings slurry carried felled trees, mud and debris, scoured the banks of Hazeltine Creek which flows out of Polley Lake, and continued into the nearby Quesnel Lake. Hazeltine Creek was temporarily expanded from 2 m in width to 50 m. The spill caused Polley Lake to rise by 1.7 m. Cariboo Creek was also affected.

In light of concerns surrounding the nature of the slurry material and possible environmental impacts, Department of Fisheries and Ocean (DFO)'s National Contaminants Advisory Group (NCAG) established this project to begin assessing information about the biological effects of priority metals and phosphorus on the life stages of Pacific salmon, with a focus on (1) Quesnel Lake sockeye and Quesnel River chinook & coho salmon, and (2) the freshwater food webs of the Quesnel Lake and River systems that support salmon. BC Ministry of Environment (MOE) made their water and sediment quality monitoring dataset available to DFO for this evaluation. DFO has authority for the management and protection of anadromous fish stocks. The NCAG is providing advice to inform DFO's decision-making.

1.2. Purpose

The purpose of this memorandum is to review selected water quality and sediment quality data related to the Mount Polley tailings release to:

1. Identify potential for direct or indirect effects on salmon and their food supply in the Quesnel system
2. Make recommendations to assist DFO in their mandate with respect to the tailings release

1.3. Scope and Budget

This memorandum was prepared based on data from samples collected by MOE using a sampling design and methods developed by MOE. These will be reported by MOE at some time in the future, but for this project water and sediment quality data (only) were made available to DFO for this analysis.

The work presented herein was conducted between September 11 and 25 2014 for a budget of $16,060. Based on review comments, the memo was finalized. As a result, the scope of work was limited but it does provide a foundation upon which DFO can build.

2. RELEVANT DATA

Water and sediment quality data used to support this technical memorandum are attached in **Appendix A** and **Appendix B** respectively. It should be noted that the water quality results are biased towards characterization of 'worst-case' conditions (i.e., the study design was somewhat dynamic in terms of locations and depths sampled in order to track the plume). Generally, this assessment is based on a limited number of samples, collected from a limited area, over a limited period of time and it may not capture the maximum levels present in the lake. Also, it is known that the sediment plume is moving with time. The conclusions of this memo should be used with caution. Ultimately, information regarding the spatial extent and temporal dynamics of the plume need to be considered along with the water quality data when evaluating the potential for adverse effects related to the tailings spill.

2.1. Units of Measurement

Units of measurement for water are typically in mg/L unless otherwise noted, with the following details:

- Hardness and alkalinity as mg/L $CaCO_3$
- Nitrate and ammonia as mg/L N
- Phosphorus is measured as mg/L P, where P is measured as a nutrient (the P in phosphate)
- Conductivity as uS/cm
- Turbidity as NTU

All units of measurement for sediment are ug/g dry weight (dw).

2.2. Water

Water quality data are available for several specific sampling stations over several sampling events. These data include conventional parameters, nutrients and metals. *In situ* data (e.g., dissolved oxygen and temperature) were not provided. There are a total of 75 samples in the data set up to and including September 4, 2014. In general, many stations and depths have not been sampled consistently across events, and meaningful evaluation of individual stations is not possible in many cases due to small sample sizes (even if data for multiple depths are considered). Consequently, and to enable use of all of the data, we have grouped some stations into areas for purposes of data exploration.

All of the station names that were used are shown in the map (**Figure 1**) and the station groupings are shown in **Table 1**. Note that Hazeltine stations were split into those near the mouth of the creek (Hazeltine-Mouth) and those at the deep station further offshore from the mouth (Hazeltine-Deep). The Green Buoy station is located approximately 4 km downstream from the confluence of Hazeltine Creek with Quesnel Lake. The Hazeltine-Deep and the Green Buoy stations were the only areas where samples were collected at depths > 30 m.

2.3. Sediment

Sediment quality data are available for a total of 9 samples collected in August 2014 (see screening table in **Appendix B**). Four of these were collected in and around the tailings pond breach (including one duplicate sample). Four samples were collected in the receiving environment: 2 samples at Hazeltine Creek Outlet; 2 samples in Quesnel Lake between Raft Creek and Hazeltine Creek, just over ½ km downstream of the outlet for Hazeltine Creek. Lastly, one sample was collected as a reference, which is located just over 3 km upstream of the outlet for Hazeltine Creek in Quesnel Lake. In addition, tailings pond sediment quality data prior to the breach are included (a sample taken May 31 2014, and mean sediment concentrations from 2010-2014 monitoring) to provide some information on characterization of the source material.

The sediment fraction that was analyzed for the above samples varied between categories of “Full”, “< 2 mm”, and “< 63 um”. Because metals concentrations differ with sediment grain size, only one of these categories could be used to make accurate comparisons among stations. Although all stations/samples are discussed in the following sections, only those samples for which the “Full” sediment fraction was analyzed are shown in the sediment figure (**Figure 2**). The selection of the “Full” fraction samples excluded the four tailings samples and one of the downstream samples. The sediment figure (**Figure 2**) thus shows two Hazeltine samples, one downstream sample and a reference compared to two tailings composite samples (one being a 2010-2014 mean) from before the tailings breach.

All of the sediment station names that were used are shown in the map (**Figure 1**) and the station groupings with sediment fraction analyzed are shown in **Table 2**.

3. CONTAMINANTS OF POTENTIAL CONCERN

3.1. Water

Water Quality Guidelines (WQGs) for the protection of aquatic life from BC MOE (2006a) and CCME (2007; **Table 3**) were used to screen the data (i.e., both sets of WQGs were used for screening, plotting figures and discussion throughout this section and **Section 4** below). Initially, any parameter that exceeds a WQG in one or more samples is identified as a Contaminant of Potential Concern (COPC). Important details regarding the application of the WQGs to the data set include:

1. pH data were missing in some cases. pH is needed for calculating some guidelines, so where data were missing we used the average of pH from all measured values (7.95).
2. For calculation of the BC ammonia guideline, a pH of 8 and temperature of 15 degrees Celsius were assumed. BC guidelines for ammonia at temp 15 and pH 8 are 5.68 mg/L N (max) and 1.09 mg/L N (30-d).
3. Total hardness was missing in many cases. Hardness is needed for calculating many of the guidelines. Thus, for that purpose where data were missing we estimated total hardness using the relationship between hardness and total calcium for cases where both are measured (linear model, $n = 66$, $r^2 = 0.93$).
4. Cadmium – The BC WQGs are currently being updated (and will apply to dissolved), so the recent CCME guidelines (CCME 2014) are used exclusively rather than the outdated BC WQGs that are still in effect.
5. Phosphorus in the metals package was ignored. Phosphorus in the nutrient package has a much better detection limit (DL) and was compared to the Phosphorus WQGs. See **Section 4.6** for more details. Not including data in the Hazeltine (-Mouth and -Deep) and Green Buoy areas, most measurements of total phosphorus were below the method detection limit (MDL) of 0.002 mg/L. Historic data for Quesnel Lake (Shortreed et al. 2001) indicated total phosphorus of between 0.002 and 0.003 mg/L. Based on these data, the CCME WQG that applies is for ultra-oligotrophic lakes (i.e., 0.004 mg/L).
6. Organic carbon (dissolved and total; DOC and TOC) – The data have not yet been formally evaluated against WQGs. The BC30d WQGs allow for up to 20% change from the background median. We do not have data at the mouth of Hazeltine Creek from before the event, thus data for other stations in the lake would need to be used to establish background. DOC data are very limited. The data for TOC indicate that the background median throughout the lake (not including the Hazeltine and Green Buoy areas) is around 2 mg/L, and the data in the Hazeltine and Green Buoy areas is variable but slightly higher (between 2 and 3 mg/L). The key concern with increases in organic carbon is anoxia resulting from bacterial activity; consequently it may be more appropriate to evaluate dissolved oxygen directly. Furthermore, increases in organic carbon – as long as not causing anoxic conditions or negative indirect effects – could be beneficial for salmon in terms of increasing food supplies and binding of metals (making them less bioavailable).
7. Dissolved Oxygen – no data have been provided regarding dissolved oxygen. These data should be collected and evaluated together with data for DOC/TOC discussed above.

There are a total of 15 parameters that exceed one or more of the relevant WQGs. The degree to which each parameter exceeds WQGs at each monitoring station group is summarized in **Table 4**. Some of these parameters clearly exceed relevant WQGs by a large margin and should be prioritized for more detailed analysis. Conversely, the few parameters that are only slightly elevated do not warrant the same level of concern. The potential cumulative effects (e.g., additive, synergistic and/or antagonistic effects) from exposure to the influence of multiple metals and/or suspended sediments have not been evaluated here. Evaluation of cumulative effects requires information beyond chemical concentrations (i.e., bioavailability assessment).

For this scope of work, DFO has expressed interest in focusing on COPCs which have the highest potential to impact fish. To that end, the parameters listed below from the COPC list are considered much less likely to be drivers of potential effects based on available results. In all cases there is uncertainty, and more detailed evaluation may be appropriate depending on objectives. The parameters and rationale for their exclusion from further consideration in this memorandum were as follows:

- Arsenic – Total arsenic (As.t) marginally exceeds the CCME chronic WQG in one sample (measured concentration 5.74 ug/L compared to the WQG of 5 ug/L). BC adopted the CCME WQG and applies it as a maximum (acute) guideline. The CCME WQG is set well below the lowest-observed-effect-concentrations (LOECs) for algae and invertebrates. Freshwater fish appear to be less sensitive to arsenic than lower trophic level organisms. It is worth noting that the US EPA uses a much higher chronic criterion of 150 ug/L. Given the low concentrations of measured arsenic, the low frequency of exceedance (n = 1), and the conservatism built into the WQG, it seems highly unlikely that arsenic would pose significant risks to aquatic life based on the available data.
- Chromium – Total chromium (Cr.t) exceeds the CCME chronic WQG in a few samples by a factor of less than 5. The BCmax WQG is based on the CCME chronic WQG but is applied in BC as a maximum (acute) WQG. Interestingly, the US EPA water quality criterion is an order of magnitude higher than the CCME chronic WQG. The CCME chronic WQG is based on application of a safety factor of 0.1 (i.e., 10-fold) to a lowest-observed-effect-concentration (LOEC) for an invertebrate. Fish appear to be less sensitive than invertebrates. Dissolved chromium is most relevant to toxicity, and when erosion and turbidity are high it is possible to have high total chromium in unfiltered samples yet have no adverse effects on biota (Environment Canada 1997, Pawlisz et al. 1997). A cursory examination of the data for Quesnel Lake indicates that dissolved concentrations are low or rarely detected even when total concentrations are elevated; for example, in the sample with the highest concentration of total chromium at 4.7 ug/L, the dissolved concentration was measured at 0.11 ug/L. Given the relatively low observed concentrations (particularly for dissolved chromium) and the large safety factor applied in derivation of the WQG, significant risks to aquatic life from chromium seem unlikely.

- Cobalt – Total cobalt (Co.t) exceeds the BC30d WQG at Hazeltine-Deep and at the Green Buoy by less than a factor of 1.5 (**Table 4**). The BC30d WQG is based on application of a safety factor of 2 to the lowest-observed-effect-concentration (LOEC) for sensitive species. The LOEC was 8 ug/L (this is the geometric mean value based on LOECs from 4 studies; two studies used a 7-day *C. dubia* test, one study used a 28-day *D. magna* test, and the other used a 21-day *D. magna* test), whereas the maximum concentration of total cobalt in the Quesnel data set is 5.5 ug/L. Consequently, it seems unlikely that cobalt would pose significant risks to aquatic life based on the available data.
- Lead – total lead (Pb.t) exceeds the CCME chronic WQG in a few samples by a factor of less than 5 (and less than 2 in all but one sample), and barely exceeds the corresponding BC30d WQG in one sample (**Table 4**). Both the BC and CCME WQGs are likely to be protective. Both were developed around the same time, and BC considered the CCME WQG to be over-protective in interpreting no-effects levels reported in the literature (BC MOE 1987). Importantly, the BC WQG acknowledges that dissolved lead is more relevant to toxic effects than total lead[1]. The data for Quesnel Lake show that mean/max concentrations of total lead are approximately an order of magnitude higher than the corresponding mean/max concentrations for dissolved lead. Consequently, it seems unlikely that lead would pose significant risks to aquatic life based on the available data.
- Mercury – Total mercury (Hg.t) slightly exceeds the BC30d WQG in one sample, but does not exceed the corresponding CCME chronic WQG. The exceedance could easily be due to measurement error because the measured value (0.022 ug/L) is not much higher than the method detection limit (which varies between 0.01 and 0.02 depending on the sample). Mercury, particularly the organic form methyl mercury, biomagnifies in the food chain, and the BC30d WQG is driven by potential effects on wildlife consumers of fish. The WQG is back-calculated from a tissue residue guideline (for fish tissue) that is assumed to be protective of wildlife consumers of fish. That tissue residue guideline is naturally exceeded in lakes across BC and is not a guideline for protection of fish themselves. Most importantly, the time frame over which fish accumulate mercury is typically on the order of 1 to 3 years (based on experience with reservoirs), with highest accumulation occurring in top predators (e.g., large lake trout); therefore short-term exceedances of the guideline associated with suspended sediment events are unlikely to be of concern. Taking into account these factors, along with the low frequency of exceedance of the guideline and the low concentrations, it may seem unlikely that mercury will pose significant risks to wildlife. However, with the

[1] "The criteria recommended in this document are primarily based on laboratory bioassays, which usually have been performed using soluble lead and dilution waters of low complex-forming capacities. The criteria are therefore likely to be over-protective for many waterbodies, especially those in which lead complexes may form." (BC MOE 1987).

addition of organic matter to the lake, conditions may be more conducive to the generation of methyl mercury. Over the medium term it may be appropriate to monitor methyl mercury and inorganic mercury using specialized methods, in both water and sediment. The need for further assessment related to mercury should be re-visited as additional data become available.

- Silver – Total silver (Ag.t) exceeds the BC30d WQG at Hazeltine-Deep and at the Green Buoy by less than a factor of 2 (**Table 4**), but does not exceed the corresponding CCME chronic WQG. Both the BC and CCME WQGs are likely to be protective. Importantly, the BC WQG acknowledges that dissolved silver is more relevant to toxic effects than total silver[2]. The data for Quesnel Lake show that dissolved concentrations are much lower than total (maximum concentration 0.02 ug/L dissolved compared to 0.088 ug/L total). Consequently, it seems unlikely that silver would pose significant risks to aquatic life based on the available data.
- Vanadium – Total vanadium (V.t) exceeds the BC WQGs (either the max or 30d) in 10 samples by a factor of less than 5 (**Table 4**). The BC WQGs are working guidelines that were adopted from other agencies. The CCME does not have guidelines for vanadium. A cursory examination of the data for Quesnel Lake indicates that for the 10 data points where total vanadium exceeds WQGs, the corresponding concentrations of dissolved vanadium were less than 10% of the total or were not detectable. Given the relatively low observed concentrations for dissolved vanadium, significant risks to aquatic life from vanadium seem unlikely. That said, there is particularly high uncertainty regarding vanadium given the lack of information available to support WQGs.
- Zinc – Total zinc (Zn.t) exceeds the BC30d WQG near the Green Buoy in a few samples by less than a factor of 5 (maximum factor 3.12), but does not exceed the corresponding CCME chronic WQG. Both the BC and CCME WQGs are likely to be protective. Importantly, soluble zinc is most relevant to toxic effects, and "it is recommended that the zinc guideline may be interpreted in terms of the dissolved metal fraction when the total zinc concentration in the environment exceeds the guideline due to particulate matter and adverse effects due to zinc are not obvious" (BC MOE 1999). Using the data for dissolved zinc in Quesnel Lake, there would be no samples exceeding the BC30d WQG. Consequently, it seems unlikely that zinc would pose significant risks to aquatic life based on the available data.

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[2] "Most existing silver criteria, objectives or regulated amounts are not based on the free ionic monovalent ion, which is acutely toxic to aquatic life. Instead they are based on total silver which includes the metal, complexes and precipitates, all of which are very much less toxic than the monovalent ion. Thus, these existing regulations and criteria are often overprotective. A method of measuring the biologically-available forms of silver is needed so that the criteria and the risk are correlated." (Warrington 1996).

After exclusion of the parameters discussed above, the key COPCs identified for water were:

- TSS
- Turbidity
- Aluminum
- Copper
- Iron
- Phosphorus

Each of the above are evaluated in greater detail in **Section 4**.

It is possible that potentially toxic parameters (e.g., process-related chemicals) are associated with the tailings plume, but these were not analyzed in the suite of parameters. It is also recognized that there are a number of parameters which were measured by the analytical laboratory, but for which WQGs do not exist. While regulatory agencies typically focus their guideline development efforts on parameters which are most prevalent and most likely to cause harm, that does not preclude the possibility that non-regulated parameters could cause potential effects in the receiving environment. These parameters were not included as COPCs. As mentioned above, the potential additive, synergistic and/or antagonistic effects from exposure to these parameters was not considered here.

3.2. Sediment

BC working guidelines for freshwater sediments (BC MOE 2006b) and CCME sediment quality guidelines for the protection of aquatic life (CCME 1999) were used to screen available sediment data (**Table 5**). However, CCME sediment guidelines are not explicitly shown in the screening table (**Appendix B**) or in the sediment figure (**Figure 2**) as they are the same guideline values as the BC guidelines and they cover fewer metals. In addition, BC Contaminated Sites Regulations (CSR) criteria are also used as a screening tool in the discussion below and associated figures and tables.

There are a total of 5 parameters that exceed one or more of the relevant sediment quality guidelines (SQGs) in the receiving environment samples (Quesnel Lake samples). The degree to which each parameter exceeds relevant SQGs at each station is summarized in **Table 6**. Some of these parameters clearly exceed SQGs by a large margin and mirror the findings for water quality; these should be prioritized for more detailed analysis. Conversely, a few that are only slightly elevated do not warrant the same level of concern.

For this effort, DFO has expressed interest in focusing on key COPCs with the highest potential to impact fish. Consequently, the following bullets provide rationale to exclude a few parameters which are less likely than others to significantly impact fish directly or indirectly (in all cases there is uncertainty, and more detailed evaluation may be appropriate depending on objectives):

- Arsenic – Total arsenic exceeds the BC ISQG (interim sediment quality guideline; 5.9 ug/g) in all tailings (onsite) samples (see **Figure 2**). Arsenic also exceeds the ISQG in Hazeltine samples (outlet into Quesnel Lake), but by less than a factor of 2 (8.1 and 8.3 ug/g). The likelihood that concentrations between the ISQG and the PEL (probable effect level) would cause adverse biological effects is dependent on the bioavailability of arsenic and generally arsenic is associated with fractions of the sediment that are not considered readily bioavailable (CCME 1999). When compared to the CSR sediment criteria for typical sites (20 ug/g; see **Figure 2**) the Quesnel Lake samples are all well below that value, meaning that if this site was being evaluated as a contaminated site in BC, arsenic would not screen in as a COPC (CSR 2014). Given that (1) arsenic concentrations in the receiving environment sediments only slightly exceed the ISQG at the Hazeltine station, (2) they are well below the CSR criteria, and (3) the water quality data for arsenic show only one sample that marginally exceeds the guideline (see **Section 3.1**), it is unlikely that arsenic would pose a risk to aquatic life based on available data.
- Chromium – Chromium exceeds the BC ISQG (37.3 ug/g) in one of the downstream samples (not shown in **Figure 2**; 46.7 ug/g). There were no other exceedances of the chromium guidelines and there were generally higher concentrations in Quesnel Lake (including the reference sample) than in onsite samples. The chromium concentrations in Quesnel Lake sediments are likely indicative of background conditions.
- Nickel – Nickel exceeds the BC ISQG (16 ug/g) in both of the downstream samples and also at the reference station (35 ug/g). There were no other exceedances of the nickel guidelines in Quesnel Lake or in the tailings in August 2014 (the 2010-2014 average concentration in tailings exceeded the PEL). The nickel concentrations in Quesnel Lake sediments are likely indicative of background conditions.

After exclusion of the parameters discussed above, the key COPCs identified for sediment were:

- Copper
- Iron

Each of these is evaluated in more detail in **Section 4**.

4. DATA EXPLORATION FOR KEY COPCS

The list of COPCs that are carried forward for more detailed consideration at this stage are:

- Water: TSS, turbidity, aluminum, copper, iron, and phosphorus.
- Sediment: copper and iron.

Both total and dissolved metals concentrations in water are relevant except for iron (there is a WQG for dissolved iron but it is not exceeded). For aluminum there are WQGs for both forms and both are exceeded. In the case of copper we apply the WQGs (for total) to dissolved for purposes of interpreting the data. A plot of key COPCs by station (**Figure 3**), highlighting values below method detection limits (MDLs), confirms that elevated concentrations during the sampling period occur primarily around the areas of Hazeltine-Mouth, Hazeltine-Deep, and the Green Buoy. The plot also confirms that the elevated concentrations are real and not artefacts of elevated MDLs (with an exception for phosphorus in one sample at the Cedar area).

Similar plots with differentiation of values by depth (**Figure 4**) shows that almost all of the highest concentrations of the COPCs occur at depth, within the plume, and not near the water surface. This is consistent with the expectation that the denser plume materials will sink through the water column. In fact, the data suggest that sediment-laden water entered the lake in the Hazeltine-Mouth area, and has generally sunk as it moved towards the Hazeltine-Deep and the Green Buoy areas (these are the only stations for which there are samples from > 30 m depth). Surface water samples appear to have much lower concentrations of COPCs.

Evaluation of COPC concentrations versus turbidity (**Figure 5**) confirms that elevated metal concentrations are associated with the turbid water. The particular relationships between particulate metals, turbidity, TSS, and dissolved metals can be complex and may change over time, space and season. For example, over time and as the plume moves, heavier/larger size particles will settle out and leave finer particles suspended in the water column. Also, with seasonal changes in lake stratification there may be differential effects on grain size classes (i.e., fines may be transported with water mixing, whereas heavier particulates may be less affected by mixing; very small fines may end up collecting at the top of a seasonal density layer). Presumably the dissolved metals will slowly disperse and dilute as the plume degrades although, where the integrity of the plume remains strong, **Figure 5** suggests the dissolved metals may remain associated with the plume zone.

Time series information is also useful for understanding the potential for biological effects, particularly in a setting like Quesnel Lake where plume transport is juxtaposed against strong seasonal changes in the lake's limnology. For this evaluation, data to support time series evaluation is very limited. Sampling has often not targeted consistent stations and depths, and appears to have been driven in part by the objective of sampling the plume (e.g., one of the station names refers to "new path" and was not sampled until mid-August). While this makes sense for understanding worse-case conditions, characterization of temporal trends ideally requires time series data for consistent stations and depths. From MOE's data reviewed for this analysis, the data set for surface samples in the Hazeltine area is by far the most comprehensive. A plot of these surface samples in the Hazeltine area (Hazeltine-Mouth and Hazeltine-Deep combined; **Figure 6**) shows that concentrations of all COPCs for the latest (September 4th) sampling event are below WQGs. Data are insufficient at other depths to make meaningful plots, but a cursory look at the data indicates that concentrations of COPCs at depth have not declined in the same way as surface samples. When DFO reviews Imperial Metal's monitoring program, the sampling design in this regard should receive scrutiny as it will ultimately be important to have a more complete characterization of spatial and temporal dynamics in COPC concentrations in the receiving environment.

4.1. TSS

TSS WQGs from CCME and BC MOE are based mainly on a review and analysis conducted by Caux et al. (1997). Appendix 1 of Caux et al. (1997) summarizes over 300 data points for fish that include TSS concentration, duration of exposure, and response. Salmonids were the most sensitive taxonomic group in their review. We have previously analyzed the Caux et al. (1997) data (for a different site) and found that the guidelines are influenced by a small number of data points indicating effects on eggs/larvae.

For sockeye salmon that spawn in the rivers and not the lake, these data points are not likely relevant when considering potential effects of TSS on sockeye salmon in Quesnel Lake. When eggs/larval life stages are omitted, salmonids can tolerate concentrations of TSS that are higher than WQGs. However, for shoreline spawners (e.g., small population of Kokanee shore spawners in Quesnel Lake from October to early November (Sebastian et al. 2003); Sockeye beach spawners in Quesnel Lake; Quesnel River spawners), the effects data for eggs/alevin would be relevant.

Finally, more detailed evaluation of all the data (i.e., in addition to MOE's dataset) may be warranted to interpret the Quesnel Lake TSS data for other salmonid species, but potential avoidance behaviour by species of interest to DFO should first be characterized, including the potential indirect consequences of displacement associated with avoidance (Birtwell 1999).

4.2. Turbidity

The turbidity WQGs put forth by CCME and BC MOE are based on extrapolation from TSS guidance assuming a particular ratio for TSS to turbidity. DFO's report on effects of sediment on fish and their habitat (DFO 2000) endorses the TSS guidelines from CCME and BC MOE, but does not recommend following the guidelines for turbidity. Rather, turbidity may be used as a surrogate for suspended sediment only when the relationship between the two parameters is established for a particular waterbody. Consequently, we do not focus on the turbidity WQGs because we have direct measures of TSS.

Nevertheless, turbidity may be relevant for predicting some of the potential effects on fish. For example, the suggestion by Robertson et al. (2006) based on available studies that fish will avoid water of turbidity above 40 NTUs is relevant for understanding potential effects. If true, fish would not be exposed to the highest measured concentrations of COPCs (**Figure 5**). On the other hand, unpublished studies by DFO have apparently indicated that fish may tolerate high levels of turbidity in wild settings when they are driven by innate behavioural patterns (e.g., during migration). This requires further evaluation.

4.3. Aluminum

The BCmax WQG for dissolved aluminum is exceeded by a factor of 3 in one sample at the Green Buoy at a depth of 90 m, and by a factor of 2 in one sample at Hazeltine-Mouth at a depth of 7.5 m (**Table 4**). The BC30d WQG for dissolved aluminum is exceeded in a total of 7 samples – 3 at Hazeltine-Deep, 1 at Hazeltine-Mouth, and the other 3 are all from the Green Buoy area on the same date (different depths). It is not possible to apply the BC30d WQG in a strict sense (i.e., the mean of 5 samples in 30 days) because no individual station has been sampled on more than three separate dates. If we consider all stations from the Hazeltine area together, then there have been 9 sampling events. The average concentration of dissolved aluminum across those events and all depths is less than the 30d guideline. If depth is stratified then only surface samples have been sampled on at least 5 separate dates – the average for those samples is also less than the 30d guideline.

The BC WQG states that the guidelines "are likely to be overprotective for many waterbodies, especially for those in a eutrophic condition in which aluminum complexes may form" (Butcher 2001). We could expect the water affected by the tailings to be more capable (due to the presence of inorganic ions such as fluoride, sulphate, and phosphate ions) of forming aluminum complexes than the lab water used in bioassays on which the WQG is based. The preliminary data suggest that exceedances of the WQG are infrequent, and the Hazeltine area (both –Mouth and -Deep) may not have concentrations of dissolved aluminum of concern for potential chronic effects, but additional data at depth will be needed to confirm. The Green Buoy area and the direction of travel of the plume certainly needs additional sampling as well before any conclusions can be drawn.

The CCME chronic WQG for total aluminum is exceeded in many samples. However, it is clear from **Figure 5** that total aluminum is associated with the suspended sediments and is therefore highly unlikely to be in a bioavailable form. Consequently we have little confidence in applicability of the CCME WQG for total aluminum, relative to the WQGs for dissolved aluminum discussed above.

4.4. Copper

For copper, both water quality and sediment quality guidelines were exceeded by a large margin.

4.4.1. Water

The BCmax WQG for total copper is exceeded by a factor of 32 at the Green Buoy area, by a factor of 25 at Hazeltine-Deep, and by a factor of 10 at Hazeltine-Mouth (**Table 4**). The BC WQGs for total copper (Singleton 1987) were adopted from the US EPA. However, BC MOE did not base their acute WQG on acute data; they derived their acute equation from US EPA's chronic criterion based on chronic effects data. Furthermore, an arbitrary intercept of 2 ug/L was added to the hardness-based equation to ensure that the acute criterion was higher than the chronic criterion. As a result of the basis and adjustment to the equation, the current acute guideline in BC (BCmax) is likely to be conservative.

The main disadvantage of using total copper to assess water quality is that a large fraction of the total copper may be in forms that are biologically unavailable, especially in a turbid waterbody (which has a high capacity for binding) (Singleton 1987). The criteria were established for total copper; however, direct toxicity would be limited for copper that is bound to particulate matter.

Although there is no BC or CCME WQG specific to dissolved copper, it is important in the case of Mount Polley (where total copper is still exceeding WQGs) to compare concentrations measured in Quesnel Lake to those that are shown to cause effects. Dissolved copper concentrations in Quesnel Lake were generally < 1 ug/L, but did reach up to 10 ug/L at the Green Buoy area (**Figure 3**). All dissolved copper concentrations > 6 ug/L were measured at depths > 60 m from the Hazeltine-Deep and Green Buoy areas (**Figure 4**), and when focused on the Hazeltine area specifically (**Figure 6**), dissolved copper concentrations in the top 5 m of Quesnel Lake are all < 2 ug/L.

A 2007 review paper looked specifically at sensory effects to juvenile salmonids from exposure to dissolved copper (Hecht et al. 2007). Their review found that juvenile salmon showed an 8 – 57 % reduction in olfactory response after being exposed to dissolved copper concentrations ranging from 0.18 – 2.1 ug/L for 3 hours. In this case, the implication of reduced olfactory response measured was reduced predator avoidance. In other cases, olfactory responses are important in finding food, navigating migratory routes, recognizing kin, reproducing and avoiding pollution (Hecht et al. 2007). In the case of Quesnel Lake sockeye salmon, the distribution of juveniles relative to the tailings plume behavior over time and space should be evaluated. The vast majority of juveniles likely use habitat further upstream in Quesnel Lake (Morton and Williams 1990; see discussion in **Section 5**). So the question is – does or will the plume with elevated concentrations of dissolved copper overlap with the distribution of juvenile sockeye? If not, then impacts might be limited at the population scale. If there is overlap (i.e., exposure) then the consequences of olfactory responses could be significant and merit focused evaluation.

For Quesnel Lake, there may be concern about copper for adult salmonids migrating upstream from Quesnel River through the Hazeltine area. Two other studies were reviewed (in Hecht et al. 2007) which looked at adult salmon and found that spawning migrations in the wild were interrupted at concentrations of copper as low as 20 ug/L (LOEC for Atlantic salmon; Sprague et al. 1965) or apparently interrupted at concentrations as low as 10 – 25 ug/L (LOEC for Chinook salmon; Mebane 2000). Given that the second study is more recent, that the salmon species more relevant, and that the water hardness level from the study (40 mg/L) was closer to being representative of Quesnel Lake hardness (about 45 – 75 mg/L from current data), this study is a good one to use as a means of comparison. Although the lower end of the concentration effect range (10 ug/L) is close to the maximum exposure concentration measured in the current dataset, there is very little overlap (and even less if we adjust the effect concentrations for hardness values of 45 – 75 mg/L). Measureable effects at these concentrations seem unlikely. Furthermore, concentrations of dissolved copper approaching 10 ug/L in Quesnel Lake are associated with turbidity in the range of 100 NTU, which may be above levels at which fish exhibit avoidance behavior (see **Section 4.2**).

4.4.2. Sediment

The BC ISQG (35.7 ug/g) for copper in freshwater sediments is only slightly exceeded in one of the downstream samples and this is likely because in that sample only the fine fraction of the sediment was analyzed (< 63 um; not shown in **Figure 2**). The same guideline is exceeded by a factor of about 21 at the Hazeltine station. When compared to the CSR sediment criteria for typical sites (240 ug/g), the Hazeltine samples exceed by a factor of about 3.

Although the copper concentrations in the sediment at the outlet appear elevated, it is difficult to know how available the copper is to biological organisms and therefore how toxic it may be without having more information. Options for following up on this issue could include synoptic collection of sediment for acid volatile sulphides/simultaneously extracted metals (AVS-SEM) and toxicity testing (CCME 1999).

4.5. Iron

For iron, both water quality and sediment quality guidelines were exceeded by a large margin.

4.5.1. Water

The BCmax WQG for total iron is exceeded in many samples, but there is a separate BCmax WQG for dissolved iron and that is not exceeded in any samples. When monitoring for toxicity, the dissolved fraction is of primary importance and there may be less concern about elevated total iron if dissolved iron is below the WQG (BC MOE 2008). Assuming that the elevated total iron is associated with particulate matter (see **Figure 5**), direct toxicity from iron seems unlikely. Importantly, the iron entering the lake is not dissolved iron that then precipitates – it is total iron that is already associated with the particulates – therefore effects such as precipitation on fish gills should not be a concern given the low concentrations of dissolved iron.

The CCME chronic WQG is exceeded by a large margin in many samples. The WQG is not supported by a fact sheet, and is likely to be based on the guideline of 1 mg/L that "seems to have been accepted over a long period of time without critical examination" (Phippen et al. 2008).

4.5.2. Sediment

Iron is generally elevated in the tailings material, exceeding the BC PEL (43,766 ug/g) in all but one tailings sample (iron exceeds ISQG on this sample). Iron concentrations in the receiving environment are considerably lower, but still exceed the BC ISQG (21,200 ug/g) in all but one of the Quesnel Lake samples (exceeding by a factor of 1.9 at Hazeltine), including the reference station (exceeding by a factor of 1.3).

Elevated iron concentrations at the reference site could indicate naturally elevated background conditions. However, there appears to be a trend of decreasing concentration for iron in sediment samples from tailings to Quesnel Lake receiving environment (**Figure 2**). It is important to note that iron can play an important role in sequestering metals in oxygenated surface sediments (i.e., through the formation of metal-iron oxyhydroxide complexes), thus reducing metals bioavailability. Given the low magnitude of exceedance of the SQGs, significant effects of iron from the sediment seem unlikely. Further work in sediments including consideration of the ability of iron to sequester other metals may be warranted.

4.6. Phosphorus

The CCME WQG for phosphorus (0.004 mg/L) is exceeded by a factor of 47 in the Green Buoy area, by a factor of 41 at Hazeltine-Deep, and by a factor of 14 at Hazeltine-Mouth (**Table 4**). Most measurements of total phosphorus in all other areas were below the method detection limit (MDL) of 0.002 mg/L. As mentioned in **Section 3.1**, Shortreed et al. 2001 indicated that total phosphorus between 0.002 and 0.003 mg/L was typical for Quesnel Lake, which would make the CCME WQG for ultra-oligotrophic lakes apply for these data (i.e., 0.004 mg/L; CCME 2004). However, the BC WQG is likely to be more relevant for DFO's purposes because it is intended to be applied to lakes where salmonid species are the fish of major importance (Nordin 2001). Almost all of the shallow water samples in Quesnel Lake have total phosphorus concentrations less than the BC WQG, whereas the deeper samples in MOE's dataset tended to exceed the WQG. Compared to the BC WQG, phosphorus exceeds by a factor of 12 at the Green Buoy and by a factor of 10 at Hazeltine-Deep (**Table 4**).

Phosphorus is an essential nutrient for plants and animals in aquatic systems. In nature it usually exists as phosphate (PO_4), either organic (i.e., associated with a carbon-based molecule) or inorganic. Inorganic phosphorus is the form required by plants. Aquatic plants take in dissolved inorganic phosphorus and convert it to organic phosphorus as it becomes part of their tissues. Animals get the organic phosphorus they need by eating either aquatic plants, other animals, or decomposing plant and animal material[3].

[3] This information taken from the US EPA website: http://water.epa.gov/type/rsl/monitoring/vms56.cfm

Phosphorus contained in rock is released to the environment as inorganic phosphate. "Aquatic plants require inorganic phosphate for nutrition, typically in the form of orthophosphate ions ($PO4^{3-}$). This is the most significant form of inorganic phosphorus, and is the only form of soluble inorganic phosphorus directly utilized by aquatic biota" (CCME 2004). In a review by Bostrom et al. (1988), it is noted that orthophosphate in the forms $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-} seem to be the only directly available P source for planktonic algae and bacteria[4].

Phosphorus is usually limiting in most fresh waters, and an increase in phosphorus may lead to adverse effects in streams such as accelerated plant growth, algae blooms, low dissolved oxygen, and associated effects on fish and invertebrates. Exploratory analysis by DFO (Shortreed et al. 2001) suggested that productivity in Quesnel Lake may be phosphorus-limited, and that sockeye salmon production could potentially be increased through artificial lake fertilization. Growth and survival of sockeye fry in the lake were strongly density-dependent (food-limited) in years when fry were abundant. Consequently, small increases in phosphorus concentrations may actually be beneficial for rearing fry.

Examination of orthophosphorus data shows that most concentrations are below MDLs (**Figure 3**), and all of the measured concentrations are below the CCME WQG (**Figure 4**). The maximum concentration of orthophosphorus in the data set is 3.2 ug/L. Most importantly, there is no apparent relationship between orthophosphorus and turbidity (**Figure 5**) consequently it seems that the phosphorus that is associated with the turbid water is not in a bioavailable form. Phosphorus should be monitored in case the additional loadings are later transformed to a more bioavailable form, but water quality reviewed here does not appear to indicate a concern for phosphorus.

5. POTENTIAL MECHANISMS OF EFFECTS ON FISH AND FISH HABITAT

DFO wants to identify where there could be effects on the relevant life stages of salmon and food webs in the Quesnel system exposed to tailings-related contaminants through

[4] Phosphorus is measured by labs as either a nutrient or as part of the metals package. In the case of the nutrient analysis, 'total phosphorus' has a typical detection limit of around 0.002 mg/L. In the case of the metals package, the typical detection limit is higher (0.3 mg/L for ALS Laboratory Group in Vancouver). In summary, labs provide two separate measures of total phosphorus, using two different methods with different detection limits. Labs also measure orthophosphate as phosphorus – in that case they filter the sample first (though field filtering is preferable) and therefore they are measuring dissolved phosphorus (in reality not all of it is truly dissolved, but passes through the filter). Half of the datasets received (6 dates) for this report were from ALS, the other datasets were either from Maxxam Analytics (2 dates) or Pacific Environmental Science Center - PESC (4 dates). For the purposes of this evaluation, we have assumed that total phosphorus and orthophosphorus were analyzed by all labs in the same way.

diet and/or direct exposure (e.g., exposure to dissolved metals in the water column). In addition, the effects of the sediment itself are of interest to DFO from a habitat perspective. Within this scope and budget, pulling together a comprehensive analysis was not feasible; however, based on the data screening and our experience we can identify numerous potential effects of the COPCs on fish and fish habitat. These include:

1. Direct physical effects of suspended sediments on fish (e.g., clogging of gills). For chinook and sockeye salmon, this could affect both returning spawners and fry, particularly salmon fry rearing in Quesnel Lake.
2. Acute toxicity to fish from exposure to metals in water.
3. Chronic toxicity to fish from exposure to metals in water, sediment and/or diet.
4. Reduction in food capture efficiency (e.g., fry predation on zooplankton) due to poor visibility.
5. Where fry can tolerate the conditions in the “plume”, decreased predation on fry (i.e., due to turbidity-related reduction in the capture efficiency of their predators) may result in an overall increase in fry survival.
6. Effects of metals or turbidity on olfaction and the ability of adult fish to find their natal spawning streams.
7. Effects of metals or turbidity on olfaction in juvenile fish and the related ecological consequences.
8. Acute or chronic toxic effects of metals in water on fish habitat and food supplies (phytoplankton, zooplankton).
9. Acute or chronic toxic effects of metals in sediment on fish habitat and food supplies (benthic plants / invertebrates).
10. Smothering of benthic food supplies for fish, resulting in a reduction in fish food and habitat (for an indeterminate amount of time related to the toxicity of the tailings in the sediment environment).
11. Smothering of fish eggs for fish that spawn downstream of Hazeltine Creek (e.g,, Sockeye beach spawners and Quesnel River spawners; kokanee subpopulation).
12. Changes in primary production and food supply to salmonid fry due to reduced light penetration in Quesnel Lake. This may fluctuate seasonally and over time.
13. Displacement of fry by the plume resulting in density-dependent growth or mortality elsewhere (in years when food or habitat is limiting juvenile production).

The potential for and the magnitude of many of these mechanisms will depend on a complex of factors such as:

- Avoidance behaviour – As turbidity increases, fish may at some point try to avoid turbid water (Robertson et al. 2006). On the other hand, unpublished studies by DFO have apparently indicated that fish may tolerate high levels of turbidity in wild settings when they are driven by innate behavioural patterns. This requires further evaluation. If avoidance behavior is expected, and if productivity in Quesnel Lake is nutrient limited (which may occur in years of high fry abundance), sediment plume avoidance by fry may result in density-dependent mortality associated with competition with other fry. For returning adults, who are not feeding, the key question is whether they would swim over or around the turbid water, or swim right through it in an effort to make it to their natal stream. Even more importantly, if returning adults from particular stocks naturally follow one shoreline of Quesnel Lake instead of another, metals and suspended sediment exposure between different stocks could be very different.

- Depth – potential exposure will depend on the location and depth at which fish are found. A past study of sockeye fry in Quesnel Lake (Morton and Williams 1990) found that fry were near shore in May and early June 1982, but by mid to late June the near shore densities diminished as they moved offshore. By August the sockeye were well dispersed in the pelagic zone. Hydroacoustic surveys in August and October 1982 showed that the fry migrate vertically each day, ascending during the night to the thermocline (August) or to within a few meters of the surface (October) and descending to tens of meters below surface during the day. This diel migration pattern should be evaluated against plume behavior over time.
- Spatial extent – The spatial extent of elevated COPC concentrations in relation to preferred fry rearing areas and preferred adult migration routes would determine the species/life stages and number of fish that could be affected. A past study of sockeye fry in Quesnel Lake (Morton and Williams 1990) during a dominant cycle year (adult escapement to the Quesnel system was approximately 750,000 in 1981, with 90% in the Horsefly River) showed relatively low densities in the areas around and downstream of Hazeltine Creek in August 1982, and by October 1982 fry were highly concentrated in the area of the lake at the junctions of the three arms (i.e., many km upstream of Hazeltine Creek) – in that area of about 20 km^2, the density of sockeye fry was approximately 8,000 individuals per hectare.
- Time frames – The temporal extent of high and low COPC concentrations in relation to presence of fry and adult salmon is important for determining potential for chronic effects on individual fish as well as potential for effects on stock abundance. Over time, if the residual tailings plume is predicted to leave Quesnel Lake, then effects to downstream resources will need to be evaluated.
- Cumulative effects – There are a multitude of combinations of exposure scenarios, stressors and receptors. It is entirely possible that there are additive, synergistic and/or antagonistic effects such as could be triggered by the influence of multiple metals and/or suspended sediments. The scientific literature on this topic is patchy with significant gaps. For this reason, the advice is to directly measure effects through field and laboratory studies as opposed to infer them from measured concentrations only.

- Contaminant fate and behavior – The metals and suspended solids released into Quesnel Lake will change in their form, fate and behavior over time and through interaction with the environment. From their entry as tailings through to their final destination (e.g., depositional basins in Quesnel Lake, uptake by food chain, loss to Quesnel River), exposure to the parameters of concern will change for the ecological receptors.
- Food sources – Analysis of stomach contents in Quesnel Lake sockeye fry in 1982 (Morton and Williams 1990) showed that they ate zooplankton and not benthic invertebrates or adult insects.
- Life stage – Direct effects on particular salmon stocks are only possible if one or more life stages are present at the time, place and depth at which tailings material is present. Similarly, indirect effects are only possible if the tailings have impacts on habitat or resources on which one or more life stages depend. Clear understanding of the detailed life history of each salmon stock in the Quesnel Lake system will be important for focusing future efforts to characterize impacts.

All of these considerations illustrate the importance of having a conceptual model that depicts (1) the resources that DFO is interested in protecting, and (2) how those resources interact with exposure to released tailings over space, depth and time.

6. RECOMMENDATIONS

This preliminary analysis has identified numerous COPCs and numerous mechanisms by which salmon in Quesnel Lake could potentially be affected. Further analysis should be focused on the COPCs and the mechanisms that are most likely to pose risks. To achieve the required focus, we have four key recommendations:

1. **Workshop:** On October 6-7 2014 scientists met to discuss findings to-date and information needs, which was useful to share information and exchange views. We recommend that a follow-up workshop or process be used to:

    a. Build a “conceptual model” of tailings plume behavior and potential impacts on fish and fish habitat

    b. Evaluate each potential mechanism of effect (i.e., identify relevant data collected by DFO, MOE or others; evaluate likelihood and magnitude of impacts from exposure pathways, etc.)

    c. Identify key data or information gaps and action items

    As an example - the workshop would likely evaluate fish exposure in detail; the tailings plume behavior in Quesnel Lake could be mapped against the seasonal and spatial distributions of fry and returning adult salmon to characterize intersections of receptors (returning adults and fry) and stressors (metals and suspended sediments). Such intersections are where the potential risks exist that may require detailed evaluation, monitoring and/or management action. Ahead of the workshop, a “strawdog” conceptual model could be prepared which would then be expanded and validated by the workshop process. Key outputs would be a prioritized assessment of the pathways that might drive potential risks (see **Section 5**) to the various receptors (chinook and sockeye, for returning spawners and fry) and related recommended actions.

2. **Monitoring Plan Review -** As soon as it becomes available, DFO should review Imperial Metal’s monitoring plan/impact assessment plan to ensure that the objectives and sampling design will meet DFO’s purposes (to the extent that DFO has mandate).
3. **Continue Monitoring -** over the medium term it is appropriate to continue monitoring of water and sediment quality parameters using a structured sampling design, at least for the key COPCs to confirm concentrations and to reassess against guidelines where exceedances occur. However, monitoring should be reconciled to the degree possible across the various parties conducting monitoring to ensure there are not gaps and unintentional overlap.
4. **Integrated Analysis -** When a broader dataset (e.g., other Third Party data, data from Imperial Metals) becomes available, an integrated analysis should be conducted for all available and relevant data (baseline data as well as all environmental and biological data collected since the event). The scope and direction for this integrated analysis could be articulated in part by the workshop process above. Ideally, all parties would be working from the same conceptual model and their work would be complementary.

Over and above these recommendations – pending the workshop process – various tools may be appropriate to further investigate potential effects. In no particular order, potential tools include but are not limited to:

- Biotic Ligand Model (BLM) – For some metals (including but not limited to copper), the BLM could be used to provide some insight into potential bioavailability and toxicity.
- Collection of water samples for specialized analysis of mercury and methyl mercury.
- Zooplankton sampling (tissue concentrations and community assessment) to assess the potential effect on food resources (quantity and quality) for salmon fry.
- Collection of sediment cores to determine the amount and spatial extent of tailings deposition.
- Sediment quality triad studies (chemistry, toxicity, benthic community) to characterize the spatial extent of sediment contamination and associated effects on benthic invertebrates.
- Direct measures of abundance and richness in the lake’s benthic invertebrate community to evaluate recovery over time.

- Use of biomarkers of exposure to metals in fish.
- Collection of fish data to evaluate health (e.g., condition) or bioaccumulation (i.e., tissue samples).
- Hydroacoustic surveys to document fry density and location and to provide a comparison dataset to previous surveys. This work should confirm diel migration patterns and compare them to plume behavior.
- Laboratory toxicity testing to determine the likelihood of toxicity of the water to key food sources for salmon fry (e.g., *Daphnia* was identified as the key food item for sockeye fry (Morton and Williams 1990) and is a standard toxicity testing organism).
- Laboratory toxicity testing of a realistic range of tailings-dosed water to juvenile fish (e.g., use rainbow trout fry as a surrogate species) to establish an exposure-response relationship that can be used to predict effects related to direct exposure.
- Modelling to predict plume behavior over time and space. Quesnel Lake is well-studied and these models may already exist or could be adapted from similar deep lakes in BC. Adaptation of these models for this situation would provide a predictive tool to evaluate exposure over different seasons. Depending on the results, the need for models to predict resource response (e.g., fry survival, growth) could be ascertained.

In conclusion, it is evident there are many factors to consider and possible outcomes that fall within DFO's mandate. If DFO and MOE decide to work alongside each other for technical tasks, the scope of further work may shift somewhat. For example, given the apparent linkage of sockeye fry to the pelagic food chain, potential effects to benthic invertebrates related to sediment toxicity or physical smothering may not be relevant to DFO's mandate. However, effects to benthos are part of MOE's mandate. This example underlines the importance of DFO having a mechanism to focus their attention. Development of a conceptual model for tailings behavior combined with information about the resources of concern would be an expedient and powerful way to prioritize issues.

7. REFERENCES

BC MOE (BC Ministry of Environment). 1987. Water quality criteria for lead – overview report. Original version 1987.

BC MOE. 1999. Ambient water quality guideline for zinc: overview report. Original version 1999.

BC MOE. 2006a. British Columbia Water Quality Guidelines (Criteria): 2006 Edition. Environmental Protection Division 1998, updated August 2006. Victoria, BC.

BC MOE. 2006b. Working Guidelines for Sediments. Environmental Protection Division. Victoria, BC.

BC MOE. 2008. Ambient aquatic life guidelines for iron – overview report. Water Stewardship Division. Ministry of Environment, BC.

Birtwell, I.K. 1999. The effects of sediment on fish and their habitat. Canadian Stock Assessment Secretariat, Research Document 99/139. Fisheries and Oceans Canada.

Bostrom, B., J. Andersen, S. Fleischer and M. Jansson. 1988. Exchange of phosphorus across the sediment-water interface. Hydrobiologia 170: 229-244.

Butcher, G.A. 2001. Water quality criteria for aluminum: overview report. Original version 1988, updated August 7, 2001.

Caux, P.-Y., D.R.J. Moore, and D. MacDonald. 1997. Ambient water quality guidelines (Criteria) for Turbidity, Suspended and Benthic Sediments. Technical Appendix prepared for the BC Ministry of Environment, Lands and Parks. April 1997.

CCME (Canadian Council of Ministers of the Environment). 1999. Canadian sediment quality guidelines for the protection of aquatic life. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CCME. 2004. Canadian water quality guidelines for the protection of aquatic life: Phosphorus: Canadian Guidance Framework for the Management of Freshwater Systems. In: Canadian environmental quality guidelines, 2004, Canadian Council of Ministers of the Environment, Winnipeg.

CCME. 2007. Canadian Water Quality Guidelines for the Protection of Aquatic Life, 1999, updated December 2007.

CCME. 2014. Canadian water quality guidelines for the protection of aquatic life: Cadmium. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CSR (Contaminated Sites Regulation). 2014. Schedule 9: Generic numerical sediment criteria. Deposited December 16, 1997. Updated to January 31, 2014. B.C. Reg. 375/96, including amendments up to B.C. Reg 4/2014.

DFO (Department of Fisheries and Oceans). 2000. Effects of sediment on fish and their habitat. Department of Fisheries and Oceans Canada Pacific Region: Habitat Status report # 2001/01: 9pp.

Environment Canada. 1997. Canadian water quality guidelines for chromium. Supporting document. Environment Canada, Science Policy and Environmental Quality Branch, Ottawa. Unpub. draft doc.

Hecht, S.A., D.H. Baldwin, C.A. Mebane, T. Hawkes, S.J., Gross, and N.L. Scholz. 2007. An overview of sensory effects on juvenile salmonids exposed to dissolved copper: Applying a benchmark concentration approach to evaluate sublethal neurobehavioral toxicity. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-83, 39 p.

Mebane, C. A. 2000. Evaluation of proposed new point source discharges to a special resource water and mixing zone determinations: Thompson Creek Mine, upper Salmon River subbasin, Idaho. Idaho Department of Environmental Quality, Boise, ID.

Morton, K.F., and I.V. Williams. 1990. Sockeye salmon (Oncorhynchus nerka) utilization of Quesnel Lake, British Columbia. Biological Science Branch of Fisheries and Oceans Canada: Canadian Technical report of fisheries and aquatic sciences # 1756: 29pp.

Nordin, R.N. 2001. Water quality criteria for nutrients and algae: overview report. Original version 1985, updated August 7, 2001.

Pawlisz, A.V., R.A. Kent, U.A. Schneider, and C. Jefferson. 1997. Canadian water quality guidelines for chromium. Environ. Toxicol. Water Qual. 12:185–193.

Phippen, B., C. Horvath, R. Nordin, and N. Nagpal. 2008. Ambient water quality guidelines for iron – technical appendix. Prepared for the Water Stewardship Division, Ministry of Environment, BC.

Robertson M.J., D.A. Scruton, R.S. Gregory, and K.D. Clarke. 2006. Effect of suspended sediment on freshwater fish and fish habitat. Science Branch of Fisheries and Oceans Canada: Canadian Technical report of fisheries and aquatic sciences # 2644: 44pp.

Sebastian, D., R. Dolighan, H. Andrusak, J. Hume, P. Woodruff and G. Scholten. 2003. Summary of Quesnel LakeKokanee and Rainbow Troup Biology with Reference to Sockeye Salmon. Stock Management Report No. 17. Province of British Columbia. 109 pp.

Shortreed K.S., K.F. Morton, K. Malange, and J.M.B. Hume. 2001. Factors limiting juvenile sockeye for selected B.C. nursery lakes. Fisheries and Oceans Canada: Research document # 2001/098: 70pp.

Singleton, H.J. 1987. Water quality criteria for copper – technical appendix. Prepared for the Ministry of Environment and Parks, BC.

Sprague, J., P. Elson, and R. Saunders. 1965. Sublethal copper-zinc pollution in a salmon river—A field and laboratory study. Int. J. Air Water Pollut. 9:531–543.

US EPA website: http://water.epa.gov/type/rsl/monitoring/vms56.cfm

Warrington, P.D. 1996. Ambient water quality criteria for silver – technical appendix. Prepared for the Ministry of Environment, Lands and Parks, BC.

Table 1. Overview of MOE water quality sampling data to September 4, 2014.

Station.Group	Station.Description	Unique Dates	Unique Depths
Likely	Quesnel River @ Likely Townsite	1	1
	Quesnel River off Likely Bridge	2	1
Island	Quesnel Lake U/S Island N. shore	1	2
	Quesnel River U/S Island N. shore	3	3
	Quesnel River U/S Island N. shore - Replicate	2	1
Cedar	Quesnel Lake East of Cedar Creek	1	2
	Quesnel Lake N. shore East of Cedar Creek	4	2
	Quesnel Lake N. shore West of 4 Cabins	1	1
Green Buoy	Quesnel Lake West arm Green Buoy Deep Station	1	4
Hazeltine-Deep	Quesnel Lake near Hazeltine Creek - Deep Station	3	9
Hazeltine-Mouth	Quesnel Lake at Hazeltine Creek	1	1
	Quesnel Lake at Hazeltine Creek Confluence	2	5
	Quesnel Lake at Hazeltine Creek, New Path	3	4
	Quesnel Lake at Hazeltine Creek, Site A (near new path)	1	4
	Quesnel Lake at Hazeltine Creek, Site B (bwt A&C)	1	1
	Quesnel Lake at Hazeltine Creek, Site C (near confl.)	1	2
	Quesnel Lake at mouth of Hazeltine Creek	2	1
	Quesnel Lake at mouth of Hazeltine Creek - Replicate	1	1
Mitchell	Quesnel Lake SE Corner of Mitchell Bay	4	4
Cariboo	Quesnel Lake, Cariboo Island Shelf	1	2
Bible	Quesnel Lake near Abbot Creek and Likely Bible Camp	1	1

Table 2. Overview of MOE sediment quality sampling data.

Station.Group	Station.Description	Date	Depth of Sample (m)	Sediment Fraction Analyzed
Tailings	Tailings Composite Metals	2010-2014 average	NA	Full
	Tailings Composite Metals	31-May-14	NA	Full
	Within Tailings Impoundment	12-Aug-14	NA	<2mm
	Outside Tailings Dam Breach	12-Aug-14	NA	<2mm
	Outside Tailings Dam Breach DUP	12-Aug-14	NA	<2mm
	Outside Tailings Impoundment @ Breach	15-Aug-14	NA	<2mm
Hazeltine	Hazeltine Outlet	10-Aug-14	2.5	Full
	Hazeltine Outlet	10-Aug-14	1	Full
Downstream	QL b/w Raft Creek & Hazletine Ck	07-Aug-14	10	Full
	QL b/w Raft Creek & Hazletine Ck	07-Aug-14	10	63um
Reference	Raft Creek	10-Aug-14	3.5	Full

Notes: NA = not available.

Table 3. Water quality guidelines for the protection of aquatic life [1].

	BC WQGs for Protection of Aquatic Life		CCME WQGs for Protection of Aquatic Life	
	30-d Average	Maximum	Chronic	Acute
Aluminum (dissolved)	if pH ≥ 6.5, d.Al = 0.05; if pH < 6.5, d.Al = $_e$(1.6 - 3.327 (med pH) + 0.402(med pH)^2)	if pH ≥ 6.5, d.Al = 0.1; if pH < 6.5, d.Al = $_e$(1.209 - 2.426 (pH) + 0.286 (pH)^2)	none	none
Aluminum (total)	none	none	0.005 at pH<6.5, 0.1 if pH ≥ 6.5	none
Ammonia as N	pH and termperature dependent	pH and temperature dependent	none	pH and temperature dependent
Antimony	none	0.02	none	none
Arsenic[2]	none	0.005	0.005	none
Barium	1	5	none	none
Beryllium	0.0053	none	none	none
Boron	none	1.2	1.5	29
Bromide	none	none	none	none
Cadmium (dissolved)	Currently being updated	Currently being updated	none	none
Cadmium (total)	Being replaced with guideline for dissolved cadmium	Being replaced with guideline for dissolved cadmium	($10^{0.83\,[\log10\,(hardness)]\,-2.46}$)/1000 at hardness range 17 to 280; 0.00004 at hardness < 17; 0.00037 at hardness > 280.	($10^{1.016\,[\log10\,(hardness)]\,-1.71}$)/1000 at hardness range 5.3 to 360; 0.00011 at hardness < 5.3; 0.0077 at hardness > 360.
Chloride	150	600	120	640
Chromium[3]	none	0.001 (CrVI); 0.0089 (CrIII)	0.001 (CrVI); 0.0089 (CrIII)	none
Cobalt	0.004	0.11	none	none
Copper	if hardness ≤ 50mg/L, then Cu ≤ 0.002mg/L, if >50mg/L, then Cu≤0.00004xhardness	(0.094(hardness)+2)/1000	($e^{0.8545[\ln(hardness)]-1.465}$*0.2)/ 1000 at hardness range 82 to 180; 0.002 at hardness <82 or if hardness unknown; 0.004 at hardness > 180	none
Fluoride	none	(-51.73+92.57 $\log_{10}$ (hardness)) x 0.01; should not exceed 0.4mg/L at a water hardness of 10 mg/L $CaCO_3$	0.12	none
Iron (total)[4]	none	1	0.3	none
Iron (dissolved)	none	0.35	none	none
Lead	(if hardness ≤ 8mg/L), no guideline; (if hardness > 8mg/L), ≤ (3.31 + $e^{(1.273\,\ln\,(mean\ hardness)\,-\,4.704)}$)/1000	(if hardness ≤ 8mg/L), ≤0.003mg/L; (if hardness > 8mg/L), =$e^{(1.273\,\ln\,(hardness)\,-1.460)}$/1000	($e^{1.273[\ln(hardness)]-4.705}$)/ 1000 at hardness range 60 to 180; 0.001 at hardness <60; 0.007 at hardness > 180	none
Magnesium	none	none	none	none
Manganese	≤0.0044 (hardness) + 0.605	≤ 0.01102 (hardness) + 0.54	none	none
Mercury	0.00002 (lower if proportion methyl > 0.5%)	none	0.000026	none
Molybdenum	1	2	0.073	none
Nickel	none	0.025 (max at hardness (as CaCO3) of 0 to 60mg/L); 0.065 (max at hardness of 60 to 120 mg/L); 0.110 (max at hardness of 120 to 180mg/L); 0.150 (max at hardness greater than 180mg/L)	($e^{0.76[\ln(hardness)]+1.06}$)/1000 at hardness range 60 to 180; 0.025 at hardness < 60 or if hardness unknown; 0.150 at hardness > 180	none
Nitrite (as N)	0.02 (higher if chloride > 2 mg/L)	0.06 (higher if chloride > 2 mg/L)	0.06	none
Nitrate (as N)	3	32.8	3	124
Nitrite + Nitrate (as N)	none	none	none	none
Organic Carbon	for DOC and TOC, guideline = 30-d median +/- 20% of the median background concentration	none	none	none
Phosphorous	For lakes only: 0.005 to 0.015 mg/L, where salmonids are the dominant fish		If trophic status known, can use the following upper limits: Ultra-oligotrophic = 0.004; Oligotrophic = 0.010; Mesotrophic = 0.020; Meso-eutrophic = 0.035; Eutrophic = 0.100. If within limits, a secondary trigger is a 50% increase over baseline.	
Selenium	0.002	none	0.001	none
Silver	if hardness≤100mg/L, then Ag≤0.00005mg/L; if hardness>100mg/L, then Ag≤0.0015mg/L	if hardness≤100mg/L, then Ag≤0.0001mg/L; if hardness>100mg/L, then Ag≤0.003mg/L	0.0001	none
Sulphate (total SO_4)	128 mg/L at hardness 0-30 mg/L $CaCO_3$; 218 at hardness 31-75; 309 at hardness 76-180; 429 at hardness 181-250); guideline requires site-specific work at hardness > 250	none	none	none
Thallium	0.0008	0.0003	0.0008	none
Titanium	2	none	none	none

Table 3. Water quality guidelines for the protection of aquatic life [1].

	BC WQGs for Protection of Aquatic Life		CCME WQGs for Protection of Aquatic Life	
	30-d Average	Maximum	Chronic	Acute
Uranium	0.5	0.3	0.015	0.033
Vanadium[5]	0.02	0.006	none	none
Zinc	If hardness < 90 mg/L, then Zn≤.0075 Else (7.5 + 0.75 x (hardness -90))/1000	If hardness < 90 mg/L, then Zn≤0.033 Else (33 + 0.75 x (hardness -90))/1000	0.03	none
pH	Range from 6.5 to 9.0. For cases where natural pH<6.5, no statistically significant decrease in pH from background	none	none	none
Dissolved Oxygen	Minimum 30 d mean is 11 mg/L O2 in the water column for buried embryo / alevin life stages; 8 mg/L O2 for all other life stages	Minimum 9 mg/L O2 in the water column for buried embryo / alevin life stages; 6 mg/L O2 for interstitial water for buried embryo / alevin life stages; 5 mg/L O2 for all other life stages	Minimum 9.5 mg/L for early life stages, 6.5 mg/L for other life stages	
Turbidity	Change from background of 2 NTU at any one time for a duration of 30 d in all waters during clear flows or in clear waters	Change from background of 8 NTU at any one time for a duration of 24 h in all waters during clear flows or in clear waters; Change from background of 5 NTU at any time when background is 8 - 50 NTU during high flows or in turbid waters; Change from background of 10% when background is >50 NTU at any time during high flows or in turbid waters	**Clear Flow**: Maximum increase of 8 NTUs from background levels for a short-term exposure (e.g., 24-h period). Maximum average increase of 2 NTUs from background levels for a longer term exposure (e.g., 30-d period). **High Flow or Turbid Waters**: Maximum increase of 8 NTUs from background levels at any one time when background levels are between 8 and 80 NTUs. Should not increase more than 10% of background levels when background is >80 NTUs	
Total Suspended Solids	Change from background of 5 mg/L at any one time for a duration of 30 d in all waters during clear flows or in clear waters	Change from background of 25 mg/L at any one time for a duration of 24 h in all waters during clear flows or in clear waters; Change from background of 10 mg/L at any time when background is 25 - 100 mg/L during high flows or in turbid waters; Change from background of 10% when background is >100 mg/L at any time during high flows or in turbid waters	**Clear Flow**: Maximum increase of 25 mg/L from background levels for any short-term exposure (e.g., 24-h period). Maximum average increase of 5 mg/L from background levels for longer-term exposures (e.g., inputs lasting b/w 24h & 30d); **High Flow**: Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is >250 mg/L.	

Notes:

1 All units in mg/L unless otherwise stated.

2 BC's aquatic life guideline for arsenic is based on the CCME guideline, and is applied in BC as a maximum.

3 The Cr(VI) number is considered applicable. According the CCME factsheet for chromium, Cr(VI) is the principal species found in surface waters while Cr(III) is more prevalent in mildly reducing environments such as sediments and wetlands. BC's guidelines for chromium are based on the CCME guideline, and is applied as a maximum.

4 The CCME iron guideline is driven by a chronic endpoint.

5 The single BC vanadium guideline is not specified as 30-d or maximum. The original Ontario document on which the guideline is based considers both acute and chronic data, but the guideline number is driven by a chronic data point. Therefore the guideline is applied as a 30-d guideline. A secondary chronic guideline for BC of 0.02 mg/L is higher than 0.006 mg/L and is therefore ignored.

Table 4. Exceedances of water quality guidelines by station group and parameter.

			CCME acute					CCME chronic					BC Max					BC 30-d					Concentrations				
Parameter	variable	Station.Group	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max
Silver	Ag.t	Green Buoy						0.10	0.48	0.47	0.83	0.88	0.10	0.48	0.47	0.83	0.88	0.20	0.96	0.93	1.65	1.76	0.0000	0.0000	0.0000	0.0001	0.0001
	Ag.t	Hazeltine - Deep						0.10	0.32	0.33	0.65	0.74	0.10	0.32	0.33	0.65	0.74	0.20	0.64	0.65	1.29	1.48	0.000	0.000	0.000	0.000	0.000
Aluminum	Al.d	Green Buoy											0.10	1.22	0.80	2.84	3.19	0.19	2.44	1.60	5.68	6.38	0.010	0.122	0.080	0.284	0.319
	Al.d	Hazeltine - Deep											0.10	0.30	0.28	0.54	0.55	0.19	0.60	0.56	1.09	1.10	0.010	0.030	0.028	0.054	0.055
	Al.d	Hazeltine - Mouth											0.06	0.22	0.13	0.28	2.05	0.12	0.44	0.26	0.56	4.10	0.006	0.022	0.013	0.028	0.205
	Al.t	Cariboo						0.15	1.29	1.29	2.31	2.42											0.015	0.129	0.129	0.231	0.242
	Al.t	Green Buoy						0.16	67.81	55.55	146.68	160.00											0.016	6.781	5.555	14.668	16.000
	Al.t	Hazeltine - Deep						0.16	36.58	34.45	91.54	99.90											0.016	3.658	3.445	9.154	9.990
	Al.t	Hazeltine - Mouth						0.20	4.24	1.33	12.70	33.59											0.020	0.424	0.133	1.270	3.359
	Al.t	Mitchell						0.18	0.49	0.36	1.10	1.32											0.018	0.049	0.036	0.110	0.132
Arsenic	As.t	Green Buoy						0.03	0.54	0.49	1.06	1.15	0.03	0.54	0.49	1.06	1.15						0.000	0.003	0.002	0.005	0.006
Cobalt	Co.t	Green Buoy											0.00	0.02	0.02	0.05	0.05	0.03	0.67	0.64	1.29	1.38	0.000	0.003	0.003	0.005	0.006
	Co.t	Hazeltine - Deep											0.00	0.01	0.01	0.03	0.04	0.03	0.37	0.35	0.89	1.07	0.000	0.001	0.001	0.004	0.004
Chromium	Cr.t	Green Buoy						0.10	2.69	2.99	4.48	4.70	0.10	2.69	2.99	4.48	4.70						0.000	0.003	0.003	0.004	0.005
	Cr.t	Hazeltine - Deep						0.10	1.68	1.82	3.52	3.79	0.10	1.68	1.82	3.52	3.79						0.000	0.002	0.002	0.004	0.004
	Cr.t	Hazeltine - Mouth						0.20	0.29	0.20	0.40	1.60	0.20	0.29	0.20	0.40	1.60						0.000	0.000	0.000	0.000	0.002
Copper	Cu.t	Cariboo						0.25	1.05	1.05	1.77	1.85	0.08	0.30	0.30	0.51	0.53	0.25	0.99	0.99	1.66	1.74	0.001	0.002	0.002	0.004	0.004
	Cu.t	Cedar						0.25	0.66	0.36	1.31	1.40	0.07	0.20	0.11	0.39	0.42	0.25	0.66	0.36	1.31	1.40	0.001	0.001	0.001	0.003	0.003
	Cu.t	Green Buoy						0.34	69.96	60.93	145.72	157.67	0.10	15.34	14.38	30.34	32.49	0.34	46.05	44.23	89.46	95.42	0.001	0.142	0.122	0.300	0.325
	Cu.t	Hazeltine - Deep						0.27	36.90	34.08	90.08	108.50	0.08	8.76	8.40	21.17	25.26	0.27	27.00	26.18	65.02	77.39	0.001	0.074	0.068	0.180	0.217
	Cu.t	Hazeltine - Mouth						0.34	4.79	2.06	10.56	35.75	0.11	1.38	0.62	3.13	10.00	0.34	4.54	2.06	10.45	32.62	0.001	0.010	0.004	0.021	0.072
	Cu.t	Likely						0.29	0.81	0.97	1.16	1.19	0.09	0.25	0.29	0.35	0.36	0.29	0.81	0.97	1.16	1.19	0.0006	0.0016	0.0019	0.0023	0.0024
	Cu.t	Mitchell						0.30	0.73	0.63	1.30	1.43	0.09	0.22	0.19	0.37	0.41	0.30	0.71	0.62	1.23	1.35	0.001	0.001	0.001	0.003	0.003
Iron	Fe.t	Green Buoy						0.06	11.82	11.85	22.04	23.53	0.02	3.55	3.56	6.61	7.06						0.017	3.547	3.555	6.612	7.060
	Fe.t	Hazeltine - Deep						0.07	6.73	6.63	15.87	18.73	0.02	2.02	1.99	4.76	5.62						0.020	2.018	1.990	4.762	5.620
	Fe.t	Hazeltine - Mouth						0.17	1.52	0.60	4.17	12.10	0.05	0.46	0.18	1.25	3.63						0.050	0.455	0.180	1.250	3.630
Mercury	Hg.t	Green Buoy						0.38	0.55	0.48	0.81	0.85						0.50	0.71	0.63	1.05	1.10	0.000	0.000	0.000	0.000	0.000
Lead	Pb.t	Green Buoy						0.05	0.96	1.01	1.69	1.78	0.00	0.04	0.04	0.07	0.07	0.01	0.39	0.38	0.73	0.78	0.000	0.002	0.002	0.004	0.005
	Pb.t	Hazeltine - Deep						0.05	0.66	0.67	1.45	1.61	0.00	0.03	0.03	0.06	0.06	0.01	0.24	0.24	0.55	0.61	0.000	0.001	0.001	0.003	0.003
	Pb.t	Hazeltine - Mouth						0.01	0.43	0.07	1.35	4.60	0.00	0.01	0.00	0.04	0.15	0.00	0.09	0.02	0.28	1.02	0.000	0.000	0.000	0.001	0.005
Phosphorus	Phos	Bible						1.20	1.20	1.20	1.20	1.20						0.32	0.32	0.32	0.32	0.32	0.005	0.005	0.005	0.005	0.005
	Phos	Green Buoy						0.50	16.71	9.54	41.85	47.25						0.13	4.46	2.54	11.16	12.60	0.002	0.067	0.038	0.167	0.189
	Phos	Hazeltine - Deep						0.50	7.33	4.25	24.23	41.00						0.13	1.95	1.13	6.46	10.93	0.002	0.029	0.017	0.097	0.164
	Phos	Hazeltine - Mouth						0.50	2.95	1.65	9.40	14.40						0.13	0.79	0.44	2.51	3.84	0.002	0.012	0.007	0.038	0.058
TSS	TSS	Green Buoy	0.12	3.35	2.23	7.90	8.80	0.60	16.74	11.17	39.50	44.00	0.12	3.35	2.23	7.90	8.80	0.60	16.74	11.17	39.50	44.00	3.000	84	56	198	220
	TSS	Hazeltine - Deep	0.12	0.97	0.40	3.55	5.88	0.60	4.86	1.98	17.74	29.40	0.12	0.97	0.40	3.55	5.88	0.60	4.86	1.98	17.74	29.40	3.000	24	10	89	147
	TSS	Hazeltine - Mouth	0.08	0.44	0.13	1.94	3.28	0.40	2.21	0.67	9.68	16.40	0.08	0.44	0.13	1.94	3.28	0.40	2.21	0.67	9.68	16.40	2.000	11.041	3.350	48	82
	TSS	Mitchell	0.12	0.14	0.12	0.24	0.33	0.60	0.71	0.60	1.18	1.66	0.12	0.14	0.12	0.24	0.33	0.60	0.71	0.60	1.18	1.66	3.000	3.530	3.000	5.915	8.300
Turbidity	Turb	Cariboo	0.04	0.27	0.27	0.47	0.49	0.16	1.06	1.06	1.87	1.97	0.04	0.27	0.27	0.47	0.49	0.16	1.06	1.06	1.87	1.97	0.320	2.125	2.125	3.750	3.930
	Turb	Green Buoy	0.04	22.68	15.96	53.03	58.75	0.17	90.70	63.83	212.13	235.00	0.04	22.68	15.96	53.03	58.75	0.17	90.70	63.83	212.13	235.00	0.330	181	128	424	470
	Turb	Hazeltine - Deep	0.08	10.14	8.22	26.18	31.13	0.32	40.55	32.88	104.70	124.50	0.08	10.14	8.22	26.18	31.13	0.32	40.55	32.88	104.70	124.50	0.640	81	66	209	249
	Turb	Hazeltine - Mouth	0.04	1.23	0.35	5.37	8.51	0.15	4.92	1.41	21.46	34.05	0.04	1.23	0.35	5.37	8.51	0.15	4.92	1.41	21.46	34.05	0.300	10	2.810	43	68
	Turb	Mitchell	0.04	0.12	0.10	0.24	0.27	0.16	0.49	0.42	0.97	1.06	0.04	0.12	0.10	0.24	0.27	0.16	0.49	0.42	0.97	1.06	0.320	0.977	0.835	1.931	2.120
Vanadium	V.t	Green Buoy											0.17	2.14	1.90	4.26	4.60	0.05	0.64	0.57	1.28	1.38	0.001	0.013	0.011	0.026	0.028
	V.t	Hazeltine - Deep											0.17	1.22	1.14	2.81	3.37	0.05	0.37	0.34	0.84	1.01	0.001	0.007	0.007	0.017	0.020
	V.t	Hazeltine - Mouth											0.03	0.20	0.10	0.57	1.35	0.01	0.06	0.03	0.17	0.40	0.000	0.001	0.001	0.003	0.008
Zinc	Zn.t	Green Buoy						0.10	0.42	0.40	0.73	0.78	0.09	0.38	0.36	0.67	0.71	0.40	1.68	1.60	2.93	3.12	0.003	0.013	0.012	0.022	0.023
	Zn.t	Hazeltine - Deep						0.10	0.27	0.25	0.53	0.64	0.09	0.24	0.23	0.48	0.58	0.40	1.07	1.01	2.12	2.55	0.003	0.008	0.008	0.016	0.019
	Zn.t	Hazeltine - Mouth						0.06	0.11	0.11	0.18	0.32	0.05	0.10	0.10	0.16	0.29	0.23	0.46	0.43	0.70	1.27	0.002	0.003	0.003	0.005	0.010

Notes:

(grey) exceedance between 1 and 10 times the WQG

(black) exceedance >10 times the WQG

Table 5. Sediment quality guidelines.

	BC Working Sediment Quality Guidelines (2006b)		CSR Sediment Criteria (2014)		CCME Sediment Quality Guidelines (1999)	
	ISQG	PEL	Sensitive	Typical	ISQG	PEL
TOTAL METALS (mg/kg dw)						
Arsenic	5.9	17	11	20	5.9	17
Cadmium	0.6	3.5	2.2	4.2	0.6	3.5
Chromium	37.3	90	56	110	37.3	90
Copper	35.7	197	120	240	35.7	197
Iron[1]	21200	43766	-	-	-	-
Lead	35	91	57	110	35	91.3
Manganese[1]	460	1100	-	-	-	-
Mercury	0.170	0.486	0.3	0.58	0.170	0.486
Nickel[1]	16	75	-	-	-	-
Selenium[2]	2	-	-	-	-	-
Silver[3]	0.5	-	-	-	-	-
Zinc	123	315	200	380	123	315

Notes: "-" = no guideline; ISQG = Interim freshwater Sediment Quality Guideline, PEL = Probable Effect Level; [1]The guidelines for iron, manganese, and nickel are derived by the Ontario Ministry of Environment where ISQG corresponds with Lowest Effects Level (LEL), and PEL corresponds with Severe Effects Level (SEL), however LEL is less conservative than ISQG; [2]The guideline for selenium is neither an ISQG nor a PEL, rather, it's part of the BC Water Quality Guidelines for the Protection of Aquatic Life; [3]The guideline for silver is derived by the Ontario Ministry of Environment, and neither an ISQG nor a PEL, rather, it's carried over from Ontario's Open Water Disposal Guidelines.

Table 6. Exceedances of sediment quality guidelines by station group and parameter.

		BC ISQG					BC PEL					CSR (Typical Sites)					Concentrations				
Parameter	Station.Group	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max	Min	Mean	Median	95%ile	Max
Arsenic (As)	Hazeltine	1.37	1.39	1.39	1.41	1.41	0.48	0.48	0.48	0.49	0.49	0.41	0.41	0.41	0.41	0.42	8.1	8.2	8.2	8.29	8.3
	Tailings	1.42	1.88	2.01	2.10	2.10	0.49	0.65	0.70	0.73	0.73	0.42	0.55	0.59	0.62	0.62	8.4	11.10	11.85	12.38	12.4
Chromium (Cr)	Downstream	0.62	0.94	0.94	1.22	1.25	0.26	0.39	0.39	0.51	0.52	0.21	0.32	0.32	0.41	0.42	23.2	34.95	34.95	45.53	46.7
Copper (Cu)	Downstream	0.52	0.81	0.81	1.07	1.10	0.09	0.15	0.15	0.19	0.20	0.08	0.12	0.12	0.16	0.16	18.6	28.85	28.85	38.075	39.1
	Hazeltine	19.89	20.69	20.69	21.40	21.48	3.60	3.75	3.75	3.88	3.89	2.96	3.08	3.08	3.18	3.20	710	738.5	738.5	764.15	767
	Tailings	18.10	21.49	20.06	25.99	26.08	3.28	3.90	3.63	4.71	4.73	2.69	3.20	2.98	3.87	3.88	646	767	716	928	931
Iron (Fe)	Downstream	0.80	0.95	0.95	1.08	1.09	0.39	0.46	0.46	0.52	0.53						17000	20100	20100	22890	23200
	Hazeltine	1.76	1.83	1.83	1.88	1.89	0.85	0.88	0.88	0.91	0.91						37400	38700	38700	39870	40000
	Reference	1.30	1.30	1.30	1.30	1.30	0.63	0.63	0.63	0.63	0.63						27600	27600	27600	27600	27600
	Tailings	1.32	2.03	2.09	2.32	2.34	0.64	0.98	1.01	1.12	1.13						27900	43009	44250	49213	49651
Nickel (Ni)	Downstream	1.23	1.74	1.74	2.20	2.25	0.26	0.37	0.37	0.47	0.48						19.7	27.85	27.85	35.19	36
	Reference	2.19	2.19	2.19	2.19	2.19	0.47	0.47	0.47	0.47	0.47						35	35	35	35	35
	Tailings	0.29	1.44	0.49	5.03	6.54	0.06	0.31	0.10	1.07	1.39						4.7	23.05	7.8	80.4	104.6

Notes:

Parameters that exceed only in tailings are not included.

(grey) exceedance between 1 and 10 times the SQG

(black) exceedance >10 times the SQG

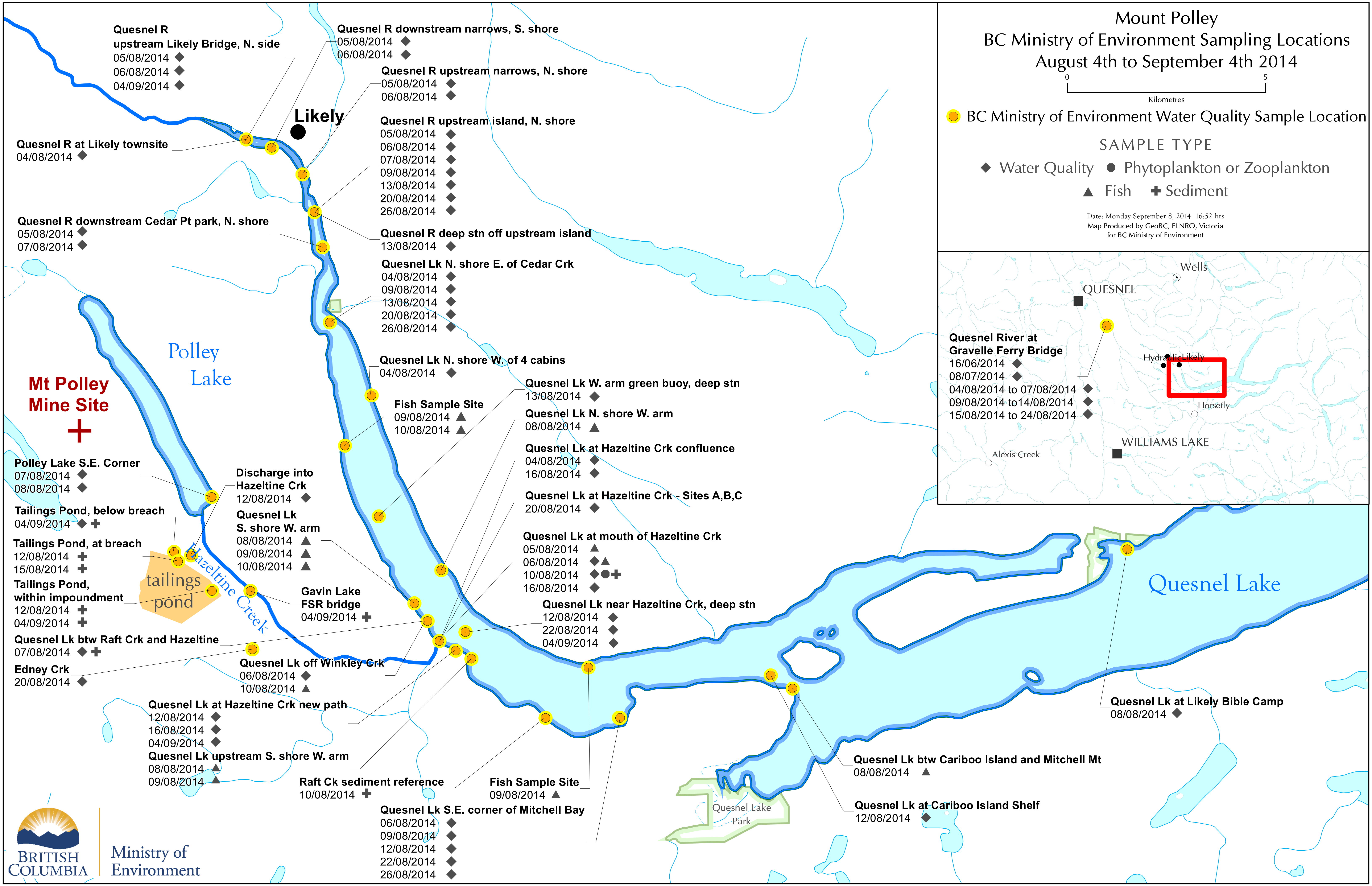
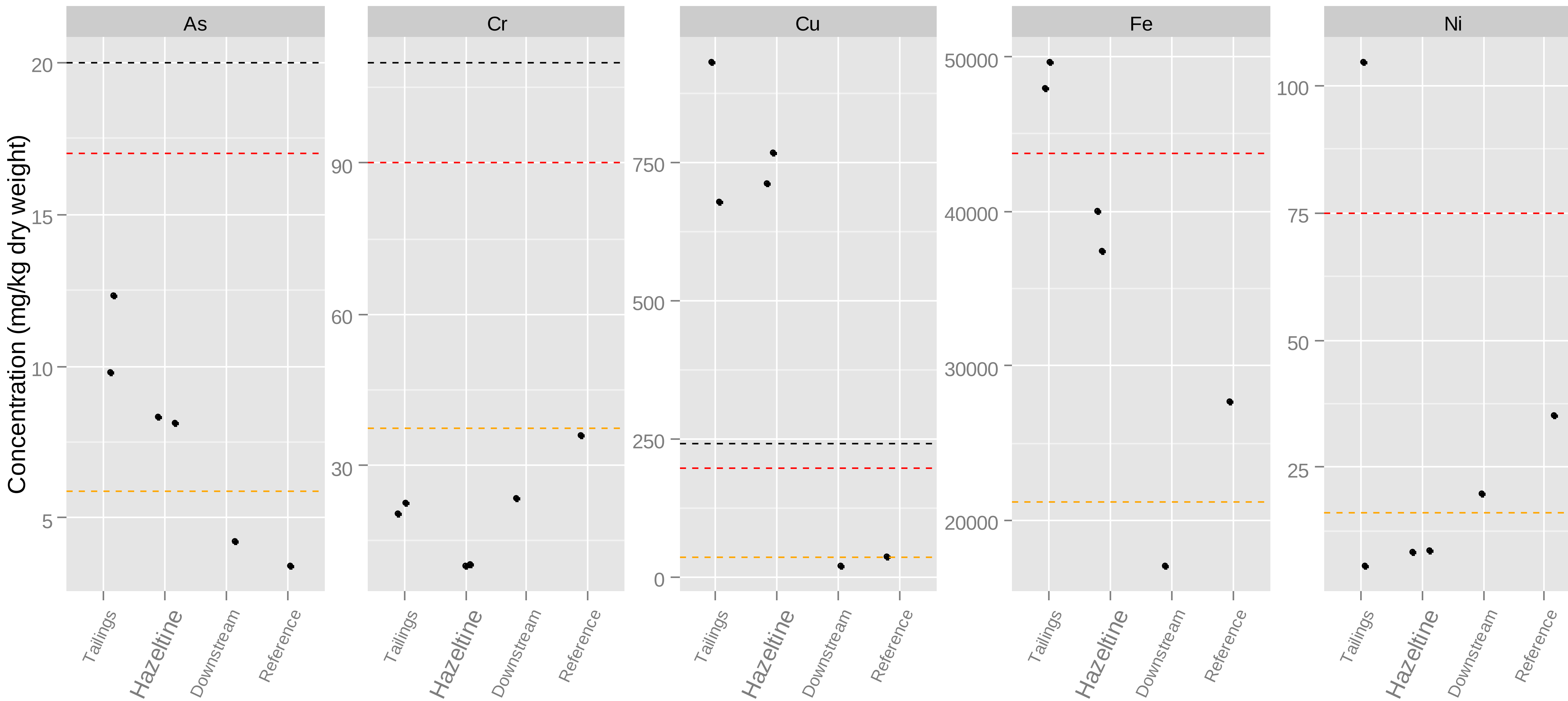
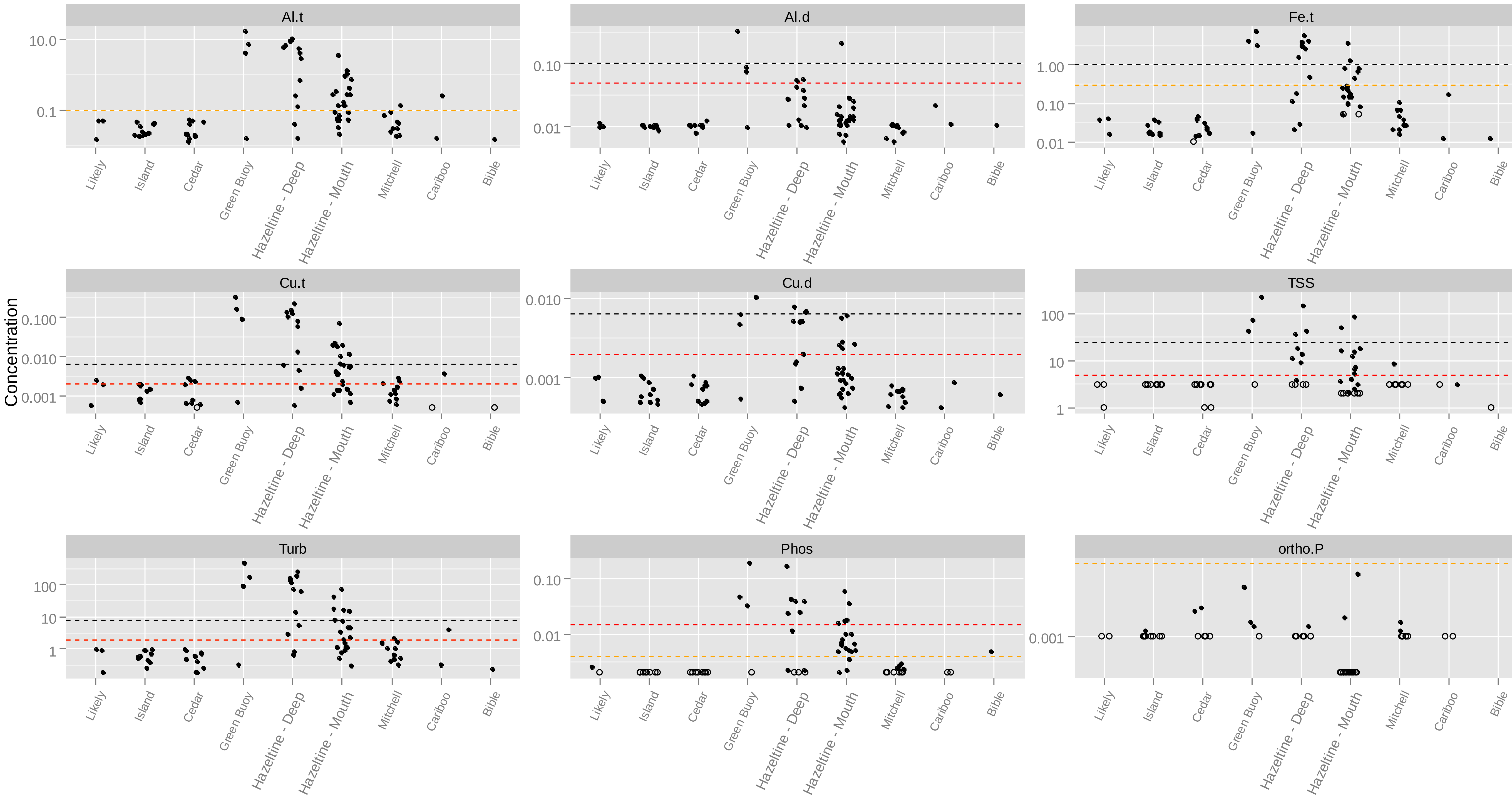

Mount Polley
BC Ministry of Environment Sampling Locations
August 4th to September 4th 2014
0
5
Kilometres
BC Ministry of Environment Water Quality Sample Location
SAMPLE TYPE
Water Quality
Phytoplankton or Zooplankton
Fish
Sediment
Date: Monday September 8, 2014 16:52 hrs
Map Produced by GeoBC, FLNRO, Victoria
for BC Ministry of Environment
Wells
QUESNEL
Quesnel River at
Gravelle Ferry Bridge
16/06/2014
08/07/2014
04/08/2014 to 07/08/2014
09/08/2014 to14/08/2014
15/08/2014 to 24/08/2014
Hydraulic
Likely
Horsefly
WILLIAMS LAKE
Alexis Creek
Quesnel R
upstream Likely Bridge, N. side
05/08/2014
06/08/2014
04/09/2014
Quesnel R downstream narrows, S. shore
05/08/2014
06/08/2014
Quesnel R upstream narrows, N. shore
05/08/2014
06/08/2014
Likely
Quesnel R at Likely townsite
04/08/2014
Quesnel R upstream island, N. shore
05/08/2014
06/08/2014
07/08/2014
09/08/2014
13/08/2014
20/08/2014
26/08/2014
Quesnel R downstream Cedar Pt park, N. shore
05/08/2014
07/08/2014
Quesnel R deep stn off upstream island
13/08/2014
Quesnel Lk N. shore E. of Cedar Crk
04/08/2014
09/08/2014
13/08/2014
20/08/2014
26/08/2014
Polley
Lake
Quesnel Lk N. shore W. of 4 cabins
04/08/2014
Mt Polley
Mine Site
Quesnel Lk W. arm green buoy, deep stn
13/08/2014
Fish Sample Site
09/08/2014
10/08/2014
Quesnel Lk N. shore W. arm
08/08/2014
Quesnel Lk at Hazeltine Crk confluence
04/08/2014
16/08/2014
Polley Lake S.E. Corner
07/08/2014
08/08/2014
Discharge into
Hazeltine Crk
12/08/2014
Quesnel Lk at Hazeltine Crk - Sites A,B,C
20/08/2014
Tailings Pond, below breach
04/09/2014
Quesnel Lk
S. shore W. arm
08/08/2014
09/08/2014
10/08/2014
Tailings Pond, at breach
12/08/2014
15/08/2014
Quesnel Lk at mouth of Hazeltine Crk
05/08/2014
06/08/2014
10/08/2014
16/08/2014
Hazeltine Creek
tailings
pond
Quesnel Lake
Tailings Pond,
within impoundment
12/08/2014
04/09/2014
Gavin Lake
FSR bridge
04/09/2014
Quesnel Lk near Hazeltine Crk, deep stn
12/08/2014
22/08/2014
04/09/2014
Quesnel Lk btw Raft Crk and Hazeltine
07/08/2014
Edney Crk
20/08/2014
Quesnel Lk off Winkley Crk
06/08/2014
10/08/2014
Quesnel Lk at Likely Bible Camp
08/08/2014
Quesnel Lk at Hazeltine Crk new path
12/08/2014
16/08/2014
04/09/2014
Quesnel Lk upstream S. shore W. arm
08/08/2014
09/08/2014
Quesnel Lk btw Cariboo Island and Mitchell Mt
08/08/2014
Raft Ck sediment reference
10/08/2014
Fish Sample Site
09/08/2014
Quesnel Lake
Park
Quesnel Lk at Cariboo Island Shelf
12/08/2014
Quesnel Lk S.E. corner of Mitchell Bay
06/08/2014
09/08/2014
12/08/2014
22/08/2014
26/08/2014
BRITISH
COLUMBIA
Ministry of
Environment

Figure 2. Concentrations of COPCs in sediment by sampling area.



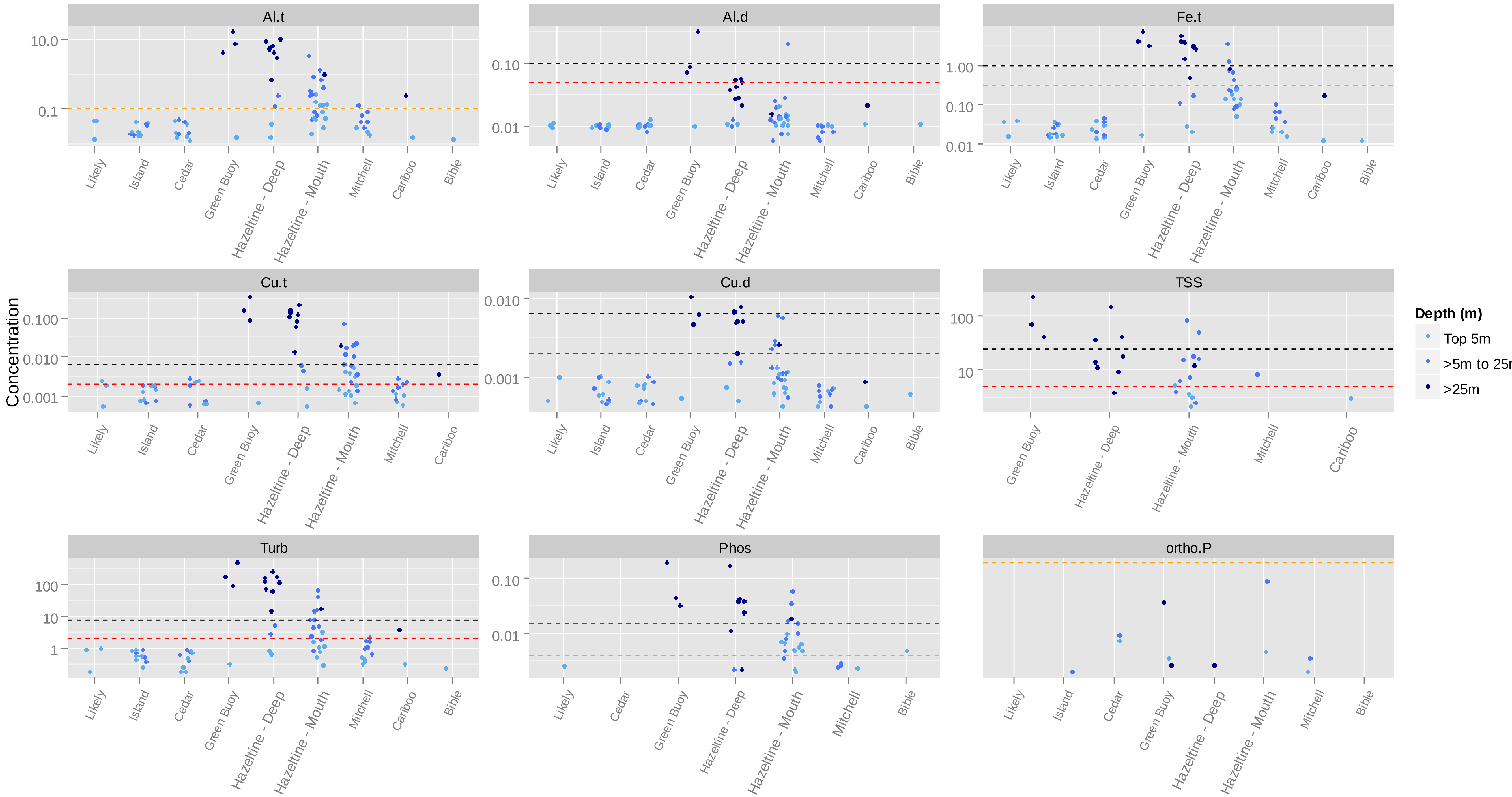
Notes: Limited to samples focusing on the full sediment fraction (not limited to < 2 mm or < 63 um). Data points are horizontally 'jittered' (offset) to minimize masking. Black dashed line = CSR Schedule 9 Criteria for Typical Sites; red = PELs; orange = ISQGs.

Figure 3. Concentrations of key COPCs in water by sampling area.



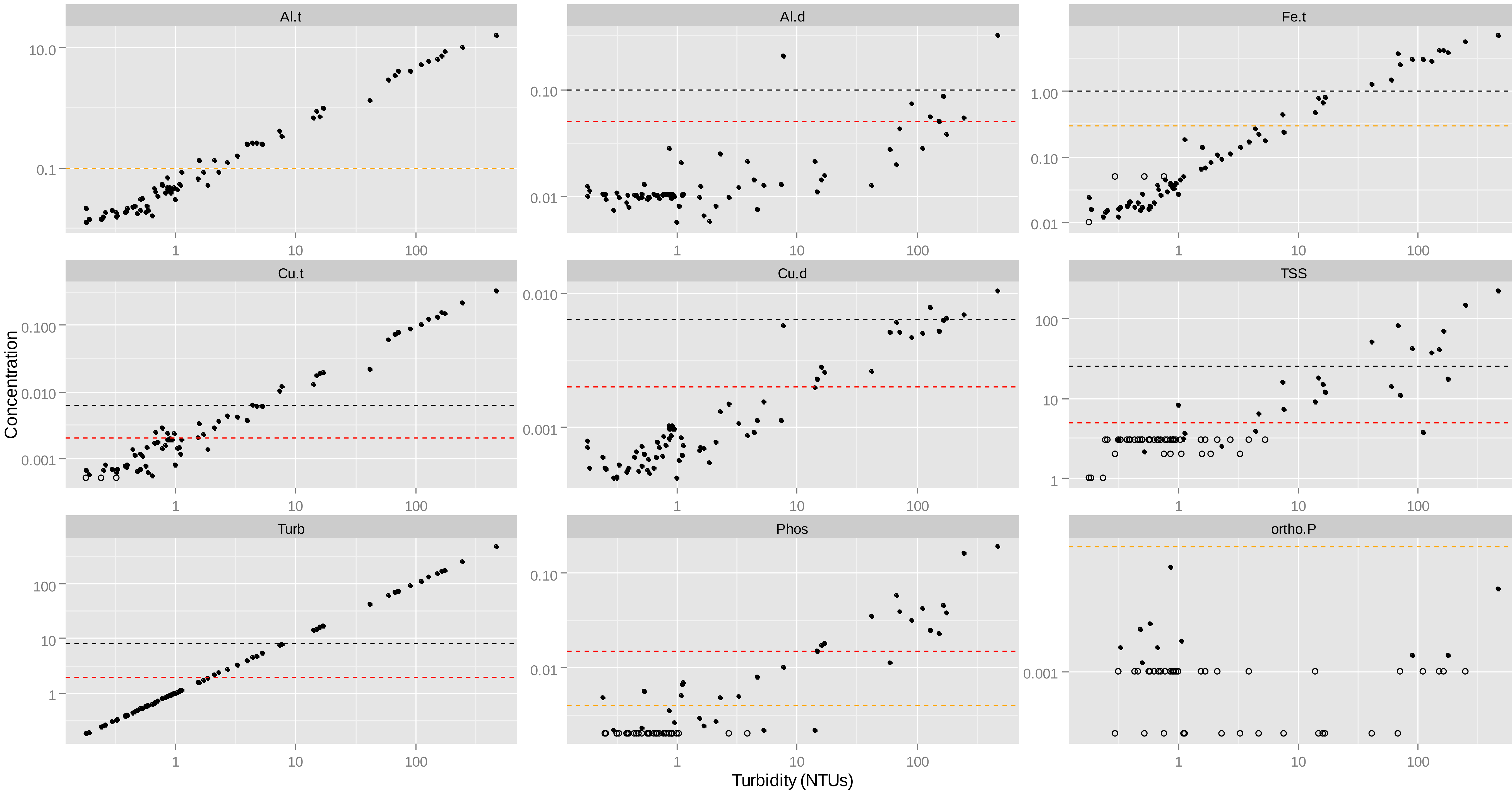
Notes: Units mg/L except turbidity (NTUs). Y axis shown on a $\log_{10}$ scale. Data points are horizontally 'jittered' (offset) to minimize masking. Open circles indicate data points that were below MDLs. Sampling areas are roughly organized from downstream to upstream in Quesnel Lake (see text for description). Black dashed line = BCmax WQGs; red = BC30d WQGs; orange = CCME chronic WQGs (only shown if different from BC). Guidelines for total copper are simplified (set at lowest hardness-dependent value in the data set) and are applied also to dissolved copper for display purposes. CCME chronic WQG for phosphorus also applied to orthophosphorus for display purposes.

Figure 4. Concentrations of key COPCs in water by sampling area, stratified by depth.



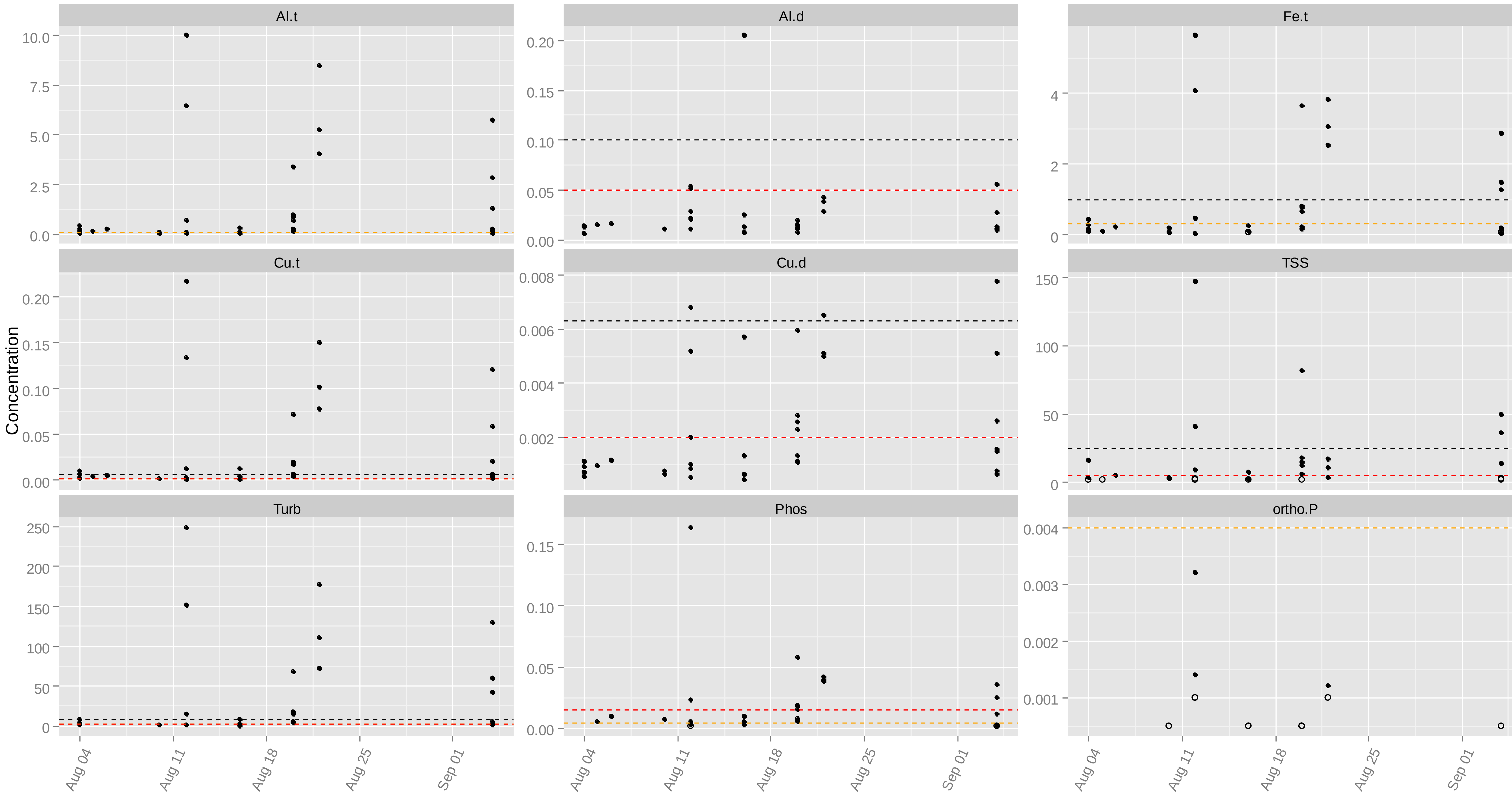
Notes: Units mg/L except turbidity (NTUs). Y axis shown on a log_{10} scale. Data points are horizontally 'jittered' (offset) to minimize masking. Data points below MDLs are omitted. Sampling areas are roughly organized from downstream to upstream in Quesnel Lake. Black dashed line = BCmax WQGs; red = BC30d WQGs; orange = CCME chronic WQGs (only shown if different from BC). Guidelines for total copper are simplified (set at lowest hardness-dependent value in the data set) and are applied also to dissolved copper for display purposes. CCME chronic WQG for phosphorus also applied to orthophosphorus for display purposes.

Figure 5. Relationship between key COPC concentrations in water and turbidity.



Notes: Units mg/L except turbidity (NTUs). Both axes shown on a log_{10} scale. Open circles indicate data points that were below MDLs. There were a small proportion of samples where turbidity was not measured, therefore those data points are not plotted. Black dashed line = BCmax WQGs; red = BC30d WQGs; orange = CCME chronic WQGs (only shown if different from BC). Guidelines for total copper are simplified (set at lowest hardness-dependent value in the data set) and are applied also to dissolved copper for display purposes. CCME chronic WQG for phosphorus also applied to orthophosphorus for display purposes.

Figure 6. Concentrations of key COPCs over time in surface waters (< 5 m depth) in the Hazeltine area (Hazeltine-Mouth and Hazeltine-Deep).



Notes: Units mg/L except turbidity (NTUs). Open circles indicate data points that were below MDLs. Black dashed line = BCmax WQGs; red = BC30d WQGs; orange = CCME chronic WQGs (only shown if different from BC). Guidelines for total copper are simplified (set at lowest hardness-dependent value in the data set) and are applied also to dissolved copper for display purposes. CCME chronic WQG for phosphorus also applied to orthophosphorus for display purposes. Hazeltine stations –Mouth and –Deep were combined in this figure.