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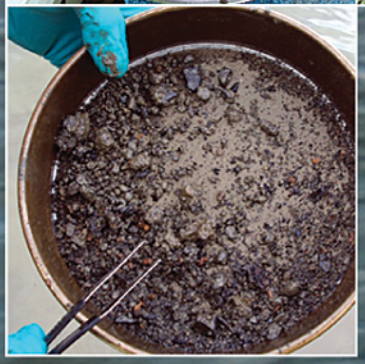
2010 Status of Mercury in Environmental Media for Site C Planning – Peace River and Dinosaur Reservoir



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This document was written by Randy Baker (M.Sc., R.P.Bio.), Ralph Turner (PhD), Gary Mann (M.Sc., R.P.Bio.) and Maggie McConnell (M.R.M.) of Azimuth Consulting Group Inc. Beth Power (M.Sc., R.P.Bio.) of Azimuth reviewed the report.

Field sampling of soils and vegetation was performed by Azimuth, Vancouver. Field collections of water, sediment, zooplankton and benthos were performed by field staff of the Golder Associates Ltd. office based in Ft. St. John BC and under senior level supervision out of Golder in Edmonton, AB.

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The report was prepared for Mr. Bruce Mattock and Mr. Hugh Smith of BC Hydro.

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ACRONYMS

COC – Chain of Custody

CRM – Certified Reference Material

DL – Detection Limit

DOC – Dissolved Organic Carbon

DQO – Data Quality Objective

DUP – Duplicate

EA – Environmental Assessment

EAC – Environmental Assessment Certificate

EB – Equipment Blank

GIS – Geographic Information System

GPS – Global Positioning System

HDPE – High Density Polyethylene

Hg – Mercury

ISQG – Interim Sediment Quality Guideline

LOI – Loss on Ignition

MDL – Method Detection Limit

MeHg – Methyl Mercury

PCD – Peace Canyon Dam

QA/QC – Quality Assurance / Quality Control

RESMERC – Reservoir Mercury model

RPD – Relative Percent Difference

SAP – Sampling and Analysis Plan

SINLAB – Stable Isotopes in Nature Laboratory (University of New Brunswick)

TEM – Terrestrial Ecosystem Mapping

THg – Total Mercury

TOC – Total Organic Carbon

TSS – Total Suspended Solids

UTM – Universal Transverse Mercator

EXECUTIVE SUMMARY

BC Hydro is considering development of the Peace River Site C Clean Energy hydroelectric project (Site C) in north eastern British Columbia. To address the issue of mercury (Hg) accumulation in aquatic biota related to Site C, Azimuth Consulting Group (Azimuth) developed a strategy and supporting rationale that provided a foundation to support informed management decisions regarding mercury at Site C. One of the key issues highlighted was the requirement to use quantitative, predictive mercury models to forecast the magnitude of increases in fish mercury concentrations over the life of the new reservoir. To satisfy this requirement, Azimuth reviewed the existing physical and chemical data on the Peace River with the aim to: 1) identify data gaps related to specific mercury model input requirements; 2) characterize baseline conditions and 3) examine Dinosaur Reservoir as a potential analogue to Site C.

A detailed Sampling and Analysis Plan (SAP) prepared by Azimuth (2010b) provided detailed guidance for the 2010 data collection by field teams to: 1) collect mercury and ancillary data in water, sediment, aquatic invertebrates, fish, soil and vegetation; and 2) use stable isotope analysis of various aquatic species (benthic invertebrates, zooplankton and fish) in Dinosaur Reservoir and Peace River to assesses current trophic linkages and estimate how trophic structure, which affects mercury accumulation, may change in the future reservoir.

This baseline report presents the 2010 results of mercury and methyl mercury in environmental media, stable isotopes and ancillary parameters. Data interpretation is limited to context with key historic data and put 2010 data in perspective with what is 'typical' for mercury in media from other comparable areas. A more complete discussion of results and their implications will be made as part of the technical mercury synthesis document within the Environmental Assessment (EA). Key results for water, sediment, invertebrates, fish, soil and vegetation are:

Water – Surface water collected from two Dinosaur Reservoir, three Peace River mainstem and three tributary streams (Farrell, Halfway, Moberly) in spring freshet and low summer flow were analyzed for conventional water quality parameters (pH, anions, TSS, etc.), nutrients, sulphate and total inorganic and methyl mercury (MeHg). Dinosaur and Peace River chemistry was similar with high oxygen and pH (8.2), low TSS (1-4 mg/L, even in spring), low concentrations of sulphate, TOC/DOC and anions. Concentrations of all parameters in tributary streams were slightly higher than in mainstem stations.

Total mercury concentration in Dinosaur and Peace River water was very low, consistently less than 1.0 ng/L (parts per trillion) (<2 ng/L in tributaries) with the majority of this in the dissolved phase and similar to concentrations observed in Williston Reservoir in 2001. Methyl mercury concentrations in Dinosaur Reservoir, Peace River

and tributaries were typically less than the laboratory detection limit (0.02 ng/L) in spring and fall. These concentrations are typical of remote, pristine systems.

Sediment – Sediment collected in fall from the same water sampling stations were analyzed for metal concentration, sediment grain size and mercury concentration. In Dinosaur, sediment was dominated by silt/clay while in Peace River sand/gravel was more common, although only the fine sediment from Peace River was analyzed for metals/mercury. Organic carbon composition in reservoir and river sediment was low (1.4% to 2.5%) while sediment pH values were slightly alkaline (~8.2). Total sediment mercury concentrations ranged from 0.03 – 0.17 mg/kg, with Dinosaur Reservoir samples having slightly higher concentrations than either Peace River or tributary samples, with all samples well below the most conservative sediment quality guidelines for aquatic life protection. Notwithstanding some QA issues for Peace River sediment, methyl mercury concentrations from Dinosaur (and Peace) were very low (<0.3 µg/kg) and typical of sediments from lakes and reservoirs in pristine areas, unaffected by anthropogenic sources, and similar to Williston Reservoir (2001 data; 0.14 – 0.44 µg/kg).

Zooplankton – Zooplankton collected in fall from the same Peace River stations as water had very low total mercury concentration (i.e., the sum of inorganic Hg^{II} and methyl mercury), ranging from 0.004 – 0.009 µg/g (ppm) wet weight (ww). In Dinosaur Reservoir, values were slightly lower (0.001 – 0.006 µg/g ww). These are similar to 2001 Williston Reservoir total mercury concentrations (0.006 – 0.009 µg/g ww). The range in concentration of methyl mercury in Dinosaur zooplankton (0.0003 – 0.001 µg/g) and Peace River (0.0001 – 0.0007 µg/g) were also low. The proportion of total mercury that was present in the methyl form ranged from 2 – 9% in Peace River (low) but 24 – 44% in Dinosaur Reservoir, which is a typical range for zooplankton.

Benthos – Total mercury (inorganic + methyl) in benthos from PR-1, -2 and -3 was 0.016 µg/g, 0.010 µg/g and 0.023 µg/g ww respectively. In Dinosaur Reservoir, a single composite sample had a concentration of 0.025 µg/g ww. Biomass of benthic invertebrates was relatively small and taxonomic representation was incomplete so there is some uncertainty about the range of mercury concentrations found. Methyl mercury concentrations in Peace River benthos ranged from 0.0016 – 0.20 µg/g (high for one station due to presence of large carnivorous beetle) and 0.002 µg/g in Dinosaur Reservoir. Despite small biomass, total mercury concentrations are within the range for benthos from remote Canadian lakes and in Williston Reservoir (0.015 – 0.05 µg/g) in 2000/2001. The difference in inorganic and methyl mercury concentration between Williston and Peace River benthos, despite the large temporal and spatial separation, is relatively small and indicative of the low mercury concentrations in environmental media of this system and low rate of methylation.

Fish – Fifty four fish were collected from the Peace River in 2010 by Mainstream Aquatics comprised of 15 bull trout, 17 mountain whitefish, 10 longnose sucker, 11

redside shiner, and one lake trout. Fifty fish were collected from Dinosaur Reservoir: 14 bull trout, 15 mountain whitefish, 20 lake trout and one longnose sucker. No redside shiner were collected. Sufficient numbers over a representative size range were collected for bull trout, mountain whitefish and lake trout (Dinosaur only) to derive mercury-size relationships that is typical for most carnivorous species. Notable results are:

- Mercury concentrations in bull trout from Dinosaur (670 mm; 0.10 mg/kg) and Peace River (470 mm; 0.055 mg/kg) were quite low and not correlated with fish size. These concentrations are similar to what was observed from Peace River bull trout in 2008 (460 mm; 0.08 mg/kg).
- Mercury concentrations in lake trout from Dinosaur (421 mm; 0.09 mg/kg) and Peace River (n=1, 391 mm; 0.07 mg/kg) were low and not positively correlated with size.
- Mercury concentrations in mountain whitefish from Dinosaur (301 mm; 0.04 mg/kg) and Peace River (318 mm; 0.03 mg/kg) were low and were similar in magnitude to Peace River concentrations in 2008 (340 mm; 0.03 mg/kg).
- Mercury concentrations in Peace River longnose sucker were low (386 mm; 0.04 mg/kg) and not correlated with size. The single sucker captured from Dinosaur (400 mm) had the highest mercury concentration of the study (0.18 mg/kg).
- Redside shiner from Peace River downstream of Site C had a mean mercury concentration of 0.05 mg/kg.

Mercury concentrations for all species captured from Dinosaur Reservoir and Peace River were very low relative to the same species of a similar size in other British Columbia lakes and reservoirs.

Stable Isotopes – In addition to mercury, tissue samples of benthos, zooplankton and fish were also analyzed for carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopes to determine and compare food web structure in Dinosaur Reservoir and Peace River. Food chain structure has been shown to influence contaminant concentrations in lake trout, particularly for mercury. Gaining an understanding of food web structure and length will increase confidence of predictions of mercury in the Site C reservoir following inundation. Results of stable isotope analysis showed that lake trout had the highest trophic position in both water bodies, followed by bull trout. Mountain whitefish, longnose sucker (LNSC) and redside shiner (RDSH) were generally lower in the food chain. For each target species caught in both water bodies, mean trophic position estimates were marginally higher in Dinosaur Reservoir than Peace River. As trophic position is generally a function of fish size, differences in trophic structure between the two water bodies were also examined using length-trophic position relationships. Significant relationships were found for all combinations except LNSC-PEACE and RDSH-PEACE, because both species had

narrower ranges of fork length than was targeted. The relationship for lake trout in Dinosaur Reservoir implied that trout of all sizes fed on the same dietary items, which could be an artifact or related to the ecology of the tailrace area, where fish entrained in the discharge from Williston Reservoir are preferential prey items. The latter explanation may help explain the lack of length-total mercury relationship results. The only longnose sucker captured in Dinosaur had a much higher trophic position than its counterparts in the Peace River, also suggesting a shift towards more fish in their diet, which may also explain its relatively high mercury concentration.

Soil - Organic soils are the major contributors of labile carbon and inorganic mercury that fuel the bacterial methylation process. Vertical soil profiles were described and collected in a stratified manner according to dominant habitat types based on Terrestrial Ecosystem Mapping (TEM). Eighty-five organic horizon soils and four mineral soils were analyzed for total mercury and total organic carbon (TOC); 14 samples were analyzed for methyl mercury concentration and grain size. Sampling effort within dominant habitat types was stratified by known contributors to methylation (e.g., wetlands, mature coniferous forest soils) and by habitats with high surface area within the flood footprint including step-moss peavine (AM), cottonwood-spruce-red osier dogwood (FM02), currant-horsetail (CH) and willow-horsetail sedge riparian wetland (WH).

The TOC content of organic horizons ranged between 30% – 45%, not including the few mineral soils sampled (i.e., <1 cm organic cover), where TOC was <5%. Average total mercury content of organic horizons, including those with some included mineral soil, was 0.079 mg/kg, spread over a relatively narrow range of 0.022 – 0.139 mg/kg (std = 0.029). Total mercury values are similar to results (<0.05 to 0.13 mg/kg) reported for "background soils" near Ft St John, BC. For the two dominant cover types (Fm02, SH), accounting for more that 60% of the Site C flood footprint, the variation in total mercury concentration was sufficiently high (due to large differences in TOC) that there was no significant difference between these cover types (*t*-test, $p<0.05$). Reporting mercury results on a carbon-normalized basis showed that where TOC concentrations were >10%, carbon-normalized mercury concentration varied much less (0.13 to 0.41 mg Hg/kg C). Soils containing <10% carbon may actually have a substantial fraction of their mercury content associated with inorganic (mineral) phases and thus normalizing to carbon would overestimate the mercury content of the organic carbon in these soils.

Methyl mercury concentrations in soils ranged over two orders of magnitude (0.071 to 7.1 µg/kg; i.e., units are 1000 times **lower** than for total mercury). This wide range was largely due to results from within discrete polygons of two cover types AM (upland step moss-peavine) and SE (wetland sedge), that were more than an order of magnitude higher than any other result. One sample from Watson Slough was expected to exhibit high methyl mercury concentration and % methyl mercury (relative to total). Another sample from an upland step moss-peavine (AM) habitat was unexpectedly high, possibly because

the soil contained much charcoal and other indications of a fire history. Excluding these two samples, methyl mercury concentrations were more narrowly constrained (0.071 – 0.29 µg/kg). The methyl mercury concentration found in sedge wetland (SE) and Fm02, SH and WH cover types are typical of wetlands and upland soils, respectively, in boreal regions of Canada.

Vegetation – Twelve dominant vegetation types were sampled for total metals including mercury from trees (spruce, willow, balsam, willow), shrubs (sarsaparilla, prickly rose, willow, alder and dogwood) and grasses (horsetail, sedge, reeds, cattail). Total mercury concentration in all plant tissues were very low, in most cases barely above the detection limit (DL) of 0.005 mg/kg dw (dry weight). The most common shrub species sarsaparilla (0.008, 0.011 mg/kg), prickly rose (0.006, 0.006 mg/kg) and alder (0.006 – 0.008 mg/kg) were low and of very similar concentration. Tree species (birch, dogwood, balsam (0.006 – 0.009 mg/kg) were also low in mercury. The sedge species, reed and cattail from Watson Slough had only slightly higher mercury concentrations (0.013 – 0.015 mg/kg) than other vegetation types. Plant tissue mercury data from the Peace River region were on the low end of the scale relative to vegetation from remote, pristine area of boreal forest in Canada, Europe and Scandinavia.

General Summary – Together, these data suggest that mercury and methyl mercury concentrations in all environmental media in the Peace River, upstream in Dinosaur Reservoir and in major tributary sources upstream of Site C are very low and typical of pristine, background conditions. Chemical conditions in water and zooplankton are very similar to what has been observed in Williston Reservoir and from a mercury perspective concentrations have not changed since 2001, indicating very stable conditions. In particular, mercury concentrations in all fish species for which we have data are very low and among the lowest concentrations observed from other lakes and reservoirs in British Columbia and elsewhere in Canada. Similarly, inorganic and methyl mercury concentrations in organic soils within the forecast flood footprint of Site C are low and again, typical of pristine, remote soils removed from anthropogenic or elevated natural sources of mercury.

Notwithstanding small deficiencies in our understanding of mercury in environmental media (e.g., small sample size of benthic invertebrates, limited temporal extent of data) our overall conclusion is that the concentrations of mercury in environmental media are low, spatially consistent within Dinosaur Reservoir and the Peace River downstream to Site C and at least for water and zooplankton, have not changed over the last 10+ years. Furthermore, we do not perceive any significant gaps in our understanding that would impair or preclude mechanistic mercury modeling, using RESMERC or another similar model, to predict concentrations of mercury in environmental media within the proposed Site C reservoir. This is important because having good confidence in the magnitude of elevation in predicted mercury concentrations in fish above baseline is the most important

driver of potential predicted risks to wildlife species that consume fish, and to humans, especially First Nations and to domestic and sport fish fishermen.

1. INTRODUCTION

1.1. Background

BC Hydro is considering developing the Peace River Site C Clean Energy hydroelectric project (Site C) in north eastern British Columbia. Azimuth Consulting Group (Azimuth) was commissioned by BC Hydro to develop a strategy and supporting rationale for addressing the issue of mercury (Hg) accumulation in aquatic biota related to Site C (Azimuth, 2010a). The strategy provides a foundation to build a cohesive body of information to fully address the issue within the context of an Environmental Assessment (EA) in order to acquire and Environmental Assessment Certificate (EAC). Data collected during 2010 are important as baseline data for the mercury component to the EA and will form the basis for: 1) a Technical Mercury Synthesis Document as an appendix to the EA; and 2) as critical data input parameters for modeling of changes to mercury concentrations in environmental media within the proposed Site C reservoir.

Mercury is a naturally-occurring element that is widespread at low concentrations in all environmental media including water, sediment, soil and tissues of all plants and animals. There are a number of forms that mercury can take in environmental media, but the forms of primary concern are inorganic (e.g., elemental Hg adhered to particles, carbon) and methyl mercury (i.e., organic mercury), the principal form of mercury found in fish. Virtually all mercury (especially methyl mercury) is acquired via dietary sources (Hall et al., 1997) and only very small concentration is absorbed from water.

The key issue is that concentrations of inorganic and methyl mercury in biota tissue (the dominant form in fish tissue, usually comprising ~95% of the total). Ingested methyl mercury is easily incorporated and sequestered into biological tissues and the amount that is acquired is much greater than the amount that is depurated, a process known as bioaccumulation. Furthermore, the concentration of methyl mercury in animal tissue increases with progressively higher steps in the food web, a process known as biomagnification. This process occurs in both in terrestrial and aquatic ecosystems but is more prevalent in aquatic systems because of the multiple steps in the food web, many of which are carnivorous (e.g., many sequential steps where invertebrate and vertebrate animals are consumed, culminating with fish). It is for this reason that in natural freshwater lakes and reservoirs, fish have higher mercury concentrations than almost all other animals, especially terrestrial animals. Thus, fish consumption is the primary means of exposure of humans and fish-eating birds and mammals to methyl mercury. Furthermore, carnivorous fish such as bull trout, lake trout and northern pike typically have higher mercury concentrations than omnivorous species including whitefish, rainbow trout and others.

1.2. Reservoir Creation and Mercury

It is well known that flooding of terrestrial soils and vegetation causes an increase in mercury above background levels throughout the aquatic food web and especially in fish (e.g., Bodaly et al., 1984 and many others). Mercury is present in very small concentrations in the gaseous form in the Earth's atmosphere, originating from natural degassing, volcanoes, forest fires and from the burning of fossil fuels (coal, oil). This gaseous Hg becomes adhered to leaves, needles and soil (dry deposition) or is deposited to soils via rainwater and snow (wet deposition). Over the course of hundreds and thousands of years Hg accumulates in the soil at low concentrations (~0.1 – 0.5 mg/kg), bound to carbon. In this form, it is very stable and the mercury is generally unavailable to be taken up by soil dwelling bacteria and invertebrates. However, inundation of forest soils during reservoir creation creates conditions that favor nutrient release and decomposition of the organic matter in the soil. Bacterial decomposition of this organic matter causes some of this inorganic to be incorporated into the bacterial tissue and is thus now incorporated within the lower aquatic food web. During the decomposition process specific bacterial species convert a small portion of the absorbed inorganic mercury into methyl mercury (MeHg). This form of mercury is more toxic than the inorganic form and is much more easily accumulated by biota and becomes increasingly concentrated at higher steps in the food web (Abernathy and Cumbie, 1977; Wright and Hamilton, 1982; Bodaly et al., 1984; Brouard et al., 1989; Hecky et al., 1987; Hecky et al., 1991, and many others). This bacterial methylation process is natural and also occurs in unflooded lakes, rivers and oceans. Note that all fish contain small amounts of methyl mercury, typically ranging between 0.05 – 1.0 mg/kg (parts per million).

Creation of new reservoirs always results in an increase in methyl mercury concentrations in all environmental media (water, sediment, invertebrates, fish). Concentrations typically persist above background levels for between 15 and 30 years after flooding (Bodaly et al., 1997), depending on the nature of the reservoir and environmental conditions. However, it is difficult to predict the magnitude of concentration and the duration that mercury will remain elevated above background in fish, especially in new reservoirs. However, there is a large body of literature from which to draw and there are well known patterns in mercury cycling. Generally speaking, the magnitude and duration of increase in mercury in run-of-the-river reservoirs (i.e., minimal flooding, short retention time, like Site C) is less than in large lacustrine systems where there is extensive flooding (relative to the original surface area) and a long retention time of water in the system.

1.3. Documentation Timeline

To-date, four documents have been prepared by Azimuth for BC Hydro to begin evaluation of the issue of mercury in environmental media relating to the proposed Site C

development. These are listed with their citations below and then described in more detail in this section:

1) *Site C Mercury Assessment Strategy and Workplan, August, 2009*. This letter report was intended to provide BC Hydro with an initial strategy to address the issue of mercury as a result of creation of the proposed Site C hydroelectric development project on the Peace River.

2) *Mercury Data Review and Planning Considerations, January, 2010.* This was considered a Phase 1study with the objective of identifying site specific data gaps in knowledge of mercury in the Peace River.

3) *2010 Site C Data Collection – Sampling and Analysis Plan June, 2010*.This was considered part of Phase 2 of the strategy to gather background data on mercury and address key data gaps in preparation for future mechanistic modeling to predict mercury concentrations in environmental media.

4) *2010 Status of Mercury in Environmental Media for Site C Planning – Peace River and Dinosaur Reservoir January, 2011*. This current data report presents results on the 2010 field investigation of mercury in water, sediment, soil, vegetation, zooplankton, benthos and fish.

Details of each of the four documents prepared to-date are briefly summarized below.

1. **Preliminary Strategy Document** – In August 2009 Azimuth initiated a strategy to address the issue of mercury in environmental media as it pertained to the proposed Site C Clean Energy Project. The objectives of this work were to:

   - Acquire and undertake a preliminary review of existing BC Hydro documents related to mercury in water, sediment, soils, vegetation and fish along the Peace River and its tributaries;
   - Review existing predictive mercury models in Canada and determine whether a modeling approach at Site C would be useful. We evaluated the applicability of several quantitative models that predict changes in mercury concentrations in environmental media following reservoir creation; and
   - Develop a strategy to address the issue of mercury, especially pertaining to public understanding, communication and increasing knowledge about the issue, while dispelling misconceptions.

This document was issued in November 2009 as a Technical Memorandum (Azimuth, 2009) and was used to guide future work.

2. **Mercury Data Review and Planning** – In January, 2010 Azimuth (2010a) issued a detailed technical memorandum to:

- Review historic water, sediment and soil chemistry data from the perspective of its suitability to support mercury modeling.
- Develop a strategy for addressing mercury as it relates to Site C including a literature review, review of mercury models, and identification of key data gaps that must be filled to provide adequate understanding of mercury in environmental media and to undertake mercury modeling; and
- Summarize field data input requirements to satisfy basic requirements of potential future modeling scenarios and provide generic Standard Operating Procedures for the collection of mercury in various environmental media.

3. **Sampling and Analysis Plan (SAP)** – In June 2010 Azimuth (2010b) prepared a detailed Sampling and Analysis Plan (SAP) that is a 'cook-book' style guide for the collection, handling, preservation, and shipping of environmental media for specialized analyses including nutrients, metals, mercury species and stable isotopes from tissue samples. This SAP was developed to provide Golder Associates, Fort St. John BC, with detailed guidance, as Golder was tasked by BC Hydro to collecting all but the soils data. Note that the cover letter to BC Hydro for this document included results of preliminary regression modeling (Harris and Hutchinson, 2008) using Site C data. This is a simple model that uses current surface area, projected reservoir area and mean residence time of water to predict the maximum increase in mercury concentration above baseline values (see **Section 1.3** below). Documentation of the locations of sampling stations for all environmental media is presented in a series of maps within **Appendix A**.
4. **2010 Status of Mercury in Environmental Media** – This current document (Azimuth, 2011) presents results of the 2010 field investigation of the Peace River and Dinosaur Reservoir. Data interpretation is limited to providing context on spatial and temporal patterns of mercury concentration in environmental media (i.e., water, soil, fish, etc.) and provides perspective on where inorganic and methyl mercury concentrations fall within the spectrum of what is typically observed in uncontaminated environments.

   An important component of the report links stable isotopes as well as mercury concentration in invertebrate and fish tissues. Food chain structure has a very strong influence on mercury concentrations in fish (Cabana and Rasmussen, 1994; Cabana et al., 1994). Mercury concentrations are higher in longer food webs than shorter ones, and in more carnivorous species. The ratio of stable carbon and nitrogen isotopes will be used to characterize the food web in Peace River and Dinosaur Reservoir and provide insight into trophic structure and feeding preferences. This will help us interpret patterns in mercury concentrations and understand key factors driving

mercury dynamics. These patterns might help us to understand what Site C might eventually resemble.

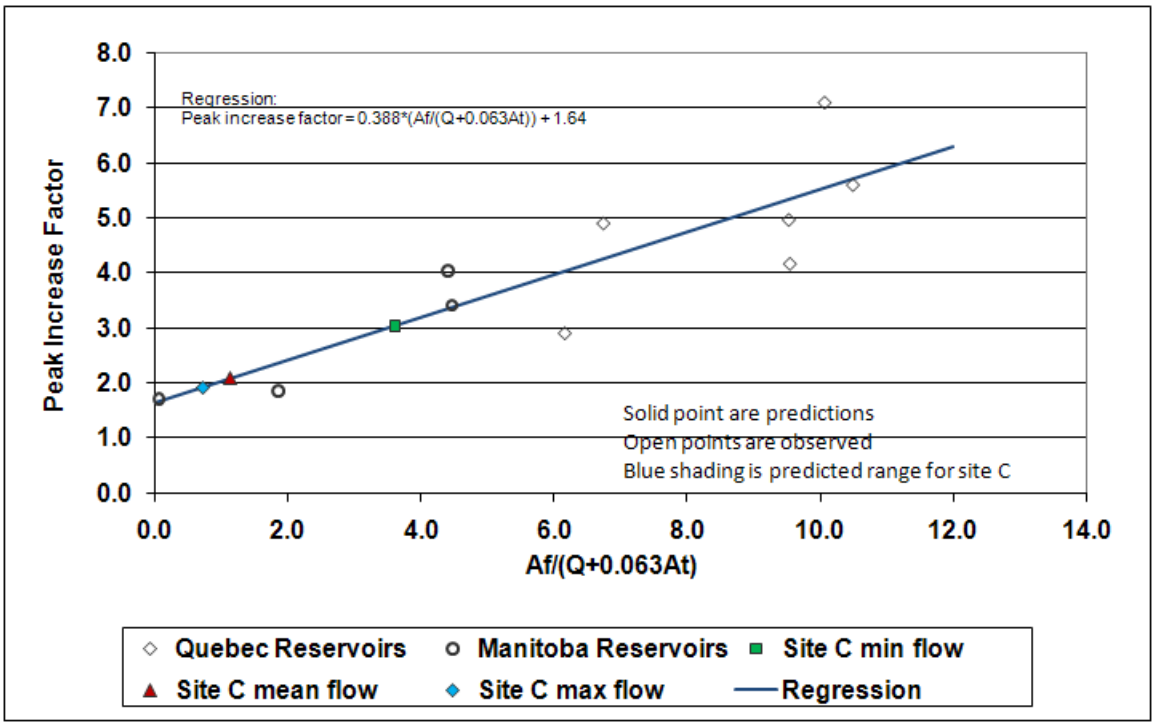
1.4. Mercury Modeling

One of the key issues of the environmental impact assessment of Site C is the magnitude and duration of increase in mercury concentration in aquatic biota in the proposed reservoir. Much has been learned over the last 30 years regarding the dynamics of mercury methylation in new reservoirs. Monitoring of the evolution of mercury in reservoirs, especially in northern Manitoba, Quebec and Newfoundland and Labrador have provided valuable insight into the timeline and dynamics of this issue. However, the mechanisms of mercury methylation remain complex. Changes in mercury concentration from baseline is very site specific and is dependent on many site specific parameters including baseline concentrations and predicted changes in specific water chemistry parameters (e.g., pH, sulphate, organic carbon), temperature and oxygen regime, hydrology (residence time, flow rate), and food web structure.

Four models have been developed to predict fish mercury concentrations in central and eastern Canadian hydroelectric reservoirs; two simple regression-based models and two multi-dimensional mechanistic models. As part of the Preliminary Strategy Document we reviewed each of the models and their data requirements to identify data gaps that must be filled in order to conduct sophisticated, mechanistic mercury modeling. The decision was made to run the Harris and Hutchinson (2008) simple regression model to develop a preliminary understanding of the maximum potential increase in mercury in reservoir fish and then follow this up during the EA process with a multi-dimensional mechanistic model, once sufficient data had been gathered and information gaps filled.

This simple regression approach predicts the maximum relative increase in mercury concentration in fish expected for a new reservoir based on total reservoir area, total flooded area, and mean annual discharge (m^3/y). The predicted peak increase factor (e.g., X times) is multiplied by existing baseline fish mercury concentrations to predict peak mercury concentration in the future reservoir. Note that the regression model does not predict timing of the response, only magnitude. Turnover or residence time of water in the reservoir plays a key role in the magnitude and duration of increase in mercury concentrations in environmental media. The peak increase for fish mercury concentrations is greater when there is more flooding and when turnover is low. The Harris and Hutchinson (2008) regression model was calibrated using data for northern pike (*Esox lucius*) from 11 reservoirs in Ontario and Quebec, where sampling of fish mercury levels was carried out at sufficient time intervals to identify peak fish mercury levels.

At Site C, the Harris and Hutchinson model predicted a peak increase factor in fish of 2.1 x baseline concentrations (ranging between 1.9x and 3.0x baseline, assuming long-term high and low discharge rates respectively). Higher flow over the long-term would result in lower predicted increases in fish Hg levels, due to a dilution effect as more water passes through the reservoir. In 2010, baseline mercury concentrations in large (i.e., 550 mm) bull trout from the Peace River averaged 0.09 mg/kg wet weight (see Section 6 of this document). If we assume that long-term discharge patterns from Williston Reservoir / Dinosaur Reservoir are similar moving forward, applying the 2.1 peak increase factor against the baseline mean of 0.09 mg/kg, we predict peak Hg concentrations in standardized 550 mm bull trout of approximately 0.2 mg/kg mercury. This value could be slightly higher or lower depending on long-term discharge or flow rates through the reservoir. The predicted relationship between Site C and other reservoirs in Quebec and Manitoba, using the simple predictive model is depicted below. More detail is in Azimuth 2010b.



Application of a mechanistic model is the next step to derive independent and more precise predictions of increases in mercury in fish (and other environmental media) at different points in time during the evolution of the proposed reservoir. Two complex models have been developed in Canada, one for use by Hydro Quebec and another by Reed Harris Environmental for use by Manitoba Hydro and Newfoundland and Labrador Hydro. Both complex models are dynamic and require a large number of detailed input parameters, including a wide range of water chemistry parameters, physical features, geochemistry, atmospheric mercury additions, fish growth and energetic and others. Running these complex models requires a large investment in time from experts intimately familiar with them. The outcomes of such a model are predictions of mercury in environmental media (e.g., water, plankton) including fish, over time.

We recommend use of the mechanistic model developed by R. Harris Environmental, known as Reservoir Mercury Model or RESMERC (Harris et al., 2009). RESMERC is a mass balance model that predicts time-dependent concentrations for three forms of mercury (methyl mercury, inorganic mercury (HgII), and elemental mercury Hg^0) in water, sediment, flood zones and a seven level food web (phytoplankton, zooplankton, benthos and up to four fish species in multiple age cohorts).

RESMERC is a complex model that considers the inputs and outputs of mercury (e.g., downstream transport, fishing loss), and mercury cycling and processes, including atmospheric deposition, import and export, adsorption/desorption, particulate settling, air/water gaseous exchange, industrial point sources, *in-situ* transformations (e.g., methylation, demethylation, MeHg photodegradation, Hg(II) reduction and oxidation, etc.), Hg kinetics in plankton and partitioning in benthos, and methyl mercury bioaccumulation in fish, and others.

Historic information gathered from the Peace River downstream of Peace Canyon Dam (PCD) to the Moberly River (e.g., Golder, 2009a, 2009b; Mainstream Aquatics, 2009), 2010 baseline data (presented herein) and data gathered from parallel modeling studies conducted on the Peace River in 2010 (e.g., predicted changes in temperature regime, nutrient concentrations, biomass of flooded vegetation, food web changes) will be incorporated into the RESMERC model, to quantitatively predict changes in fish mercury concentrations over time. **Appendix B** outlines the key data input requirements to run the RESMERC model, summarizes existing data and the status of new data needs. Note that data requirements of RESMERC were used as the basis for the study design for the 2010 Hg investigation in order that as much empirical data as possible could be used. Ultimately, predictions of mercury concentrations in invertebrates and fish will be used in the EAC process to predict potential risks to insectivorous birds and fish-eating wildlife and humans.

1.5. Phase 2 Report Objective

This report is primarily a data report to document baseline information and support future use of RESMERC to address issues specific to Hg in the proposed Site C development EAC. The specific objectives of the 2010 investigation were to:

1. Gather and document results of the 2010 field study on mercury and ancillary parameters in environmental media from the Peace River and Dinosaur Reservoir to fill existing data gaps and support RESMERC.
2. Provide perspective on the relative magnitude of inorganic and methyl mercury concentrations in soil, vegetation, water, sediment, zooplankton, benthos and key fish species from the Peace River and flood footprint. An investigation of stable carbon and nitrogen isotopes in biota tissue was also undertaken to assist in our understanding of the trophic structure of the Peace River and Dinosaur Reservoir food web and fish Hg concentrations.
3. Place the 2010 water and biota mercury data into context with historic data; for example, to similar data collected in 2001 from Williston Reservoir (Baker et al., 2002) and to fish data collected in earlier studies (i.e., in 1990 and 2008) from the Peace River (e.g., Mainstream Aquatics, 2009).

The intent is to provide the reader with an understanding of where Dinosaur Reservoir and Peace River mercury concentrations fall within the spectrum of what are considered 'typical' concentrations from remote, pristine areas removed from anthropogenic sources and 'elevated' concentrations that might result from naturally high background, recently created reservoirs, and/or anthropogenic inputs.

More detailed analyses and interrelationships among environmental media will be provided in a (future) technical appendix to the EA. Relationships between mercury and methyl mercury in water, sediment and lower trophic level biota will be explored, as well as how these and other environmental parameters may influence observed mercury concentrations in fish and implications following reservoir creation.

1.6. Phase 2 Report Structure

This document is organized according to major environmental media collected during the 2010 sampling campaign, documented in the 2010 SAP (Azimuth, 2010b).

- ***Section 2.0 – Mercury:*** The monitoring strategy and study design are paraphrased here from the SAP (Azimuth, 2010b) as well as the overall strategy for collection of mercury in environmental media.

Subsequent sections describe the approach, methodology and key results for each of the following media:

- ***Section 3.0 – Water:*** This section describes the collection procedures for water samples for analysis of total and methyl mercury and key ancillary parameters (e.g., pH, nutrients, anions, sulphate) from three locations in the Peace River, two from Dinosaur Reservoir and one from each of three tributary streams. Results of seasonal water sampling data are provided and contrasted with historic data from Peace River (Golder, 2009a and 2009b) and Williston Reservoir (Baker, et al., 2002).
- ***Section 4.0 – Sediment:*** This section describes methodology for sediment collection from depositional areas within the Peace River and in Dinosaur Reservoir. Results of sediment grain size, pH, total metals and inorganic and methyl mercury are presented and contrasted with results from historic work in Williston Reservoir.
- ***Section 5.0 – Aquatic Invertebrates:*** This section addresses benthos and zooplankton collected from Dinosaur Reservoir and Peace River. Pelagic zooplankton were collected from the same three locations as water along the Peace River mainstem and from three locations in Dinosaur Reservoir and analyzed for total and methyl mercury and stable carbon and nitrogen isotopes. Benthic invertebrates were collected from riffle areas at three locations along the Peace River and where possible, from depositional areas in Dinosaur Reservoir. Benthic tissues were analyzed for total and methyl mercury concentrations and for stable carbon and nitrogen isotopes.
- ***Section 6.0 – Fish & Trophic Structure:*** Four fish species, bull trout (*Salvelinus confluentus*), mountain whitefish (*Prosopium williamsoni*), longnose sucker (*Catostomus catostomus*) and redside shiner (*Richardsonius balteatus*) were collected by Mainstream Aquatics, Edmonton, from the Peace River and Dinosaur Reservoir. Tissue samples were analyzed for total mercury and stable isotopes. Mercury data from fish, benthos and zooplankton were combined with the stable isotope data to gain an understanding of current food web dynamics and to understand trophic food web structure and transfer and bioaccumulation of methyl mercury.
- ***Section 7.0 – Soil:*** Soil samples were collected from representative habitat types (i.e., stratified according to Terrestrial Ecosystem Mapping (TEM) by Keystone, 2009) throughout the forecast footprint area of Site C. This section also describes the rationale and methodology used to select discrete terrestrial habitat types for the purposes of characterizing soil chemistry, organic content and vegetation

cover. Information collected on soil depth is combined with geographic information system (GIS) data of representative polygons to derive total biomass (kg) of carbon and mercury within the flood zone. The quantity and quality of carbon is a major driver of the mercury methylation process and is an especially important component of mechanistic mercury modeling.

- ***Section 8.0 – Vegetation:*** Leaves and needles of representative vegetation types were analyzed for total metals and inorganic mercury. Methyl mercury was analyzed for a sub-set of vegetation types.

There are well-established protocols for sampling of inorganic mercury and methyl mercury and standard methods, including quality assurance/quality control (QA/QC) procedures. The methods used and their results are provided within each section.

2. MONITORING STRATEGY

2.1. Background

One of the objectives of the previous phase of work (Phase 1; see **Section 1.2**) was to develop a strategy for addressing mercury as it relates to Site C. Phase 1 delivered a literature review, review of mercury models, and identification of key data gaps. This section provides a review and update of that strategy.

Based on existing data (e.g., Baker et al., 2002; Golder, 2009a and 2009b; Mainstream Aquatics, 2009), mercury concentrations in water and fish in the Peace River are relatively low. However, it has been nearly a decade since total and methyl mercury concentrations were measured in water, sediment, benthos and zooplankton in Williston Reservoir (Baker et al., 2002) and mercury data from each of these media in the Peace River and Dinosaur Reservoir are lacking. To use the RESMERC mechanistic mercury model during the EA process, recent data for appropriate background concentrations prior to hydroelectric development are needed for reliable predictions. The dynamics of mercury methylation and bioaccumulation by aquatic biota is very site specific and depends on baseline conditions and expected changes in water chemistry, temperature, oxygen, and food web structure over time in the new reservoir.

A principal goal of mercury-related studies for Site C will be to predict how key conditions are likely to change over time as a result of reservoir creation. This information will be used to estimate the magnitude and duration of elevated mercury concentrations in fish, which is an important consideration for humans and fish-eating wildlife. Thus, running the REMERC model not only depends on baseline data but also on predictions, over time (i.e., during flooding and evolution of conditions especially during the first 5 – 10 years after flooding) of limnology, water chemistry and food web structure (e.g., changes in fish community structure, diet, life history).

Insight into potential changes in mercury and methyl mercury can also be gained from examining conditions in Dinosaur Reservoir. Dinosaur can serve as an analog to some extent, for what might be observed at Site C because it receives the same water from Williston and has similar physical/chemical conditions and hydraulics (i.e., limited storage capacity and a similar assemblage of fish). However, ecological conditions and mercury concentrations observed in Dinosaur would be considered ‘end game’ concentrations, as the reservoir phenomenon would have largely disappeared by now, given the age of Dinosaur Reservoir (>30 years). Williston Reservoir was created nearly 45 years ago and is well past the age at which residual impacts of flooding are observable (Bodaly et al., 2007).

2.2. Study Design

As part of the Phase 1 mercury strategy for Site C (Azimuth, 2010a), we reviewed previous studies with relevant supporting data within the Peace River over the past few years:

- Golder, 2009a. Water Quality, River Sediment, Soil and Vegetation Samples from the Peace River Watershed – 2007. Baseline Data Collection.
- Golder, 2009b. Peace River Watershed Water Quality and Dinosaur Lake Limnology Sampling – 2008.
- Mainstream Aquatics Ltd, 2009. Site C Fisheries Studies Mercury Levels in Peace River Fish Tissue Data Report. June, 2009.
- Terrestrial Ecosystem Mapping (TEM) 2009. Keystone Wildlife Research.

Based on that review and selection of the RESMERC model (see **Section 1.3**), data gaps were identified that formed the basis for SAP (see **Section 1.2**) which was then executed resulting in the 2010 field investigation, reported herein. Thus, the 2010 field program fulfilled two major objectives: 1) gather essential data to run the RESMERC mechanistic mercury model; and 2) determine trophic, food-web relationships in Dinosaur Reservoir and in the Peace River upstream of Site C through the use of stable carbon (C) and nitrogen (N) isotopes.

Eight media types were collected; water, sediment, zooplankton, benthic invertebrates, fish, soil and vegetation. Proposed sample collection locations for most abiotic parameters (water, sediment, soil) and biotic factors (zooplankton, benthos, vegetation) were described in the SAP.

In most cases, actual collection locations for each media were very close to the forecast locations. Locations for samples from the various media are depicted as follows:

- Water, sediment, benthos and zooplankton
    - **Figure 2-1** for the Peace River
    - **Figure 2-2** for Dinosaur Reservoir
    - **Appendix A** for detailed map views, split into 11 maps along the Peace River between Peace Canyon Dam (PCD) and the proposed Site C dam location.
    - **Table 2-1** for field UTM coordinates
- Soil and vegetation

- **Appendix A –** These maps depict the precise location of all soil and vegetation sampling locations during the 2010 field survey. The field UTM coordinates for collections of water, sediment, zooplankton and benthic invertebrates are presented in **Table 2-1**.

- Fish
  - Collected from various locations throughout the mainstem of the Peace River between Hudson Hope and Moberly River
  - Specific locations of their collection are generally noted on **Figure 6-1** because fish are migratory within the Peace River system.

2.2.1. Abiotic Parameters

Abiotic parameters include water, sediment and soil. This section describes the rationale for the sample location and sample size of abiotic parameters collected from Dinosaur Reservoir and Peace River between Peace Canyon Dam (PCD) and Moberly River.

Water – Water was collected from three mainstem locations along the Peace River, two locations in Dinosaur Reservoir and one samples from each of three major tributary streams (Farrell, Halfway, Moberly) to characterize seasonal discharge of total and methyl mercury (particulate bound and dissolved) and select water chemistry parameters. Vertical temperature, oxygen and conductivity profiles were also measured from Dinosaur Reservoir to determine water column conditions and determine if any vertical stratification had been established in the reservoir at the time of sampling. The water sampling locations were co-located with historic sampling locations as follows:

Mainstem:

- PR WQ-1 – Below PCD, upstream of Hudson's Hope, corresponding to Golder (2009a) Peace 1 location.
- PR WQ-2 – Upstream of the confluence with Halfway River corresponding to Golder (2009a) Peace 2 location.
- PR WQ-3 – Upstream of the confluence with Moberly River corresponding to Golder (2009a) Peace 3 location just above the planned Site C dam location.

Tributaries:

- Farrell Creek (FER-WQ) – To estimate suspended sediment and mercury loading from north shore tributary streams, corresponding to Golder (2009a) Farrell 11A.

- Halfway River (HALF-WQ) – To estimate sediment and mercury loading from the largest north shore tributary stream, corresponding to Golder (2009a) Halfway 9.
- Moberly River (MOB-WQ) – To estimate sediment and mercury loading from the largest south shore tributary stream, corresponding to Golder (2009a) Moberly 7, or downstream of 7 so long as the station is upstream of influence from Peace River.

Dinosaur Reservoir:

- Upper Reservoir (DINO-UP-WQ) – To determine mercury loading from Williston Reservoir to Dinosaur and ultimately to Peace River.
- Middle Reservoir (DINO-MID-WQ) – To determine mercury concentrations middle and lower reservoir prior to exit from Dinosaur to Peace River.

Sediment – Sediments within the river floodplain consisted primarily of sand and gravel and this medium is not expected to contribute to mercury methylation within the new reservoir. Nevertheless, to characterize baseline conditions we collected fine sediments from the vicinity of the three mainstem Golder (2009a) Peace River stations. We also attempted collection of sediment from within Dinosaur Reservoir. This met with limited success because of the general lack of depositional areas. This is discussed in more detail in **Section 4.0**.

Soil – Organic soils are the major contributors of organic carbon as a nutrient source and inorganic mercury that is available to be methylated. These parameters are the major drivers of methylation in new reservoirs and considerable effort was made to adequately characterize soil chemistry, stratified by habitat type, across the proposed footprint of the Site C reservoir. We stratified sampling according to dominant habitat types and to habitat types known to have higher inorganic and methyl mercury concentrations such as wetlands and bogs. All of the vegetation and soil types / descriptions within habitat polygons were derived from Keystone Wildlife Research (2009) report entitled *Expanded Legend for the Peace River Terrestrial Ecosystem Mapping Project*.

The strategy for sampling soils was as follows:

- Focus on habitat types/polygons associated with carbon enriched-soils [e.g., step moss peavine (AM), willow horsetail sedge wetland (WH)].
- Establish greater sampling effort within the two largest habitat classes, Fm02 (cottonwood spruce red-osier dogwood) and SH (currant horsetail).

- Exclude low frequency or low mercury habitats including CB (cutbank), GB (gravel bar), RI (river), RZ (road) and those with <1% coverage except habitats with a wetland component.
- Prioritize polygons representing wetlands BL, BT, SE (sedge wetland) and proportional number of polygons for SW (wildrye peavine) and SH
- Avoid polygons located on private property.

2.2.2. Biotic Parameters

Plants – Representative tissue samples (leaves, needles) of dominant terrestrial plant species including trees (e.g., hemlock, Douglas fir, balsam), shrubs (alder, sarsaparilla) and grasses were collected from various locations along the Peace River between Hudson Hope and Site C from within the proposed flood footprint. Plant tissues were analyzed for total mercury. Although terrestrial organic material is an important driver of the methylation process in new reservoirs, living plant material typically has very low mercury concentration and is a much less important driver than organic material in soils. Nevertheless, we characterized mercury in dominant vegetation types for input into the mercury model.

Benthic Invertebrates – Benthic invertebrates are an important component of the base of the aquatic food web and are particularly important in rivers. Benthic invertebrates were collected from riffle habitats at the same Peace River locations as for water and sediment. Samples of benthos collected from each station (PR-BEN-1, PR-BEN-2 and PR-BEN-3) were divided in half for analysis of total and methyl mercury by ALS and for stable isotopes by University of New Brunswick.

We also attempted benthic invertebrate collections from Dinosaur Reservoir. However, given the very hard nature of the bottom and near absence of depositional areas, it was difficult to collect benthos. In the end there was only sufficient tissue collected to comprise a single composite sample from Dinosaur as described in **Section 5.0** that was analyzed for mercury, methyl mercury and stable isotopes.

Zooplankton –Similar to benthos, zooplankton were collected from the three Peace River stations and two locations in Dinosaur Reservoir for mercury, methyl mercury and stable isotopes.

Fish – Four species representing different levels of the trophic food web were sampled for total mercury in tissue and stable isotopes from various locations along the Peace River and from Dinosaur Reservoir. These fish species were:

- Longnose sucker (*Catostomus catostomus*) a benthic forager that consumes algae and benthic invertebrates.

- Redside shiner (*Richardsonius balteatus*) a common forage species that feeds on insect larvae and zooplankton and is consumed by other fish species.
- Mountain whitefish (*Prosopium williamsoni*), a common benthic feeder that is an important intermediate species in the food web.
- Bull trout (*Salvelinus confluentus*) an important piscivorous species that is at the top of the food web and also targeted by humans for food.

These results will be compared to results of the 2008 survey of fish mercury (Mainstream Aquatics, 2009). Sampling was stratified across the size range encountered to provide a size-mercury relationship from which to calculate size-adjusted comparisons (i.e., at a common size between areas and over time) in mercury concentration for each species. Combined with results of stable isotope analyses and dietary analysis, these data will provide insight into mercury and food web dynamics within the Peace River. The findings for Dinosaur Reservoir may provide insight into what Site C might resemble should it be developed, using Dinosaur Reservoir as an analogue.

Table 2-1. Sample types, IDs and sampling location coordinates, BC Hydro 2010.

Sample Type & Location		Date	Sample ID	UTM Location Northing	UTM Location Easting
Water	Peace River	29-Jun-10	PR1-WQ	6207857	566155
		29-Jun-10	PR2-WQ	6229346	594775
		30-Jun-10	PR3-WQ	6230725	628277
		29-Aug-10	PR1-WQ	6207873	566098
		29-Aug-10	PR2-WQ	6229491	594899
		28-Aug-10	PR3-WQ	6230830	628451
	Dinosaur Reservoir	2-Jul-10	DINO-MID-WQ	6203176	557610
		2-Jul-10	DINO-UP-WQ	6201204	553260
		30-Aug-10	DINO-MID-WQ	6202811	557578
		30-Aug-10	DINO-UP-WQ	6201221	553327
	Tributaries	3-Jul-10	FER-WQ	6220375	578867
		3-Jul-10	HALF-WQ	6231901	596482
		3-Jul-10	MOB-WQ	6228032	622756
		31-Aug-10	FER-WQ	6220354	578737
		27-Aug-10	HALF-WQ	6231912	596425
		7-Oct-10	MOB-WQ	6228032	622756
Zooplankton	Peace River	18-Sep-10	PR-ZOOP-1	6207848	566195
		18-Sep-10	PR-ZOOP-2	6229433	594929
		18-Sep-10	PR-ZOOP-3	6230657	628503
	Dinosaur Reservoir	2-Sep-10	DINO-ZOOP-DOWN	6203460	562049
		2-Sep-10	DINO-ZOOP-MID	6202366	557736
		2-Sep-10	DINO-ZOOP-UP	6201434	552709
Sediment	Peace River	18-Sep-10	PR-SED-1	6208886	567452
		18-Sep-10	PR-SED-2	6229415	594987
		18-Sep-10	PR-SED-3	6230657	628252
	Dinosaur Reservoir	19-Oct-10	DINO-SED-DOWN-5m	6203520	561588
		19-Oct-10	DINO-SED-DOWN-10m	6203515	561559
		19-Oct-10	DINO-SED-DOWN-15m	6203554	561598
		19-Oct-10	DINO-SED-MID-5m	6202405	557470
		19-Oct-10	DINO-SED-MID-10m	6202439	557143
	Tributaries	16-Sep-10	FER-SED	6220349	578741
		16-Sep-10	HALF-SED	6231918	596444
		15-Sep-10	MOB-SED	6228014	622759
Benthic Invertebrates	Peace River	29-Aug-10	PR-BEN-1	6207778	566337
		29-Aug-10	PR-BEN-2	6229450	595017
		28-Aug-10	PR-BEN-3	6230750	628266
	Dinosaur Reservoir	2-Sep-10	DINO-BEN-DOWN	6203218	562155
		2-Sep-10	DINO-BEN-MID	6201056	553848
		2-Sep-10	DINO-BEN-UP	6204646	549157

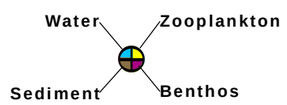
Notes:
UTM coordinates are in NAD83 for zone 10V.

N

Halfway River
Cache Creek
Charlie Lake
Tea Creek
Fort St. John
97
HALFWAY
PR3
Old Fort
PR2
Peace River
Farrell Creek
Moberly River
MOBERLY
Location of Proposed Site C Dam
FARRELL
Lynx Creek
29
Pine River
Williston Lake
Hudson's Hope
WAC Bennett Dam
Peace Canyon Dam
PR1
Dinosaur Reservoir
DINO - DOWN
DINO - MID
DINO - UP

MAP NOTES:
1. Datum: NAD83.
2. Projection: UTM Zone 10N.
3. Hydrology data is from TRIM.
4. Road/Access data is from TRIM.

Figure 2 - 1
Legend of Parameters Collected



0 2.5 5 10 15 Km

Construction of the Site C Clean Energy Project is subject to required regulatory approvals including environmental certification.

BC hydro

SITE C CLEAN ENERGY PROJECT

Site C

Figure 2-1
Water, Sediment, Zooplankton and Bethnic Invertibrate Sampling Locations, Peace River 2010

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

548000 550000 552000 554000 556000 558000 560000 562000

6208000 6206000 6204000 6202000

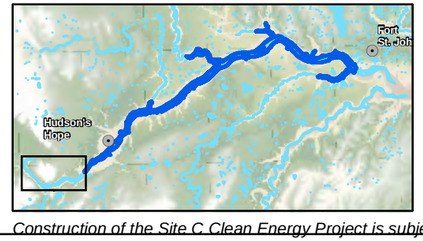
N

WAC Bennett Dam

Peace Canyon Dam

DINO-SED-DOWN-5m
DINO-SED-DOWN-10m
DINO-ZOOP-DOWN
DINO-BEN-DOWN
DINO-MID-WQ - Spring
DINO-MID-WQ - Fall
DINO-SED-MID-10m
DINO-SED-MID-5m
DINO-ZOOP-MID
DINO-ZOOP-UP
DINO-UP-WQ - Fall
DINO-UP-WQ - Spring
DINO-BEN-MID

Dinosaur Reservoir



MAP NOTES:
1. Datum: NAD83
2. Projection: UTM Zone 10N
3. 1:40,000 scale orthophotography (2007) provided by BC Hydro LANDSAT Imagery shown from Site C to the Alberta border.
4. Property information provided by ICIS, updated by BC Hydro
5. Hydrology data is from TRIM
6. Proposed reservoir area (461.8m maximum normal elevation) from Digital Elevation Models (DEM) generated from LiDAR data acquired July/August 2006

- Benthos
- Sediment
- Water
- Zooplankton

0 250 500 1,000 1,500 2,000 m

1:40,000

Construction of the Site C Clean Energy Project is subject to required regulatory approvals including environmental certification.

BC hydro

SITE C CLEAN ENERGY PROJECT

Site C

FIgure 2.2
Water, Sediment, Zooplankton and Bethnic Invertibrate Sampling Locations, Dinosaur Reservoir 2010

DATE	SEP 2011	DWG NO	1016-C14-B4134	R	0

3. WATER

Seasonal (i.e., late spring and late summer) water samples from Peace River and Dinosaur Reservoir were analyzed for parameters that are important to characterize baseline conditions and/or because they are important moderators or contributors to mercury methylation. Water was collected seasonally to capture freshet flow and summer low flow contributions of inorganic mercury and nutrients to the Peace River (mainstem and major tributaries). Water samples were collected by Golder Associates (Golder) under contract to BC Hydro. They also collected water for analysis of nutrients, which are not required by the mercury model, but were important to other consultants conducting nutrient modeling. This data set builds on the more comprehensive data collected by Golder from the Peace River in 2007 (2009a) and 2008 (2009b) and fills in gaps for certain parameters. For example, detection limits used in 2007/2008 were not low enough to document actual mercury concentrations in water from the Peace River. As a result, the 2010 data are the only data that exist for inorganic and methyl mercury in the Peace River, exclusive of historic data from Williston Reservoir (Baker et al., 2002).

3.1. Methods

3.1.1. Field Sampling

Water quality samples collected by Golder generally followed the methods outlined in the 2010 SAP (Azimuth, 2010b) and this document should be consulted for greater detail on sampling procedures if required.

Water was collected during late spring (29 June – 2 July) and late summer (29 – 31 August) from three locations in the mainstem of the Peace River (PR1-WQ, PR2-WQ and PR3-WQ), one from each of three major tributary streams (**Figure 2-1**), and two stations in Dinosaur Reservoir (DINO-UP-WQ and DINO-MID-WQ) (**Figure 2-2**) (also see maps in **Appendix A**). These stations were situated in approximately the same locations as sampled by Golder in 2009 (2009a, 2009b). Collection locations were situated within the mainstem but away from direct influence from three tributary streams. Similarly, collections in tributary streams were not influenced by water from the mainstem. **Table 2-1** provides UTM coordinates (NAD 83) of actual sample collections.

Seasonal sampling was conducted to characterize chemical parameters during spring freshet (late June/early July) and during low flows in late summer (August/September). Spring freshet carries large suspended sediment loads that are responsible for transport of particulate-bound inorganic mercury that, depending on where particles are deposited and can contribute to mercury methylation.

Water was collected from approximately 3 m depth in Dinosaur Reservoir and from near-surface from the Peace River (0.2 – 0.5 m) and tributaries (0.2 m). To acquire samples, water was pumped from below the surface using a battery operated peristaltic pump through weighted flexible (food-grade silicone) tubing. After flushing the tubing for at least one minute, sample water was discharged directly into the laboratory-supplied sampling containers, acidified if necessary, sealed and immediately placed on ice. To acquire filtered samples for dissolved parameters (e.g., dissolved organic carbon, dissolved mercury) a 45 um Voss inline filter was connected to the end of the outflow tube. Thus filtered water was discharged directly to the sampling vessel.

Field measurements of pH, temperature, oxygen content, and conductivity were also made at each station and sampling event (**Table 3-2**) using a portable Hydrolab DS-5 meter. In Dinosaur Reservoir vertical profiles of temperature, oxygen, pH and conductivity were taken at 1 m intervals between the surface and up to 23 m depth to determine water column limnology and stratification, if any.

Water chemistry concentrations were tabulated and compared against each other, and, when available, compared to the 30-day average and maximum BC Approved and Working Water Quality Guidelines for the protection of aquatic life. These guidelines are intended to provide a conservative level of protection to freshwater aquatic life from anthropogenic contaminants or other physical changes (suspended solids, temperature) and comparisons are made here for reference purposes.

With respect to mercury, because this metal naturally occurs at very low concentrations in water, concentration is typically measured and reported as nanograms per liter (ng/L), which is one million times less than 1 mg/L, the concentration that most other parameters is typically reported. The Environment Canada mercury guideline for the protection of aquatic life is 26 ng/L (CCME, 2002). British Columbia recently revised its mercury water quality guideline for the protection of aquatic life based on the amount (as a percentage) of methyl mercury in water as a percentage of the total. The 30-day guideline concentration ranges from 1.25 ng/L when methyl mercury is 8% of total, to 20 ng/L when methyl mercury is 0.5% of total. The guideline was developed to provide a concentration of mercury in water below which (in theory), mercury in the tissue of aquatic life would not exceed a concentration of 0.033 mg/kg (this value is referred to as the ‘tissue residue guideline’ in BC). The intent is that if mercury concentrations in water are low enough, there is insufficient mercury in the aquatic system to eventually end up being accumulated (by diet, not by absorption from the water) by fish and other aquatic organisms.

The CCME and BC drinking water guideline is 1,000 ng/L (1 µg/L).

3.1.2. Parameters Measured

The following parameters were measured for all samples and analyzed by the laboratory listed for each bullet:

- Conventional parameters including pH, hardness, anions, nutrients, alkalinity, total & dissolved organic carbon (TOC & DOC), and total suspended solids (TSS) (**ALS**).
- Low-level TSS (detection limit = 0.2 mg/L) for calculating particle-bound Hg and MeHg (**RT Geosciences**).
- Total mercury and methyl mercury both in filtered and unfiltered water samples to estimate total particulate bound and dissolved fractions (**ALS**, Vancouver for spring samples; **CEBAM**, Seattle, WA for fall samples). Note that CEBAM was erroneously used for water samples during the fall collection. However CEBAM is a highly experienced laboratory specializing in mercury analysis and there was no compromise in data quality. In fact, CEBAM's detection limits for total mercury are an order of magnitude lower than for ALS, so slightly more accurate data were acquired for total mercury concentrations during the fall sampling event.

3.1.3. QA/QC

Three kinds of sample analyses were conducted for QA/QC purposes:

- **Field Duplicate –** Field duplicate samples (i.e., independent duplicate sample) were collected during the spring and fall sampling events to assess sampling variability and sample homogeneity; a RPD (see definition below) of 50% for concentrations that exceed 10x the MDL is considered acceptable. The sampling station used as a field duplicate was selected at random.
- **Equipment Blank** – Equipment blank (EB) samples were collected during the spring (2 samples) and fall sampling events. EB samples are acquired by pumping de-ionized water through the water sampling equipment (pump, tubing and inline filter) and filling the specified sample containers at the site; these samples are used to assess the potential introduction of any contamination accountable to sample handling and sampling techniques. Results from the equipment blanks are examined for detectable concentrations of any of the parameters measured; no parameter should exceed detection.
- **Laboratory Duplicate** – The laboratory routinely analyses random independent aliquots of sample from the original sample as part of the laboratory's internal QA/QC program for every batch of samples shipped to the laboratories. This was

true for ALS and CEBAM. Data quality objectives (DQO) for laboratory duplicates these should be within ± 25% of the first count (i.e., the RPD, see below).

- In addition, all laboratories routinely run certified reference materials (CRM). CRM samples are samples with known quantities of mercury and are used to verify that recovery of mercury (± from 100%) is within acceptable boundaries and that there is no consistent over or under estimation.

Laboratory QA/QC – Data Quality Objectives (DQOs) are numerically definable measures of analytical precision and completeness. Analytical precision is a measurement of the variability associated with duplicate analyses of the same sample in the laboratory. Completeness for this study is defined as the percentage of valid analytical results. Results that were made uncertain due to improper calibration, contamination of analytical blanks, or poor calibration verification results were deemed invalid.

Duplicate results were assessed using the relative percent difference (RPD) between measurements. The equation used to calculate a RPD is:

$$RPD = \frac{(A - B)}{((A + B)/2)} \times 100$$

where: A = analytical result; B = duplicate result. Note that a duplicate can be a laboratory duplicate (i.e., a separate aliquot from the same sample) or a field duplicate (an independently collected sample from the same time and location) so this is specified with the data.

The laboratory DQOs for this project were:

- Analytical Precision = 25% RPD for concentrations that exceed 10x the detection limit (DL).
- Completeness = 95% valid data obtained.

RPD values may be either positive or negative, and ideally should provide a mix of the two, clustered around zero. Consistently positive or negative values may indicate a bias. Large variations in RPD values are often observed between duplicate samples when the concentrations of analytes are very low and approaching the detection limit. The reason for this is apparent if one considers duplicate samples with concentrations of an analyte of 0.0005 and 0.0007 mg/L. In absolute terms, the concentration difference between the two is only 0.0002 mg/L, a very tiny amount; however, the RPD value is 33.3%. This may sometimes lead to a belief that the level of precision is less than it actually is; that is the reason that elevated RPD values are only significant when values are more than 10 times the DL.

3.2. Results

3.2.1. QA/QC

QA/QC procedures consisted of a combination of careful field collection and sample handling, the collection of field duplicate samples and the analysis of laboratory replicates and standard reference materials. Results of the QA/QC analyses are presented in **Table 3-1** and results of field sample water chemistry analyses are presented in **Table 3-2**.

ALS Environmental is an analytical laboratory accredited by the Canadian Association of Environmental Analytical Laboratories. This accreditation ensures that laboratories achieve and demonstrate the highest levels of technical and management excellence for their services. Laboratory QA/QC procedures performed on the water samples met all of the laboratory's internal data quality objectives for accuracy, precision and completeness.

CEBAM is an accredited Washington State laboratory specializing in analysis and speciation of trace metals, especially for mercury, arsenic and selenium in various samples using EPA's 1600 Method Series and other innovative analytical techniques. For further details, go to www.cebam.net

An important component of QA/QC is proper field collection methods and in the case of mercury, using the 'clean hands – dirty hands' technique as described in the SAP (Azimuth, 2010b). These procedures were followed at all times by Golder, the company contracted by BC Hydro for field sample collection for all media except soils and fish.

Field Duplicates – Analysis of field duplicate samples (i.e., independent field samples, submitted as blind duplicates to the lab) in spring from Dinosaur Reservoir (DINO-UP) by CEBAM and in fall for Peace River (PR1) by ALS revealed that values for all chemical constituents were very consistent between the original and the blind duplicate samples (DUP-WQ). RPD values were very low in spring (<3.6) and fall (<4.4). The only exception for this was the dissolved methyl mercury concentration in spring. The reason for this and implications are discussed below.

Laboratory Duplicates – Laboratory duplicates (i.e., randomly selected aliquots from the same sample [e.g., DOC bottle) that are re-analyzed) from various stations and parameters (only one example for each parameter is shown, although sometimes multiple re-analyses exist for the same parameter from different locations at different times) also had very low RPD values, indicating good precision by the laboratory.

Equipment Blank – The equipment blank sample consists of distilled water that is run through the hose and pump after sample collection. Concentrations of all measured parameters were below detectable concentrations, confirming that the sampling

equipment was not contaminated or contributing detectable concentrations of any constituent to the field samples.

Completeness – This is a measure of the number of prescribed stations and/or relative proportion of analytes measured in samples from each prescribed station for each sampling period. Only one station in Dinosaur Reservoir (Sed-15 m) was abandoned because the sampling crew could not locate fine sediments from 15 m depth as the bottom was very coarse. No sampling stations were missed (for example due to weather, equipment, access) and at least 99% of prescribed analytes were analyzed for (e.g. some analytes were inadvertently not requested). The dissolved mercury concentration from DINO-UP in spring was not acquired due to a broken sample bottle. However, given that total mercury in the same sample was less than detection (<1.0; **Table 3-1**), this is not an issue. Hardness, calcium and magnesium (DINO-MID in fall) and pH (all fall stations except Moberly River) were not analyzed because Golder accidentally did not request for this analyte. Moberly River was not sampled in late August because of difficulty with access due to low water and time constraints. Sampling was thus deferred until early October.

During the fall sampling event water samples were inadvertently delivered to CEBAM, Seattle rather than ALS, Vancouver. Although it is preferable to use the same laboratory, CEBAM is a very qualified laboratory and actually has lower detection limits than ALS, so this oversight did not compromise data quality. The use of a different laboratory actually provides confirmation of results and confirmed the very low mercury concentrations observed in water during this study.

One QA issue that was noticed by the laboratory and by us, was that dissolved concentrations of methyl mercury were slightly higher than total concentrations during the spring sampling event (**Table 3-1**), but barely exceeding the detection limit (DL) of 0.05 ng/L. Because 'total' mercury concentrations represent the sum of the dissolved fraction plus the particulate bound fraction, the total concentration should always be higher. Only Ferrell and Moberly rivers had detectable concentrations (0.10 ng/L and 0.12 ng/L respectively) of total methyl mercury (i.e., sum of dissolved and particulate-bound). Dissolved methyl mercury concentrations were just above the DL (0.07 – 0.12 ng/L) from the Peace River and Dinosaur River and slightly higher than the total (0.12 ng/L) from the tributary streams. Thus, dissolved methyl mercury concentrations were consistently about 0.02 – 0.05 ng/L higher than totals. While these are relatively very low concentrations, this trend led ALS to investigate the possible cause. Ultimately, it was determined that the certified reference material (CRM) sample for methyl mercury was stored in the same refrigerator as the dissolved methyl mercury samples. It was speculated that a tiny portion of the methyl mercury passed *through* the glass storage bottle of the CRM sample and then passed *into* the glass bottle containing our sample

water within the refrigerator. This finding has subsequently led ALS to store CRM materials in a different refrigerator. Note that where detectable, CEBAM's measured dissolved methyl mercury concentrations were lower than total concentrations in two of three samples during the fall sampling event. CEBAM actually has lower DLs than ALS and these data should be considered slightly more accurate than the spring data. Nevertheless, there was still one instance where the dissolved fraction (0.039 ng/L) exceeded the total (<0.02). As discussed previously, this is not uncommon when concentrations of either dissolved or total fractions of analytes are very near to the laboratory DL.

3.2.2. Chemistry

3.2.2.1. Chemical Limnology

During late June, early July 2010 water temperature of Dinosaur River and the Peace River was about 8^{o}C, well oxygenated (100% saturation) and had relatively low total suspended solids concentrations (<3 mg/L) (**Table 3-2**). Water entering Dinosaur Reservoir and passing downstream is water that is discharged from Williston Reservoir and physical / chemical parameters of the Peace River mainstem are a direct reflection of conditions in the Peace Reach of Williston Reservoir. Vertical temperature, oxygen and conductivity profiles taken at two locations in Dinosaur Reservoir revealed a nearly uniform temperature profile between the surface (11.9^{o}C) and the deepest depth sampled (10.2^{o}C at 20 m). Oxygen concentration was fully saturated from top to bottom with uniform conductivity (169 µS/cm) and pH (8.2). This virtual lack of stratification within Dinosaur Reservoir was consistent with other studies and is also expected given the very short residence time of water within the reservoir (2-3 days) that is insufficient to establish stratification.

Water hardness (~100 mg/L) and alkalinity (90 mg/L) concentrations were low to moderate, as was nitrate (0.04 mg/L) while nitrite was non-detectable (<0.05 mg/L) (**Table 3-2**). Chloride and bromide anions were also below DLs. Dissolved calcium (30 – 36 mg/L) and magnesium (6 – 8 mg/L) concentrations were relatively low.

Total suspended solids (TSS) concentrations in the Peace River were also low, ranging from 0.8 – 4.7 mg/L. This is atypical for large rivers during spring freshet because large rivers typically have higher suspended sediment loads in spring due to erosion caused by snowmelt and precipitation; however, the settling capacity of up-gradient Williston Reservoir appears to ameliorate seasonal fluctuations in TSS.

Sulphate, a nutrient source for sulphate-reducing bacteria (responsible for mercury methylation) ranged from 12 – 18 mg/L in spring. Total (TOC) and dissolved carbon (DOC) concentrations were also very similar at 2.0 mg/L indicating that the vast majority

of carbon in the water column is in the dissolved phase with negligible amounts of particulate bound carbon. Again, this is due to the large settling capability of Williston Reservoir and the very low relative input of particulate carbon from tributary streams to the Peace River relative to spring flow. DOC and TOC were higher in fall (2.8 mg/L) reflecting net carbon productivity over the course of the summer and possibly greater tributary input relative to mainstem flow in fall.

During fall, water temperature was also quite cool, around 8^{o}C with high oxygen saturation (97 – 100%), uniform conductivity (163 µS/cm) and moderately high pH (7.9; field measured). Dinosaur Reservoir was similarly unstratified in late summer/fall with very small differences in temperature between surface and near bottom (20 m) and consistent conductivity, oxygen and pH. Total suspended solids (0.7 – 2.3 mg/L), hardness (90 – 100 mg/L), anions, sulphate (11 – 13 mg/L) and TOC/DOC concentrations were quite consistent between spring and fall in the mainstem of the Peace River. Again, this is a reflection of the consistency within the large reservoir of water stored within Williston that is discharged and characterizes or defines water quality of the Peace River downstream of PCD.

It is noteworthy that low temperature (Ullrich et al., 2001; Benoit et al., 2003; Fitzgerald et al., 2007) and moderate pH (>7) (Miskimmin et al., 1992; Ullrich et al., 2001 and others) do not favor mercury methylation and may partially explain why mercury concentrations in environmental media are relatively low (see subsequent sections). The physical/chemical values observed in Dinosaur Reservoir and along the Peace River mainstem are typical of moderately oligotrophic waterbodies with low productivity (Wetzel, 1983) and are also characteristic of water quality in Williston Reservoir (Baker et al., 2002).

Chemical parameters of smaller tributary streams Farrell, Halfway and Moberly rivers were slightly warmer with similar conductivity and pH as Peace River but had higher TSS concentrations (4 – 2 mg/L) with slightly higher values in spring than in fall. Partly for this reason and because these streams drain forested areas that are not associated with upstream reservoirs, the values of most chemical parameters were higher than Peace River. For example, hardness (200 mg/L), alkalinity (150 mg/L), DOC / TOC (2 – 7 mg/L), anions, and calcium and magnesium were about 2 – 3 x higher. Analytes in the Halfway and Moberly rivers were similar to Peace River, while analyte concentrations were highest and most different from the mainstem in the smallest system, Farrell Creek. The parameter that stood out as being most different in pattern within the tributary streams was sulphate. Sulphate is an important nutrient for sulphate-reducing bacteria that play a key role in the mercury methylation process. Sulphate concentrations were much higher in Farrell Creek in spring and fall (67 and 130 mg/L respectively) than the other streams (maximum 40 mg/L). The reason for this is unknown. It is possible that

elevated concentrations in Farrell Creek may be related to upstream oil and gas development, although this is highly speculative.

3.2.2.2. Mercury

Total mercury concentration in water from Dinosaur Reservoir and Peace River were consistently below 1.0 ng/L (i.e., <1.0 ng/L DL in spring [ALS Laboratory] and 0.6 – 0.8 ng/L in fall [CEBAM, Seattle]) (**Table 3-2**). Because total mercury measurements are the sum of total and dissolved fractions, dissolved mercury concentrations were also consistently below the DL in spring. If fall, total and dissolved mercury concentrations were very similar within stations, however in several cases, dissolved mercury exceeded total mercury concentrations. This is not unusual when measuring very close to the detection limits and in systems where there is virtually no suspended material on which inorganic mercury can adhere to. In these systems, the proportion of total mercury that is in the dissolved phase was very high; in Dinosaur River this was 90% and 97% at Dino-Up and –Mid stations and ranged from 107% - 111% in Peace River.

In general, there were no meaningful differences in total mercury concentration between spring and fall measurements as all values were around 1.0 ng/L. These low and consistent concentrations are a reflection of the consistency of water quality within up-gradient Williston Reservoir. Because of the large pool of water within Peace Reach that is discharged to Dinosaur Reservoir and down the Peace River, a transit time of only a few days, there is insufficient time or sufficient input from other sources to alter the chemistry of Williston Reservoir water.

It is worth repeating that because mercury typically occurs at very low concentrations in water, and is present mostly in the particulate-bound phase, concentrations are typically reported as nanograms per liter (ng/L; parts per trillion), or 1,000 µg/L (parts per billion). These concentrations are much lower than nearly all other elements and a specialty laboratory is needed to measure detectable concentrations. As noted above, BC's mercury water quality guideline is based on the percentage of the total that is comprised of methyl mercury in water and in this case would be 2 ng/L, which is exceedingly low. Nevertheless, total mercury in Peace River water is well below this concentration.

These values observed in Peace River in 2010 are very similar to total mercury concentrations observed in Williston Reservoir in August 2000 and June 2001 by Baker et al. (2002). Total mercury in surface and profundal zones of Finlay reach ranged from 0.6 – 1.06 ng/L which are very similar values to the most recent dataset, reported herein some 10 years later, suggesting that these values are stable and typical of Peace River, and by inference, Williston Reservoir as noted above. In Williston, dissolved total mercury concentrations were low and ranged from 0.4 – 0.7 ng/L, again indicating that

the majority of mercury is in the dissolved phase which is similar to the Peace River and is to be expected given the very low total suspended solids concentrations in the reservoir.

Total mercury concentrations in the tributary streams Farrell, Halfway and Moberly (1.4 ng/L – 2.0 ng/L) were slightly higher than in the Peace River in spring probably because of higher TSS concentrations (4 – 20 mg/L). Inorganic mercury is typically bound to fine suspended sediment particles and there is a correlation between TSS and total mercury. For example, total mercury concentrations in water of tributaries to Williston Reservoir were considerably higher in spring freshet 2001, ranging up to 12.5 ng/L and 28 ng/L in Finlay and Ospika rivers respectively, where TSS concentrations were much higher (266 mg/L and 1180 mg/L respectively; Baker et al., 2002). In fall 2000, total mercury values in these tributaries returned to low levels (~1 ng/L) with low TSS (<3.0 mg/L at the DL). Thus loading of inorganic mercury from tributary streams can be an important source of mercury, depending on the watershed and the relative contribution of tributary flow relative to the mainstem of the river.

In summary for total mercury, concentrations in Peace River (and Dinosaur Reservoir) are very low and typical of what would be observed in remote, pristine systems removed from anthropogenic influence (e.g., mercury mines, chlor-alkali facilities, coal fired generating facilities) or natural geologic sources of mercury (e.g., from cinnabar sources, faults, volcano's). Total mercury concentrations on the order of 2 ng/L or less are considered to be very low (Hurley et al., 1995; Krabbenhoft et al., 1999) and typical of "lakes and streams lacking local anthropogenic or geological sources are usually in the range of 0.3 to 8.0 ng/L" (Krabbenhoft et al., 2007).

Methyl mercury is the most toxic and bioaccumulative form of mercury in food webs, but is typically found at very low concentrations in water, usually at concentrations less than 0.1 ng/L. In Dinosaur Reservoir and Peace River, methyl mercury concentrations were, for the most part, below the CEBAM laboratory DL of 0.02 ng/L in fall (**Table 3-2**). Only Farrell Creek had a barely detectable methyl mercury concentration (0.03 ng/L). In spring, total methyl mercury concentrations (i.e., adhered to sediment particles) were also less than the ALS DL of 0.05 ng/L. As discussed in the QA section of this chapter, dissolved concentrations were slightly higher than the DL apparently because of a presumed contamination issue at the laboratory. Because the dissolved fraction should always be less than the total (which is the sum of particulate-bound and dissolved fractions) the total concentrations are considered most accurate in both seasons and only the dissolved fraction of methyl mercury in fall.

In uncontaminated systems methyl mercury comprises between 1% and 10% of the total mercury in water. This was true for Peace River, as methyl mercury comprised less than

7% of the total in those instances where DLs were exceeded. However, because total mercury concentrations in water from the Peace River are so low and in most cases, below the DL of 1.0 ng/L, there is uncertainty as to what proportion methyl mercury actually comprises of the total.

Again, the 2010 methyl mercury concentrations in water are similar to what was observed in Williston Reservoir in 2000/2001 (Baker et al., 2002). Methyl mercury concentrations in the reservoir ranged from 0.02 – 0.05 ng/L in fall and 0.04 – 0.08 ng/L in spring. Dissolved methyl mercury concentrations were lower, about half of total concentrations. Methyl mercury concentrations were higher in tributary streams to Williston River in spring 2001 (0.03 – 0.14 ng/L) which is expected given the high suspended sediment load and proportionally greater transport of mercury. As a percentage, the concentration of methyl mercury was only 3% - 6% of the total mercury concentration.

In remote, pristine lakes methyl mercury concentrations typically range from 0.04 to 0.8 ng/L (St. Louis et al., 1995; Bodaly et al., 1998; Krabbenhoft et al., 1999), which is very consistent with what was observed in the present study. Similarly the proportion of total mercury that is in the methyl form is also less than about 5% in pristine systems and systems where there are not wetlands, that generate proportionately greater amounts of methyl mercury. This will be explored more fully in the mercury technical appendix to the EIA.

Note that methyl mercury concentrations in water have been reported to be positively but weakly correlated with fish mercury concentrations (Brumbaugh et al., 2001). Given how extremely low mercury concentrations in Peace River water are, this may partially explain the low concentrations measured in fish (see **Section 6**).

Table 3-1. QA/QC data for water parameters, BC Hydro 2010.

		Dinosaur Reservoir Field Duplicate			Peace River Field Duplicate			Various Stations			Various Stations			Equipment Blanks		
		Dino-Up-WQ	Dup-WQ	RPD	PR1-WQ	Dup-WQ	RPD	Original	Laboratory Duplicate	RPD	Original	Laboratory Duplicate	RPD	Spring	Spring	Fall
	MDLs	2-Jul-10	2-Jul-10	(%)	29-Aug-10	29-Aug-10	(%)	Spring		(%)	Fall		(%)	1-Jul-10	13-Jul-10	1-Sep-10
CONVENTIONAL PARAMETERS																
Physical Tests mg/L)																
Hardness	0.50	90.5	91.5	-1.1	90.1	93.5	-3.7	-	-	-	-	-	-	<0.50	<0.50	-
pH	0.10	8.20	8.21	-0.1	-	-	-	-	-	-	-	-	-	5.78	5.60	-
Total Suspended Solids	3.0	<3.0	<3.0	NA	3.0	3.0	0	<3.0	<3.0	NA	<3.0	<3.0	NA	<3.0	<3.0	<3.0
Total Suspended Solids - Low level	0.2	1.3	0.9	31	1.2	1.8	-42	-	-	-	-	-	-	0.10	-	**0.21**
Anions & Nutrients (mg/L)																
Alkalinity - Total (as $CaCO_3$)	2.0	81.5	82.3	-1.0	84.4	83.2	1.4	<2.0	<2.0	NA	-	-	-	<2.0	<2.0	-
Bromide	0.050	<0.050	<0.050	NA	<0.10	<0.10	NA	-	-	-	<0.10	<0.10	NA	<0.050	<0.050	-
Chloride	0.50	<0.50	<0.50	NA	0.13	0.15	-14	-	-	-	0.15	0.14	6.9	<0.50	<0.50	-
Fluoride	0.020	0.027	0.026	3.8	<0.10	<0.10	NA	-	-	-	<0.10	<0.10	NA	<0.020	<0.020	-
Nitrate (as N)	0.0050	0.0479	0.0462	3.6	<0.050	<0.050	NA	-	-	-	<0.050	<0.050	NA	<0.0050	<0.0050	-
Nitrite (as N)	0.0010	<0.0010	<0.0010	NA	<0.050	<0.050	NA	-	-	-	<0.050	<0.050	NA	<0.0010	<0.0010	-
Sulfate (SO_4)	0.50	12.2	12.1	0.82	10.8	11.1	-2.7	-	-	-	11.1	11.2	-0.9	<0.50	<0.50	-
ORGANIC / INORGANIC CARBON																
Dissolved Organic Carbon (mg/L)	0.50	2.03	2.03	0	2.80	2.70	3.6	-	-	-	-	-	-	<0.50	<0.50	<1.0
Total Organic Carbon (mg/L)	0.50	2.08	2.03	2.4	2.90	2.80	3.5	-	-	-	-	-	-	<0.50	<0.50	<1.0
TOTAL METALS																
Mercury (ng/L)	1.0	<1.0	<1.0	NA	0.63	0.96	-42	-	-	-	3.29	3.37	-2.4	<1.0	<1.0	-
DISSOLVED METALS																
Calcium (mg/L)	0.050	26.3	26.6	-1.1	26.6	27.8	-4.4	-	-	-	-	-	-	<0.050	<0.050	-
Magnesium (mg/L)	0.10	6.03	6.08	-0.8	5.72	5.82	-1.7	-	-	-	-	-	-	<0.10	<0.10	-
Mercury (ng/L)	1.0	-	<1.0	NA	0.70	0.72	-3.4	<1.0	<1.0	NA	<1.0	<1.0	NA	<1.0	<1.0	-
SPECIATED METALS (ng/L)																
Methyl Mercury - Dissolved	0.050	0.11	0.055	63	<0.020	<0.020	NA	0.066	0.063	4.7	0.039	0.040	-2.5	<0.050	-	-
Methyl Mercury -Total	0.050	<0.050	<0.050	NA	<0.020	0.037	NA	-	-	-	<0.020	<0.020	NA	<0.050	-	-

Notes:

RPD = Relative Percent Difference (%) = ((original - duplicate) / (original + duplicate)/2) x 100.

Shaded RPDs exceed 25% (lab duplicates) or 50% (field duplicates).

Bolded equipment blanks exceed MDLs, but are < 10 x MDL.

Shaded equipment blanks exceed MDLs, and are > 10 x MDL.

NA = RPDs have not been calculated for cases where one of the samples is below detection and the other is not and in cases where both are below detection.

Samples were analyzed for T-Hg and MeHg by CEBAM (fall samples), Seattle, WA; for TSS-low by RT Geosciences, Squamish, BC; and for the remainder by ALS Laboratories, Burnaby, BC.

Table 3-2. Conventional water chemistry, mercury and methyl mercury, BC Hydro 2010.

Area & Season			SPRING								FALL							
			Peace River			Dinosaur Reservoir		Tributaries			Peace River			Dinosaur Reservoir		Tributaries		
Station ID	**BC Approved and Working**		PR1-WQ	PR2-WQ	PR3-WQ	Dino-Up-WQ	Dino-Mid-WQ	FER-WQ	HALF-WQ	MOB-WQ	PR1-WQ	PR2-WQ	PR3-WQ	Dino-Up-WQ	Dino-Mid-WQ	FER-WQ	HALF-WQ	MOB-WQ
Lab ID	**Water Quality Guidelines[1]**		L903918-1	L903918-2	L903918-3	L903918-4	L903918-6	L904378-2	L904378-3	L904378-1	L926835-6	L926835-7	L926835-1	L926835-4	L926835-3	L926835-5	L926835-2	L942044-1
Date	**30-day Average**	**Maximum**	29-Jun-10	29-Jun-10	30-Jun-10	2-Jul-10	2-Jul-10	3-Jul-10	3-Jul-10	3-Jul-10	29-Aug-10	29-Aug-10	28-Aug-10	30-Aug-10	30-Aug-10	31-Aug-10	27-Aug-10	7-Oct-10
Water Quality (Field) Surface - 0.5m																		
pH	-	-	8.64	7.93	8.20	8.22	8.09	8.51	8.43	8.38	7.92	7.89	8.23	7.91	NA	7.98	8.23	7.49
Temperature (° C)	-	-	10.3	12.0	13.5	12.0	11.1	23.3	16.9	17.6	13.0	13.3	13.1	13.1	NA	11.7	14.5	8.6
Specific Conductivity (uS/cm)	-	-	172	176	215	169	170	471	369	192	163	163	176	162	NA	553	379	217
Dissolved Oxygen (%)	-	-	104	104	100	100	100	108	98	98	98	101	100	97	NA	99	100	100
CONVENTIONAL PARAMETERS																		
Physical Tests (mg/L)																		
Hardness	NG	NG	100	102	126	91	91	251	220	112	90	91	100	91	-	270	219	137
pH	NG	6.5-9	8.13	8.16	8.23	8.20	8.19	8.50	8.44	8.31	-	-	-	-	-	-	-	8.26
Total Suspended Solids	5	25	<3.0	<3.0	3.6	<3.0	<3.0	<3.0	11	16	3.0	<3.0	<3.0	3.0	<3.0	<3.0	15	15
Total Suspended Solids - Low level	NG	NG	0.80	1.2	4.7	1.3	1.4	4.4	15	20	1.2	1.6	2.3	0.71	1.1	2.1	16	4.0
Anions & Nutrients (mg/L)																		
Alkalinity - Total (as $CaCO_3$)	NG	NG	82.6	83.4	99.2	81.5	81.1	200	171	98.7	84.4	84.3	90.5	83.2	86.0	178	173	124
Bromide	NG	NG	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.050
Chloride	150	600	<0.50	<0.50	<0.50	<0.50	<0.50	1.4	<0.50	<0.50	0.13	0.14	0.15	0.14	0.14	3.2	3.7	<0.50
Fluoride	NG	0.3	0.027	0.027	0.036	0.027	0.026	0.21	0.091	0.067	<0.10	<0.10	<0.10	<0.10	<0.10	0.25	0.39	0.055
Nitrate (as N)	3.0	31.3	0.042	0.039	0.020	0.048	0.045	<0.0050	<0.0050	<0.0050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	5.650	<0.0050
Nitrite (as N)	0.02 - 0.04	0.06 - 0.120	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.0010
Sulfate (SO_4)	NG	100	12.9	13.4	18.9	12.2	11.8	67.5	40.0	7.43	10.8	11.2	13.0	10.8	10.7	136	31.4	10.9
ORGANIC / INORGANIC CARBON																		
Dissolved Organic Carbon (mg/L)	NG	NG	2.00	2.06	2.06	2.03	2.21	7.05	1.87	5.08	2.80	2.70	2.50	2.60	2.30	5.90	1.90	4.24
Total Organic Carbon (mg/L)	NG	NG	1.94	2.00	1.03	2.08	2.14	7.46	1.89	5.04	2.90	2.70	2.60	2.60	2.40	6.00	2.00	4.37
TOTAL METALS																		
Mercury [2] (ng/L)	2 - 10	NG	<1.0	<1.0	<1.0	<1.0	<1.0	1.4	1.5	2.0	0.6	0.7	0.8	0.6	0.6	1.3	3.4	<1.0
DISSOLVED METALS																		
Calcium (mg/L)	NG	NG	29.9	30.4	36.8	26.3	26.6	64.7	61.6	31.3	26.6	27.0	29.5	26.9	-	64.7	59.9	38.1
Magnesium (mg/L)	NG	NG	6.22	6.37	8.26	6.03	6.04	21.8	16.0	8.27	5.72	5.84	6.43	5.74	-	26.3	17.0	10.2
Mercury (ng/L)	NG	NG	<1.0	<1.0	<1.0	-	<1.0	<1.0	<1.0	<1.0	0.70	0.77	1.24	0.54	0.62	1.40	1.40	<1.0
SPECIATED METALS (ng/L)																		
Methyl Mercury - Dissolved	NG	NG	<0.050	0.067	0.066	0.11	<0.050	0.12	<0.050	0.12	<0.020	<0.020	0.039	<0.020	<0.020	0.022	<0.020	0.029
Methyl Mercury -Total	NG	NG	<0.050	<0.050	<0.050	<0.050	<0.050	0.10	<0.050	0.093	<0.020	<0.020	<0.020	<0.020	<0.020	0.030	<0.020	0.064
Calculation of BC AWQG for T-Hg																		
Total Mercury (ng/L)			<1.0	<1.0	<1.0	<1.0	<1.0	1.4	1.5	2.0	0.63	0.70	0.85	0.60	0.64	1.31	3.44	<1.0
% MeHg/Total Hg (%)			NA	NA	NA	NA	NA	7.2%	NA	4.7%	NA	NA	NA	NA	NA	2.3%	0.6%	NA
BC AWQG for Total Hg [2] (ng/L)			2	2	2	2	2	2	2	2	2	2	4	2	2	4	10	2

Notes:

NG = no guideline, NA = not appropriate.

[1]BC MOE Science and Information Branch: BC Approved Water Quality Guidelines (WQG), 1998, Updated January 2010. Criteria for the protection of Freshwater Aquatic Life.
BC MOE Science and Information Branch: A Compendium of Working Water Quality Guidelines (WQG) for BC, 1998, Updated September 2009. Table 1.

[2]BC WQG for total mercury ranges from 2 ng/L to 20 ng/L, depending on the percentatge of MeHg. Where % MeHg (of total) <= 0.5%, BC WQG = 20 ng/L;
where % MeHg <= 1%, BC WQG = 10 ng/L; where % MeHg <= 2.5%, BC WQG = 4 ng/L; where % MeHg <= 5%, BC WQG = 2 ng/L.

Shaded concentration exceeds 30-day average BC WQG.

Boxed concentration also exceeds maximum BC WQG.

Samples were analyzed for T-Hg and MeHg by CEBAM (fall samples), Seattle, WA; for TSS-low by RT Geosciences, Squamish, BC; and for the remainder by ALS Laboratories, Burnaby, BC.

4. SEDIMENT

4.1. Methods

4.1.1. Field Sampling

Sediment was collected once, during the fall sampling event, on 18 September from the Peace River and 19 October in Dinosaur Reservoir. It is only necessary to collect sediment once because chemical conditions of sediment are generally quite stable and do not change substantially over the course of time, independent of large events (e.g., floods, landslide, and spills). To characterize sediment chemistry and mercury concentrations, sediment was collected from three locations in the Peace River, one location upstream of the confluence of Farrell Creek and Halfway and Moberly rivers (**Figure 2-1**) from the Peace River, and two locations from multiple depths in Dinosaur Reservoir (**Figure 2-2**) (see maps in **Appendix A**).

Sediment from the middle (SED-MID) and lower (SED-DOWN) reaches of Dinosaur Reservoir was collected using a Petite Ponar grab (0.023 m^2). The following guidelines were followed when selecting a station: attempt to locate a fairly flat piece of bottom, avoid tributary stream mouths (to ensure sediment is collected from the reservoir and not recently deposited by the stream) and attempt to target fine sediment grain size consisting predominantly of silt/clay. Samples from three depths were attempted at each station, at 5 m, 10 m, and 15 m depth (+/- 1 m). Sediment could not be collected from SED-MID 15 m because of the lack of fine sediments, so no sample was acquired here. In all cases, multiple failed grabs were encountered because of the steep slope and coarse rocky grain size. In successful grabs, the top 3-5 cm of sediment was removed from the grab and placed into a stainless steel bowl. At least 3 grabs, and in some cases in excess of 10 grabs (mostly because of grab failure), were required to collect sufficient sediment. These results and field observations suggested that the amount of fine sediment deposition within this area of the Dinosaur Reservoir is relatively small.

Material from all grabs was composited and well mixed using a stainless steel spoon before allocating to the appropriate sampling vessel for analysis of pH, grain size, total metals including mercury, methyl mercury and total organic carbon content. Further information on sampling protocols can be found in the SAP (Azimuth, 2010b).

In the Peace River and tributary streams a Ponar grab was not used. Depth was relatively shallow and the bottom is hard and scoured of fine sediments. Therefore, to acquire fine sediments trapped beneath the gravel and rock of the river bottom we used a ‘Beckson Pump’ (the type typically used as a manual bilge pump) to recover fine-grain sediment from substrate that consists mostly of cobble and gravel. The method is also referred to as the “Guzzler” method because it allows for collection of fine sediments from the rocky-

gravel bottom of the river. The lower end of the Beckson pump is pushed against the bottom, just beneath the sediment-water interface and then used to suction fine materials from the bottom that are discharged directly into a 20 L plastic bucket. The fine materials are allowed to settle for at least one hour before the surface water was carefully decanted out of the bucket. The remaining sediment was mixed well in the bucket using a stainless steel spoon and allocated to the appropriate sampling vessel. **Table 2-1** provides details with respect to UTM coordinates (NAD 83) of actual sampling coordinates that also correspond to map locations (**Figures 2-1 and 2-2**).

4.1.2. Parameters Measured

The following parameters were measured in all samples and analyzed by the laboratory listed for each bullet:

- Grain size, pH, and total organic carbon (TOC) (**ALS**).
- Total metals, including mercury (**ALS**).
- Methyl mercury (**Brooks Rand, Seattle**).

4.1.3. QA/QC

Field QA/QC procedures for sediment focused on limiting cross contamination and generation of appropriate QC samples. QA included frequent glove changes, rinsing of spoons and confirmation of decontamination effectiveness to control of cross-contamination by preparation of an **equipment blank**. In the SAP we prescribed that one **field duplicate** sample be collected during the sampling event in the Peace R. During the field investigation, the field duplicate was instead collected from the lower reach of Dinosaur Reservoir at 5 m water depth. However, this sample was not strictly a field duplicate sample, in that they should have been collected independently from the original sample. Instead, second samples of sediment were retained from the same bucket and are more accurately termed **homogenization duplicates**. In the case of field duplicates, independent collections of sediment are typically made at the same location and time with the same equipment to assess variability of sediment chemistry in the field. Results of both samples are compared to one another and RPD values calculated. An RPD value of 50% for concentrations that exceed 10x the MDL is considered acceptable in field duplicate samples. In the case of a homogenization duplicate, the acceptable RPD value is $<\pm$ 25%.

Note that the laboratory also conducts routine re-analysis of sediment from the same jar (**matrix duplicates**) to ensure reproducibility of results. In a well-homogenized sample there should only be minor differences in concentration. Data quality objectives (DQO) for the laboratory replicates should be within ± 25% of the first count. In addition, there

are routine comparisons against concentrations of certified reference materials (CRM) to ensure adequate recovery of specific metals including mercury, as well as analysis of field samples that have been fortified with analytes prior to analysis (**matrix spikes**) to assess recovery. There were no exceedences of RPD DQOs for laboratory replicates (i.e., homogenization duplicates) by the laboratory.

Effectiveness of decontamination and cross-contamination procedures was assessed by collecting a single **equipment blank**. An equipment blank for sediment sampling entails collecting distilled water used to rinse the Ponar, spoons and bowl after routine decontamination (scrubbing with Liquinox soap) and rinsing with field water (i.e., Peace River water) and analyzing the equipment blank for total metals and mercury in water. Ineffective decontamination is indicated in the field by visible suspended matter in rinse water and is dealt with immediately by more aggressive decontamination of equipment. Laboratory analysis of equipment rinse waters provides further evidence of effective contamination control. In the rare event that there are detectable metals concentrations, the total mass of metals (volume of equipment blank multiplied by the concentration) in water can be added to the mass in sediment. However, provided that equipment is washed well between stations, the amount of cross contamination in usually very small, typically less than 0.01% of sediment mass.

4.2. Results

4.2.1. QA/QC

There were no laboratory QA issues for sediment samples analyzed for any constituents other than for methyl mercury, for which there were numerous field and laboratory QA failures - described as follows.

- Some of sediment samples for methyl mercury analysis from the Peace River and its tributaries did not reach the analytical laboratory in a frozen state (as required) nor is the full history of their condition during transport to the laboratory documented. Accordingly these methyl mercury results have been designated “estimates” and are unreliable for most purposes (e.g., model calibration/verification). The samples for methyl mercury from Dinosaur Reservoir were received frozen but still had some QA issues that qualified the results for these samples. The issues are summarized in the following:
- Due to misinterpretation of the SAP both field duplicates from Dinosaur Reservoir were prepared by collecting a second jar of sediment from the composite of Ponar samples from a single series of casts, not from a second series of casts at the same location. Thus field duplicate results (**Table 4-1**) for Dinosaur sediment are really homogenization or matrix duplicates and not

indicative of true field variability. The same qualification applies to all other constituents analyzed, including grain size. This explains why the RPD values for all parameters (except methyl mercury) are so similar.

- Four of the five samples from Dinosaur Reservoir were noted to have broken glass containers, with pieces of glass in two of the samples, at the time of sample preparation (post-thawing). This was likely due to a combination of their high water content, the jars being completely filled and inadequate packing for shipment. Salvage of sample material may not have affected results but the laboratory designated these results as "qualified" based on the possible loss of sample integrity.
- All RPDs for the Dinosaur homogenization duplicates at "DINO-SED-DOWN-5M", met the ±25% criterion established for laboratory matrix duplicates. The exception for this was methyl mercury, which is what led us to pursue the QA issue further. The failing sample had replicate concentrations of methyl mercury of 0.274 and 0.097 µg/kg, yielding a % RPD of 95%. This result suggests measurement error or that there were biological processes occurring within the sediment jar that produced different amounts of methyl mercury than were probably originally in the sediment; we cannot be sure if the processes created slightly more (i.e., from net methylation) or slightly less (i.e., net demethylation) in the samples.
- Poor recovery (45%) of one matrix spike as well as the reproducibility of the matrix spike (% RPD=43) resulted in qualification of all but one of the five sediment samples. The allowable range of spike recoveries is generous, 65 to 135%, so the 45% and 70% recoveries for this batch of samples suggests the reported sediment methyl mercury concentrations could be low by as much as a factor of two.

All laboratory results whether qualified or not are presented in **Table 4-1** but the reader is cautioned to consider that all sediment methyl mercury concentrations, especially those for the Peace River and tributaries, as "best estimates".

4.2.2. Chemistry

This section presents and discusses the results for organic carbon, sediment particle grain size (% sand, silt, clay), total metals concentrations and total and methyl mercury concentrations in 11 samples collected in September and October 2010. Complete results, including for full particle size distribution, sediment paste pH and all metals, are given in **Table 4-2**. Note that results for sediment metals concentrations (e.g., arsenic, cadmium, copper, lead, zinc, etc.) in addition to mercury are reported but are not discussed here.

Should some other metal besides mercury be of interest, these data are available but because these have no bearing on mercury methylation (except for total organic carbon) the data are not examined here. . We have provided the data in context with CCME (2002) sediment quality guidelines for reference only and the data are not screened against these values. **Table 4-3** provides a summary of these results by location (Peace River, Tributaries, and Dinosaur Reservoir).

The sediments collected in Dinosaur Reservoir are probably most similar in particle size distribution to future sediment accumulations in Site C. Specifically these sediments were richer in silt- and clay-sized particles than those from the Peace River and tributaries. It should be noted that sediments were collected using different methods (Ponar vs pump) between the reservoir sites and the river sites, probably causing the sediments from the river sites to be biased towards having fewer larger particles on the present river bed than on the bottom of the reservoir. Organic carbon contents in reservoir sediments were relatively low (1.4 to 2.1%) while sediment paste pH values were narrowly constrained in the alkaline range (8.16 to 8.20). Methylation of mercury is often reported to be higher in lakes with lower pH and alkalinities (Ramlal et al., 1985).

Total mercury in sediments ranged from 0.03 mg/kg to 0.17 mg/kg, with Dinosaur Reservoir samples having slightly higher concentrations than either Peace River or tributary samples. All of the samples were well below the Probable Effects Level (PEL) sediment quality guideline (CCME, 2002) for total mercury (0.486 mg/kg). All samples were also less than the Interim Sediment Quality Guideline (ISQG; a threshold level below which adverse effects have never been observed), except Dino-Mid-10m that was equal to this guideline. By way of comparison, total mercury in sediments from the Finlay Reach of Williston Reservoir range from 0.024 to 0.091 mg/kg (Baker et al., 2002).

Total mercury concentrations in sediments are often correlated with particle size (e.g., % silt) and % organic carbon. For example, the sand fraction of sediments typically has lower concentrations of metals and mercury than silt and clay fractions and thus samples with high sand content typically have lower mercury concentrations than samples with high silt and clay content. Similarly, sediments with higher organic carbon content are often higher in mercury than those with low organic carbon content. Sand and especially organic carbon in sediments also affects the partitioning of both total mercury and methyl mercury in sediment porewater. In addition, bioavailability, as reflected by concentration ratios between benthic organism and sediment, is often lower in sediments with higher organic carbon and lower sand content (e.g., Mason and Lawrence, 1999; Hammerschmidt et al., 2008). The sediment data for Site C do not show clear and consistent associations among total mercury, % organic carbon and % sand. The two samples with high sand content (68.6 and 37.5%) are among the lowest in total mercury

(0.03 and 0.05 mg/kg) but the sample with the highest total mercury (0.17 mg/kg) was not distinguished in having an especially high organic carbon (2.07%) or low sand (16.4%) content. The absence of clear relationships may be due to difficulties in resolution due to the low concentrations measured. Nevertheless, the concentration of total mercury in sediment from sampled stations is quite low and would be considered typical of pristine or 'uncontaminated' lakes in BC (Rieberger, 1992).

Useful results for methyl mercury in sediments are somewhat limited due to QA issues as noted above. Suffice to state that the results for Dinosaur are more reliable than those for the Peace River and its tributaries. Methyl mercury concentrations and the fractions that are methyl mercury (% methyl Hg) for Dinosaur are very typical of sediments from lakes and reservoirs unaffected by anthropogenic sources. Background methyl mercury concentrations of < 1 μg/kg and % methyl Hg values <1% are widely observed. For example, methyl mercury in sediments from the Finlay Reach of Williston Reservoir ranged from 0.14 to 0.44 mg/kg while the % methyl Hg ranged from 0.27 to 1.2 % (Baker et al., 2002).

The present sediment data for Site C are fairly sparse and originate from samples collected in both fluvial and lacustrine habitats that are expected to differ due to inherent differences in particle size distribution. Because of the paucity of data we cannot glean much additional information concerning interrelationships among sediment properties and their implications for future mercury cycling. However, given the generally coarse and heterogeneous grain size of Peace River sediments, we would expect mercury and methyl mercury concentrations of fluvial sediments to be low, notwithstanding QA issues.

Table 4-1. QA/QC data for sediment parameters, BC Hydro 2010.

Analytes	MDLs	Dinosaur Reservoir Field Duplicate			PR-SED-2			DINO-SED-DOWN-10m			EB-SED	
		DINO-SED-DOWN-5M	DUP-SED	RPD	Original	Laboratory Duplicate	RPD	Original	Laboratory Duplicate	RPD	Equipment Blank	
		19-Oct-10	19-Oct-10	(%)	18-Sep-10		(%)	19-Oct-10		(%)	20-Oct-10	
CONVENTIONAL PARAMETERS												
Physical & Organic Parameters												
Hardness (mg/L)												
pH	0.10	8.16	8.13	0.4	-	-	-	8.16	8.2	-0.5		
Total Organic Carbon (% dw)	0.10	1.69	1.62	4.2	-	-	-	2.07	2.04	1.5		
Particle Size												
% Gravel (>2mm)	0.10	<0.10	<0.10	NA	<0.10	<0.10	NA	<0.10	<0.10	NA		
% Sand (2.00mm - 0.063mm)	0.10	14.8	14.3	3.4	11.4	11.5	-0.9	6.22	5.89	5.5		
% Silt (0.063mm - 4µm)	0.10	70.8	70.1	1.0	81.1	80.9	0.2	69.3	69.6	-0.4		
% Clay (<4µm)	0.10	14.5	15.6	-7.3	7.46	7.6	-1.9	24.5	24.5	0.0	**MDLs**	**Results**
TOTAL METALS (mg/kg)											**(mg/L)**	**(mg/L)**
Antimony	10	1.08	1.12	-3.6	-	-	-	1.23	1.22	0.8	0.00050	<0.00050
Arsenic	5.0	7.59	7.69	-1.3	-	-	-	10.7	11.3	-5.5	0.00050	<0.00050
Barium	1.0	356	380	-6.5	-	-	-	433	445	-2.7	0.020	<0.020
Beryllium	0.50	0.36	0.36	0.0	-	-	-	0.46	0.44	4.4	0.0010	<0.0010
Cadmium	0.50	1.43	1.45	-1.4	-	-	-	1.58	1.67	-5.5	0.000017	**0.000047**
Chromium	2.0	17.6	19.2	-8.7	-	-	-	21.6	21.7	-0.5	0.0010	**0.0015**
Cobalt	2.0	7.84	7.95	-1.4	-	-	-	9.44	9.70	-2.7	0.00030	<0.00030
Copper	1.0	22.1	22.6	-2.2	-	-	-	26.2	27.1	-3.4	0.0010	**0.0050**
Lead	30	8.69	8.88	-2.2	-	-	-	11.0	11.7	-6.2	0.00050	<0.00050
Mercury	0.0050	0.102	0.101	1.0	-	-	-	0.0688	0.0671	2.5	0.000010	<0.000010
Molybdenum	4.0	1.51	1.50	0.7	-	-	-	1.75	1.79	-2.3	0.0010	<0.0010
Nickel	5.0	27.5	28.0	-1.8	-	-	-	32.7	33.4	-2.1	0.0010	**0.0012**
Selenium	2.0	0.66	0.69	-4.4	-	-	-	0.75	0.81	-7.7	0.0010	<0.0010
Silver	2.0	0.23	0.23	0.0	-	-	-	0.26	0.26	0.0	0.000020	<0.000020
Thallium	1.0	0.184	0.196	-6.3	-	-	-	0.227	0.224	1.3	0.00020	<0.00020
Tin	5.0	<2.0	<2.0	NA	-	-	-	<2.0	<2.0	NA	0.00050	**0.00055**
Uranium	0.050	0.759	0.805	-5.9	-	-	-	0.803	0.820	-2.1	0.00020	<0.00020
Vanadium	2.0	37.9	41.9	-10.0	-	-	-	45.3	45.8	-1.1	0.0010	<0.0010
Zinc	1.0	87.7	90.2	-2.8	-	-	-	112	116	-3.5	0.0050	**0.0213**
SPECIATED METALS (ug/kg)											**(ug/kg)**	**(ug/kg)**
Methyl Mercury	0.007 - 0.015	0.274	0.097	95.4	-	-	-	0.132	0.108	20.0	0.007	**0.008**

Notes:

RPD = Relative Percent Difference (%) = ((original - duplicate) / (original + duplicate)/2) x 100.

Shaded RPDs exceed 25% (lab duplicates) or 50% (field duplicates).

Bolded equipment blanks exceed MDLs, but are < 10 x MDL.

Shaded equipment blanks exceed MDLs, and are > 10 x MDL.

NA = RPDs have not been calculated for cases where one of the samples is below detection and the other is not, and in cases where both are below detection.

Samples were analyzed for MeHg by Brooks Rand, Seattle, WA; and for everything else by ALS Laboratories, Burnaby, BC.

Table 4-2. Conventional sediment chemistry, particle size and total metals, BC Hydro 2010.

Area & Season			FALL										
			Peace River			Dinosaur Reservoir					Tributaries		
Station ID	Sediment Quality Guidelines (CCME 2002)[1]		PR-SED-1	PR-SED-2	PR-SED-3	DINO-SED-MID-5M	DINO-SED-MID-10M	DINO-SED-DOWN-5M	DINO-SED-DOWN-10M	DINO-SED-DOWN-15M	FER-SED	HALF-SED	MOB-SED
Lab ID			L933387-4	L933387-5	L933387-3	L945741-2	L945741-1	L945741-3	L945741-4	L945741-5	L933387-2	L933387-1	L932259-1
Date	ISQG	PEL	18-Sep-10	18-Sep-10	18-Sep-10	19-Oct-10	19-Oct-10	19-Oct-10	19-Oct-10	19-Oct-10	16-Sep-10	16-Sep-10	15-Sep-10
CONVENTIONAL PARAMETERS													
Physical & Organic Parameters													
pH	NG	NG	8.26	8.17	8.25	8.18	8.16	8.16	8.16	8.20	8.00	7.97	7.86
Total Organic Carbon (% dw)	NG	NG	2.48	2.11	0.81	1.40	2.07	1.69	1.51	1.43	6.12	2.13	0.84
Particle Size													
% Gravel (>2mm)	NG	NG	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
% Sand (2.00mm - 0.063mm)	NG	NG	12.2	11.4	68.6	9.96	16.4	14.8	6.22	6.10	9.8	11.1	37.5
% Silt (0.063mm - 4µm)	NG	NG	81.1	81.1	30.8	79.7	74.2	70.8	69.3	76.4	86.2	73.1	56.3
% Clay (<4µm)	NG	NG	6.8	7.5	0.7	10.4	9.45	14.5	24.5	17.5	4.1	15.8	6.2
TOTAL METALS (mg/kg)													
Antimony	NG	NG	<10	<10	<10	0.81	0.75	1.08	1.23	1.01	<10	<10	<10
Arsenic	5.9	17.0	9.4	8.6	7.3	5.78	6.10	7.59	10.7	8.45	11.6	8.0	7.0
Barium	NG	NG	227	374	273	279	245	356	433	324	588	540	351
Beryllium	NG	NG	<0.50	<0.50	<0.50	0.38	0.31	0.36	0.46	0.36	<0.50	0.57	<0.50
Cadmium	0.6	3.5	1.3	0.91	0.57	1.17	1.08	1.43	1.58	1.43	1.1	1.0	0.71
Chromium	37.3	90.0	23.6	16.3	11.7	16.5	13.8	17.6	21.6	19.0	12.2	17.6	11.9
Cobalt	NG	NG	8.9	9.1	5.8	6.80	6.43	7.84	9.44	8.19	12.0	8.5	7.7
Copper	35.7	197	27.6	25.1	11.7	18.8	16.8	22.1	26.2	23.1	22.5	22.7	18.2
Lead	35.0	91.3	<30	<30	<30	8.71	7.65	8.69	11.0	9.44	<30	<30	<30
Mercury	0.17	0.486	0.061	0.060	0.032	0.060	0.172	0.102	0.069	0.074	0.059	0.054	0.049
Molybdenum	NG	NG	<4.0	<4.0	<4.0	1.06	1.01	1.51	1.75	1.46	<4.0	<4.0	<4.0
Nickel	NG	NG	33.0	25.7	17.2	25.5	24.1	27.5	32.7	28.9	26.7	26.1	21.9
Selenium	NG	NG	<2.6	<2.9	<2.0	0.70	0.68	0.66	0.75	0.71	<2.3	<2.0	<2.0
Silver	NG	NG	<2.0	<2.0	<2.0	0.18	0.20	0.23	0.26	0.22	<2.0	<2.0	<2.0
Thallium	NG	NG	<1.0	<1.0	<1.0	0.161	0.147	0.184	0.227	0.193	<1.0	<1.0	<1.0
Tin	NG	NG	<5.0	<5.0	<5.0	<2.0	<2.0	<2.0	<2.0	<2.0	<5.0	<5.0	<5.0
Uranium	NG	NG	1.1	0.9	0.7	0.782	0.742	0.759	0.803	0.752	0.9	1.0	0.7
Vanadium	NG	NG	46.2	27.3	25.6	31.1	26.7	37.9	45.3	38.8	22.8	37.9	22.1
Zinc	123	315	102	86.3	64.1	95.2	83.2	87.7	112	98.7	92.2	95.7	71.3
SPECIATED METALS (ug/kg)													
Methyl Mercury	NG	NG	*0.569*	*1.77*	*0.505*	0.286	0.132	0.274	0.117	0.170	*2.36*	*0.636*	*1.78*
% MeHg/Total Hg (%)	NG	NG	*0.94*	*3.0*	*1.6*	0.48	0.08	0.27	0.17	0.23	*4.0*	*1.2*	*3.6*

Notes:

[1]CCME (Canadian Council of Ministers of the Environment) Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, 1999, updated in 2002.

ISQG = Interim freshwater Sediment Quality Guideline, PEL = Probable Effect Level, NG = no guideline.

Shaded concentration = > ISQG. Results have not been screened against above guidelines, except for mercury.

Boxed concentrations also > PEL. Results have not been screened against above guidelines, except for mercury.

Underlined and italized values are estimates; see text for further explanation.

Samples were analyzed for MeHg by Brooks Rand, Seattle, WA; and for everything else by ALS Laboratories, Burnaby, BC.

Table 4-3. Summary of sediment analyses of importance to reservoir mercury cycling.

Stations	%Organic Carbon	% Sand	Total Hg (mg/kg)	Methyl Hg (µg/kg)[a]	% Methyl[a]
Peace River					
PR-SED-1	2.48	12.2	0.06	(0.57)	(0.94)
PR-SED-2	2.11	11.4	0.06	(1.8)	(3.0)
PR-SED-3	0.81	68.6	0.03	(0.51)	(1.6)
Dinosaur Reservoir					
DINO-SED-MID-5M	1.40	9.96	0.06	***0.29***	***0.48***
DINO-SED-MID-10M	2.07	16.4	0.17	***0.13***	***0.08***
DINO-SED-DOWN-5M	1.69	14.8	0.10	***0.27***	***0.27***
DINO-SED-DOWN-10M	1.51	6.22	0.07	***0.12***	***0.17***
DINO-SED-DOWN-15M	1.43	6.10	0.07	***0.17***	***0.23***
Tributaries					
FER-SED	6.12	9.80	0.06	(2.4)	(4.0)
HALF-SED	2.13	11.1	0.05	(0.64)	(1.2)
MOB-SED	0.84	37.5	0.05	(1.8)	(3.6)

Notes: [a] Values in brackets are “estimated” because of inadequate sample preservation during transport to laboratory; values in **bold** are qualified because of low recovery of matrix spikes.

5. AQUATIC INVERTEBRATES

This section presents data for zooplankton and benthic invertebrates collected from Dinosaur Reservoir and the Peace River. These organisms were grouped together for discussion because of their important status in the food web as a nutrient source for fish. They are also important as a source of mercury to fish, because the vast majority of mercury acquired by fish is from dietary sources. In this study we also analyzed zooplankton and benthos for stable carbon and nitrogen isotopes to determine the relative contribution that zooplankton and benthos make to the diet of fish, and hence their relative contribution to dietary mercury.

Mercury concentrations in zooplankton have been documented to increase following reservoir creation. Documentation of baseline inorganic and methyl mercury concentrations in zooplankton from Peace River (and Dinosaur Reservoir as a reference) are important input parameters for mercury modeling (**Appendix B**). Taxonomic composition or biomass estimates are not required for modeling purposes.

5.1. Zooplankton

5.1.1. Methods

5.1.1.1. Field Sampling

Zooplankton were collected using a Wisconsin-style zooplankton net with mesh size of 153 μm, a mouth opening diameter of 0.3 m and a length of 2 m, yielding an aspect ratio of 6 – 7x mouth diameter. To acquire zooplankton the net was lowered over the side of the boat and towed at 0.5 m below the water surface for up to 10 minutes to collect at least 3 – 5 g of zooplankton mass. Zooplankton were removed from the net by rinsing and placed into a HDPE sampling vial with most of the water drained away and then placed on dry ice in the field to freeze them quickly and prevent any denaturing.

Table 2-1 provides UTM coordinates (NAD 83) of zooplankton sampling stations, corresponding roughly to water sampling locations. Zooplankton were collected from three stations along the mainstem of the Peace River (**Figure 2-1**) and three stations within the Dinosaur Reservoir (**Figure 2-2**). Samples were collected only once from both regions, on September 2, 2010 from Dinosaur Reservoir and September 18, 2010 from Peace River. Zooplankton integrate mercury over time and, like benthos, it is typical to make annual collections during fall when animals are largest and have integrated dietary acquired mercury over the course of the summer.

In Dinosaur Reservoir, zooplankton was collected from the upper, middle, and downstream ends of the reservoir, at least 1 km upstream from Peace Canyon Dam. The

locations were close to sediment and benthic sampling stations. Zooplankton collections from the Peace River were made in close proximity to water sampling stations (**Figures 2-1 and 2-2**).

Each sample of zooplankton collected was divided into two equal amounts for separate analyses of mercury and for stable isotopes. It was important that the taxonomic composition of zooplankton was the same between the two aliquots; this was accomplished by collecting a large enough sample size to minimize the chance that taxonomic composition might differ between the two halves.

5.1.1.2. Parameters Collected

The following parameters were collected for all samples and analyzed by the laboratory listed for each bullet:

- Total inorganic mercury, methyl mercury (µg/g or ppm) and percent moisture content (**Quicksilver Scientific, Lafayette, CO**). Note that to determine 'total mercury' concentration, one must sum the inorganic and methyl fractions. When total mercury in fish is reported, this is also the sum of the inorganic and methyl fractions (although the proportion of methyl mercury of the total is typically about 95%; Bloom, 1992). Inorganic and methyl mercury were analyzed using high pressure liquid chromatography speciation system and cold vapor atomic florescence.
- Carbon and nitrogen stable isotope analysis **(Stable Isotopes in Nature Laboratory** [**SINLAB], New Brunswick**).

The second half of the split zooplankton sample and preserved on dry ice in the field was delivered to SINLAB located in the biology department at the University of New Brunswick in Fredericton, New Brunswick. SINLAB uses Continuous Flow Isotope Mass Spectrometry (CFIRMS) technology to analyze a variety of sample and tissue types for ratios of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$).

Further information can be found in the SINLAB interpretation guide provided in **Appendix C**.

5.1.1.3. QA/QC

QA/QC procedures for zooplankton consisted of a combination of field and laboratory/analytical procedures. In the field, the protocols set out by the SAP (Azimuth, 2010b) were followed, including the use of sterile Whirlpac™ bags, immediate freezing of zooplankton samples on dry ice in the field and rinsing of the collection net between

sampling stations. In addition, a single field duplicate sample was collected from the Peace River (PR-2).

Quicksilver Scientific has a QA system that includes analysis of quality control samples on 5-point blank samples + calibration curve, reference blanks, standardized reference material, laboratory control samples, matrix spikes and matrix spike duplicate samples. A full QA report from Quicksilver is available upon request. The laboratory matrix spike sample was run on the Dinosaur Reservoir (DINO-Mid) sample for both total inorganic and methyl mercury to ensure adequate recovery of mercury by the analytical equipment.

5.1.2. Results

5.1.2.1. QA/QC

QA/QC procedures for zooplankton chemistry are summarized in **Table 5-1** and included a single duplicate sample collection from PR-2 and a laboratory duplicate of the DINO-Mid sample. Quicksilver Scientific did not report any failures of their QA procedure and reported successful runs of calibration curves and reference blank samples.

Results of the field replicate samples met the DQO for this project. Inorganic mercury concentration of the original and field PR-2 duplicate samples were 0.04 µg/g and 0.03 µg/g wet weight (i.e., equivalent to mg/kg ww or ppm) respectively, yielding an RPD value of 22%, well within the DQO for field duplicate samples (±50%). The RPD for methyl mercury concentration (31%) was also below the DQO of ± 50%, despite the very low concentrations measured (0.00008 – 0.00012 µg/g), just above laboratory DLs.

The recovery of mercury in laboratory matrix standards was also very high for two replications for total mercury (89% and 91%) and methyl mercury (99% and 92%) (**Table 5-1**), so we have good confidence in results of mercury concentration data for zooplankton.

5.1.2.2. Mercury

Total mercury concentration (i.e., the sum of inorganic Hg^{II} and methyl mercury) in zooplankton from the Peace River ranged from 0.004 – 0.009 µg/g (ppm) wet weight (**Table 5-2**). In Dinosaur Reservoir, values were slightly lower ranging from 0.001 – 0.006 µg/g ww. Although total mercury concentrations were very low, the slightly higher range in Peace River means that the possibility of accumulation of mercury by zooplankton in Peace River can't be ruled out.

The range in concentration of methyl mercury in zooplankton was reversed, with slightly higher concentrations in Dinosaur Reservoir (0.0003 – 0.001 µg/g) than in Peace River

(0.0001 – 0.0007 µg/g). However, these concentrations are so low that differences of this magnitude (i.e., 0.0003) are likely not meaningful.

The proportion of total mercury that was present in the methyl form ranged from 2 – 9% in Peace River. In Dinosaur Reservoir, the range was from 24 – 44% which is a much more typical range for zooplankton (Watras and Bloom, 1992). The difference in % methyl mercury may be related to small sample size and the difficulties at measuring near the DL (i.e., a 0.0001 µg/g difference is 20% of the average methyl mercury concentration).

In Williston Reservoir in August 2002 (Baker et al., 2002) wet weight total mercury concentrations (assuming 90% moisture content because 2002 data were reported as dry weight) ranged from 0.006 – 0.009 µg/g in Finlay Reach; slightly higher at Finlay Junction (0.01 µg/g). Methyl mercury concentrations ranged from 0.002 – 0.004 µg/g. The percent methyl mercury relative to the total from Finlay Reach was 19% and 37%, which is fairly typical for zooplankton. These concentrations are low and similar to what were observed in 2010 from Dinosaur Reservoir and Peace River. These data suggest that mercury concentrations in Peace River that originate from Williston are similar, which is to be expected given their hydraulic connectivity, and that concentrations have not changed in the last 10 years, implying stable, baseline conditions in Williston.

Mercury is one of the few elements that becomes more concentrated in higher trophic levels, at increasing steps up the food chain (Wren and MacCrimmon, 1983; Watras and Bloom, 1992). Concentrations of inorganic and methyl mercury generally increase from phytoplankton to zooplankton and benthos, with highest concentrations in fish, a phenomenon known as biomagnification. In addition the proportion of methyl mercury relative to the total also typically increases with increasing steps up the food chain. For example, in Onondaga Lake NY, methyl mercury accounted for 5% of the total in water, 14% in phytoplankton, 28% for and benthos and 51% in zooplankton (Becker and Bigham, 1995), a similar magnitude as observed here. Similar results have been observed elsewhere including Wisconsin lakes (0.04 µg/g, 29% methyl; Miele and Parkman, 1988; and 0.003 – 0.02 µg/g, 50 – 78% methyl; Watras et al. 1998), Clear Lake California (0.004 – 0.004 µg/g; 6 – 50% methyl; Suchanek et al., 2008) and many others. Mercury concentrations in zooplankton from Peace River are on the extreme low end of the range that has been observed in other studies.

5.2. Benthic Invertebrates

Benthic invertebrates are a key food chain component of the aquatic food web and an important food group for many fish species including juveniles of piscivorous fish. Composite samples of benthic invertebrates from the Peace River and Dinosaur Reservoir were analyzed for inorganic and methyl mercury. Taxonomic composition and relative

abundance estimates are not required for modeling, although these data were collected by the Golder/ESSA/Limnotek team in summer 2010 and data can be found in Golder, ESSA, Limnotek (Draft, 2011). However, taxonomic composition is important because it influences the magnitude of inorganic and methyl mercury concentrations, depending on the benthic community composition. More carnivorous invertebrates will have higher total and methyl concentrations than their omnivorous or herbivorous counterparts.

In addition, a sub-sample of benthos split off from the sample analyzed for mercury was analyzed for carbon and nitrogen stable isotopes, to support food chain modeling and to provide insight into trophic structure related to mercury bioaccumulation through the food web.

5.2.1. Methods

5.2.1.1. Field Sampling

Attempts were made to collect benthic invertebrates from three locations in Dinosaur Reservoir (Dino-Up, Dino-Mid and Dino-Down) using a Petite Ponar grab (0.023 m^2). Locations of the benthos collections were in a similar location as sediment collections (**Figure 2-1**, **Table 2-1**) so that benthic tissue data and sediment data can be correlated. Detailed methods for benthic sampling are provided in the SAP. Briefly, the sampling crew attempted to locate fine sediment depositional areas within the reservoir at depths of 6 – 9 m within the photic zone and away from tributary stream mouths. The boat was anchored and the Ponar grab was used to locate depositional areas to acquire sediment samples. Sediment from successful grabs were removed from the Ponar, sieved through a 500 µm screen and individual animals were picked out of the sediment using tweezers, rinsed to remove excess sediment and immediately placed into a clean WhirlPac™ bag and frozen in the field on dry ice. It proved very difficult to collect benthic samples from Dinosaur Reservoir, which is discussed in the QA/QC section following.

Benthos were collected from three locations along the Peace River at the same stations as water, sediment and zooplankton collections (**Figure 2-1**, **Table 2-1**) on 29 August 2010. However, a sampling different method was used because of the river environment and substrate, relative to Dinosaur Reservoir's more lacustrine environment. A kicknet with a 500 µm mesh bag was used to collect a bulk sample targeting epibenthic organisms such as mayflies and caddisflies. To collect the organisms from the river, sampling was conducted in depths of <0.5 m along shore in or near riffle areas. One person would disturb rocks and sediment upstream of the person with the kicknet who would gather all dislodged and drifting invertebrates. The SAP provides further detail on the protocol. Once sufficient biomass was collected over a small area of the river, the organisms were

removed from the kick net, placed into a labeled WhirlPac™ bag and immediately frozen on dry ice in the field.

Once all benthos collections were made from Peace River and Dinosaur Reservoir, the frozen WhirlPac™ bags were cut in half to create two roughly equal composites of organisms. These were re-bagged, frozen and the split samples sent to Quicksilver Scientific, Lafayette CO for mercury analysis and to SINLAB, UNB for stable isotope analysis.

5.2.1.2. Parameters Collected

Composite samples of benthic invertebrates were analyzed for total and methyl mercury and for stable isotopes. Quantitative estimates of taxonomic composition or biomass is not required for mercury modeling (**Appendix B**). However, we have noted the general taxonomic composition to Order (e.g., Trichoptera, Ephemeroptera, Chironomidae, etc.).

The following parameters were collected for all samples and analyzed by the laboratory listed for each bullet:

- Total mercury, methyl mercury and moisture (**Quicksilver Scientific, Lafayette Co, USA**).
- Carbon and nitrogen stable isotope analysis (**SINLAB, University of New Brunswick**). Further information can be found in the SINLAB interpretation guide provided in **Appendix C**.

These are the same laboratories used for mercury and stable isotope analysis of the zooplankton tissues. The benthic sample was split among laboratories in the same fashion as for zooplankton and delivered frozen to SINLAB at the UNB facility, Fredericton, NB. Benthos were analyzed using the CFIRMS technology for ratios of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$), the same as for zooplankton.

5.2.1.3. QA/QC

Field QA/QC procedures for benthos chemistry focused on contamination control and generation of replicates. Use of sterile gloves, rinsing of tweezers, rinsing of bags to prevent cross-contamination of biota and rinsing of benthos to eliminate adherence by sediment particles reduced interference with mercury analyses. Note that animals were not depurated prior to analysis, and gut contents might contain sediment particles that might contribute to inorganic mercury burden. Samples were also rinsed in the laboratory prior to analysis.

Quicksilver Scientific has a QA system that includes analysis of quality control samples on 5-point blank samples + calibration curve, reference blanks, standardized reference material, laboratory control samples, matrix spikes and matrix spike duplicate samples. The laboratory matrix spike sample was run on the DINO-Mid zooplankton sample for inorganic and methyl mercury to ensure adequate recovery of mercury by the analytical equipment. Because the zooplankton and benthic samples were run at the same time, the QA data for zooplankton also apply here.

A single blind field replicate sample was collected PR-1-Ben and analyzed for inorganic and methyl mercury and an RPD calculated. This was a completely independent sample and not a split of one of the original samples. Quicksilver received the samples on September 23 and conducted the analysis on October 7 2010.

5.2.2. Results

5.2.2.1. QA/QC

For benthos chemistry, Quicksilver Scientific did not report any failures of their QA procedure and reported successful runs of calibration curves and reference blank samples. QA/QC procedures for benthos (**Table 5-1**) included a single duplicate sample collection from PR-1-Ben. Inorganic mercury concentration of the original 0.012 µg/g ww) and duplicate sample (0.014 µg/g ww) for inorganic mercury were quite similar giving a RPD value of 15%, well within the DQO for field duplicate samples (±50%). Methyl mercury concentrations were also very similar (0.0040 and 0.0039 µg/g) with a very low RPD (2%).

The recovery of mercury in laboratory matrix standards was also very high for two replications for total mercury (89% and 91%) and methyl mercury (99% and 92%) from the zooplankton samples (**Table 5-1**). Because benthos and zooplankton were run at the same time, these results are also applicable to the benthic data.

Despite the laboratory data quality, there some QA issues that arose during the field program. Due to a delay by the courier in delivering the benthic samples to Quicksilver, the benthic samples had thawed and the bags had leaked some water because they were not completely sealed. Fortunately no biota were lost and the samples arrived cold, but not frozen.

It was very difficult to collect benthos from Dinosaur Reservoir. Many grab attempts failed because of the rocky bottom. This made it difficult to collect fine sediments. The steep slope of the bottom resists sedimentation and given the exceedingly low TSS concentrations in water coming out of Williston Reservoir, there does not appear to have been much accumulation of sediment on the bottom of the reservoir, especially at depths

<10 m. The relative lack of fine sediments made it difficult to collect sufficient tissue volume. This resulted in compositing of all benthic organisms from Dinosaur Reservoir into a single composite sample for the whole reservoir. Even then very few individual animals were collected for mercury analysis and stable isotopes. As a matter of fact only 4 or 5 individual animals including chironomid larvae, an individual dagger fly larvae (Empididae) and a small gastropod. Many gastropod shells were collected, but these were empty and not analyzed.

SINLAB reported similar difficulties with the small numbers of invertebrate from the Dinosaur Reservoir benthic sample. However, because even individual animals can be analyzed for stable isotopes, to gather more data from the single invertebrate sample from Dinosaur, we chose to analyze individual organisms, rather than a composite, as was done for mercury analysis. In this case, SINLAB derived isotopes for individual chironomids, a dagger fly (Empididae) and a gastropod (**Table 5-2**).

5.2.2.2. Mercury

In Dinosaur Reservoir, sediment in successful grabs was comprised of clay silt with some fine sand. Qualitative observations of benthos were that benthos were sparse and when present consisted of a few midge larvae and gastropods.

Field observations of sediment grain size in Peace River indicated that substrate was comprised of cobble and shale at PR-1 and PR-2 but sand/silt at PR-3. Qualitative observations of benthic invertebrate taxa included caddisfly, mayfly and aquatic worms (probably chironomids). At PR-3 a single large invertebrate, a backswimmer beetle (F. Notonectidae) was captured and analyzed within the Hg fraction. Backswimmers, 3-12 mm long, are highly carnivorous and feed on small crustaceans, insect larvae, snails, and sometimes on small fish and tadpoles from which they suck the body juices. As a result of their carnivorous diet it is expected it would have high mercury concentrations.

Total mercury (inorganic + methyl) concentrations from stations PR-1, PR-2 and PR-3 were 0.016 µg/g, 0.010 µg/g and 0.023 µg/g (**Table 5-2**). In Dinosaur, the single composite sample, which comprised only a few organisms, had a similar concentration, 0.025 µg/g. However, we do not know how the taxonomic composition of invertebrates between Dinosaur and Peace River differed, which is a source of uncertainty. Some light may be shed on this from the Golder / ESSA / Limnotek (2011) ecology study. Nevertheless, these concentrations are quite low relative to what has been observed in other studies, but about 10x higher than what were observed in zooplankton in Peace River and Dinosaur Reservoir.

Methyl mercury concentrations in Peace River benthos ranged from 0.0016 – 0.20 µg/g and 0.002 µg/g in Dinosaur (**Table 5-2**). The percent methyl mercury of the total was

25% and 15% for PR-1 and PR-2 respectively, which is fairly typical for benthos. However, for PR-3, the vast majority of mercury was in the methyl form (85%). This was because of the inclusion of the aquatic beetle. This large, carnivorous animal dominated biomass of the sample analyzed and had a similarly high relative proportion of methyl mercury to total as do fish (Bloom, 1992). In Dinosaur Reservoir where only a few organisms were analyzed (chironomid, gastropod), methyl mercury concentration was also low (0.0002 µg/g) and similar to the other Peace River samples.

In Williston Reservoir, total mercury concentrations in benthos for August 2000 ranged from 0.020 – 0.05 µg/g (except Finlay littoral station, 0.37 µg/g) and in June 2001 concentrations were very similar ranging from 0.015 – 0.028 µg/g (Baker et al., 2002). Thus, there do not appear to be large differences in inorganic or methyl mercury between Williston and Peace River benthos, despite the spatial and temporal differences of the tissue collections, differences in sample methods, and different environments. The reason is that mercury concentrations are very low in all environmental media and there is an absence of the environmental conditions that support mercury methylation (Ullrich et al., 2001).

Total mercury concentrations in benthos from other Canadian lakes are similar to or higher than concentrations measured in the current study. Total mercury in chironomids from Wisconsin lakes ranged from 0.001 – 0.013 µg/g (Watras et al., 1998), 0.02 – 0.21 µg/g in Manitoba lakes (Jackson, 1988) and 0.01 – 0.018 µg/g in Ontario lakes (Wong et al., 1977). Although the taxonomic composition may be different, the magnitude of concentration is within a similar range and illustrates the consistently low mercury concentrations across the Peace River basin, including two reservoirs. However, these are relatively old reservoirs (e.g., Williston was created in 1968, Dinosaur in 1979) and are past the period of time where mercury concentrations in fish remain above background, which is generally 20 – 30 years after impoundment (Bodaly et al., 1997; 2007).

Mercury concentration in benthic invertebrates is not necessarily expected to be related to sediment mercury concentrations. In areas where this has been studied, mercury concentration in all benthic groups was not significantly correlated with mercury concentrations and methylation rates in their immediate surroundings (in sediments). Furthermore, mercury concentrations in all groups are not correlated with inorganic or methyl mercury concentrations in sediments, or the methylating capability of the sediment (Jackson, 1988). Most studies have shown that the net rate of mercury accumulation by benthic invertebrates was more strongly influenced by environmental and biological processes (feeding habits, diet) than by the abundance of mercury in their habitats.

Table 5-1. QA/QC data for aquatic invertebrates, BC Hydro 2010.

FIELD QA

STABLE ISOTOPES				MERCURY		
Sample IDs	Date	δ ^{13}C (‰)	δ ^{15}N (‰)	Moisture (%)	Hg^{II} (ug/g ww)	MeHg (ug/g ww)
PR-ZOOP-2	18-Sep-10	-25.49	6.73	90.4	0.004	0.00012
DUP-ZOOP	18-Sep-10	-26.41	5.18	93.0	0.003	0.00008
RPD (%)		-3.54	26.1	-2.8	21.2	31.3
PR-BEN-1	29-Aug-10	-31.44	6.34	52.6	0.012	0.00393
DUP-BEN	29-Aug-10	-31.44	6.31	67.4	0.014	0.00401
RPD (%)		-0.01	0.6	-24.7	-13.3	-1.9

LABORATORY QA

STABLE ISOTOPES		MERCURY			
δ ^{13}C (‰)	δ ^{15}N (‰)	Sample IDs	Lab ID	Hg^{II} (ug)	MeHg (ug)
NA	NA	DINO-ZOOP-MID	Added	0.0203	0.0200
			Recovered	0.0187	0.0199
		RECOVERY (%)		92.1	99.5
NA	NA	DINO-ZOOP-MID	Added	0.0203	0.0200
			Recovered	0.0181	0.0183
		RECOVERY (%)		89.2	91.5

Notes:

RPD = Relative Percent Difference (%) = ((original - duplicate) / (original + duplicate)/2) x 100.

Shaded RPDs exceed 25% (lab duplicates) or 50% (field duplicates).

Samples were analyzed for Hg^{II} and MeHg by Quicksilver Scientific, Lafayette, CO; and for stable isotopes by SINLAB, Fredericton, NB.

Table 5-2. Stable isotopes and mercury concentrations in aquatic invertebrates, BC Hydro 2010.

Sample Type & Area	ZOOPLANKTON					
	Peace River			Dinosaur Reservoir		
Station ID	PR-ZOOP-1	PR-ZOOP-2	PR-ZOOP-3	DINO-ZOOP-DOWN	DINO-ZOOP-MID	DINO-ZOOP-UP
SINLAB ID	RBA 002	RBA 003	RBA 004	RBA 006	RBA 007	RBA 005
Date	18-Sep-10	18-Sep-10	18-Sep-10	2-Sep-10	2-Sep-10	2-Sep-10
Sampling Locations (Zone 10V)						
UTM Coordinates - Northing	6207848	6229433	6230657	6203460	6202366	6201434
UTM Coordinates - Easting	566195	594929	628503	562049	557736	552709
STABLE ISOTOPES						
$\delta^{13}C$ (‰)	-33.42	-25.49	-26.27	-37.06	-37.59	-35.29
$\delta^{15}N$ (‰)	6.69	6.73	2.56	5.78	5.70	5.82
MERCURY (ug/g ww)						
Moisture Content (%)	87.6	90.4	88.5	98.2	92.5	87.2
Inorganic (Hg^{II})	0.0080	0.0040	0.0068	0.0011	0.0019	0.0046
Methyl Mercury (MeHg)	0.0007	0.0001	0.0001	0.0003	0.0008	0.0011
Total Hg (Hg^{II} + MeHg)*	0.0087	0.0041	0.0070	0.0014	0.0028	0.0058
% Methyl Mercury	9.0	2.9	1.7	25.8	43.9	24.0

Sample Type & Area	BENTHOS					
	Peace River			Dinosaur Reservoir Composite		
Station ID / Taxa Sampled	PR-BEN-1	PR-BEN-2	PR-BEN-3	Chironomidae	Empididae	Gastropoda
SINLAB ID	RBA 008	RBA 009	RBA 010	RBA 124	RBA 125	RBA 126
Date	29-Aug-10	29-Aug-10	28-Aug-10		2-Sep-10	
Sampling Locations (Zone 10V)						
UTM Coordinates - Northing	6207778	6229450	6230750	6203218	6201056	6204646
UTM Coordinates - Easting	566337	595017	628266	562155	553848	549157
STABLE ISOTOPES						
$\delta^{13}C$ (‰)	-31.44	-31.94	-25.89	-24.34	-26.64	-26.61
$\delta^{15}N$ (‰)	6.34	5.11	3.74	6.72	5.64	4.77
MERCURY (ug/g ww)				**Composite Sample**		
Moisture Content (%)^	52.6	80.3	66.6	-	NA	NA
Inorganic (Hg^{II})	0.0120	0.0087	0.0033	0.0232	NA	NA
Methyl Mercury (MeHg)	0.0039	0.0016	0.0197	0.0021	NA	NA
Total Hg (Hg^{II} + MeHg)*	0.0160	0.0103	0.0230	0.0253		
% Methyl Mercury	24.6	15.5	85.6	8.3		

Notes:

* Note that to determine 'Total Hg', the inorganic and methly mercury fractions are added together.

^ In some cases moisture content is not reported due to insuffient sample mass required to conduct this analysis.

NA = mercury was analyzed from a composite sample of organisms, not individual taxa, as for stable isotopes.

Samples were analyzed for Hg^{II} and MeHg by Quicksilver Scientific, Lafayette, CO; and for stable isotopes by SINLAB, Fredericton, NB.

6. FISH

Predicting changes in mercury concentrations in aquatic biota requires, among many other important input parameters, a good understanding of baseline mercury concentrations in representative fish species occupying a range of trophic levels (e.g., secondary consumers through top predators) and a good understanding of the ecological changes (e.g., to community structure and food chains) and food web structure that could occur after impounding the Peace River for the Site C Clean Energy Project. The former is important because it is the starting point from where mercury increases associated with the flooding of terrestrial and wetland habitats (i.e., the "reservoir effect") occur. The latter is important because adding any steps in the food chain between primary producers and the fish species of interest (i.e., changing its trophic position) can significantly affect mercury concentrations (i.e., due to biomagnifications up the food chain) and exacerbate the reservoir effect.

While a range of fish species are known to occur in the Peace River system, this study targeted common ones over a range of trophic positions. The selected fish species (all analyzed for total mercury and stable isotopes in muscle tissue), number and size ranges targeted from Dinosaur Reservoir and the Peace River were as follows:

- Bull trout (*Salvelinus confluentus*; BLTR) is a piscivorous predator. Targets were for five specimens each from within the following three size classes: 250 – 300 mm; 400 – 450 mm; and >600 mm. Sampling was conducted non-lethally (Baker et al., 2004) using tissue biopsy needles.
- Mountain whitefish (*Prosopium williamsoni*; MNWH) is a benthic feeder and important food chain species. Targets were for five specimens each from within the following three size classes: 200 – 250 mm; 300 – 350 mm; and >400 mm.
- Longnose sucker (*Catostomus catostomus*; LNSC) is a non-discriminant benthic forager that consumes algae and benthic invertebrates. Targets were for ten adult specimens (>300 mm).
- Redside shiner (*Richardsonius balteatus*; RDSH) is a forage species with a mixed invertebrate diet. Targets were for ten adult specimens measuring >100 mm.

Lake trout (*Salvelinus namaycush*; LKTR), while not directly targeted due to presumed low numbers in the Peace River, were opportunistically sampled using non-lethal methods to help assess their mercury and trophic status relative to bull trout. Lake trout were targeted in Dinosaur Reservoir because this species has established itself within the reservoir and there is purportedly a popular sport fishery for this species in the tailrace area of Shrum G.S. It is well known that fish may target the tailrace area of generating stations, feeding on dead or wounded fish coming from upstream reservoirs.

Mainstream Aquatics, Edmonton AB was under contract to BC Hydro for collection of all fish tissue samples. They were provided a copy of the SAP (Azimuth, 2010b) where detailed methods on fish collection can be found.

While the primary intent of data collection was to support the RESMERC modeling (**Appendix B**), the specific objectives of this phase of work were to comparatively assess mercury concentrations and trophic position (i.e., using stable isotopes of nitrogen and carbon to determine position in the food chain) of target species in the Peace River and Dinosaur Reservoir.

6.1. Methods

6.1.1. Field Sampling

In order to accurately represent mercury concentrations across the size range typically observed for most non-minnow species, up to 30 – 35 fish are required, stratified (5-7 fish) within discrete size intervals (e.g., 200 – 300 mm; 300 – 400 mm). This is because in most waterbodies mercury concentrations increase within increasing fish size and it is important to represent mercury concentrations according to a mean, standardized size in order for the data to be comparable over time or to other waterbodies for the same species. Fewer than 30 fish were sampled for all species and actual numbers are described in the results section. The strategy and sampling methods employed in 2010 are briefly described here, but will be more fully described by Mainstream Aquatics (2011, Draft Report).

All fish were collected by gill net, beach seine, angling or boat electro fisher. Bull trout and lake trout were sampled using non-destructive methods, using biopsy tools to extract small tissue quantities, following the protocol of Baker et al. (2004) and Environment Canada (*http://www.ec.gc.ca/esee-eem/D450E00E-61E4-4219-B27F-88B4117D19DC/mmfishtissueEn.pdf*). Fish that met the required size category were placed into a 20 liter bucket and anaesthetized using clove oil mixed with rubbing alcohol at a ratio of 1:10 and then further mixed with water at a ratio of 4.4 ml /10 L.

Muscle tissue was collected from anaesthetized fish using a sterile 4 mm wide Miltex™ Biopsy Punch. One plug was transferred using forceps to a sterile, labeled 6 mL HDPE vial (for stable isotope analysis), and two plugs transferred to a second 6 mL HDPE vial (for mercury analysis). These were placed on dry ice in an insulated cooler. After the plugs were taken, each wound was dried with sterile gauze and covered with a waterproof liquid bandage compound (Vetbond™) to stop any minor bleeding, act as an infection barrier and facilitate healing. Upon completion of the above steps, the sampled fish was transferred to a 60 L aerated recovery tank until fully recovered and then released. Sampling instruments that were to be reused were sterilized with 95% isopropyl alcohol.

Mountain whitefish, longnose suckers, and redside shiner that met the required size category were euthanized by severing the spinal cord just posterior to the head using a fillet knife. A 5 g to 10 g tissue fillet of exposed muscle was removed and split into two equal-sized samples. Each sample was placed in a labeled Whirl-pac™ bag.

For redside shiner, which is a small fish, two fillets were collected from each fish using the procedure described above. The fillets were combined and then cut into two equal samples.

In addition to tissues, the following information was collected from each fish prior to tissue extraction:

- Length (mm) and weight (g)
- Gender (male or female)
- Maturity (immature, maturing to spawn current year, ripe, spent, resting)
- Age (using scales or fin rays for trout)

For destructively-sampled fish:

- Visual inspection and documentation of stomach contents
- Internal and external examination for abnormalities, tumors, growths, parasites
- Age (removing otoliths from whitefish, fin rays from suckers and scale samples from shiner)

See Mainstream Aquatics (2011) for further detail.

6.1.2. Parameters Collected

The following parameters were collected for all samples and analyzed by the laboratory listed for each bullet:

- Total mercury and moisture (**ALS**)
- Carbon and nitrogen stable isotope analysis (**SINLAB, New Brunswick**). See **Appendix C** for further information on analytical methods.

6.1.3. QA/QC

Fish meristic data (i.e., length, weight, condition) were used to identify potential outliers (e.g., due to transcription errors, etc.) in the data set that might confound the interpretation of the mercury and stable isotope results.

QA/QC for tissue chemistry consisted of testing of laboratory duplicates within the laboratory as well as routine testing of SRMs to ensure adequate precision of analysis.

Laboratory duplicates could only be performed for mountain whitefish or longnose sucker, where there was sufficient tissue. Biopsy plugs are too small to be split.

Field duplicate samples for tissue chemistry were collected from eight fish, split among Dinosaur Reservoir and Peace River and were mostly from whitefish and sucker, to avoid unnecessary mortality of bull trout and lake trout.

6.2. Results

Fifty four (54) fish were collected from the Peace River in 2010 (Mainstream Aquatics, 2011): 15 bull trout, 17 mountain whitefish, 10 longnose sucker, 11 redside shiner, and one lake trout. All fish were captured in Section 3 of the Peace River except for redside shiner, which were all captured in Section 5 (**Figure 6-1**). In the Peace River, fish were collected by boat electrofisher and angling.

Fifty (50) fish were collected from Dinosaur Reservoir: 14 bull trout, 15 mountain whitefish, one longnose sucker, no redside shiner, and 20 lake trout. In Dinosaur Reservoir fish were collected by gill net, beach seine, angling, and boat electrofisher (Mainstream Aquatics, 2011). Despite lower than ideal numbers of fish, the sample size of whitefish and bull trout, from Dinosaur Reservoir and Peace River was large enough to compare size-standardized mercury concentrations between these waterbodies. There were insufficient numbers of longnose sucker, redside shiner and lake trout captured to make comparisons between Dinosaur and Peace River. Fish collection raw data, meristics, and chemical analyses are summarized in **Appendix D**. **Figure 6-2** presents length-frequency diagrams for each species captured, depicting the numbers of fish captured within discrete size categories.

6.2.1. QA/QC

6.2.1.1. Fish Meristics

Fish meristic data (i.e., length, weight, condition) were used to identify potential outliers in the data set that might confound the interpretation of the mercury and stable isotope results. Length-frequency histograms are shown in **Figure 6-2** for the target species by water body. A reasonable size range was collected for most species/water body combinations, with the following exceptions:

- Lake trout – only one fish was caught in the Peace River.
- Bull trout – a bimodal size range was collected in Dinosaur Reservoir.
- Longnose sucker – only one fish caught in Dinosaur Reservoir and a limited size range for the Peace River.

- Redside shiner – no shiners in Dinosaur Reservoir and a limited size range for the Peace River, collected downstream of Moberly River.

Condition-frequency histograms and length-weight scatter plots are shown in **Figures 6-3 and 6-4**, respectively. The condition histograms look reasonable for all species, with the exception of mountain whitefish, that had four abnormally low-condition fish and one high-condition fish. Mainstream Aquatics, who collected and processed the fish, was contacted to verify the results. They agreed that the results were anomalous, but verified data entry relative to their field log books (i.e., the error was not transcriptional). They also noted that no fish appeared "overly thin" during sampling. Their field crews indicated that it was windy on Dinosaur Reservoir during field collections and that scale imprecision during weight measurements is a possible explanation for the abnormal condition results.

Given the lack of transcription error, the identification of weight measurements as the most likely issue and our planned analyses (i.e., they rely on length rather than on weight), the fish in question were flagged in the data set and retained for subsequent analyses (data points are circled in subsequent figures for easy identification).

6.2.1.2. Mercury

Blind duplicate samples for total mercury were submitted to ALS for eight fish tissues (i.e., replicate tissue samples from the same fish). Of these, four were mountain whitefish (two each from Dinosaur and Peace River), three were longnose sucker and one lake trout. RPD values met the DQO of ±25% in all but one case (**Table 6-1**) with all values less than ± 20%. The exception was for a mountain whitefish where original (0.04 mg/kg) and duplicate samples (0.07 mg/kg) differed significantly. Although the absolute difference was small (0.03 mg/kg), this was sufficient to generate a high RPD (56%).

6.2.2. Meristics

Five species were captured from Peace River and four from Dinosaur (i.e., no redside shiner). Length-frequency distributions were plotted for each species to determine the size range and distribution across the prescribed range to derive length – mercury relationships (**Figure 6-2**). **Figure 6-3** shows condition factor (K) – frequency distributions as a measure of fish health but also as a means of identifying outliers (see above). Length-weight relationships are plotted for each species (**Figure 6-4**) with very tight distributions except for the outlying mountain whitefish as described above in **Section 6.2.1.1.**

Bull trout from Dinosaur Reservoir (mean 671 mm, 2155 g) were larger than bull trout from Peace River (mean 470 mm, 1688 g) and condition factor of both groups was high

(1.14) suggesting that all fish were reasonably healthy (**Table 6-2**). Mean age (7.0 and 4.5 years respectively) correlated with size differences however, because fin rays were used for ageing, there is some uncertainty with these values.

Twenty lake trout were captured in Dinosaur Reservoir (mean 421 mm, 905 g, K=1.01) (**Table 6-2**). Although trout were captured over a fairly wide size range (322 – 630 mm), suitable for length-mercury relationships mean size was relatively small for this species. Only one small lake trout (391 mm, 570 g) was captured from Peace River, which is to be expected; note this species was an incidentally sampled as opposed to targeted in the SAP.

Mountain whitefish were captured in reasonable numbers from both environments across a wide size range (211 – 480 mm). Mean length and weight from Dinosaur (301 mm, 333g) and Peace River (318 mm, 419 g) were relatively similar although Peace River fish were larger at similar weights and thus had higher condition factors (1.08, and 1.18 respectively).

Ten longnose sucker (mean 386 mm, 720 g, 1.25 K) were captured in Peace River but only one from Dinosaur (400 mm, 852 g, 1.33 K). All fish were robust with relatively high condition factor, even from Dinosaur Reservoir (**Table 6-2**).

Eleven redside shiner within a narrow size range were captured in Peace River, but none in Dinosaur Reservoir. Redside shiner have been reported from Dinosaur Reservoir (Murphy and Blackman, 2004), but comprised less than 1% of total catch.

6.2.3. Mercury

Mercury concentrations in fish in new reservoirs are typically of concern to human consumers of fish, but also to fish-eating wildlife (birds and mammals). That mercury concentrations in fish increase following impoundment and flooding of terrestrial habitats is very well known (i.e., termed the “reservoir effect”); but what is less certain is the magnitude and duration of increase in concentrations above baseline. Recent baseline mercury concentration data from 2008 (Mainstream Aquatics, 2009) suggest that mercury concentrations in fish species are quite low, with arithmetic mean concentrations less than 0.10 mg/kg ww for bull trout and mountain whitefish.

The 2010 mercury concentrations for our target species are summarized in **Table 6-2.** There is a well-known positive relationship between increasing mercury and fish length (or weight or age) (Scott and Armstrong, 1972; Bodaly et al., 1984; Strange et al., 1991; Somers and Jackson, 1993), as larger, older fish tend to have higher mercury concentrations than smaller, younger fish. This is partly due to differences in diet and the length of time of exposure. This positive relationship is typically seen for strongly carnivorous species (e.g., bull trout, lake trout, walleye) and sometimes for whitefish

(mountain and lake whitefish) but seldom for suckers, forage fish or fish that consume terrestrial insects such as rainbow trout. In **Table 6-3** we present the statistical relationships between $\log_{10}$(mercury) and $\log_{10}$(length) for bull trout, lake trout, and mountain whitefish from Dinosaur Reservoir and Peace River and redside shiner from Peace River. The relationships and their statistical significance (only significant $p<0.05$ relationships are depicted by solid [Dinosaur] or dashed [Peace River] lines) Following are the key results related to mercury concentrations in fish from the current study:

Bull Trout

- The arithmetic mean size (length and weight) and mean mercury concentration for Dinosaur Reservoir bull trout (671 mm, 2155 g) was 0.10 mg/kg with a non-significant relationship between length and mercury (**Figure 6-5**). The lack of a relationship is due to a combination of a limited size range collected and generally low mercury concentrations in all environmental media, including prey that may have originated from upstream in Williston Reservoir.
- Arithmetic mean mercury concentration of Peace River bull trout (470 mm, 1688 g) was lower (0.055 mg/kg), primarily because of smaller fish size. The mercury-size relationship for Peace River bull trout was statistically significant ($p=0.005$).
- Mean bull trout mercury concentration in the Peace River in 2008 (460 mm, 1513 g; Mainstream Aquatics, 2009) was 0.08 mg/kg (range = 0.02 – 0.14 mg/kg), which is quite similar to the concentration in the present study. Overall, these data indicate that mercury concentrations of bull trout are low.

Lake Trout

- The arithmetic mean size (length and weight) and mercury concentration for Dinosaur Reservoir lake trout (421 mm, 905 g) was 0.09 mg/kg. The $\log_{10}$(length) – $\log_{10}$(mercury) was not positive (**Figure 6-5**). The low mercury concentrations in lake trout suggests that trout are foraging on low mercury concentration food, possibly originating from Williston Reservoir and possibly targeting zooplankton (see **Section 6.3** Stable Isotopes). Diet data are not yet available for this fish species. The reasons why mercury concentrations are so low will be addressed briefly in the next section on trophic structure.
- The mercury concentration for the only lake trout captured from Peace River (391 mm, 570 g) was 0.07 mg/kg, and similar to Dinosaur Reservoir fish, despite being somewhat smaller.
- Mainstream Aquatics (2009) did not collect any lake trout from the Peace River in 2008.

Mountain Whitefish

- The arithmetic mean size (length and weight) and mercury concentration for Dinosaur Reservoir mountain whitefish (301 mm, 373 g) was 0.04 mg/kg, with a positive $\log_{10}$(length)-$\log_{10}$(mercury) relationship (**Figure 6-5**).
- The arithmetic mean size (length and weight) and mercury concentration for Peace River mountain whitefish (318 mm, 449 g; larger than Dinosaur Reservoir fish) was 0.03 mg/kg, also significantly positive $\log_{10}$(length) – $\log_{10}$(mercury) relationship (**Figure 6-5**).
- Mean mountain whitefish mercury concentration in 2008 (340 mm, 482 g; Mainstream Aquatics, 2009) was 0.03 mg/kg (range: 0.02 – 0.06 mg/kg), which is quite similar to the mean concentration measured in the present study. These data indicate that mercury concentrations in Peace River mountain whitefish have not changed in the last two years and are low.

Longnose Sucker

- The arithmetic mean size (length and weight) and mercury concentration for Peace River longnose sucker (386 mm, 720 g) was 0.04 mg/kg (i.e., similar to mountain whitefish). The mercury – length regression was not statistically significant (**Table 6-3**).
- The only longnose sucker captured in Dinosaur Reservoir (400 mm, 852 g) had a mercury concentration of 0.18 mg/kg, the highest concentration recorded in the 2010 study across all species. Interestingly, this fish also has a much higher trophic position (see **Section 6.3** for details) than the Peace River suckers, suggesting that it may be feeding on fish (or fish remains), possibly from Williston Reservoir. In addition, because longnose sucker do not reach the large sizes of lake trout or bull trout, there is less 'growth dilution' of mercury, so they tend to magnify the concentration because body size does not increase in proportion to dietary intake. Further data are needed to verify these results and provide additional information on the likely mechanisms involved.
- Mainstream Aquatics (2009) did not analyse longnose sucker for mercury concentrations in Dinosaur or Peace River in 2008.

Redside Shiner

- The arithmetic mean size (length and weight) and mercury concentration for Peace River redside shiner (captured downstream of Moberly River) (99 mm, 14

g) was 0.05 mg/kg. This species was not analyzed for mercury in 2008 (Mainstream Aquatics, 2009).

6.2.4. Discussion

Mercury concentrations for all species captured from Dinosaur Reservoir and Peace River were very low relative to the same species of a similar size in other BC lakes and reservoirs. In fact, these mercury concentrations are an order of magnitude lower than for the majority of bull trout and lake trout from reservoirs and lakes in British Columbia (Baker, 2002). In the current study, arithmetic mean mercury concentrations of bull trout and lake trout from Dinosaur Reservoir and Peace River were less than 0.1 mg/kg. For comparison, here is a brief summary of arithmetic mean tissue mercury concentrations in bull trout from other BC reservoirs.

- Arrow Reservoir (1995) – 0.21 mg/kg for a 595 mm fish
- Kinbasket Reservoir (1995) – 0.25 mg/kg for a 658 mm fish
- Revelstoke Reservoir (1995) – 0.30 mg/kg for a 670 mm fish
- Williston Reservoir (Peace Reach, 1988) – 0.55 mg/kg for a 437 mm fish

Although we do not have mercury data for lake trout in BC reservoirs, Baker (2001) conducted a mercury survey of lakes in north-central BC with the following results (all data 2000). Stuart Lake (0.31 mg/kg; 556 mm); Tchentlo Lake (0.25 mg/kg, 551 mm); Tezzeron Lake (0.50 mg/kg, 619 mm); Trembleur Lake (0.32 mg/kg, 621 mm) and Francois Lake (0.26 mg/kg, 544 mm).

Further analyses directed to providing context from a spatial (i.e., comparisons to other areas in BC and Canada) or temporal (i.e., documented changes relative to historical studies and expected trends in the future) will be explored in the technical mercury synthesis document, compendium to the EIA. This document will also use the stable isotope data to help understand trends and patterns in mercury concentrations and fish diet once these data become available.

6.3. Relationship between trophic structure and mercury concentrations

6.3.1. Introduction

The goal of this component of the 2010 study was to compare trophic structure (based on stable isotopes of nitrogen and carbon) to mercury concentrations in fish the two water bodies studied (Dinosaur Reservoir and the Peace River). At this stage, it is not unreasonable to assume that ecological conditions in Dinosaur Reservoir might be similar to those in a post-impounded Site C. Thus, these comparisons can provide insights into the potential ecological relationships that affect mercury uptake.

This section addresses the following:

- An overview on stable isotopes and estimation of trophic position for fish.
- Trophic position results for target fish species and how they correlate to fish length for each water body.
- The relationship between mercury in fish and their trophic position for each target species and water body.
- A discussion of data gaps and uncertainties in the 2010 data set.

6.3.2. Stable Isotopes Analysis and Trophic Structure – An Overview

Food chain structure has been shown to influence contaminant concentrations in lake trout, particularly for mercury and persistent organo-chlorine compounds (Cabana and Rasmussen, 1994; Cabana et al., 1994). Mercury (particularly the more harmful methyl form) biomagnifies up the food chain as tissue concentrations increase substantially with each successive step. This process starts with the bioaccumulation of mercury by lower trophic level organisms (e.g., phytoplankton) and then the magnification of mercury concentrations moving up the food web through zooplankton, benthos and ultimately fish. Consequently, food chain length, which can vary across aquatic ecosystems, can have a profound effect on mercury concentrations in top predators such as lake trout or bull trout (Rasmussen and Vander Zanden, 2004).

Figure 6-6 shows the trophic position of lake trout in the simplified food chains for three lake classes. Traditionally, trophic position (i.e., how high an animal is situated in the food web) was determined by examining the gut contents of fish, which essentially represent a brief "snap-shot" in time of their diet (e.g., typically on the order of days). Advances in stable isotope analysis (SIA) over the past two decades have resulted in a powerful time-integrated tool for determining trophic position that is literally based on

the premise that "you are what you eat". SIA targets the stable isotopes (same number of protons, but different number of neutrons and thus mass; stable in that they do not decay like radioactive isotopes) of particular elements (e.g., C, N and others). Studies have shown that consumers experience the preferential loss of the lighter isotope during metabolic processes (e.g., excretion or respiration), resulting in varying degrees of heavy isotope enrichment relative to their diet. This trophic fractionation is the underlying mechanism that results in different patterns of stable isotope ratios in nature. Identifying these patterns provides valuable insights into the trophic structure of the system of interest.

How Stable Isotope Values Are Calculated.

Isotopic fractionation (i.e., the preferential use of certain isotopes during biological processes like photosynthesis, excretion or respiration) results in enrichment (positive values) or depletion (negative values) of the isotopic ratio relative to internationally-used standard material (i.e., atmospheric nitrogen or PeeDee Belemnite carbon). The difference, represented by $\delta^{15}N$ or $\delta^{13}C$ (in parts per thousand, ‰; or per "mil"), is calculated using the following equation:

$\delta^{15}N$ or $\delta^{13}C$ ‰ = $([R_{sample} / R_{standard}]-1) \times 1000$
Eq.1

where $R = {}^{15}N:{}^{14}N$ or ${}^{13}C:{}^{12}C$.

The stable isotopes of nitrogen and carbon have been used to complement one another in the characterization of food webs over a broad range of systems. Nitrogen isotopes have been used extensively as a fairly robust means of distinguishing between and quantifying the trophic positions of consumers in aquatic systems (e.g., Peterson and Fry, 1987; Bilby et al., 1996; Vander Zanden et al., 1999; Harvey and Kitchell, 2000; Leggett et al., 2000; Vander Zanden and Rasmussen, 2001; Vander Zanden et al., 2003; Herwig et al, 2004). Carbon isotopes have been used to trace the flow of energy through food webs and are particularly valuable in identifying dietary preferences of consumers (e.g., Rounick and Winterbourn, 1986; Peterson and Fry, 1987; France, 1995*a* and 1995*b*; Hecky and Hesslein, 1995; Herwig et al., 2004; da Silva et al., 2005). Together, stable nitrogen and carbon isotopes provide good insights into trophic structure and feeding preferences that are invaluable in interpreting observed patterns in contaminant uptake and biomagnification (Rasmussen et al., 1990; Cabana and Rasmussen, 1994; Cabana et al., 1994; Atwell et al., 1998; Kidd et al., 1999). This being said, there can be considerable variability in both $\delta^{15}N$ and $\delta^{13}C$ that needs to be taken into account in the interpretation of results. We present this information as a means of assisting in the interpretation of food web relationships within Dinosaur Reservoir and Peace River and mercury concentration data.

The derivation of stable isotope values is presented in the accompanying text box. Studies have shown that $\delta^{15}N$ is about 3.4‰ and $\delta^{13}C$ between 0-1‰ higher in consumers relative to their diet for a range of taxa (Minagawa and Wada, 1984; Peterson and Fry, 1987; Vander Zanden and Rasmussen, 2001).

For nitrogen isotopes, while the relative difference in $\delta^{15}N$ between consumers and their diet is fairly constant, the absolute $\delta^{15}N$ values of both consumers and dietary items can vary considerably within and among lakes (e.g., Kling et al., 1992; Kline et al., 1998). Vander Zanden et al. (2000) looked at within- and among-population variation in trophic position and found that 78% of the total variation was due to lake-to-lake differences. While the trophic structure of lakes (e.g., presence/absence of pelagic forage fish [e.g., whitefish] and/or presence of a large zooplankton predator [e.g., mysids]) will clearly affect $\delta^{15}N$ values (and thus trophic position) among top predator consumers, significant variability in $\delta^{15}N$ values has been shown at the base of the food web (Cabana and Rasmussen, 1996; Vander Zanden and Rasmussen, 1999; Vander Zanden and Rasmussen, 2001). This variability is observed both within lakes (i.e., among specific habitats in a lake) and among lakes (i.e., due to variability in N sources), with serious implications for accurate characterization of trophic position of higher level consumers.

Carbon isotopic ratios show an even greater variability, particularly among primary producers. Most terrestrial plants typically have $\delta^{13}C$ values around -28 ppt (parts per thousand), with others differing primarily as a result of distinct fractionation patterns among photosynthetic pathways. Aquatic plants routinely have a much higher range of $\delta^{13}C$ values due to variability in isotopic ratios of the dissolved inorganic carbon pool, physical factors limiting the rate of carbon diffusion through the boundary layer around plant tissue and other reasons (Rounick and Winterbourn, 1986). The boundary layer/diffusion factor is thought to be responsible for the significant differences observed in $\delta^{13}C$ values between pelagic (depleted) and benthic (enriched) algae. These diverse carbon signatures, coupled with the subsequent low degree of fractionation by consumers, provide a means of identifying feeding preferences of primary consumers.

Thus, while $\delta^{15}N$ values are known to increase with successive trophic steps, $\delta^{13}C$ values show only a slight increase with each step, essentially conserving the $\delta^{13}C$ signature of the base of the food chain. The variability at the base of the food chain and minimal increase up the food chain allows the interpretation of energy sources to higher consumers (e.g., profundal-based food chains will have depleted $\delta^{13}C$ compared to those based in littoral zones).

6.3.3. Fish Trophic Position Estimation using Stable Isotopes

6.3.3.1. Stable Isotope Results for the Peace River and Dinosaur Reservoir

Stable isotope results are shown in mean (and standard deviation) $\delta^{15}N$ and $\delta^{13}C$ values for target fish species for each water body in **Figures 6-7 and 6-8**, for the Peace River and Dinosaur Reservoir, respectively. While the $\delta^{15}N$ values provide a rough estimate of

the relative positions of each target fish species in the food chain, further discussion of trophic position is deferred to **Section 6.3.3.2** due to a need to correct trophic position estimates for inter-water body differences in $\delta^{15}N$. The $\delta^{13}C$ values distinguish between various energy flow paths in these water bodies. Interestingly, the range of primary consumer $\delta^{13}C$ values is low in the Peace River relative to Dinosaur Reservoir, which might be due to more depleted $\delta^{13}C$ in pelagic relative to littoral zones (Vander Zanden and Rasmussen, 1999). While the observed pattern (particularly for zooplankton) might be somewhat seasonal (e.g., possible reduction in the $\delta^{13}C$ of the dissolved inorganic carbon pool later in the summer as respiration increases), the wide range of $\delta^{13}C$ values among target fish species suggests that the pattern might be more persistent. Specifically, the $\delta^{13}C$ values of bull trout and lake trout are more negative and further from the other fish species in Dinosaur Reservoir. This suggests that bull trout and lake trout in Dinosaur Reservoir may be feeding on prey items more depleted in $\delta^{13}C$ (e.g., pelagic- or profundal-based energy flow paths). Given the proximity of the captured fish to the tailrace area (see **Figure 6-1**) it is possible that their prey items (i.e., smaller fish) may be coming from Williston Reservoir.

6.3.3.2. Estimation of Trophic Position using Stable Isotopes

Cabana and Rasmussen (1996) recommended that absolute trophic position estimates of consumers should take into account the $\delta^{15}N$ of primary consumers as a baseline. Vander Zanden and Rasmussen (1999) further refined this approach to also take the stable carbon isotopes into consideration, as $\delta^{13}C$ was shown to generally decrease from littoral to pelagic to profundal habitats. However, use of the latter refinement was only deemed valuable when $\delta^{15}N$ values varied substantially among three or more primary consumer groups (i.e., they followed the pattern of increasing $\delta^{15}N$ values with decreasing $\delta^{13}C$ values).

Stable isotope results for primary consumers were presented in **Table 6-2** and are shown in **Figures 6-7 and 6-8** for the Peace River and Dinosaur Reservoir, respectively. The figures show little difference in primary consumer $\delta^{15}N$ values over a fairly broad range of $\delta^{13}C$. Consequently, we did not apply the refined approach (i.e., considering primary consumer $\delta^{13}C$ in establishing the baseline $\delta^{15}N$) and instead relied solely on the primary consumer $\delta^{15}N$ values to establish the baseline for each water body. Consequently, baseline-corrected trophic position was estimated using the following equation (Vander Zanden and Rasmussen, 2001):

$$TP_{\text{fish species}} = (\delta^{15}N_{\text{fish species}} - \delta^{15}N_{\text{primary consumer}})/3.4 + 2 \qquad \text{Eq.2}$$

Where $\delta^{15}N_{primary\ consumer}$ was the mean value of benthos and zooplankton samples from each water body (see **Table 6-2**) and $\delta^{15}N_{fish\ species}$ was either the mean $\delta^{15}N$, standard size $\delta^{15}N$ or individual fish $\delta^{15}N$ for a given species depending on the analysis.

Mean trophic position of target fish species for the Peace River and Dinosaur Reservoir are shown in **Figure 6-9**. Lake trout had the highest trophic position in both water bodies (however, note the low sample size in the Peace River, n=1), followed by bull trout (n=15). As expected, mountain whitefish, longnose sucker and redside shiner were generally lower in the food chain. For each target species caught in both water bodies, mean trophic position estimates were higher in Dinosaur Reservoir than the Peace River. However, as trophic position is generally a function of fish size (i.e., for most species, fish feed progressively higher on the food chain as they grow larger), differences in trophic structure between the two water bodies are best examined using length-trophic position relationships.

Fork length-trophic position relationships are shown for each target fish species and water body (**Figure 6-10**); linear regression results for each species-water body combination (with sufficient data) are provided in **Table 6-4**; only statistically significant ($p>0.05$) relationships are shown in **Figure 6-10**. Significant relationships were found for all combinations except LNSC-PEACE and RDSH-PEACE, because both species had narrower ranges of fork length than was targeted. Interesting, while statistically significant, the relationship for lake trout in Dinosaur Reservoir had a slight negative slope, implying that lake trout of all sizes are feeding on the same dietary items. These results could be a sampling artifact or somehow related to the ecology of the tailrace area (e.g., feeding on small fish entrained in the discharge from Williston Reservoir). The latter explanation would be consistent with the length-total mercury relationship results (**Section 6.2.3**), which also showed a negative relationship over the size range of lake trout captured in Dinosaur Reservoir. Interestingly, the only longnose sucker captured in Dinosaur Reservoir had a much higher trophic position than its counterparts in the Peace River (**Figure 6-9**), which suggests a shift towards more fish in their diet; this is also consistent with the mercury results, as that fish had the highest mercury concentration (0.18 mg/kg), much higher than the mean mercury concentration of suckers in Peace River (0.04 mg/kg) (**Table 6-2**).

It should be noted that the reported relationship for bull trout in Dinosaur Reservoir should be treated with caution due to the non-normal distribution of the length data. Also note the flagged data (circled points); these are fish (see QA) where we believe the weight data to be wrong. These were left here because this is a length-based regression. Notwithstanding, ANCOVA results indicate that once fish size has been taken into consideration, the trophic position estimates for standardized fish (i.e., a 300-mm

MNWH or a 550-mm BLTR) for Dinosaur and Peace River are very similar (**Figure 6-10**).

6.3.4. Total Mercury and Trophic Position

As discussed in **Section 6.3.2**, trophic position has been shown to be well-correlated to tissue concentrations for biomagnifying substances such as mercury and organo-chlorine compounds. This relationship was examined for each species-water body combination and across species and water bodies. The results of the species-water body combinations are presented in **Table 6-5** and shown in **Figure 6-11** (regression lines provided for statistically significant relationships only [$p<0.05$]). Mountain whitefish was the only species with significant relationships for both water bodies; ANCOVA results showed approximately 30% higher total mercury tissue concentrations in Dinosaur Reservoir relative to the Peace River.

The importance of feeding ecology driving total mercury tissue concentrations is exemplified in **Figure 6-12**, which shows the trophic position-total mercury relationship across all target species and water bodies.

These results will be explored, in context with dietary information from fish (these data were not available at the time of publication of this report) and with historic fish mercury data, in the technical mercury synthesis document as part of the EIA.

6.3.5. Data Gaps and Uncertainties

This information is relatively new and would benefit from further scrutiny and discussion. Nevertheless, while the data answer some key questions, some data gaps and uncertainties have surfaced. In addition, the information on mercury and stable isotopes have not yet been integrated with diet information from fish, nor with complete results of the 2010 fishing effort on the Peace River and Dinosaur Reservoir and the efforts by Golder / ESSA / Limnotek on reservoir and river productivity.

This section briefly outlines data gaps and uncertainties and suggests possible solutions to reduce uncertainties and tighten up our overall conclusions, especially related to the relationships between trophic position, diet and tissue mercury concentrations in secondary producers and fish.

- Poor primary consumer characterization – Sample sizes for zooplankton and benthos were small. Because of difficulties in acquiring organisms, only one composite sample of benthos was analyzed for Hg and stable isotopes from Dinosaur Reservoir. We also do not know the mass or taxonomic composition of benthos from Peace River, so there is some uncertainty in the representativeness of benthic stable isotope or mercury data. Given that the stable isotope signature

of benthic organisms is important in linking position of different trophic levels together, the collection of more benthos for mercury and stable isotopes would reduce uncertainty. Azimuth is working with Limnotek to rectify this by analyzing representative benthic invertebrates from archive samples for mercury and stable isotopes.

- Inadequate size range for some fish species – Size range and sample size of certain fish species is smaller than is necessary to fully understand mercury – size relationships and trophic position and mercury in Dinosaur and Peace River. Additional fish mercury data from discrete size ranges (gaps) would improve our understanding of mercury – size relationships. However, notwithstanding this deficiency, the low mercury concentrations observed in all fish collected, despite size differences, suggests that having data from more fish would not alter our conclusion. Further tissue samples are being collected in 2011 to address this gap, as well as collecting mercury from other species such as rainbow trout (*Oncorhynchus mykiss*) that is relatively abundant in Dinosaur Reservoir (Murphy and Blackman, 2004).

- Lack of fish diet information – The premise of interpreting stable isotopes is 'you are what you eat'. Currently, site-specific diet information for most fish species on the Peace River is lacking. These data would provide us with better insight into trophic position and mercury data and we expect to receive diet information in spring 2011. Lack of site-specific data is not critical because dietary requirements of these species is generally well known and will be a reflection of what is in the river, which is known.

- Influence of Williston Reservoir – We have presumed that water quality, sediment chemistry and lower trophic level biota in Dinosaur Reservoir and Peace River are very strongly influenced by water discharged from Williston Reservoir. However the differences in stable carbon isotope signatures of zooplankton in Dinosaur and Peace River add some uncertainty to this assumption. Part of this might be related to small sample size and/or taxonomic differences (further exacerbated by the small mass analyzed) between the two water bodies. Further discussions with Golder / ESSA / Limnotek may shed some light on this.

- Selenium in fish tissue – Recently the molar ratio between selenium and mercury in fish tissue has garnered much attention. It has been postulated, but still heavily debated, (see Raymond et al., 2004; Ralston, 2008; Choi et al., 2008 and many others) that when there is an excess of selenium (on a molar basis) than mercury

in fish muscle tissue, the risks posed by methyl mercury in fish tissue is much reduced or eliminated. Fish tissue collections in 2011 will be analyzed for a suite of metals including selenium as well as mercury.

Table 6-1. QA/QC data for fish, BC Hydro 2010.

FIELD QA

STABLE ISOTOPES				MERCURY	
Sample IDs	Date	δ ^{13}C (‰)	δ ^{15}N (‰)	Moisture (%)	T-Hg (mg/kg ww)
GN02 MNWH 8	18-Aug-10	-26.56	7.97	77.3	0.04
DUP-DI-FISH-1	18-Aug-10	-26.46	7.93	73.8	0.03
RPD (%)		0.40	0.53	4.6	12
GN02 MNWH 9	18-Aug-10	-26.43	8.56	78.5	0.07
DUP-DI-FISH-2	18-Aug-10	-26.40	8.46	75.1	0.04
RPD (%)		0.11	1.08	4.4	56
EF09 LNSC 8	23-Aug-10	-28.46	9.37	80.6	0.18
DUP-DI-FISH-3	23-Aug-10	-27.87	9.01	80.3	0.21
RPD (%)		2.10	3.87	0.4	-17
GN01 BLTR 39	27-Aug-10	-29.09	11.08	75.9	0.08
DUP-DI-FISH-4	27-Aug-10	-29.56	11.13	77.3	0.08
RPD (%)		-1.61	-0.47	-1.8	6.0
EF0303 LNSC 6	24-Aug-10	-29.26	6.32	76.2	0.02
DUP-PE-FISH-1	24-Aug-10	-30.09	6.21	78.4	0.02
RPD (%)		-2.82	1.81	-2.8	-19
EF0303 LNSC 9	24-Aug-10	-30.06	6.14	77.3	0.03
DUP-PE-FISH-2	24-Aug-10	-30.49	5.95	77.8	0.02
RPD (%)		-1.43	3.18	-0.6	32
EF0305 MNWH 1	24-Aug-10	-28.94	6.99	72.3	0.02
DUP-PE-FISH-3	24-Aug-10	-29.38	6.92	73.0	0.02
RPD (%)		-1.50	1.08	-1.0	3.1
EF0307 MNWH 1	25-Aug-10	-30.66	8.77	75.1	0.04
DUP-PE-FISH-4	25-Aug-10	-31.34	8.54	74.5	0.03
RPD (%)		-2.19	2.65	0.8	26

LABORATORY QA

STABLE ISOTOPES				MERCURY			
Sample IDs	Sample Type	δ ^{13}C (‰)	δ ^{15}N (‰)	Sample IDs	Sample Type	Moisture (%)	T-Hg (mg/kg ww)
GN04	Original	-26.77	8.85	EF0306	Original	71.2	0.04
MNWH 18	Replicate	-26.02	8.67	MNWH30	Replicate	71.6	0.04
RPD (%)		2.8	2.0	**RPD (%)**		-0.6	-1.2
ANG02	Original	-35.13	12.29	DUP-DI-	Original	73.8	0.03
LKTR 28	Replicate	-35.10	12.09	FISH-1	Replicate	74.4	0.03
RPD (%)		0.08	1.7	**RPD (%)**		-0.8	7.0
BS01 BLTR	Original	-35.48	11.56	DUP-DI-	Original	77.3	0.08
7	Replicate	-35.43	11.35	FISH-4	Replicate	77.0	0.08
RPD (%)		0.15	1.8	**RPD (%)**		0.4	-6.5
EF0305	Original	-27.41	7.48				
MNWH 13	Replicate	-28.16	7.65				
RPD (%)		-2.7	-2.2				
EF0308	Original	-28.25	9.51				
BLTR Pit:	Replicate	-28.32	9.45				
RPD (%)		-0.25	0.60				
DUP-DI-	Original	-27.87	9.01				
FISH-3	Replicate	-28.05	9.02				
RPD (%)		-0.66	-0.10				

Notes:

RPD = Relative Percent Difference (%) = ((original - duplicate) / (original + duplicate)/2) x 100.

Shaded RPDs exceed 25% (lab duplicates) or 50% (field duplicates).

Samples were analyzed for mercury by ALS Laboratories, Burnaby, BC; and for stable isotopes at SINLAB, Fredericton, NB.

Table 6-2. Fish biology results for the Peace River and Dinosaur Reservoir, BC Hydro 2010.

Species	Sample Size	Length (mm)		Sample Size	Weight (g)		Sample Size	Condition Factor (K)		Fillet or Biopsy	% Moisture
		Range	Mean		Range	Mean		Range	Mean		
Peace River											
Bull trout	15	292 - 806	470	15	308 - 7160	1688	15	0.99 - 1.37	1.14	Biopsy	70.4
Lake trout	1	-	391	1	-	570	1	-	0.95	Biopsy	76.0
Longnose sucker	10	363 - 410	386	10	518 - 888	720	10	1.08 - 1.50	1.25	Fillet	77.9
Mountain whitefish	17	211 - 480	318	17	108 - 1252	449	17	0.85 - 1.40	1.18	Fillet	74.1
Redside Shiner	11	85 - 119	99	11	6 - 26	14	11	0.98 - 1.54	1.30	Fillet	75.9
Dinosaur Reservoir											
Bull trout	14	285 - 835	671	4	262 - 7775	2155	4	0.94 - 1.46	1.15	Biopsy	63.6
Lake trout	20	322 - 630	421	20	262 - 2676	905	20	0.77 - 1.23	1.01	Biopsy	71.4
Longnose sucker	1	-	400	1	-	852	1	-	1.33	Fillet	80.6
Mountain whitefish	15	218 - 395	301	11*	70 - 692	373	11*	0.68 - 1.54	1.08	Fillet	76.6

Species	Sample Size	Age (yr)		Sample Size	Hg (mg/kg ww)		Sample Size	$\delta^{13}C$ (‰)		$\delta^{15}N$ (‰)	
		Range	Mean		Range	Mean		Mean	SD	Mean	SD
Peace River											
Bull trout	15	3 - 6	4.5	15	0.031 - 0.082	0.055	15	-28.77	0.74	10.16	0.50
Lake trout	1	-	4	1	-	0.066	1	-26.86	-	11.01	-
Longnose sucker	9	7 - 10	7.8	10	0.020 - 0.122	0.040	10	-29.21	0.88	6.85	0.85
Mountain whitefish	17	2 - 12	5.9	17	0.010 - 0.063	0.029	17	-29.57	1.16	7.74	0.86
Redside Shiner	11	5 - 8	-	11	0.034 - 0.068	0.054	11	-25.47	0.45	8.12	0.27
Dinosaur Reservoir											
Bull trout	13	3 - 10	7.2	14	0.038 - 0.176	0.100	14	-34.18	2.04	11.27	0.48
Lake trout	18	5 - 10	6.7	20	0.048 - 0.137	0.092	20	-32.64	1.49	11.85	0.47
Longnose sucker	1	-	17	1	-	0.178	1	-28.46	-	9.37	-
Mountain whitefish	15	2 - 15	6.6	15	0.020 - 0.075	0.044	15	-27.35	1.17	8.49	0.50

Notes:

Fish Condition Factor: calculated as $K = (\text{Weight} \times 10^5)/(\text{Length}^3)$; unitless.

* indicates that fish which were determined to be outliers were removed from summary data.

Table 6-3. Regression results for total mercury (log_{10}[y mg/kg ww]) on length (log_{10}[x mm]) relationships by species and water body.

Species-Water body	Intercept	SE(int)	Slope	SE(slope)	Residual df	p-value
BLTR-PEACE	-3.094	0.540	0.686	0.203	13	0.005
BLTR-DINO	-1.724	0.942	0.242	0.336	12	0.484
LKTR-DINO	0.709	0.759	-0.674	0.290	18	0.032
LNSC-PEACE	-1.106	13.302	-0.135	5.144	8	0.980
MNWH-PEACE	-5.663	0.557	1.640	0.224	15	<0.001
MNWH-DINO	-5.223	1.132	1.549	0.458	13	0.005
RDSH-PEACE	-2.381	1.100	0.555	0.552	9	0.341

Notes: SE = standard error
Residual df = residual degrees of freedom
Equation: log10(T.Hg) = Intercept + Slope * Log10(Length.mm)

Table 6-4. Regression results for trophic position (y) on length (log_{10}[x mm]) relationships by species and water body.

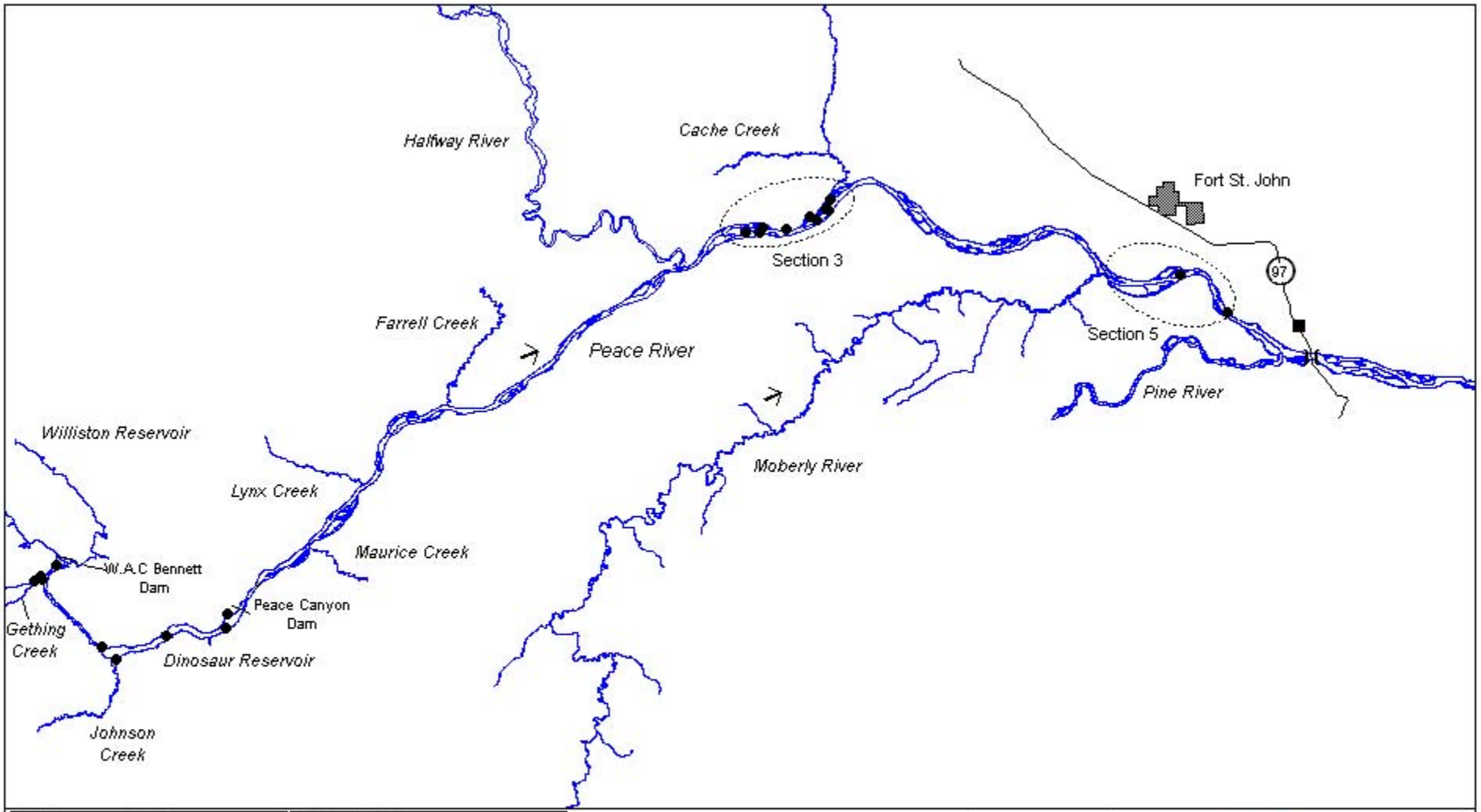
Species-Water body	Intercept	SE(int)	Slope	SE(slope)	Residual df	p-value
BLTR-PEACE	1.212	0.527	0.847	0.198	13	0.001
BLTR-DINO	1.981	0.420	0.589	0.150	11	0.002
LKTR-DINO	5.616	0.836	-0.695	0.319	18	0.043
LNSC-PEACE	1.890	15.560	0.231	6.017	8	0.970
MNWH-PEACE	-1.534	0.888	1.721	0.357	15	<0.001
MNWH-DINO	-0.606	0.687	1.382	0.278	13	<0.001
RDSH-PEACE	2.457	1.003	0.202	0.504	9	0.697

Notes: SE = standard error
Residual df = residual degrees of freedom
Equation: TP = Intercept + Slope * Log10(Length.mm)

Table 6-5. Regression results for total mercury (log_{10}[y mg/kg ww]) on trophic position (x) relationships by species and water body.

Species-Water body	Intercept	SE(int)	Slope	SE(slope)	Residual df	p-value
BLTR-PEACE	-4.026	0.416	0.795	0.120	13	<0.001
BLTR-DINO	-2.019	1.570	0.263	0.433	11	0.555
LKTR-DINO	-1.702	0.811	0.170	0.214	18	0.436
LNSC-PEACE	-0.643	0.697	-0.327	0.279	8	0.276
MNWH-PEACE	-3.341	0.388	0.640	0.141	15	<0.001
MNWH-DINO	-3.413	0.870	0.718	0.309	13	0.037
RDSH-PEACE	-3.162	0.894	0.660	0.313	9	0.064

Notes: SE = standard error
Residual df = residual degrees of freedom
Equation: log10(T.Hg) = Intercept + Slope * TP



BC Government Data

Trim Map: 94A001, 94A003, 94A004, 94A011 - 94A017, 94A022 - 94A026, 94A032, 94A034, 93P091 - 93P093, 93P082, 93P083, 94B020, 93O099, 93O100, 94B009, 94B010

Trim 20K Vector Representational Digital Map Sheet 2D, contours, planimetry, IGDS format (BC Crown Registry and Geographic Base)

BC Hydro Data

Potential inundation level (461.8 m maximum elevation) from Digital Elevation Model [DEM] generated from LiDAR data acquired July and August, 2006.

Legend

- Flow Direction
- Sample Sites

0 10 20 Km

N

DRAFT

SITE C CLEAN ENERGY PROJECT

mainstream

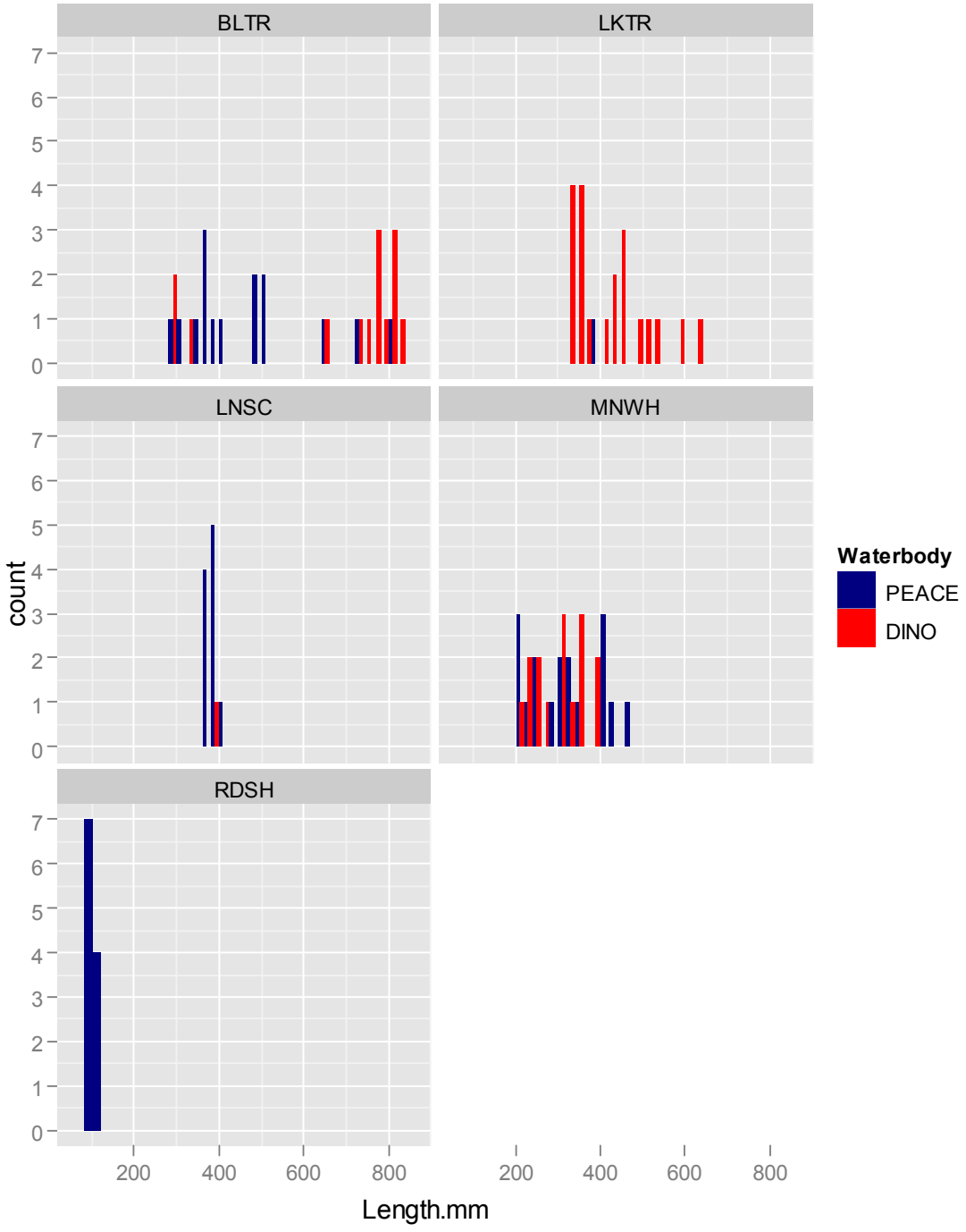
Figure 1.1

Peace River Site C Hydro Project
Stage 2 Preliminary Reference Information
2010 Fish Tissue Collections Study Area

January 2011

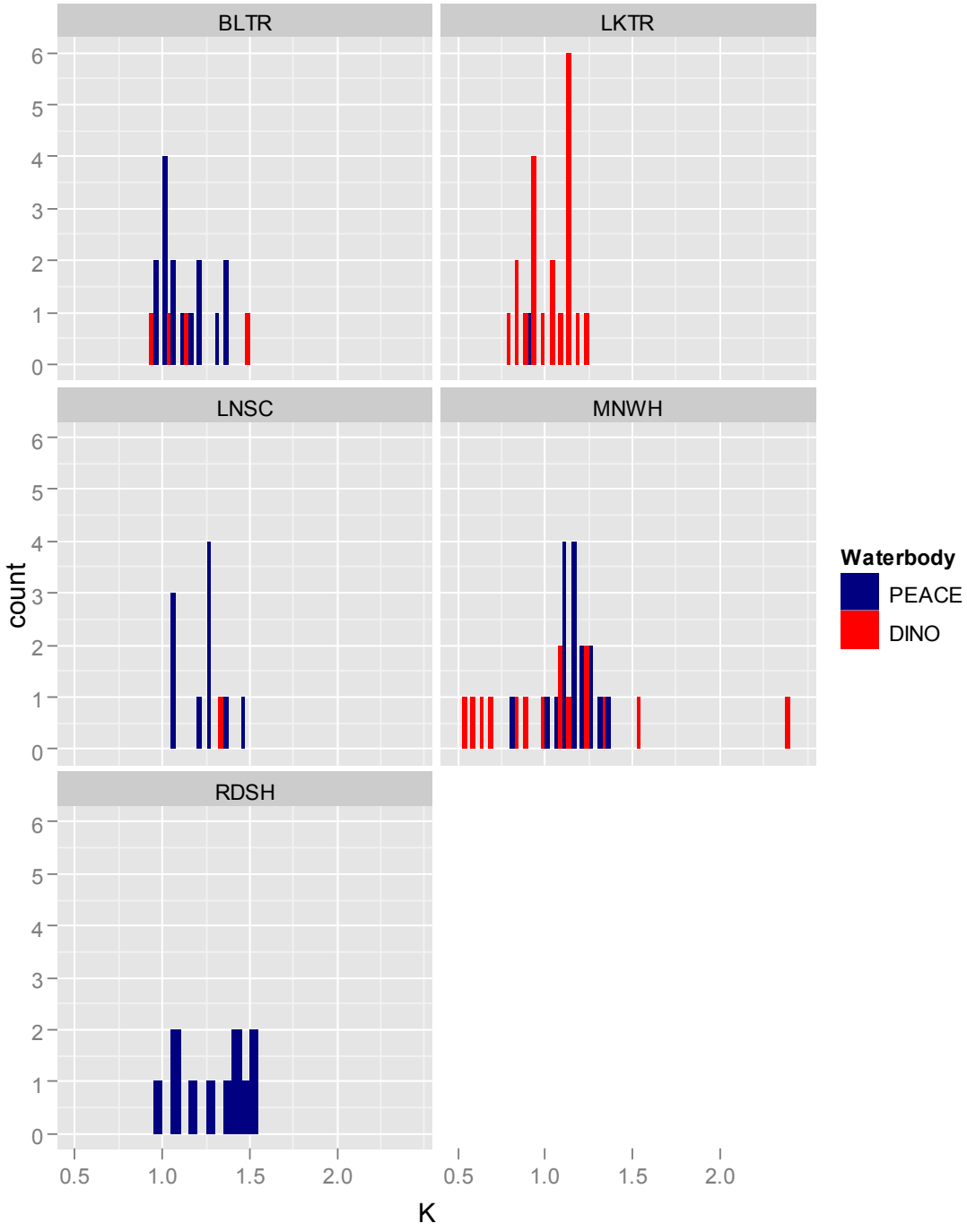
No decision has been made to build the Site C Hydro Project. This map is for information only, for preliminary analysis and planning in stage 2 of the Site C Project. Construction of the Site C Clean Energy Project is subject to required regulatory approvals including environmental certification.

Figure 6-2. Length-frequency histograms for all fish species, Dinosaur Reservoir and Peace River.



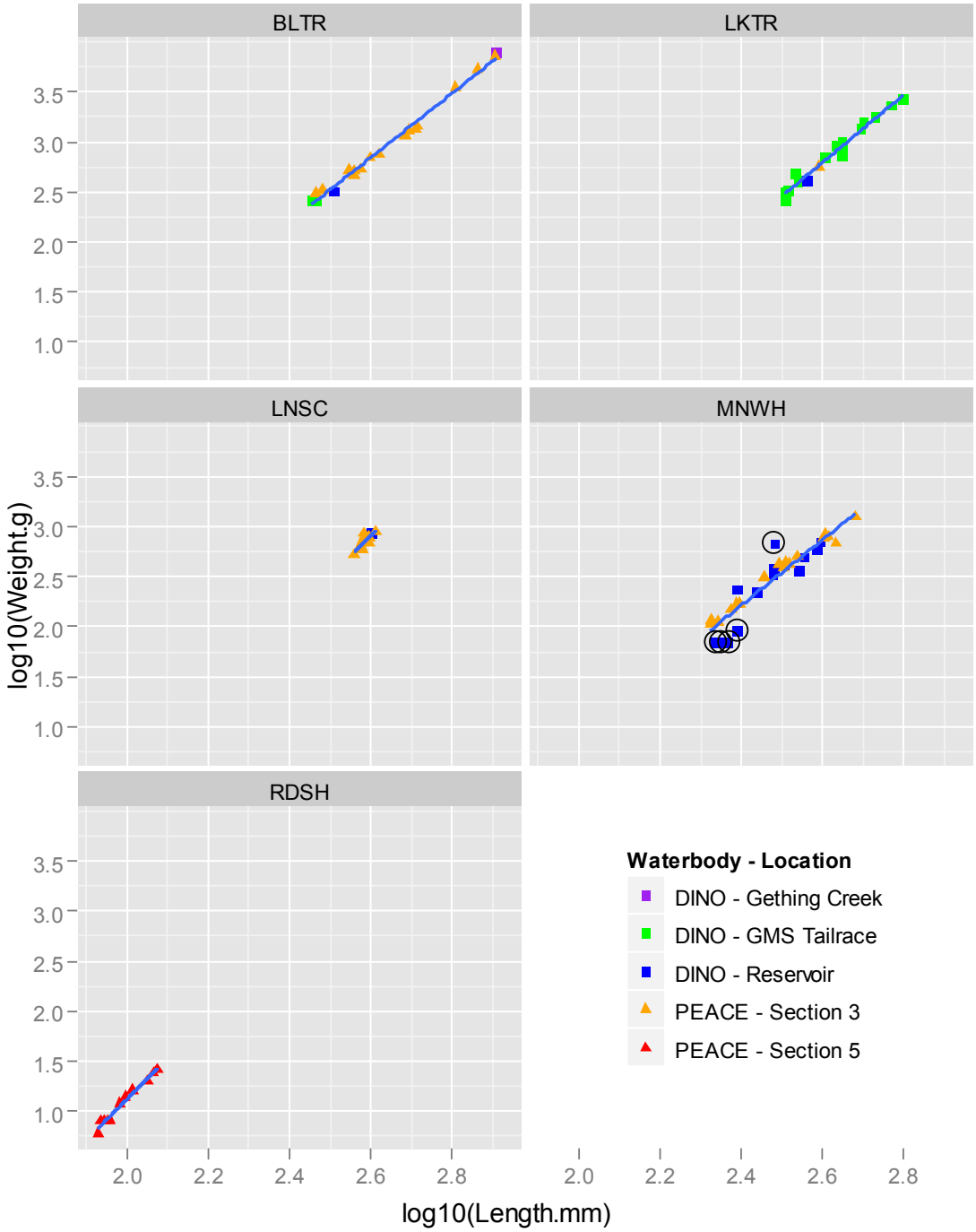
Note: length is fork length (mm).

Figure 6-3. Condition (K) frequency for all species, Dinosaur Reservoir and Peace River.



Note: Condition (K) is calculated as K = (Weight x 10^5)/(Length^3); unitless.

Figure 6-4. Length-weight relationships for all species, Dinosaur Reservoir and Peace River.



Note: Length is fork length (mm); weight in grams; flagged data circled.

Figure 6-5. Log_{10}(Length) – Log_{10}(Mercury) relationships for all species, Dinosaur Reservoir and Peace River.

Note: Length is fork length (mm); total mercury in mg/kg wet weight; flagged data circled.

Figure 6-6. Conceptual diagram of lake trout trophic position for three generalized lake classes (based on Rasmussen et al., 1990).

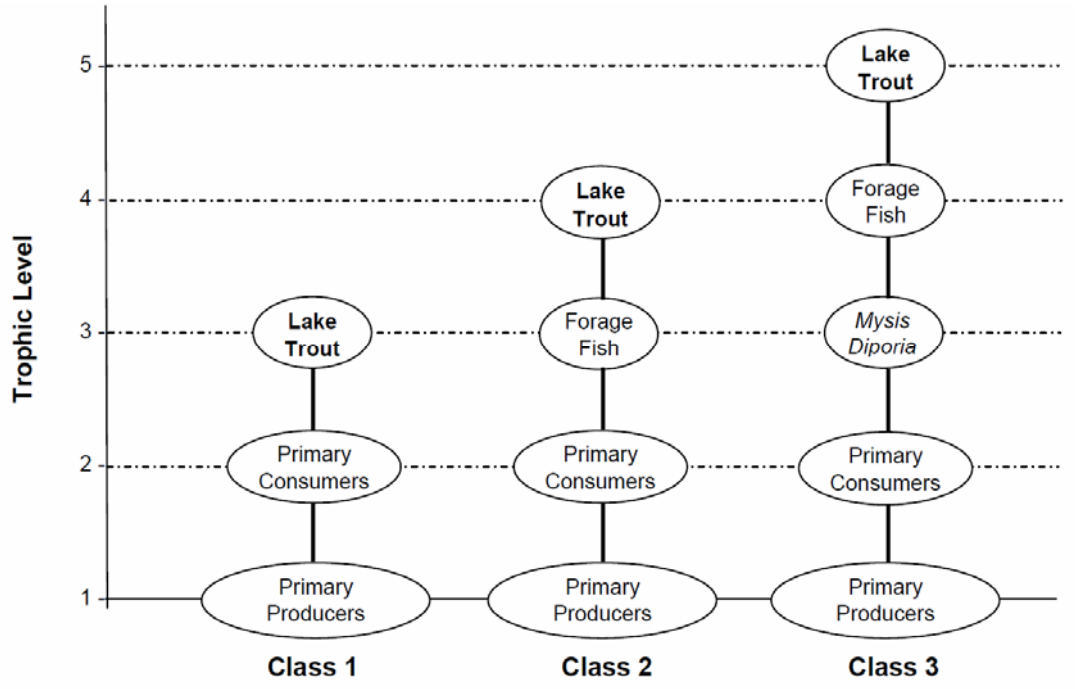


Figure 6-7. Mean (±SD) fish and primary consumer δ15N and δ13C value plots for the Peace River.

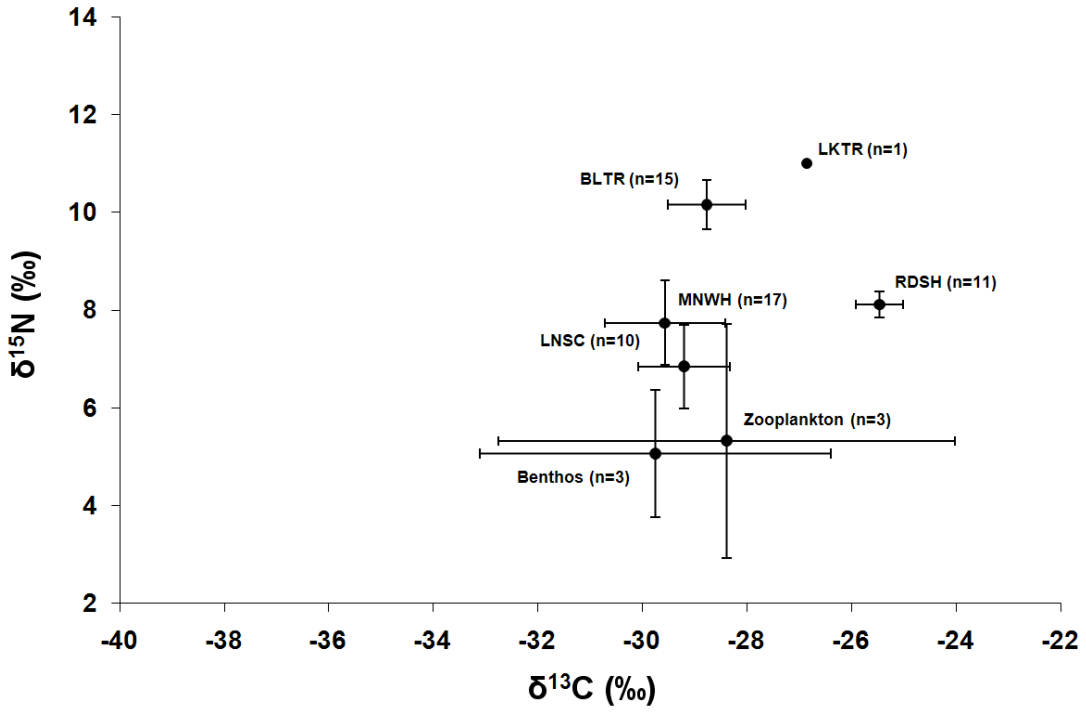


Figure 6-8. Mean (±SD) fish and primary consumer δ15N and δ13C value plots for Dinosaur Reservoir.

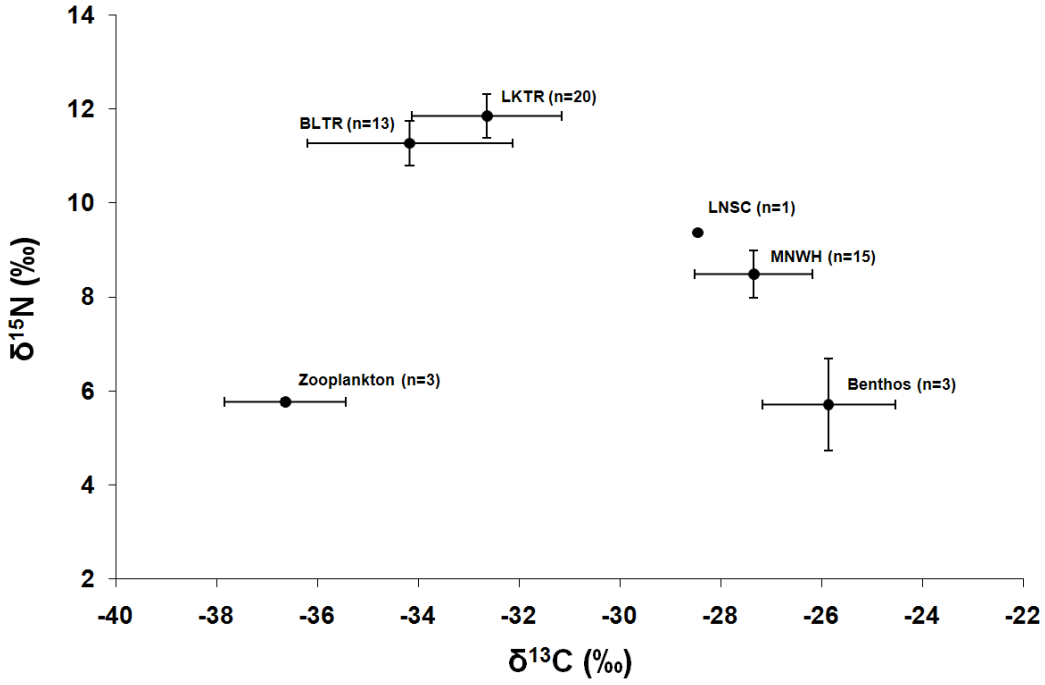
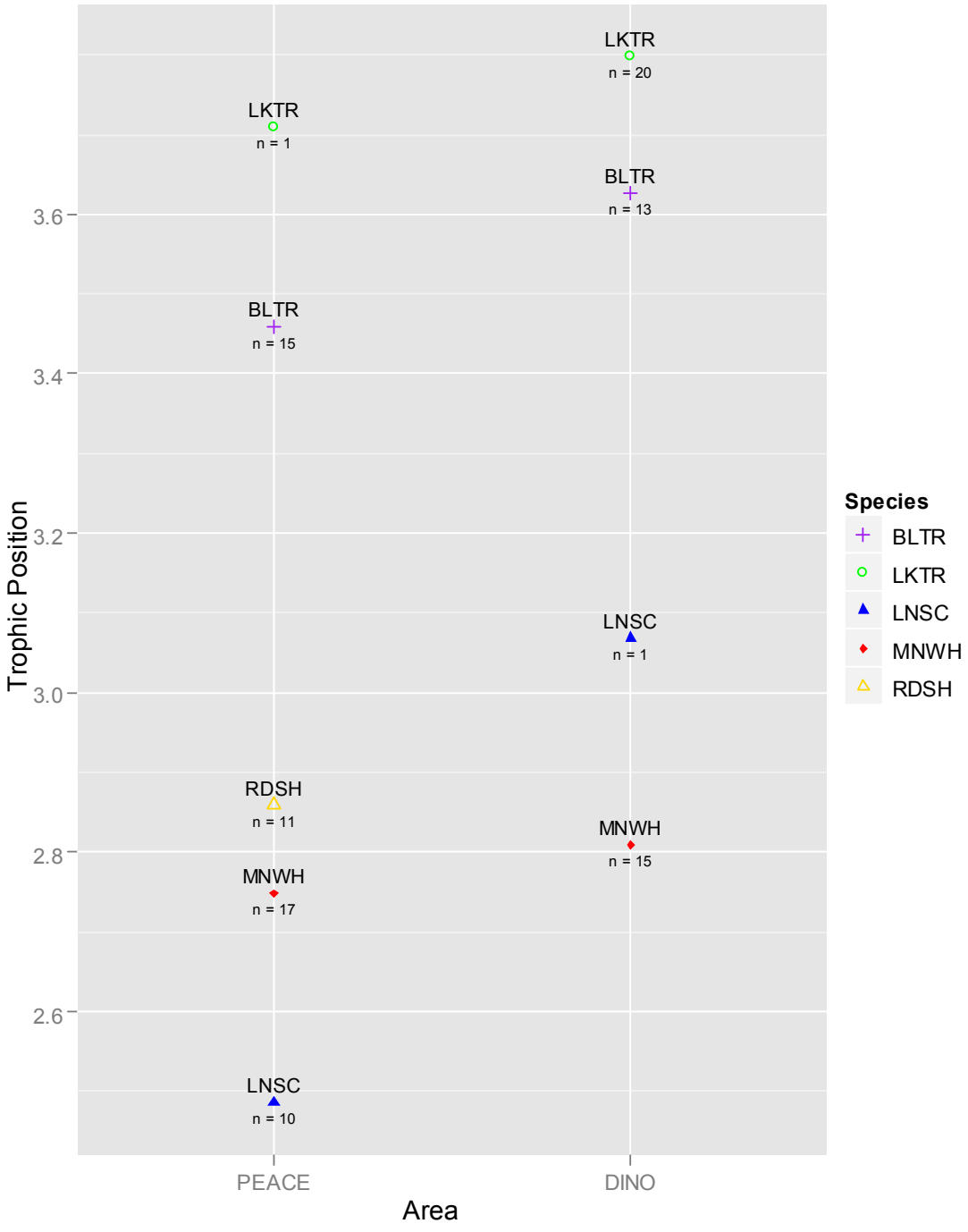
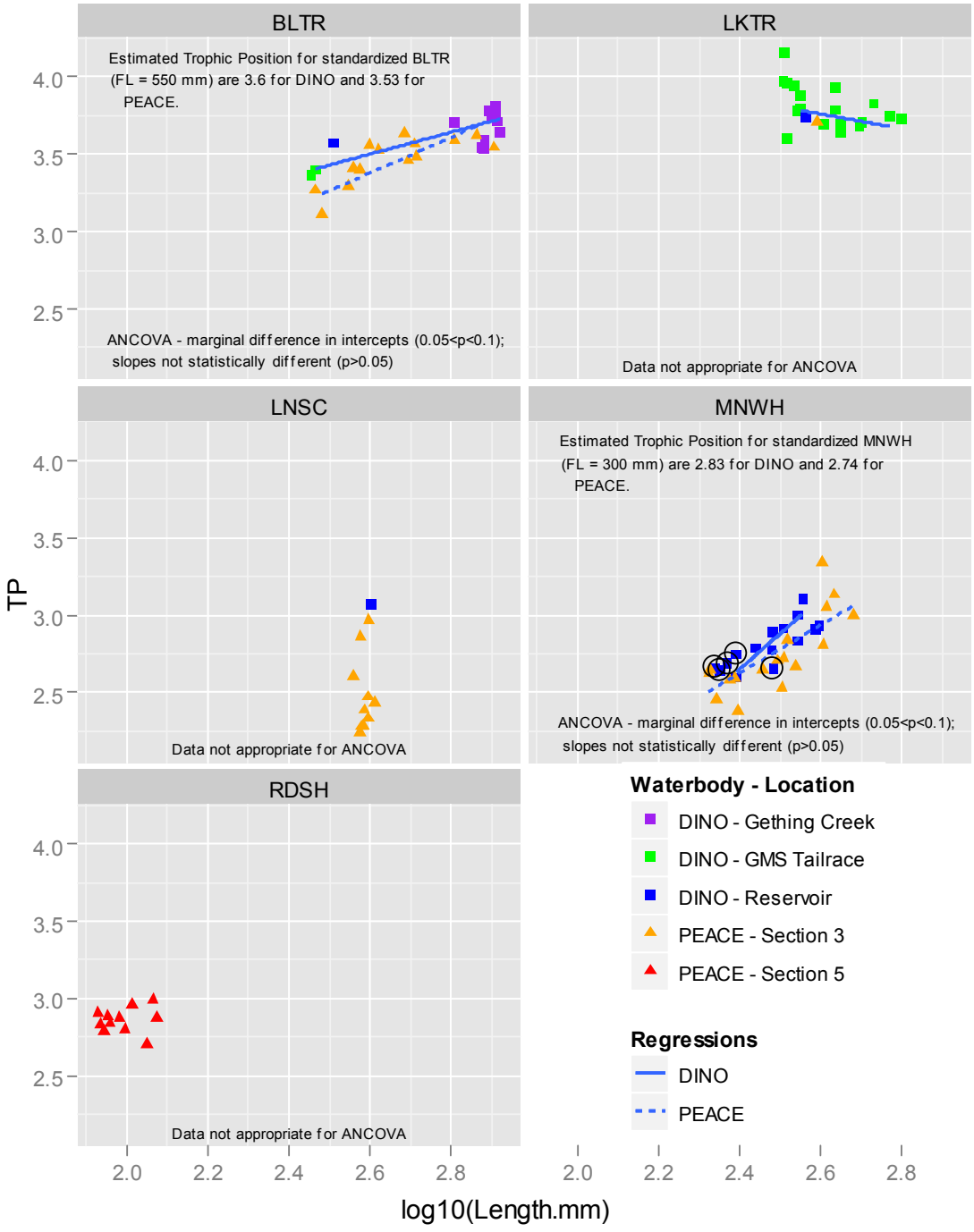


Figure 6-9. Mean trophic position estimate by species and water body.



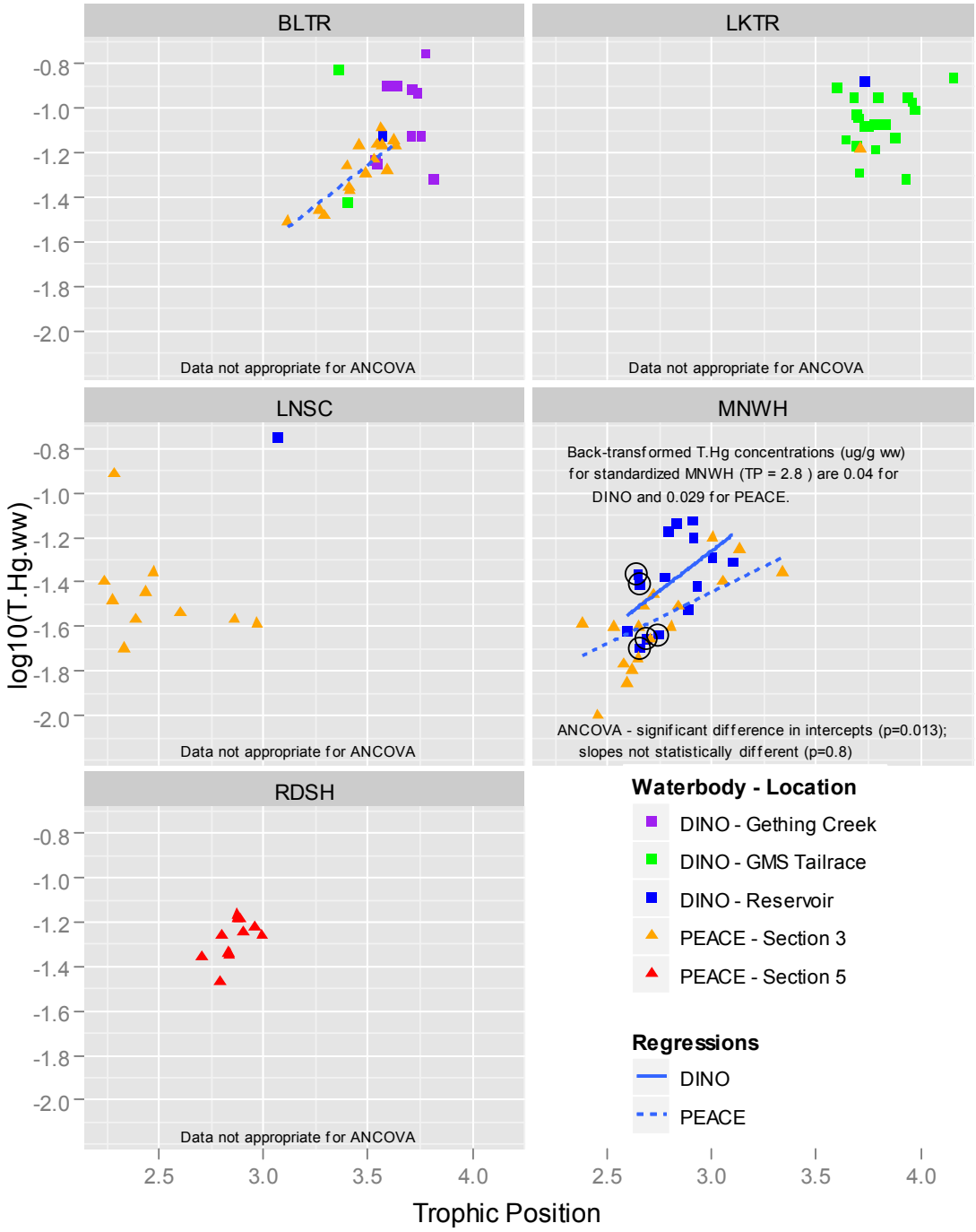
Note: Trophic Position (TP; unitless).

Figure 6-10. Log_{10}(Length) – trophic position (TP) relationships for each species by water body.



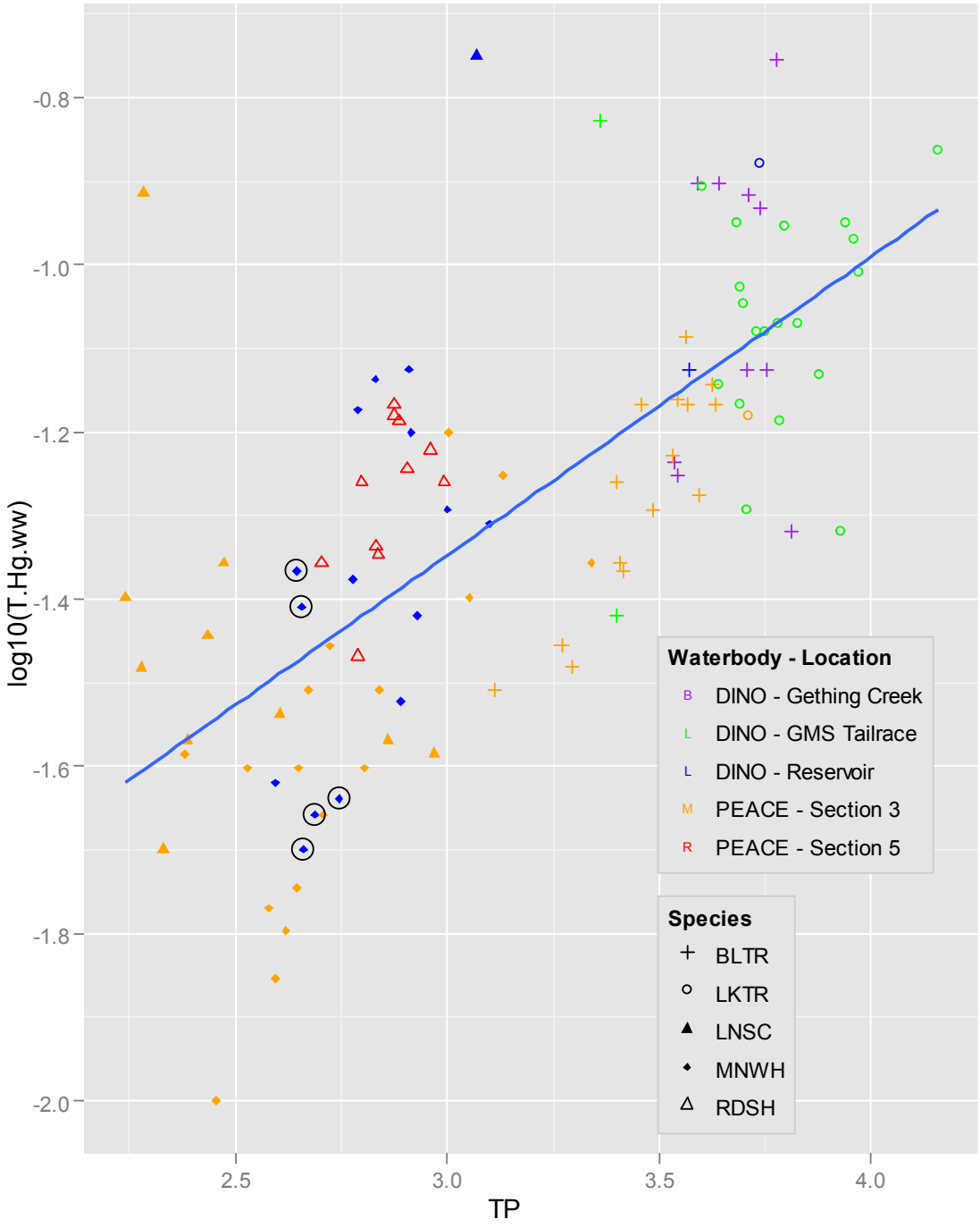
Note: Length is fork length (mm); trophic position (TP; unitless); flagged data circled.

Figure 6-11. Trophic position (TP) – $\log_{10}$(Mercury) relationships for each species by water body.



Note: Total mercury in mg/kg wet weight; Trophic Position (TP; unitless); flagged data circled.

Figure 6-12. Trophic position (TP) – $\log_{10}$(Mercury) relationships across species and water bodies.



Note: Total mercury in mg/kg wet weight; Trophic Position (TP; unitless); flagged data circled.

7. SOIL

The majority of 'new' mercury that is introduced and cycled within the aquatic food web following flooding and inundation is contained within organic soils, bound to carbon. The mass of carbon (and mercury) available to be broken down by bacteria and methylated is directly proportional to the quantity and quality of organic soils that are flooded. Soil types with the greatest quantity and highest quality of carbon (and Hg) are typically found in wetlands, bogs, fens and peatlands, and in rich organic soils within well developed forests. Shallow (<3 cm), sandy, highly inorganic soils that do not contain much carbon (or Hg) are typically poor contributors to the methyl mercury pool that is generated following reservoir creation. In addition, chemical conditions within the newly flooded soils also have a strong influence on the magnitude of mercury methylation, generally being favored in anoxic, slightly acidic soils with sulphate as a nutrient source.

The objective of the 2010 investigation of the terrestrial footprint of the proposed Site C development was to characterize the quantity and general quality of the soils (and vegetation) by measuring soil depth, organic carbon content, pH, and total mercury concentration. As mentioned, the distribution and behavior of mercury in soils are strong determinants and drivers of methylation potential of new reservoirs, both in terms of the magnitude and duration of elevated methyl mercury concentrations. The proposed Site C area is blanketed with a variety of floodplain and upland soils that will be impacted by permanent flooding. An earlier Terrestrial Ecosystem Mapping (TEM) project (Keystone, 2009) provided detailed maps of all habitats within the post-flood footprint. All habitat types that were targeted and characterized with respect to soil chemistry and mercury concentrations were based on the Keystone (2009) definitions.

7.1. Methods

7.1.1. Field Sampling Design

Soil sampling was conducted in a single field program during mid-July 2010 by R. Turner and R. Baker of Azimuth, Vancouver. Prior to going into the field, TEM information was used to generate a sampling design to characterize the physical composition and chemical makeup of soils within the flood footprint, targeting those habitat types with the greatest potential to contribute towards methylation and minimizing effort in habitat types with low methylation potential.

The sampling design consisted of randomly selecting locations within discrete habitat polygons, roughly apportioned according to spatial area (ha), both within habitat types and within discrete polygons. That is, the total number of stations was selected based on the cumulative area of each habitat type. These were further divided among discrete

polygons according to their size (ha). Small polygons had one station while larger polygons may have had up to five discrete soil sampling stations. To identify locations for soil sampling we used information from the TEM maps and associated spatial areas covered by each vegetation type (habitat). Characterization of all habitats was not conducted nor required because some habitat types (e.g., gravel bars GB), do not contain organic soils and will not affect post-flooding mercury cycling. On the other hand, habitats of particular interest in predicting post-flooding mercury cycling included the habitat units designated as: AM, BL, BT, CF, Fm02, SE, SH, SW and WH (**Textbox 1)** and were given special emphasis. Textual descriptions of the dominant habitat/vegetation types of these are provided below and are based on Keystone (2009). Collectively, these habitat units cover 3600 ha of the proposed flooded footprint. Of these two habitat types, Fm02 and SH occupy more than 60% of the footprint. Accordingly a proportionally higher sampling frequency was imposed on these habitats. Wetland habitats (BT, SE and WH) rank very high as contributing significantly to post-flooding mercury cycling and thus all accessible examples of these within the flooded footprint were included in the sampling program, regardless of spatial area. **Textbox 1** provides a list of specific habitat types that were targeted, the number of polygons of each type, and total areas (ha). The Azimuth field sampling crew had some flexibility in choosing exact locations within each targeted polygon. The guiding logic in selecting a specific polygon for inclusion in the soil sampling program was based on the following criteria:

- Some sampling in every map reach (11 maps; **Appendix A**) spanning the distance between PCD and Site C.
- Highest sample frequency in two largest habitat classes, Fm02 and SH that collectively comprise more than 60% of flooded habitat.
- Exclude habitats not contributing to mercury cycling including Cut banks (CB), Gravel bars (GB), River (RI), Roads (RZ) and those with <1% coverage excepting habitat types containing wetland, namely BL and BT.
- Exclude private property where permission to sample was not granted or acquired.
- Include all polygons representing wetlands BL, BT, SE and proportional number of polygons for SW and SH.
- Accessible by road or boat (this eliminated a few polygons located far up tributary valleys to be flooded).
- Favor Crown or BCH-owned/leased properties and avoid private property during this first sampling effort [*Note: this item eliminated sampling in the only polygon classified as BT*].

Table 7-1 provides information used to guide sampling including map number, polygon number, cover/habitat type, surface area (ha) and number of samples taken within each polygon. Note that where multiple samples were collected within a polygon, these were followed by the suffix '-A', '-B', etc. as necessary (e.g., P21-B). The coordinates for the actual locations sampled are summarized, along with soil chemistry results in **Table 7-3**, and are presented station by station with photos in **Appendix E**. Maps showing all soil sampling locations can be found in **Appendix A**.

Textbox 1: **Habitats of importance to mercury cycling**

Class	Area (ha)	% of Total	# of polygons	Cover descriptions
AM	208	5.8	16	Step moss-Peavine
BL	10.6	0.3	1	Labrador tea-Lingonberry
BT	19.7	0.5	2	Labrador tea-*Sphagnum*
CF	538	15.0	50	Cultivated field
Fm02	1096	30.5	166	Cottonwood-Spruce-Red osier Dogwood
SE	56.1	1.6	3	Sedge Wetland
SH	1068	29.7	109	Currant-Horsetail
SW	230	6.4	85	Wildrye-Peavine
WH	365	10.2	78	Willow-Horsetail-Sedge Riparian Wetland
Totals	**3591**	**100**	**510**	

Following are definitions of the dominant habitat types selected for soil sampling. These descriptions are paraphrased from the Keystone (2009) report entitled "*Expanded Legend for the Peace River TEM Project*".

AM: SwAt - Step moss: The AM unit typically occurs in submesic to mesic forest on gentle slopes with deep, moderately fine to coarse - textured soil. Nutrient regimes range from poor to rich, and the unit can occur on fluvial, glaciofluvial, morainal or lacustrine parent materials Parent materials were mainly fluvial and glaciolacustrine. The AM was very variable in terms of vegetation, containing a diverse assemblage of plant types.

BL: Labrador tea: Typically submesic to hygric forest on gently sloping sites or depressions with deep, fine to coarse- textured soils. Black spruce forest dominates on gently sloping sites with deep, fine to coarse-textured soils. The seral association normally occurs on morainal or fluvial parent materials with very poor to poor nutrient regimes.

SH: Currant – Horsetail: Typically subhygric to hygric forest on gentle slopes with deep, coarse to fine- textured soils. The SH normally has a medium to very rich nutrient regime and occurs on lacustrine or fluvial parent materials. In the study area, the SH was typically found on level sites with subhygric to hygric moisture regimes and medium to rich nutrient regimes, on imperfectly to moderately well-drained soils. The SH was found mainly on fluvial parent materials, and was mapped on the lower slopes of the Peace River valley and on the islands in the river. This polygon type represents mature climax forest with large-diameter white spruce and balsam poplar that is excellent habitat for wildlife.

BT: Labrador tea – *Sphagnum*: Typically a forested organic wetland with deep, peaty soil. The BT unit normally has a poor to very poor nutrient regime and occurs on organic or fluvial parent materials, often on cold sites underlain by permafrost. Habitat of this type is rare in the Peace River Valley but was common along the power line route on the plateau. It was generally found on poorly drained, level to depressional sites (0-12% slope) on organic surficial materials, with subhygric to subhygric moisture regimes and poor to medium nutrient regimes. [*Note: There was no access to the single polygon with this cover type and thus no samples were collected*]

Fm02: Cottonwood-Spruce-Red-osier dogwood: Typically a medium bench floodplain found on sandy or gravelly fluvial materials adjacent to streams and rivers. Characterized by an open canopy of *P. balsamifera* with a sparse to well-developed understorey, subject to short flood durations followed by continual subirrigation. This soil type is found on fluvial surficial materials with submesic to hygric moisture regimes and medium to rich nutrient regimes. Plots in this unit were mostly moderately well-drained to well-drained, and located adjacent to the Peace River or its tributaries. Large-diameter balsam poplar are present in its older structural stages.

SE: Sedge Wetland: Typically a sedge wetland (marsh or fen) with a deep to thin peat layer and has a medium to rich nutrient regime; hygric moisture regime. The SE wetland unit was mapped on level to depressional sites on organic surficial materials with subhygric to hygric moisture regimes. Nutrient regimes were generally medium to rich, and sites were poorly to very poorly drained.

SW: Wildrye – Peavine: Typically submesic to mesic forest on gentle slopes with deep, medium to coarse - textured soils. This soil type normally occurs on sites with a poor to medium nutrient regime, and can occur on a variety of parent materials (Delong, 1990). In the study area, this unit was usually found on level sites or on mid- to upper-slopes on cool aspects. This habitat was uncommon in the study area.

CF: Cultivated Field: A flat or gently rolling, non-forested open area with current or historic human agricultural practices. Cultivated fields are present extensively on both the north and south sides of the Peace River.

WH: Willow-Horsetail-Sedge: This non-forested polygon unit is described as a riparian wetland on coarse to fine-textured fluvial soils with subhygric to hygric moisture regime.

7.1.2. Field Methods

For each sampling location, field descriptions of each locale (dominant vegetation types; trees, shrubs, understory), soil profile (depth of A-horizon, observable features, color, consistency, nature of material) and sample photographs were recorded on field data sheets. All data sheets are provided in **Appendix E**. All soil samples were analyzed for metals, mercury and total organic carbon by ALS Laboratories. Of these, a subset was analyzed for methyl mercury. Soil samples targeted for methyl mercury analysis were frozen immediately on dry ice. Sample remaining after filling all containers were placed in a plastic bag for archive. Soil from a subset of stations was also delivered to Golder Edmonton for analysis of nutrient concentrations by Maxxam Analytical laboratories.

On arrival at a sampling location one or more photographs were taken of the surroundings, including the ground surface, to document the habitat. An additional photograph was also taken of the soil profile after excavation but before sampling. A card with the sample ID and a ruler for scale was included in these photographs (**Appendix E**). Full details of the sampling program can be found in the SAP (Azimuth, 2010b).

Locations within polygons were determined using the "position averaging (PA)" function using a handheld Garmin GPS 76Cx unit. Accuracy of these coordinates depends on several factors including canopy cover but is typically on the order of 5 meters or less when PA is used. A plot of ground that was deemed to be representative of the dominant habitat type within the polygon was selected for soil sampling by visually surveying the general area. In preparation for sampling living vegetation, coarse litter debris and rocks were removed from the sampling location. A tile spade was then used to cut vertically a block the width and length of the spade. Depth of the block was at least 20 cm in humic soils. The block was carefully lifted from the ground. Two additional blocks were collected within a 5 meter radius of the first block and arranged beside the first block, for photography and depth measurement of the organic horizon where present. The range of organic layer thicknesses was recorded along with a brief description of each soil section (**Appendix E**). Where the organic layer thickness was at least 1 cm all or equal portions of this layer were carefully transferred into a stainless steel mixing bowl for homogenization and sub-sampling. Where the organic horizon was <1 cm in thickness (e.g., CF habitats) equal portions of the uppermost 5 cm of soil were transferred to the mixing bowl for homogenization and sub-sampling. Mineral (or inorganic) soil

immediately beneath the organic horizon was collected using a similar compositing procedure at a few stations after removal of the organic horizon. Excess sample material remaining after filling of all jars for target constituents was transferred to Ziploc bags for archival storage. Sample jars containing aliquots for methyl mercury were placed in a cooler with dry ice for immediate freezing in the field. These were transferred frozen to a freezer and kept frozen. All other sample jars were placed in coolers with blue ice. Detailed soil sampling procedures can be found in the SAP (Azimuth, 2010b).

7.1.3. Parameters Collected

The following parameters were measured for all samples and analyzed by the laboratory listed for each bullet:

- Total metals, including inorganic mercury, total organic carbon (TOC) and pH (**ALS, Vancouver**) from the organic A-horizon of all stations sampled. The inorganic B-horizon was sampled for a subset of soils.
- Grain size from a subset of B-horizon soils (**ALS, Vancouver**)
- Methyl mercury from a subset of soils (**ALS**; **Brooks Rand, Seattle**)

7.1.4. QA/QC

Field QA/QC procedures for soil focused on limiting cross contamination and generation of appropriate QC samples. QA included frequent glove changes, rinsing of spoons/bowls and confirmation of decontamination effectiveness to control of cross-contamination via preparation of equipment blanks.

Field duplicate soil samples were collected at an approximate rate of 1 to 20 (5 total). Four samples (P-8, P-21B, P38-B, P42) were independent samples collected from the immediate vicinity of the original sample and were used to test consistency in sampling methodology and spatial heterogeneity within discrete areas. A fifth sample (P-50) was a homogenization duplicate, that is, a second sample was split from the mixing bowl containing the original sample. All duplicate samples were submitted blind to the laboratory, for example as “P DUP-2”.

In addition, the laboratory independently performs ‘matrix duplicates’. These are subsamples taken from the original jar that are analyzed and compared against the original data. If effect these are also homogenization duplicates and are designed to test the homogeneity of the sample and to test laboratory recovery rates for each metal. RPD values were calculated for field duplicates with a DQO of <± 50 and homogenization or laboratory matrix samples with a DQO of <± 25.

7.2. Results

7.2.1. QA/QC

Results of the QA/QC analyses are presented in **Table 7-2**. There were no laboratory QA issues for organic carbon, total mercury or other metals. RPD values for all four field duplicate samples for all metals were well within the DQO of <± 50. RPD values of the homogenization and laboratory matrix standard duplicates were also low and all well within the DQO of <± 25. These data suggest that field practices were consistent and there was fairly good uniformity in soil chemistry for those stations where field duplicate soil samples were collected.

One of two laboratory duplicates (P47-A) for methyl mercury had a 41 % RPD, and thus exceeded the acceptable limit of ± 25%. Recoveries (71 and 82%) of methyl mercury from the certified reference material [CRM IAEA-405 (estuarine sediment)] were low but within the recommended limit (70 to 130%). This is likely a reflection of natural variability of sampling very low concentrations (~0.3 µg/kg) that is less than 10x the laboratory DL of 0.05 µg/kg for methyl mercury in soils.

The only potential QA issue that we identified was for methyl mercury samples. The field crew collected and immediately placed soil samples for methyl mercury analysis on dry ice in the field and these were kept frozen prior to delivery to the laboratory. The chain-of-custody (COC) form indicated that two coolers containing soils for methyl mercury analysis were received at the ALS depot in Fort St John on July 17, upon which time the samples were transferred to the ALS freezer. From there, ALS shipped the frozen samples, on blue ice to the Vancouver laboratory. However, the COC indicated that the air temperature inside the cooler temperature on receipt on July 17 at the ALS receiving facility in Fort St John was 4^{o}C indicating that this sample and the other twelve samples in the same cooler were not frozen (although they certainly were). The second cooler containing only three samples (P56, P99 and PDUP-5) was recorded as received at 20^{o}C, also impossible. This was not noticed until we received the final laboratory results with the attached COC. Given that the field crew had maintained samples on dry ice in the field on a daily basis and were stored frozen overnight, we suspect that the recorded cooler temperature readings may be in error. Nevertheless, for transparency purposes, the issues are noted here.

Due to an initial misunderstanding, total organic carbon (TOC) and % Loss-on-Ignition (LOI) was measured on only 63 of the 89 samples submitted. However total carbon (TC) by combustion was measured in all samples. Therefore, these results were used to estimate total TOC in the samples not analyzed for this form of carbon. The relationship (regression) between TC and total TOC in samples with at least 5% was slightly different

from that where TOC was less than 5%. Accordingly we used the following regression equations to generate TOC values for 26 samples with missing TOC values:

TOC > 5% TOC = (1.0059 x TC) – 0.4246 r^2=0.999

TOC < 5% TOC = (1.0046 x TC) – 0.9051 r^2=0.983

7.2.2. Chemistry

This section presents and discusses results for organic matter, total mercury and methyl mercury concentrations in 89 soil samples collected in July 2010. Complete results, including for particle size distribution and total metals concentrations including mercury, are presented in **Table 7-3**. Results for metals other than mercury are not discussed here because this document's focus in on mercury; the data may be useful to others.

To facilitate interpretation and comparison between habitat types, **Table 7-4** provides a summary of these results broken down by vegetation cover type and soil horizon sampled. A total of 89 organic horizons were analyzed for total mercury, with 14 of these also analyzed for methyl mercury. As planned, sampling and analysis of organic horizons focused on the locations covered by the two most abundant vegetation assemblages by area, Fm02 (28%) and SH (38%), with fewer samples collected and analyzed from sub-dominant covers: WH (13%), AM (5.9%), SW (4.8%), SE (3.5%), BT (3.5%), and CF (4.7%). Thus, results are reasonably representative of the distribution of cover types within the Site C project area with an emphasis on those that are most important to assess for mercury cycling implications (**Table 7-1**). Only four inorganic (mineral) horizons, two under Fm02 and one each under SH and AM, were collected and analyzed.

7.2.2.1. Organic Matter (Carbon)

Figure 7-1 summarizes the organic carbon content of all organic horizon samples from each of the cover types. The grand average organic carbon content of all organic horizons was 27.2% (272,000 mg/kg). In a few cases (e.g., CF) where the actual organic horizon was < 1 cm in thickness, the inclusion of underlying mineral soil to variable depths reduced the organic carbon content of these samples. As explained in the Methods section, the uppermost 3 to 5 cm of soil are the most important in generating and releasing methyl mercury to overlying water after flooding and thus the decision to maintain a minimum sampling thickness of 5 cm whenever the organic layer thickness was <1 cm.. [*The RESMERC model considers two depth ranges in flooded soil, 0 to 1 cm and 2 to 4 cm, as the "sediment" layers in which methyl mercury is generated and released to overlying water.*] Where "dilution" of organic horizon samples by mineral layers was not present (i.e., where samples were composed of only litter-fermentation-humus (LFH) layers), organic carbon contents were typically 30 to 45%. All of the

samples (N=14) selected for analysis of methyl mercury were composed entirely of LFH layers and thus their organic carbon contents averaged 35.4% and showed relatively low variability (range 30.9 to 42.5%). Although the results for inorganic horizons are limited because of small sample size (N=4) organic carbon content of these horizons (**Table 7-4**) was consistently low (<5.0%) as was expected, given the sandy, inorganic nature of the underlying soil.

7.2.2.2. Total Mercury

Figure 7-2 summarizes the total mercury content of all organic horizon samples from each of the cover types. The average total mercury content of all samples of organic horizons, including those with some included mineral soil, was 0.079 mg/kg over a relatively narrow range of 0.022 – 0.139 mg/kg (std = 0.029). Where the samples of the organic horizon were composed of only organic matter total mercury was slightly higher. For example, all 14 samples analyzed for methyl mercury were composed of "undiluted" organic matter (% organic carbon = 30% to 42%) and averaged 0.10 mg/kg total mercury. The total mercury values are similar to results (<0.05 to 0.13 mg/kg) reported for "background soils" near Ft St John, BC (Soilcon, 1996; BCMOE, 2005). For the two cover types (Fm02, SH) accounting for more that 60% of the Site C project area, total mercury concentrations varied greatly within each cover type and it was not possible to demonstrate a significant difference between these cover types (t-test, $p<0.05$).

Mercury in soils is commonly strongly associated with organic matter and thus it is appropriate to determine if the large variability in total mercury concentrations is related to the large variability in % organic carbon content of these soils. Shown in **Figure 7-3** the % organic carbon content of Site C soils does appear to explain a good portion (~48%) of the variability in total mercury in these soils. Because of the strong association of mercury with organic carbon in soils, mercury concentrations are often normalized to organic carbon (i.e., mg Hg/ kg carbon) content. Converting mercury results to this basis showed that where organic carbon concentrations were >10%, carbon-normalized mercury concentration varied less (0.13 to 0.41 mg Hg/kg C) than un-normalized mercury concentrations (0.04 to 0.14 mg/kg) (**Figure 7-4**). Soils containing <10% carbon may actually have a substantial fraction of their mercury content associated with inorganic (mineral) phases and thus normalizing to carbon would overestimate the mercury content of the organic carbon in such soils. In fact, carbon-normalized mercury concentrations in samples with <10% organic carbon ranged from 0.90 to 3.7 mg/kg. It is very unlikely that organic carbon in such soils is this elevated in mercury.

7.2.2.3. Methyl Mercury

Methyl mercury concentrations in soils (**Table 7-5**) ranged over two orders of magnitude (0.071 to 7.1 µg/kg; i.e., units are 1000x times lower than for total mercury). This wide range, and a similarly wide range in % methyl mercury, is largely due to results for the AM and SE cover types that are more than an order of magnitude higher than any other result. The main reason for this is because sample (P31) was collected from Watson Slough, classified as a sedge wetland (SE). This habitat is expected to exhibit high methyl mercury and % methyl mercury (relative to total). Sample (P41) was collected in an upland step moss-peavine habitat (AM) and the unexpectedly high values of methyl mercury and % methyl remain unexplained. The latter sample was also unusual in that it contained charcoal and other indications of a fire history. So, aside from these two samples, methyl mercury concentrations were quite narrowly constrained between 0.071 and 0.29 µg/kg, with % methyl mercury values also ranging narrowly between 6% and 32%. These methyl mercury concentration for the sedge wetland (SE) and those for the Fm02, SH and WH cover types are typical of wetlands and upland soils, respectively, in boreal regions (Moore et al., 1995; Grigal, 2003).

7.2.2.4. Preliminary Estimate of Carbon and Mercury Pool Sizes

This section presents trial calculations of carbon and mercury pool sizes (i.e., mass/m^2) using the available data that will be refined later for input to the mercury cycling model after incorporating additional information from BC Hydro on organic soil thickness. Ultimately this information will be combined with the surface area of individual polygons within the flooded footprint to estimate the total standing stock of carbon flooded (kg).

The spatial distribution and thickness of the organic soils within the flooded footprint of Site C will have a significant impact on the methylation potential of the flooded soils. Methylation is driven largely by the availability of organic materials as a food source for sulphate-reducing bacteria and the mass of mercury contained within the carbon pool. Data for thickness of the organic soil horizon (**Figure 7-5**) and bulk density can be converted to estimates of the pool size (kg C/m^2) of organic carbon stored in the forest floor (the organic LFH horizon) under each cover type. For example, using a bulk LFH density of 100 kg/m^3 (e.g., Chojnacky et al., 2009) and 5 cm thickness of the organic horizon yields a carbon pool size of 5 kg C/m^2. Multiplying this carbon pool size by the total mercury concentration (e.g., 0.1 mg/kg) yields an estimate of the mercury pool size of 0.05 mg/m^2. Other published estimates of pool sizes suggest higher values of about 1 mg/m^2 for total mercury in forest floor (LFH horizon) samples from a comparable habitat (e.g., Norway spruce forest in Germany, Grigal, 2003). More refined estimates of the pool sizes of organic carbon and total mercury will be prepared prior to parameterization

of the reservoir model using site specific LFH thickness data from another BC Hydro study of Site C soils. Bulk densities will be refined with actual measurements. As well, it may be useful to assess “labile” carbon (McLaughlan and Hobie, 2004) concentration in the archived samples. The decision to proceed with assessment of labile carbon will be made after consultation with the modeler.

Table 7-1. Map number, polygon and location (UTM, 10V) of soil sampling stations, BC Hydro 2010.

Map #	Polygon	Northing	Easting	Cover Type	Area (ha)	Samples / Polygon	Sample Site Identifier
1	94A001_165	6207938	566712	WH	6.88	1	P1
1	94A001_167	6208356	567243	SH	23.20	1	P2
1	94A001_197	6208609	567258	Fm02	5.13	1	P3
2	94A001_336	6211601	569752	WH	3.98	1	P4
2	94A001_350	6212142	570808	WH	7.30	1	P5
2	94A001_365	6212674	571478	SH	11.50	1	P6
3	94A012_816	6219189	577284	Fm02	15.50	1	P8
3	94A012_895	6219601	578487	Fm02	14.00	1	P9
3	94A012_925	6219485	578807	SH	28.10	2	P11
3	94A012_972	6219647	577014	CF	14.00	1	P7
4	94A012_1159	6220278	581792	CF	29.60	2	P12
4	94A012_1266	6220739	578766	AM	12.50	1	P10
4	94A012_1275	6220846	583177	SH	34.60	2	P13
4	94A012_2226	6223662	586276	SW	13.70	1	P14
4	94A012_2488	6224039	586868	SH	13.40	1	P15
5	94A013_2783	6226404	590300	SH	95.30	5	P17
5	94A013_2862	6226352	589011	SW	10.00	1	P16
5	94A013_3077	6228232	592177	SW	11.90	1	P18
5	94A023_3286	6229508	594602	SW	17.40	1	P19
6	94A023_15018	6233138	593341	Fm02	27.00	2	HW5
6	94A023_15057	6234261	590966	WH	41.90	2	HW6
6	94A023_3365	6230080	595539	SH	29.10	2	P57
6	94A023_3468	6230663	595423	SH	29.90	2	P20
6	94A023_3610	6231250	597327	SH	35.40	2	P21
6	94A023_3652	6231331	595242	Fm02	17.70	1	HW4
6	94A023_3680	6231874	597672	CF	52.10	2	P22
6	94A023_3735	6231911	595368	SH	85.40	4	HW3
6	94A023_3750	6231730	596389	Fm02	12.90	1	HW1
6	94A023_3759	6231783	595832	AM	3.57	1	HW2
7	94A024_4032	6233232	603548	Fm02	14.30	1	P26
7	94A024_4039	6233237	600885	SH	11.10	1	P24
7	94A024_4071	6233492	601094	Fm02	62.90	3	P25
7	94A024_4156	6233808	604545	CF	11.30	1	P27
7	94A024_4450	6234809	605579	SE	18.10	1	P28
7	94A024_4499	6235004	605600	BT	7.40	1	P29
7	94A024_4533	6235309	606163	BT	12.30	1	P30
7	94A024_4570	6235649	606575	SE	17.40	1	P31
7	94A024_4575	6235831	607203	AM	16.80	1	P32
7	94A024_4588	6236005	607199	SE	20.60	1	P33
7	94A024_4625	6236101	607224	BL	10.60	1	P34
7	94A024_4742	6237487	609868	CF	75.60	1	P40
7	94A024_9025	6232766	599486	WH	25.80	1	P23
8	94A024_4522	6236078	608182	WH	65.60	3	P35
8	94A024_4658	6236832	608468	Fm02	45.20	2	P38
8	94A024_4675	6236242	608504	WH	3.23	1	P37
8	94A024_4682	6236529	609058	WH	11.90	1	P39
8	94A024_4702	6237027	608099	CF	23.70	1	P36
8	94A024_4740	6237475	611378	AM	20.00	1	P41
8	94A025_4609	6236065	613392	Fm02	26.20	2	P43
8	94A025_4668	6236506	612052	SW	14.90	1	P42
9	94A025_3782	6232218	618061	Fm02	69.50	4	P49
9	94A025_3854	6232501	621630	Fm02	31.00	1	P56
9	94A025_3870	6232900	616210	SH	45.50	2	P47
9	94A025_3875	6232439	620553	Fm02	18.70	1	P50
9	94A025_3931	6232814	622724	SH	25.90	1	P55
9	94A025_3998	6233212	616655	Fm02	17.10	1	P48
9	94A025_4015	6233727	614732	SW	11.30	1	P45
9	94A025_4099	6233752	615186	SH	53.80	3	P46
9	94A025_4532	6235510	613852	Fm02	14.90	1	P44
10	94A015_20056	6227513	623521	Fm02	15.70	1	M6
10	94A015_20139	6228067	621683	SH	15.70	1	M7
10	94A016_20072	6227640	625361	Fm02	12.30	1	M5
10	94A016_20157	6228272	626176	SH	9.08	1	M4
10	94A016_3321	6229618	627550	Fm02	12.60	1	M3
10	94A016_3347	6229825	628069	SH	10.00	1	M2
11	94A016_3428	6230275	628509	Fm02	12.80	1	M1
11	94A026_3578	6232268	626788	AM2	87.30	4	P52
11	94A026_3913	6232540	626849	SW	3.25	1	P53
11	94A026_4024	6233233	624276	Fm02	13.90	1	P54
11	94A026_4906	6231159	628702	SW	19.10	1	P51

Notes:

UTM coordinates refer to center of polygons.

Table 7-2. QA/QC data for soil parameters, BC Hydro 2010.

Analytes		Peace River Field Duplicate			Peace River Field Duplicate			Peace River Homogenization Dup			Peace River Field Duplicate		
		P38-B	P DUP-1	RPD	P8	P DUP-2	RPD	P50	P DUP-3	RPD	P21-B	P DUP-4	RPD
	MDLs	10-Jul-10	10-Jul-10	(%)	11-Jul-10	11-Jul-10	(%)	13-Jul-10	13-Jul-10	(%)	14-Jul-10	14-Jul-10	(%)
CONVENTIONAL PARAMETERS													
Loss on Ignition @ 550°C	1	-	-	-	-	-	-	48	69	-36	75	64	16
pH	0.10	6.75	6.82	-1.03	5.92	5.82	1.7	7.13	7.08	0.7	5.79	6.26	-7.8
Total Carbon by Combustion (%)	0.1	30.5	32.9	-7.57	35.4	32.2	9.5	32.7	33.9	-3.6	32.7	31.0	5.3
Total Organic Carbon (%)	0.1	-	-	-	-	-	-	32.4	33.6	-3.6	32.6	30.7	6.0
Particle Size													
% Gravel (>2mm)	1.0	-	-	-	-	-	-	-	-	-	-	-	-
% Sand (2.00mm - 0.063mm)	1.0	-	-	-	-	-	-	-	-	-	-	-	-
% Silt (0.063mm - 4µm)	1.0	-	-	-	-	-	-	-	-	-	-	-	-
% Clay (<4µm)	1.0	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL METALS (mg/kg dw)													
Antimony	10	<10	<10	NA	<10	<10	NA	<10	<10	NA	<10	<10	NA
Arsenic	5.0	<5.0	<5.0	NA	<5.0	<5.0	NA	<5.0	<5.0	NA	<5.0	<5.0	NA
Barium	1.0	236	241	-2.1	216	184	16.0	178	159	11.3	247	273	-10.0
Beryllium	0.50	<0.50	<0.50	NA	<0.50	<0.50	NA	<0.50	<0.50	NA	<0.50	<0.50	NA
Cadmium	0.50	2.62	2.84	-8.1	0.55	0.67	-19.7	4.17	3.92	6.2	1.53	2.14	-33.2
Chromium	2.0	7.9	7.5	5.2	5.8	6.5	-11.4	4.3	3.7	15.0	4.8	6.2	-25.5
Cobalt	2.0	3.6	3.4	5.7	2.2	2.6	-16.7	2.6	2.4	8.0	<2.0	2.6	NA
Copper	1.0	16.6	16.1	3.1	7.5	8.7	-14.8	19.4	18.5	4.7	12.3	14.8	-18.5
Lead	30	<30	<30	NA	<30	<30	NA	<30	<30	NA	<30	<30	NA
Mercury	0.0050	0.0893	0.0887	0.7	0.125	0.104	18.3	0.0621	0.0565	9.4	0.125	0.116	7.5
Molybdenum	4.0	<4.0	<4.0	NA	<4.0	<4.0	NA	<4.0	<4.0	NA	<4.0	<4.0	NA
Nickel	5.0	13.2	11.2	16.4	6.1	7.3	-17.9	9.7	8.5	13.2	7.20	10.5	-37.3
Selenium	2.0	1.12	<2.5	NA	<2.0	<2.0	NA	1.81	<2.4	NA	<2.0	<2.4	NA
Silver	2.0	<2.0	<2.0	NA	<2.0	<2.0	NA	<2.0	<2.0	NA	<2.0	<2.0	NA
Thallium	1.0	<1.0	<1.0	NA	<1.0	<1.0	NA	<1.0	<1.0	NA	<1.0	<1.0	NA
Tin	5.0	<5.0	<5.0	NA	<5.0	<5.0	NA	<5.0	<5.0	NA	<5.0	<5.0	NA
Uranium	0.050	0.483	0.417	14.7	0.242	0.282	-15.3	0.337	0.304	10.3	0.239	0.383	-46.3
Vanadium	2.0	17.8	14.1	23.2	9.70	12.0	-21.2	8.2	6.8	18.7	8.50	13.4	-44.7
Zinc	1.0	218	230	-5.4	209	165	23.5	340	325	4.5	145	211	-37.1
SPECIATED METALS (ug/kg)													
Methyl Mercury	0.050	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

RPD = Relative Percent Difference (%) = ((original - duplicate) / (original + duplicate)/2) x 100.

Shaded RPDs exceed 25% (lab duplicates) or 50% (field duplicates).

Bolded RPDs exceed 50% (field duplicates) or 25% (laboratory duplicates), but < 10 x MDL.

NA = RPDs have not been calculated for cases where one of the samples is below detection and the other is not, and in cases where both are below detection.

Samples were analyzed for MeHg by Brooks Rand, Seattle, WA; and for everything else by ALS Laboratories, Burnaby, BC.

Table 7-2. QA/QC data for soil parameters, BC Hydro 2010.

Analytes		Peace River Field Duplicate			Peace River Stations			Peace River Stations			Halfway River Stations			Peace River Stations		
		P42	PDUP-5	RPD	Original	Laboratory Duplicate	RPD	Original	Laboratory Duplicate	RPD	Original	Laboratory Duplicate	RPD	Original	Laboratory Duplicate	RPD
	MDLs	16-Jul-10	16-Jul-10	(%)	11-Jul-10		(%)	13-Jul-10		(%)	14-Jul-10		(%)	16-Jul-10		(%)
CONVENTIONAL PARAMETERS																
Loss on Ignition @ 550°C	1	67	8.0	157	-	-	-	86	85	1.2	-	-	-	85	82	3.6
pH	0.10	6.11	5.48	10.9	-	-	-	-	-	-	7.67	7.69	-0.26	6.11	6.11	0
Total Carbon by Combustion (%)	0.1	37.6	36.7	2.4	36.9	36.5	1.09	40.7	40.8	-0.2	4.3	4.5	-4.5	34.7	35.1	-1.1
Total Organic Carbon (%)	0.1	37.4	36.7	1.9	-	-	-	-	-	-	-	-	-	-	-	-
Particle Size																
% Gravel (>2mm)	1.0	-	-	-	-	-	-	-	-	-	<1.0	<1.0	NA	-	-	-
% Sand (2.00mm - 0.063mm)	1.0	-	-	-	-	-	-	-	-	-	1.4	1.9	**-30**	-	-	-
% Silt (0.063mm - 4µm)	1.0	-	-	-	-	-	-	-	-	-	84.3	87.6	-3.8	-	-	-
% Clay (<4µm)	1.0	-	-	-	-	-	-	-	-	-	14.3	10.6	29.7	-	-	-
TOTAL METALS (mg/kg dw)																
Antimony	10	<10	<10	NA	<10	<10	NA	<10	<10	NA	<10	<10	NA	<10	<10	NA
Arsenic	5.0	<5.0	<5.0	NA	<5.0	<5.0	NA	<5.0	<5.0	NA	6.5	7.6	-15.6	<5.0	<5.0	NA
Barium	1.0	473	428	10.0	152	162	-6.4	92.9	94	-1.2	510	556	-8.6	473	467	1.3
Beryllium	0.50	<0.50	<0.50	NA	<0.50	<0.50	NA	<0.50	<0.50	NA	<0.50	0.55	NA	<0.50	<0.50	NA
Cadmium	0.50	0.93	0.76	20.1	2.40	2.47	-2.9	3	3	0.0	1.12	1.06	5.5	0.93	0.93	0.0
Chromium	2.0	3.6	3.9	-8.0	<2.0	<2.0	NA	3.2	3.4	-6.1	13.5	14.6	-7.8	3.6	3.7	-2.7
Cobalt	2.0	3.1	2.9	6.7	<2.0	2.0	NA	<2.0	<2.0	NA	6.4	6.6	-3.1	3.1	3.0	3.3
Copper	1.0	10.0	9.1	9.4	10.5	11.2	-6.5	12.6	12.5	0.8	19.7	19.5	1.0	10	9.8	2.0
Lead	30	<30	<30	NA	<30	<30	NA	<30	<30	NA	<30	<30	NA	<30	<30	NA
Mercury	0.0050	0.0898	0.0887	1.2	0.0742	0.0841	-12.5	0.0614	0.0649	-5.5	0.0620	0.0631	-1.8	0.0898	0.0942	-4.8
Molybdenum	4.0	<4.0	<4.0	NA	<4.0	<4.0	NA	<4.0	<4.0	NA	<4.0	<4.0	NA	<4.0	<4.0	NA
Nickel	5.0	6.8	6.3	7.6	<5.0	5.1	NA	5.3	5.6	-5.5	24.4	24.6	-0.8	6.8	6.6	3.0
Selenium	2.0	<2.0	<2.0	NA	<2.0	<2.0	NA	<2.0	<2.0	NA	-	-	-	<2.0	<2.0	NA
Silver	2.0	<2.0	<2.0	NA	<2.0	<2.0	NA	<2.0	<2.0	NA	<2.0	<2.0	NA	<2.0	<2.0	NA
Thallium	1.0	<1.0	<1.0	NA	<1.0	<1.0	NA	<1.0	<1.0	NA	<1.0	<1.0	NA	<1.0	<1.0	NA
Tin	5.0	<5.0	<5.0	NA	<5.0	<5.0	NA	<5.0	<5.0	NA	<5.0	<5.0	NA	<5.0	<5.0	NA
Uranium	0.050	0.083	0.104	-22.5	0.616	0.668	-8.1	0.138	0.142	-2.9	1.16	1.21	-4.2	0.083	0.077	7.5
Vanadium	2.0	7.0	5.8	18.8	3.3	3.6	-8.7	5.3	5.4	-1.9	32.2	36.1	-11.4	7.0	5.5	24.0
Zinc	1.0	62.3	47.9	26.1	304	316	-3.9	217	219	-0.9	101	103	-2.0	62.3	63.4	-1.8
SPECIATED METALS (ug/kg)																
Methyl Mercury	0.050	0.358	0.290	21.0	-	-	-	0.240	0.157	**41.8**	-	-	-	-	-	-

Notes:

RPD = Relative Percent Difference (%) = ((original - duplicate) / (original + duplicate)/2) x 100.

Shaded RPDs exceed 25% (lab duplicates) or 50% (field duplicates).

Bolded RPDs exceed 50% (field duplicates) or 25% (laboratory duplicates), but < 10 x MDL.

NA = RPDs have not been calculated for cases where one of the samples is below detection and the other is not, and in cases where both are below detection.

Samples were analyzed for MeHg by Brooks Rand, Seattle, WA; and for everything else by ALS Laboratories, Burnaby, BC.

Table 7-3. Conventional soil chemistry, particle size and total metals, BC Hydro 2010.

Area				Peace River																Peace River				
Station ID	Soil Quality Guidelines (CCME 2007)[1]		BC Background Soil	P1	P2	P2 INORG	P3	P4	P5	P6	P8	P9	P11-A	P11-B	P12-A	P12-B	P13-A	P13-B	P15	P17-A	P17-B	P17-B INORG	P17-C	P17-D	P17-E
Lab ID			(BC MOE 2010)[2]	L907154-14	L907154-15	L907154-35	L907154-17	L907154-18	L907154-19	L907154-20	L907154-21	L907154-22	L907154-23	L907154-24	L907154-25	L907154-26	L907154-27	L907154-28	L909390-32	L909390-33	L909390-34	L909390-35	L909390-36	L909390-37	L909390-38
Date	Agricultural Land	Parkland	Region 7 - Omenica Peace	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	11-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10
Sampling Locations[3]																								
UTM Coordinates - Northing	-	-	-	6207931	6208354		6200621	6211614	6212143	6212670	6219141	6219694	6219569	6219599	6220100	6220164	6220566	6220600	6223987	6225856	6226038		6226440	6226420	6226746
UTM Coordinates - Easting	-	-	-	566725	567243		567261	569756	570815	571493	577329	578625	578762	578900	581700	581800	582973	583097	566812	589245	589498		590113	590288	590718
Habitat cover type	-	-	-	WH	SH		Fm02	WH	WH	SH	Fm02	Fm02	SH	SH	CF	CF	SH	SH	SH	SH	SH		SH	SH	SH
Mean thickness of organic layer (cm)	-	-	-	4	2.5		1.5	2.5	0.5	3.5	4	3.5	7	7	0.5	0.5	5.5	5	5	7.5	2		11	7	9
CONVENTIONAL PARAMETERS																									
Loss on Ignition @ 550°C	NG	NG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	79	81	51	11	66	76	63
pH	NG	NG	-	5.64	6.11	-	7.10	6.19	6.68	6.45	5.92	6.53	6.41	6.22	7.69	7.54	5.16	5.41	6.04	6.07	7.17	7.87	7.13	6.05	6.68
Total Carbon by Combustion (%)	NG	NG	-	32.6	36.6	1.6	21.8	34.9	34.9	36.2	35.4	36.2	36.9	39.5	4.9	4.5	23.6	38.7	37.2	39.5	25.1	3.7	31.2	36.8	31.2
Total Organic Carbon (%)	NG	NG	-	32.4	36.4	1.2	21.5	34.7	34.7	36.0	35.2	36.0	36.7	39.3	4.0	3.6	23.3	38.5	37.0	39.3	24.7	2.7	30.9	36.6	31.0
Particle Size																									
% Gravel (>2mm)	NG	NG	-	-	-	<1.0	-	-	-	-	-	-	-	-	<1.0	<1.0	-	-	-	-	-	<1.0	-	-	-
% Sand (2.00mm - 0.063mm)	NG	NG	-	-	-	88.5	-	-	-	-	-	-	-	-	38.1	19.4	-	-	-	-	-	<1.0	-	-	-
% Silt (0.063mm - 4µm)	NG	NG	-	-	-	11.4	-	-	-	-	-	-	-	-	58.4	73.6	-	-	-	-	-	44.4	-	-	-
% Clay (<4µm)	NG	NG	-	-	-	<1.0	-	-	-	-	-	-	-	-	3.6	7.0	-	-	-	-	-	55.3	-	-	-
TOTAL METALS (mg/kg)																									
Antimony*	20	20	4	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Arsenic	12	12	15	<5.0	<5.0	-	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	7.2	7.9	<5.0	<5.0	<5.0	<5.0	5.2	12.4	<5.0	<5.0	<5.0
Barium	750	500	600	171	233	-	227	125	214	152	216	180	211	251	176	221	80.2	252	253	232	245	312	229	201	181
Beryllium*	4	4	2.0	<0.50	<0.50	-	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.97	<0.50	<0.50	<0.50
Cadmium	1.4	10	0.90	0.52	0.79	-	1.82	1.87	2.35	2.40	0.55	3.21	2.01	1.32	1.07	1.45	1.23	1.63	3.66	2.38	4.00	2.11	4.42	2.56	2.89
Chromium	64	64	85	4.8	3.9	-	6.5	4.1	2.1	<2.0	5.8	5.1	3.6	<2.0	21.5	24.4	2.5	<2.0	6.1	3.0	16.8	40.5	5.7	5.9	9.2
Cobalt*	40	50	35	<2.0	<2.0	-	4.0	<2.0	<2.0	<2.0	2.2	2.3	<2.0	<2.0	8.3	9.7	<2.0	<2.0	2.8	<2.0	6.7	14.9	2.6	2.1	3.7
Copper	63	63	75	7.6	7.8	-	14.4	10.5	10.1	10.5	7.5	12.1	11.3	8.9	19.9	24.0	7.1	8.2	8.6	12.8	32.6	51.0	17.7	12.7	21.7
Lead	70	140	35	<30	<30	-	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Mercury	6.6	6.6	0.025	0.129	0.118	-	0.0634	0.0876	0.0586	0.0742	0.125	0.0812	0.126	0.136	0.0363	0.0408	0.0849	0.0989	0.138	0.0698	0.0666	0.0649	0.115	0.0969	0.102
mgHg / kgC - calculated[4]	-	-	-	0.399	0.324	-	0.295	0.253	0.169	0.206	0.355	0.226	0.343	0.346	0.904	1.128	0.364	0.257	0.373	0.178	0.270	2.431	0.372	0.265	0.329
Molybdenum*	5	10	1.0	<4.0	<4.0	-	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0
Nickel	50	50	60	5.5	<5.0	-	13.3	<5.0	<5.0	<5.0	6.1	7.5	<5.0	<5.0	27.6	31.7	<5.0	<5.0	7.7	9.3	27.1	52.5	13.0	8.5	16.0
Selenium	1	1	4.0	<0.50	<2.0	-	0.65	<2.0	<2.0	<2.0	<2.0	<2.5	<2.5	<2.0	<2.0	<2.0	<2.0	<2.8	<0.50	<2.0	<2.0	<2.0	<2.2	<2.6	<2.4	5.02
Silver*	20	20	1.0	<2.0	<2.0	-	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Thallium	1	1	-	<1.0	<1.0	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Tin*	5	50	4.0	<5.0	<5.0	-	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Uranium	23	23	-	0.206	0.168	-	0.530	0.150	0.102	0.616	0.242	0.200	0.149	0.078	0.860	0.752	0.087	0.067	0.211	0.133	1.53	1.46	0.278	0.424	0.528
Vanadium	130	130	200	8.8	6.3	-	14.7	6.5	6.0	3.3	9.7	8.4	5.5	2.4	38.8	44.1	3.9	2.6	10.7	4.6	33.8	76.8	10.9	10.3	16.0
Zinc	200	200	150	88.7	214	-	188	160	270	304	209	367	273	236	107	131	83.1	286	281	267	257	167	328	181	163
SPECIATED METALS (ug/kg)																									
Methyl Mercury	NG	NG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.240	-	-	-	0.109	-	-
% MeHg/Total Hg (%)	NG	NG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.17	-	-	-	0.09	-	-

Notes:

NG = no guideline.

[1]CCME (Canadian Council of Ministers of the Environment) Canadian Soil Quality Guidelines (CSQG) for the Protection of Environmental and Human Health, 1999, updated in September 2007.

* indicates interim criteria that have not yet been replaced by CSQGs.

[2]BC MOE (British Columbia Ministry of Environment) CSR Protocol 4: Determining Background Soil Quality, Table 1 for the Omineca Peace Region, updated in October 2010.

Results have not been screened against above guidelines.

Total organic carbon (%TOC) was not available from the laboratory for a number of samples in the dataset:

Shaded values were determined by regression analysis for TOC >5%.

Boxed values were determined by regression analysis for TOC <5%.

[3]UTM coordinates are in NAD83 for Zone 10V.

[4]Calculated as: [Hg] in mg/kg / (%TOC*0.01).

Samples were analyzed for MeHg by Brooks Rand, Seattle, WA; and for everything else by ALS Laboratories, Burnaby, BC.

Table 7-3. Conventional soil chemistry, particle size and total metals, BC Hydro 2010.

Area				Peace River																			Peace River	
Station ID	Soil Quality Guidelines (CCME 2007)[1]		BC Background Soil	P19	P20-A	P20-B	P21-A	P21-B	P23	P24	P25-A	P25-B	P25-B INORG	P25-C	P28	P29	P30	P31	P32	P33	P34	P35-A	P35-B	P35-C	P37
Lab ID			(BC MOE 2010)[2]	L909390-39	L907154-12	L907154-13	L909390-29	L909390-30	L909390-40	L909390-41	L909390-42	L909390-43	L909390-44	L909390-45	L907154-1	L907154-2	L907154-3	L907154-4	L907154-5	L907154-6	L907154-7	L909938-1	L909938-2	L909938-3	L909938-4
Date	Agricultural Land	Parkland	Region 7 - Omenica Peace	15-Jul-10	9-Jul-10	9-Jul-10	14-Jul-10	14-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10	10-Jul-10	10-Jul-10	10-Jul-10	10-Jul-10	10-Jul-10	10-Jul-10	10-Jul-10	16-Jul-10	16-Jul-10	16-Jul-10	16-Jul-10
Sampling Locations[3]																								
UTM Coordinates - Northing	-	-	-	6229515	6230796	6230352	6231198	6231232	6232961	6233263	6233564	6233488		6233343	6234891	6235008	6235315	6235555	6235836	6236008	6236006	6235721	6236062	6236678	6236254
UTM Coordinates - Easting	-	-	-	594627	595393	595460	597457	597327	599547	600831	600832	601087		601274	605584	605608	606156	606636	607187	607166	607305	607649	608161	608738	608484
Habitat cover type	-	-	-	SH	SH	SH	SH	SH	WH	SH	Fm02	Fm02		Fm02	BT	BT	BT	SE	SE	SE	SE	WH	WH	WH	WH
Mean thickness of organic layer (cm)	-	-	-	6	4	3.5	13.5	10.5	3.5	5	5	4		6	30	10	30	50	50	2	30	4	4.5	2.5	0
CONVENTIONAL PARAMETERS																									
Loss on Ignition @ 550°C	NG	NG	-	84	-	-	69	75	44	85	83	70	5	86	-	-	-	-	-	-	-	73	43	31	3
pH	NG	NG	-	6.58	6.91	6.86	6.32	5.79	7.17	6.32	6.12	6.07	7.92	5.66	7.83	8.13	7.55	8.07	7.81	6.75	7.84	7.52	7.34	7.37	8.12
Total Carbon by Combustion (%)	NG	NG	-	39.0	16.4	17.8	31.1	32.7	15.4	40.5	39.7	31.6	2.7	40.8	29.1	30.6	32.2	34.2	21.1	8.8	15.8	36.7	22.7	12.0	1.7
Total Organic Carbon (%)	NG	NG	-	38.7	16.1	17.5	30.9	32.6	15.1	40.3	39.5	31.4	1.5	40.5	28.8	30.4	32.0	34.0	20.8	8.4	15.5	36.4	22.4	11.5	0.9
Particle Size																									
% Gravel (>2mm)	NG	NG	-	-	-	-	<1.0	-	-	-	-	-	<1.0	-	-	-	-	-	-	-	-	-	-	-	-
% Sand (2.00mm - 0.063mm)	NG	NG	-	-	-	-	6.6	-	-	-	-	-	56.5	-	-	-	-	-	-	-	-	-	-	-	-
% Silt (0.063mm - 4µm)	NG	NG	-	-	-	-	83.2	-	-	-	-	-	41.8	-	-	-	-	-	-	-	-	-	-	-	-
% Clay (<4µm)	NG	NG	-	-	-	-	10.2	-	-	-	-	-	1.7	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL METALS (mg/kg)																									
Antimony*	20	20	4	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Arsenic	12	12	15	<5.0	<5.0	6.1	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	6.1	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	6.4	<5.0	<5.0	<5.0	6.7
Barium	750	500	600	175	236	312	286	247	130	98.9	168	230	159	210	57.3	54.6	199	65.4	390	577	398	162	264	181	263
Beryllium*	4	4	2.0	<0.50	<0.50	0.56	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.62	<0.50	<0.50	<0.50	<0.50
Cadmium	1.4	10	0.90	2.70	1.96	1.70	3.04	1.53	2.30	3.00	1.36	0.84	0.70	0.76	<0.50	<0.50	<0.50	<0.50	1.33	0.75	0.85	4.03	7.96	1.75	0.52
Chromium	64	64	85	2.1	18.2	23.6	6.7	4.8	12.6	2.4	3.1	4.7	19.1	3.4	2.3	<2.0	2.0	4.8	15.6	28.1	22.4	3.5	9.8	10.8	10.8
Cobalt*	40	50	35	<2.0	7.5	9.2	2.7	<2.0	4.0	<2.0	<2.0	2.0	7.1	<2.0	<2.0	<2.0	2.4	<2.0	8.2	8.8	9.6	<2.0	4.5	4.1	4.9
Copper	63	63	75	7.4	23.8	29.0	14.4	12.3	13.7	11.8	8.6	9.0	18.1	7.2	5.8	2.5	4.8	6.4	27.8	19.4	30.9	16.6	19.2	14.6	11.5
Lead	70	140	35	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Mercury	6.6	6.6	0.025	0.103	0.0568	0.0500	0.126	0.125	0.0524	0.0875	0.130	0.121	0.0395	0.129	0.0614	0.0679	0.0767	0.0557	0.0461	0.0262	0.0482	0.0635	0.0659	0.0421	0.0244
mgHg / kgC - calculated[4]	-	-	-	0.266	0.353	0.286	0.408	0.383	0.347	0.217	0.329	0.385	2.705	0.319	0.213	0.224	0.240	0.164	0.222	0.311	0.312	0.174	0.294	0.366	2.711
Molybdenum*	5	10	1.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0
Nickel	50	50	60	<5.0	25.0	29.8	11.8	7.2	12.7	<5.0	<5.0	6.3	23.9	<5.0	<5.0	<5.0	<5.0	5.2	31.5	16.5	33.2	6.4	18.0	13.8	17.7
Selenium	1	1	4.0	<2.0	<2.9	2.00	<2.4	<2.0	<2.0	<2.0	<2.0	<2.5	<2.5	<2.0	<2.0	<2.0	<2.2	<2.0	6.24	<2.0	1.49	<2.0	2.07	<2.0	<2.0
Silver*	20	20	1.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Thallium	1	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Tin*	5	50	4.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Uranium	23	23	-	0.278	0.631	1.14	0.404	0.239	0.361	0.123	0.152	0.235	0.761	0.143	0.198	0.081	1.97	0.325	1.40	0.485	1.81	0.185	0.743	0.340	0.891
Vanadium	130	130	200	3.6	31.9	42.1	13.9	8.5	19.4	3.9	5.1	9.3	33.8	5.5	5.1	<2.0	4.0	8.7	28.1	48.8	39.3	5.8	20.2	21.4	25.6
Zinc	200	200	150	245	153	156	221	145	208	332	219	242	69.6	145	59.5	14.3	44.7	37.9	250	162	129	323	344	161	62.8
SPECIATED METALS (ug/kg)																									
Methyl Mercury	NG	NG	-	-	-	-	-	0.086	-	-	-	0.071	-	-	-	-	-	4.000	-	-	-	-	-	-	-
% MeHg/Total Hg (%)	NG	NG	-	-	-	-	-	0.07	-	-	-	0.06	-	-	-	-	-	7.18	-	-	-	-	-	-	-

Notes:

NG = no guideline.

[1]CCME (Canadian Council of Ministers of the Environment) Canadian Soil Quality Guidelines (CSQG) for the Protection of Environmental and Human Health, 1999, updated in September 2007.

* indicates interim criteria that have not yet been replaced by CSQGs.

[2]BC MOE (British Columbia Ministry of Environment) CSR Protocol 4: Determining Background Soil Quality, Table 1 for the Omineca Peace Region, updated in October 2010.

Results have not been screened against above guidelines.

Total organic carbon (%TOC) was not available from the laboratory for a number of samples in the dataset:

Shaded values were determined by regression analysis for TOC >5%.

Boxed values were determined by regression analysis for TOC <5%.

[3]UTM coordinates are in NAD83 for Zone 10V.

[4]Calculated as: [Hg] in mg/kg / (%TOC*0.01).

Samples were analyzed for MeHg by Brooks Rand, Seattle, WA; and for everything else by ALS Laboratories, Burnaby, BC.

Table 7-3. Conventional soil chemistry, particle size and total metals, BC Hydro 2010.

Area				Peace River																				
Station ID	Soil Quality Guidelines (CCME 2007)[1]		BC Background Soil	P38-A	P38-B	P38-B INORG	P39	P41	P42	P43	P44	P46-A	P46-B	P46-C	P47-A	P47-B	P48	P49-A	P49-B	P49-C	P49-D	P50	P51	P52-A	P52-B
Lab ID			(BC MOE 2010)[2]	L907154-8	L907154-9	L907154-10	L909938-5	L909938-6	L909938-12	L909938-7	L909938-8	L909390-1	L909390-2	L909390-22	L909390-4	L909390-5	L909390-11	L909390-7	L909390-8	L909390-9	L909390-10	L909390-12	L909390-13	L909390-14	L909390-15
Date	Agricultural Land	Parkland	Region 7 - Omenica Peace	10-Jul-10	10-Jul-10	10-Jul-10	16-Jul-10	16-Jul-10	16-Jul-10	16-Jul-10	16-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	12-Jul-10	12-Jul-10	12-Jul-10
Sampling Locations[3]																								
UTM Coordinates - Northing	-	-	-	6236880	6236798		6236528	6237450	6236510	6236144	6235555	6233738	6233603	6235761	6232923	6232939	6233261	6232107	6232169	6232798	6232204	6232500	6231338	6232055	6232574
UTM Coordinates - Easting	-	-	-	608523	608424		609059	611364	612085	613280	613888	615484	615221	615514	616219	616304	616666	618220	618019	617175	617475	620577	628555	627311	626604
Habitat cover type	-	-	-	Fm02	Fm02		WH	AM	SW	Fm02	Fm02	SH	SH	SH	SH	SH	Fm02	Fm02	Fm02	Fm02	Fm02	Fm02	SW	AM	AM
Mean thickness of organic layer (cm)	-	-	-	7	2		0	4.5	4.5	0	0	3.5	4.5	6.5	8	8	1	6	6	4.5	10.5	3.5	12.5	6	8
CONVENTIONAL PARAMETERS																									
Loss on Ignition @ 550°C	NG	NG	-	-	-	-	5	73	67	6	4	86	85	83	80	86	7	84	79	79	85	48	76	76	73
pH	NG	NG	-	7.01	6.75	7.61	7.85	6.50	6.11	7.77	7.94	6.45	6.26	6.63	6.49	6.65	7.77	6.42	6.36	6.60	6.69	7.13	6.96	6.41	6.63
Total Carbon by Combustion (%)	NG	NG	-	30.7	30.5	6.5	2.5	34.9	37.6	2.3	1.9	42.1	39.9	34.0	36.4	40.9	3.7	39.4	35.8	37.7	40.7	32.7	37.0	35.4	36.4
Total Organic Carbon (%)	NG	NG	-	30.5	30.3	6.1	1.7	34.6	37.4	1.4	1.0	41.8	39.5	34.0	36.2	40.7	2.7	39.1	35.5	37.5	40.5	32.4	36.8	35.4	36.4
Particle Size																									
% Gravel (>2mm)	NG	NG	-	-	-	<1.0	<1.0	-	-	<1.0	<1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
% Sand (2.00mm - 0.063mm)	NG	NG	-	-	-	6.5	38.9	-	-	23.2	84.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
% Silt (0.063mm - 4µm)	NG	NG	-	-	-	75.8	58.4	-	-	71.5	13.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
% Clay (<4µm)	NG	NG	-	-	-	17.7	2.7	-	-	5.3	2.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL METALS (mg/kg)																									
Antimony*	20	20	4	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Arsenic	12	12	15	<5.0	<5.0	7.6	6.5	<5.0	<5.0	6.4	6.3	<5.0	<5.0	<5.0	<5.0	<5.0	6.8	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Barium	750	500	600	278	236	279	372	591	473	431	239	160	191	173	164	115	429	237	236	92.9	86.4	178	166	238	241
Beryllium*	4	4	2.0	<0.50	<0.50	0.52	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Cadmium	1.4	10	0.90	2.48	2.62	1.31	0.66	3.79	0.93	0.69	0.50	1.79	1.46	1.98	2.49	7.78	0.99	1.01	1.43	3.00	3.65	4.17	2.21	1.82	2.24
Chromium	64	64	85	6.2	7.9	20.8	11.0	5.7	3.6	13.3	11.7	<2.0	3.9	4.4	3.2	<2.0	12.5	<2.0	4.2	3.2	<2.0	4.3	2.3	3.0	3.3
Cobalt*	40	50	35	3.1	3.6	8.5	6.2	10.2	3.1	5.8	5.4	<2.0	<2.0	<2.0	<2.0	<2.0	6.7	<2.0	<2.0	<2.0	<2.0	2.6	2.7	2.3	3.2
Copper	63	63	75	18.6	16.6	20.4	15.3	23.9	10.0	15.9	11.0	9.8	10.9	9.9	16.7	15.0	19.1	7.5	16.1	12.6	10.4	19.4	13.1	12.5	13.7
Lead	70	140	35	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Mercury	6.6	6.6	0.025	0.0916	0.0893	0.0608	0.0437	0.113	0.0898	0.0513	0.0225	0.113	0.113	0.108	0.0885	0.0632	0.0631	0.0920	0.0789	0.0614	0.0702	0.0621	0.101	0.0725	0.0806
mgHg / kgC - calculated[4]	-	-	-	0.301	0.295	0.994	2.556	0.327	0.240	3.691	2.228	0.270	0.286	0.318	0.244	0.155	2.311	0.235	0.222	0.164	0.173	0.192	0.274	0.205	0.221
Molybdenum*	5	10	1.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0
Nickel	50	50	60	10.0	13.2	28.8	20.6	27.2	6.8	21.7	18.1	<5.0	5.1	5.1	7.1	5.6	23.9	<5.0	8.3	5.3	<5.0	9.7	5.9	6.0	9.1
Selenium	1	1	4.0	<2.0	1.12	0.85	<2.0	<2.5	<2.0	<2.0	<2.5	<2.4	<2.0	<2.0	<4.0	<2.4	<2.0	<2.0	<2.0	<2.0	<2.0	1.81	<2.0	<2.0	<2.2
Silver*	20	20	1.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Thallium	1	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Tin*	5	50	4.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Uranium	23	23	-	0.330	0.483	1.04	0.931	0.254	0.083	0.897	0.820	0.120	0.164	0.190	0.173	0.082	1.02	0.107	0.208	0.138	0.087	0.337	0.121	0.140	0.196
Vanadium	130	130	200	13.9	17.8	43.5	25.7	13.1	7.0	33.3	27.4	2.9	6.6	6.2	5.5	<2.0	28.2	3.2	6.9	5.3	2.1	8.2	3.7	5.3	6.9
Zinc	200	200	150	256	218	112	78.0	465	62.3	81.6	66.9	220	198	251	227	400	92.9	121	162	217	338	340	268	161	113
SPECIATED METALS (ug/kg)																									
Methyl Mercury	NG	NG	-	-	-	-	-	7.090	0.358	-	-	-	-	-	0.240	-	-	-	-	-	-	-	0.233	-	-
% MeHg/Total Hg (%)	NG	NG	-	-	-	-	-	6.27	0.40	-	-	-	-	-	0.27	-	-	-	-	-	-	-	0.23	-	-

Notes:

NG = no guideline.

[1]CCME (Canadian Council of Ministers of the Environment) Canadian Soil Quality Guidelines (CSQG) for the Protection of Environmental and Human Health, 1999, updated in September 2007.

* indicates interim criteria that have not yet been replaced by CSQGs.

[2]BC MOE (British Columbia Ministry of Environment) CSR Protocol 4: Determining Background Soil Quality, Table 1 for the Omineca Peace Region, updated in October 2010.

Results have not been screened against above guidelines.

Total organic carbon (%TOC) was not available from the laboratory for a number of samples in the dataset:

Shaded values were determined by regression analysis for TOC >5%.

Boxed values were determined by regression analysis for TOC <5%.

[3]UTM coordinates are in NAD83 for Zone 10V.

[4]Calculated as: [Hg] in mg/kg / (%TOC*0.01).

Samples were analyzed for MeHg by Brooks Rand, Seattle, WA; and for everything else by ALS Laboratories, Burnaby, BC.

Table 7-3. Conventional soil chemistry, particle size and total metals, BC Hydro 2010.

Area				Peace River								Halfway River										Moberly River					
Station ID	Soil Quality Guidelines (CCME 2007)[1]		BC Background Soil	P52-B INORG	P52-C	P52-D	P53	P54	P55	P56	P99	HW1	HW2	HW3-A	HW3-B	HW3-C	HW4	HW5-A	HW5-B	HW6-A	HW6-B	M1	M2	M3	M4	M5	M6
Lab ID			(BC MOE 2010)[2]	L909390-16	L909390-17	L909390-18	L909390-19	L909390-20	L909390-21	L909390-6	L909390-10	L909390-23	L909390-24	L909390-25	L909390-26	L909390-46	L909390-47	L909390-48	L909390-49	L909390-27	L909390-28	L909938-9	L909938-13	L909938-14	L909938-15	L909938-16	L909938-17
Date	Agricultural Land	Parkland	Region 7 - Omenica Peace	12-Jul-10	12-Jul-10	12-Jul-10	12-Jul-10	12-Jul-10	12-Jul-10	13-Jul-10	16-Jul-10	14-Jul-10	14-Jul-10	14-Jul-10	14-Jul-10	14-Jul-10	14-Jul-10	14-Jul-10	14-Jul-10	14-Jul-10	14-Jul-10	16-Jul-10	17-Jul-10	17-Jul-10	17-Jul-10	17-Jul-10	17-Jul-10
Sampling Locations[3]																											
UTM Coordinates - Northing	-	-	-		6232171	6232717	6232588	6233292	6232817	6232493	6234880	6231750	6231752	6231918	6231968	6231842	6231333	6232333	6232210	6234330	6234464	6230272	6229796	6229602	6228248	6227673	6227618
UTM Coordinates - Easting	-	-	-		627204	646604	626639	624392	622919	621627	614297	596397	595750	595361	595562	595739	595242	593591	593673	591167	591048	628507	628026	627552	626160	625372	623701
Habitat cover type	-	-	-		AM	AM	SW	Fm02	SH	Fm02	Fm02	Fm02	CF	SH	SH	CF	Fm02	SH	SH	WH	WH	Fm02	SH	Fm02	SH	Fm02	SH
Mean thickness of organic layer (cm)	-	-	-		5.5	7.5	6.5	4	6	5	5	0.5	1	1	1	0.5	1.5	1	2.5	1.5	4.5	1	9.5	9.5	10.5	2	15
CONVENTIONAL PARAMETERS																											
Loss on Ignition @ 550°C	NG	NG	-	37	65	82	67	78	76	88	85	7	9	8	12	8	39	4	51	11	49	10	81	76	79	61	77
pH	NG	NG	-	7.30	6.75	6.26	6.70	6.33	6.67	5.91	6.58	7.78	7.83	7.82	7.73	7.75	6.95	7.90	7.10	7.67	7.14	7.56	6.81	6.32	6.54	7.22	6.64
Total Carbon by Combustion (%)	NG	NG	-	4.9	32.6	39.2	33.9	38.8	36.3	42.8	34.7	2.6	4.3	3.4	5.3	3.5	22.0	1.9	31.7	4.4	20.8	4.3	36.3	33.7	38.4	31.5	35.5
Total Organic Carbon (%)	NG	NG	-	4.3	32.6	39.2	33.9	38.7	36.3	42.5	34.6	1.9	3.4	2.3	4.4	2.6	21.6	1.1	31.4	3.4	20.6	3.6	36.0	33.5	38.4	30.9	35.3
Particle Size																											
% Gravel (>2mm)	NG	NG	-	<1.0	-	-	-	-	-	-	-	<1.0	<1.0	<1.0	<1.0	-	-	-	-	<1.0	-	<1.0	-	-	-	-	-
% Sand (2.00mm - 0.063mm)	NG	NG	-	2.4	-	-	-	-	-	-	-	59.6	<1.0	1.5	<1.0	-	-	-	-	1.4	-	12.7	-	-	-	-	-
% Silt (0.063mm - 4µm)	NG	NG	-	82.3	-	-	-	-	-	-	-	34.5	84.2	58.7	83.9	-	-	-	-	84.3	-	73.7	-	-	-	-	-
% Clay (<4µm)	NG	NG	-	15.4	-	-	-	-	-	-	-	5.9	14.9	39.8	15.3	-	-	-	-	14.3	-	13.6	-	-	-	-	-
TOTAL METALS (mg/kg)																											
Antimony*	20	20	4	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Arsenic	12	12	15	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	7.0	7.7	7.3	8.6	7.0	<5.0	7.3	<5.0	6.5	<5.0	7.8	<5.0	<5.0	<5.0	<5.0	<5.0
Barium	750	500	600	225	195	218	365	204	206	129	129	445	513	501	565	466	326	319	277	510	426	483	176	213	221	218	198
Beryllium*	4	4	2.0	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.52	0.50	0.58	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.53	<0.50	<0.50	<0.50	<0.50	<0.50
Cadmium	1.4	10	0.90	3.62	2.62	3.86	3.33	1.77	3.07	1.50	1.80	0.70	1.06	1.02	1.19	0.96	2.41	0.71	2.27	1.12	2.43	1.07	2.25	1.70	2.23	3.45	2.54
Chromium	64	64	85	7.7	5.7	2.6	5.3	3.4	5.2	<2.0	4.4	11.0	15.6	14.4	15.8	12.4	6.6	8.3	4.2	13.5	8.3	16.6	2.1	4.0	5.9	8.8	6.5
Cobalt*	40	50	35	5.1	3.3	<2.0	2.9	<2.0	2.2	<2.0	<2.0	5.4	6.6	6.7	7.3	6.2	3.3	4.8	2.2	6.4	3.6	7.3	2.8	2.7	2.9	5.0	3.0
Copper	63	63	75	25.2	16.0	11.9	15.2	10.2	12.8	9.5	11.9	12.1	19.4	19.8	22.2	17.0	13.0	10.5	11.5	19.7	19.7	21.5	13.9	12.1	13.9	24.6	15.7
Lead	70	140	35	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Mercury	6.6	6.6	0.025	0.0510	0.0876	0.0863	0.106	0.104	0.100	0.111	0.0904	0.0379	0.0657	0.0633	0.0626	0.0535	0.0464	0.0249	0.0601	0.0620	0.0596	0.0559	0.0877	0.0637	0.0687	0.0399	0.0742
mgHg / kgC - calculated[4]	-	-	-	1.181	0.269	0.220	0.313	0.269	0.275	0.261	0.261	2.005	1.944	2.813	1.429	2.050	0.215	2.327	0.191	1.818	0.289	1.570	0.244	0.190	0.179	0.129	0.210
Molybdenum*	5	10	1.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0
Nickel	50	50	60	18.0	12.0	<5.0	11.0	<5.0	7.4	<5.0	6.1	17.8	24.9	24.9	27.2	21.9	11.3	16.7	7.5	24.4	12.7	25.6	6.0	6.6	9.6	18.1	12.2
Selenium	1	1	4.0	<2.0	<2.0	<2.0	<2.0	<2.0	1.42	<2.0	<2.0	<2.0	<2.0	0.92	<2.0	<2.5	<2.5	<2.0	<2.0	0.87	<2.0	0.96	<2.0	<2.5	<2.0	<2.0	<2.0
Silver*	20	20	1.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Thallium	1	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Tin*	5	50	4.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Uranium	23	23	-	1.19	0.367	0.084	0.285	0.164	0.231	0.097	0.152	1.02	1.21	1.22	1.13	1.03	0.635	0.995	0.455	1.16	0.532	1.00	0.103	0.162	0.164	0.935	0.308
Vanadium	130	130	200	14.9	10.6	4.1	11.4	6.0	8.7	2.5	7.2	26.4	36.2	35.5	38.4	29.9	16.2	23.6	10.0	32.2	19.9	37.7	3.4	6.0	6.8	15.8	11.5
Zinc	200	200	150	335	246	379	298	276	267	241	266	79.6	104	101	112	94.7	238	75.9	236	101	272	104	273	158	121	318	247
SPECIATED METALS (ug/kg)																											
Methyl Mercury	NG	NG	-	-	-	-	-	-	0.278	0.197	0.287	-	-	-	-	-	-	-	-	-	-	-	0.088	-	-	-	0.182
% MeHg/Total Hg (%)	NG	NG	-	-	-	-	-	-	0.28	0.18	0.32	-	-	-	-	-	-	-	-	-	-	-	0.10	-	-	-	0.25

Notes:

NG = no guideline.

[1]CCME (Canadian Council of Ministers of the Environment) Canadian Soil Quality Guidelines (CSQG) for the Protection of Environmental and Human Health, 1999, updated in September 2007.

* indicates interim criteria that have not yet been replaced by CSQGs.

[2]BC MOE (British Columbia Ministry of Environment) CSR Protocol 4: Determining Background Soil Quality, Table 1 for the Omineca Peace Region, updated in October 2010.

Results have not been screened against above guidelines.

Total organic carbon (%TOC) was not available from the laboratory for a number of samples in the dataset:

Shaded values were determined by regression analysis for TOC >5%.

Boxed values were determined by regression analysis for TOC <5%.

[3]UTM coordinates are in NAD83 for Zone 10V.

[4]Calculated as: [Hg] in mg/kg / (%TOC*0.01).

Samples were analyzed for MeHg by Brooks Rand, Seattle, WA; and for everything else by ALS Laboratories, Burnaby, BC.

Table 7-4. Summary of soil organic carbon and total mercury concentrations, BC Hydro 2010.

Organic Horizons - Total Hg (mg/kg)

	Fm02	SH	WH	AM	SW	SE	BT	CF[a]	Means
N	24	32	11	5	3	3	3	4	(N=85)
%Carbon	27.6	30.4	19.4	35.6	36.0	23.4	30.4	3.4	27.2
THg	0.078	0.088	0.063	0.088	0.099	0.050	0.069	0.049	0.079
Carbon-Hg[b] (mgHg/kgC)	0.69	0.46	0.85	0.25	0.28	0.23	0.22	1.51	0.59

Inorganic (Mineral) Horizons - Total Hg

N	2	1	ns	1	ns	ns	ns	ns	Means (N=4)
%Carbon	3.7	2.7	-	4.3	-	-	-	-	4.5
THg	0.050	0.065	-	0.051	-	-	-	-	0.054
Carbon-Hg (mgHg/kgC)	1.81	2.40	-	1.19	-	-	-	-	1.8

Notes: [a] Samples from cultivated fields (CF) had little or no "organic" layer; [b] Carbon-Hg is mercury concentration normalized to carbon content (mgHg/kgC).

Table 7-5. Methyl mercury results and associated carbon and total mercury contents for soil.

Station	Cover Type	%Carbon	Total Hg (mg/kg)	Hg-Carbon (mg Hg/g C)	Methyl Hg (µg/kg)	% Methyl Hg
P41	AM	34.6	0.11	0.32	7.1	6.3
P25-B	Fm02	31.4	0.12	0.38	0.071	0.06
P56	Fm02	42.5	0.11	0.26	0.20	0.18
P99	Fm02	34.6	0.09	0.26	0.29	0.32
M6	Fm02	35.3	0.074	0.21	0.18	0.25
Means		**36.0**	**0.099**	**0.28**	**0.19**	**0.20**
P31	SE	34.0	0.056	0.16	4.0	7.2
P15	SH	37.0	0.14	0.38	0.24	0.17
P17-C	SH	30.9	0.12	0.39	0.11	0.09
P21-B	SH	32.6	0.12	0.37	0.086	0.07
P47-A	SH	36.2	0.088	0.24	0.24	0.27
P55	SH	36.3	0.10	0.28	0.28	0.28
M2	SH	36.0	0.088	0.24	0.088	0.10
Means		**34.8**	**0.109**	**0.32**	**0.17**	**0.16**
P42	SW	37.4	0.09	0.24	0.36	0.4
P51	SW	36.8	0.10	0.27	0.23	0.23
Means		**37.1**	**0.095**	**0.26**	**0.30**	**0.32**
Grand Means		**35.4**	**0.10**	**0.29**	**0.96**	**1.1**

Notes: Methyl mercury is expressed as µg/kg, 1000 x less than mg/kg.

Figure 7-1. Box and whisker plot of % organic carbon in soil horizons under vegetation cover types important in mercury cycling.

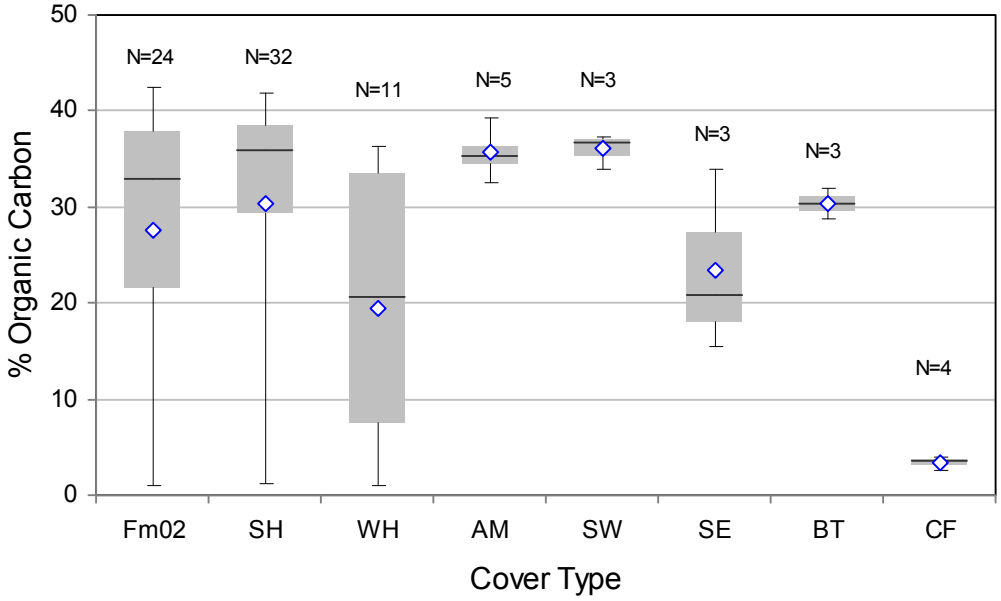
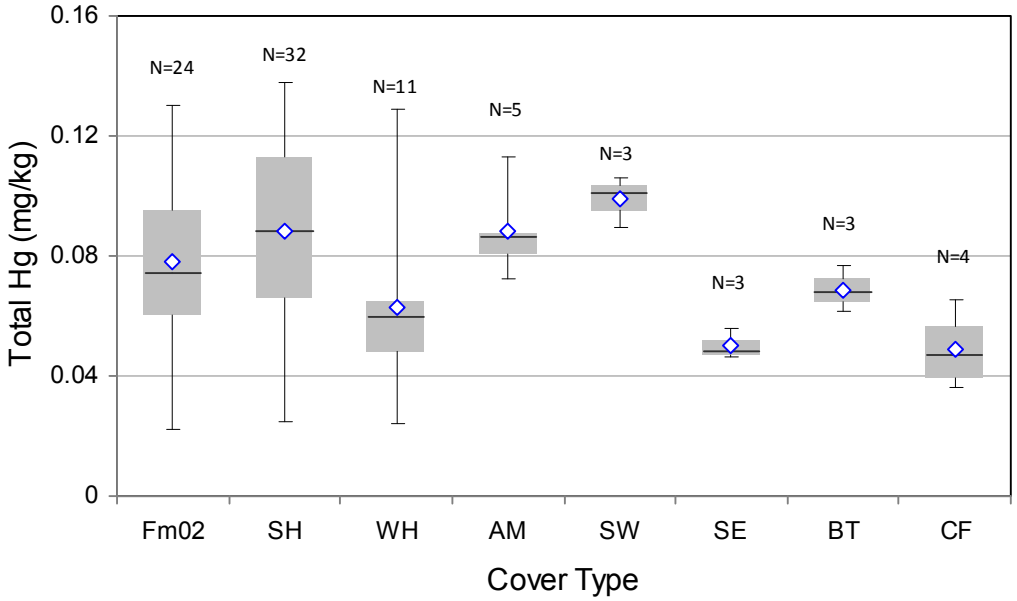


Figure 7-2. Box and whisker plot of total mercury in organic soil horizons under vegetation cover types important in mercury cycling.



Notes: N = number of samples, diamond = average, line = median, box = 25 and 75 quartiles, whisker = range.

Figure 7-3. Relationship between total mercury and organic carbon in soil.

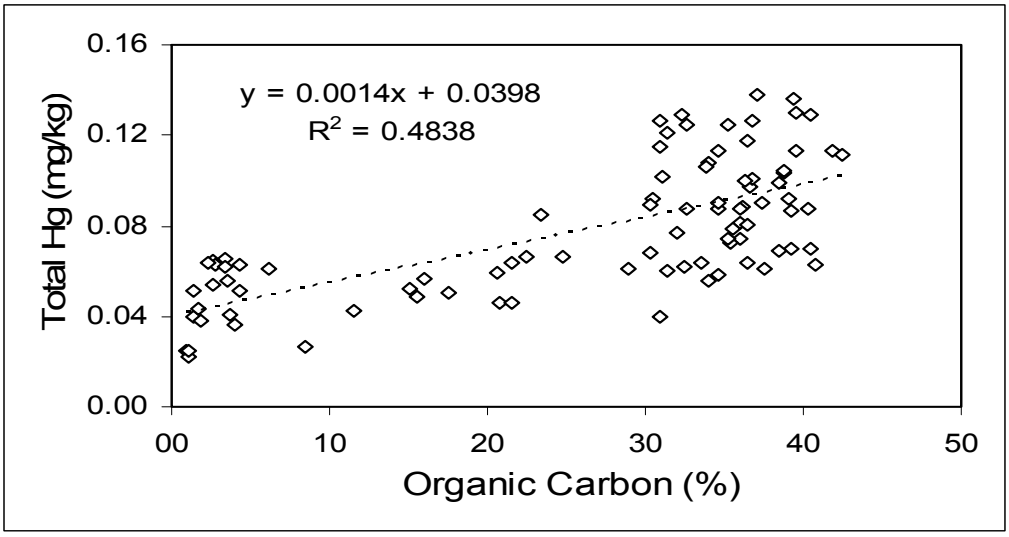


Figure 7-4. Carbon-normalized mercury concentrations as a function of % organic carbon in soils.

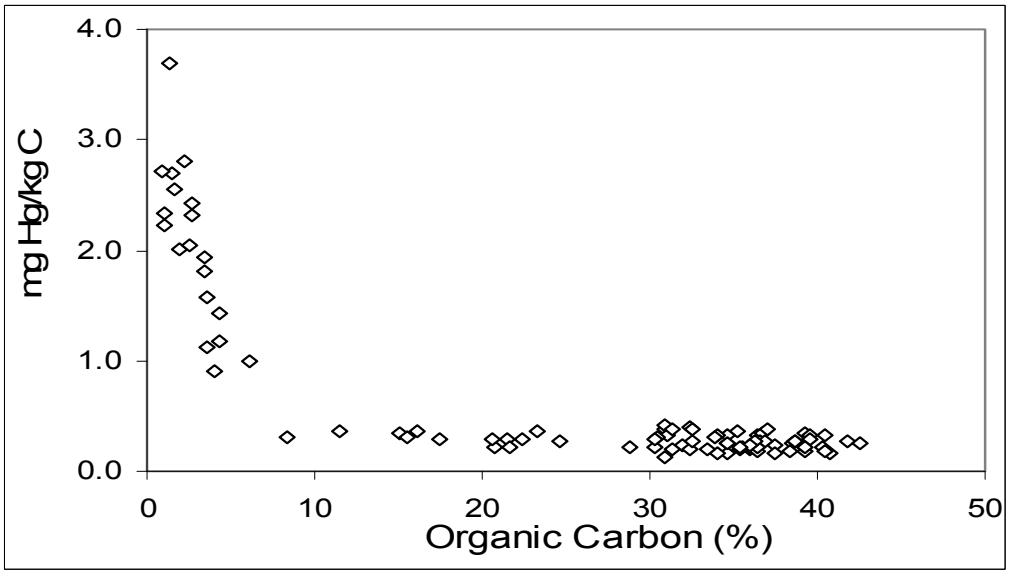
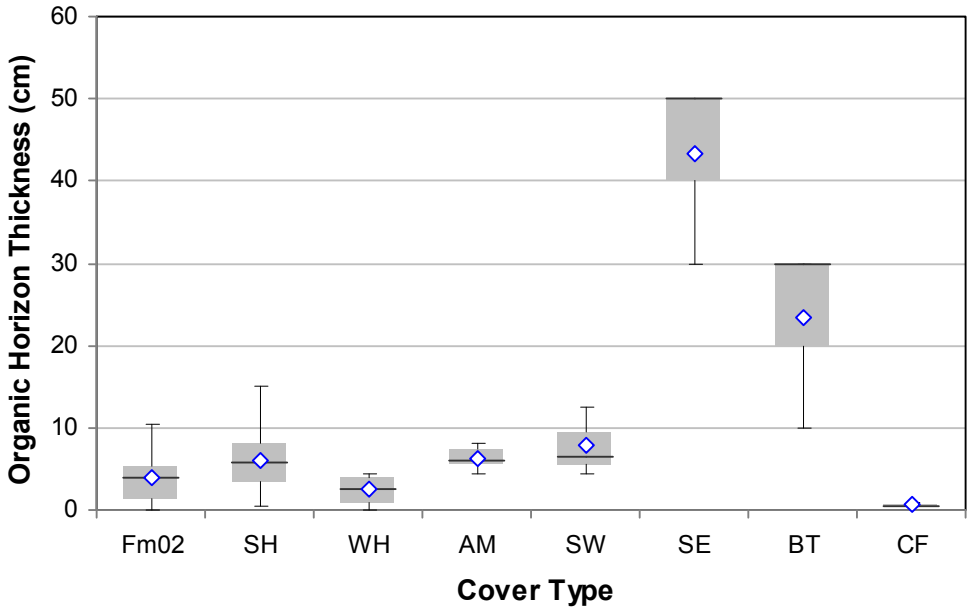


Figure 7-5. Box and whisker plot of thickness of organic horizons as a function of cover type.



Notes: Diamond = average, line = median, box = 25 and 75 quartiles, whisker = range.

8. VEGETATION

Given the lack of large-scale industrial or urban sources of atmospheric mercury in the vicinity of the Peace River near Ft. St. John, elevated concentrations of mercury adhered to plant tissues along the 83 km reach of river are not expected. However, given the importance of plant material as a source of labile (i.e., easily decomposable, readily available) carbon and its role in mercury methylation, a samples of vegetation that are representative of dominant plant types were collected and analyzed for total metals including mercury.

Representative vegetation types of common, abundant species were collected from dominant habitat types within the proposed footprint of Site C. Effort and intensity was stratified to accurately represent the dominant vegetation types with a focus on those habitats with soils that have abundant carbon stores such as peatlands, bogs, fens, marshes and well-developed humic soils beneath deciduous forests. This is more fully explored in the soils section above.

8.1. Methods

8.1.1. Field Sampling

Based on the expected relative abundance of vegetation types represented in the most common habitat types (**Table 7-1** in soils section) and on field observations, we selected the most abundant tree and shrub species for collection. These collections corresponded to soil stations where these plant species were relatively abundant, especially within the habitat types (Fm02 and SH) containing highly developed organic soils. Nineteen (19) samples representing 12 different plant species were collected opportunistically during the field investigation, along the length of the Peace River and from within the inundation zone along the Moberly River.

Vegetation samples were collected by randomly wandering through the habitat polygon collecting leaves or needles from live vegetation (as opposed to the forest floor) where appropriate (excluding twigs and branches) by hand using sterile nitrile gloves and placing plant material into a large zip-loc bag until it was full. We collected at least one sample of each dominant wetland plant species (e.g., balsam, willow, sedge, horsetail, black spruce, alder, prickly rose etc.).When a sample was taken, we recorded the polygon number, plant species and UTM coordinate of the collection location. Samples were kept cold on ice or in a refrigerator and sent cold to ALS Vancouver.

8.1.2. Parameters Collected

The following parameters were measured for all samples and analyzed by the laboratory listed for total metals, including mercury in mg/kg dw (**ALS, Vancouver**)

8.1.3. QA/QC

Field QA/QC procedures for vegetation include focus on contamination control and generation of replicates. Because vegetation has typically very low mercury concentrations, commonly 10- to 100-fold lower than soil, we were very careful to ensure strict division of soil and vegetation sampling to avoid cross-contamination. Thus, for sites designated for vegetation sampling, sampling was conducted by a different person than the one handling soil and clean gloves were used and changed between collection of different vegetation types.

Field duplicate samples were not collected because of the large volume of vegetation that was collected within each bag of which only a small portion is analyzed by the laboratory. It was more important that ALS conduct homogenization duplicates from the submitted samples, in addition to the routine laboratory QA procedures (e.g., use of matrix standards and standard reference materials).

8.2. Results

8.2.1. QA/QC

RPD results from two homogenization duplicates (for dogwood and willow) were very low and did not exceed 13% for any parameter, well below the DQO of ± 25% (**Table 8-1**). Vegetation metals data was very low in general with more than half (13 of 25) of the metals analyzed for being routinely below detection limits. No contamination of vegetation was noted from inadvertent introduction of soils in these QA runs nor from the raw data (**Table 8-2**).

8.2.2. Mercury

Twelve vegetation species (**Table 8-2**) were sampled for total metals including mercury including trees (spruce, balsam, willow), shrubs (sarsaparilla, prickly rose, willow, alder and dogwood) and grasses (horsetail, sedge, reeds, cattail). UTM coordinates of stations where plant collections were made are in **Table 8-2** and photographs appear in **Appendix E**. In some cases, more than one sample of common vegetation types (sarsaparilla, prickly rose, alder, spruce) were collected to provide perspective on possible spatial differences (including up the Moberly River) in plant tissue mercury concentrations. The grass samples were collected from the area known as Watson Slough, a natural wetland and area with naturally higher soil mercury concentrations (e.g., P31 in **Table 7-3**). A full

species list of common vegetation species observed during the soil sampling survey is presented in **Appendix F**.

Total mercury concentration in all plant tissues were very low, in most cases barely above the DL of 0.005 mg/kg dw (dry weight). The most common shrub species sarsaparilla (0.008, 0.011 mg/kg), prickly rose (0.006, 0.006 mg/kg) and alder (0.006 – 0.008 mg/kg) were low and of very similar concentration. Tree species (birch, dogwood, balsam (0.006 – 0.009 mg/kg) were also low in mercury. The sedge species, reed and cattail from Watson Slough had only slightly higher mercury concentrations (0.013 – 0.015 mg/kg) than other vegetation types (**Table 8-2**).

According to Moore et al. (1995), shrubs and trees typically have lower mercury concentrations than other vegetation types such as aquatic macrophytes < moss and lichen < fungi and mushroom. Plants typically accumulate mercury from atmospheric sources, primarily dry and wet deposition (Grigal, 2003), with very small amounts absorbed from water contained in the soil. In general, plant tissue does not transport mercury from inorganic soils via the root system to overlying, terrestrial tissues and very seldom are plants a source of inorganic mercury to biota. In terrestrial plants (leaves and needles of spruce, birch and tamarack; the same as sampled in this study) from northwestern Ontario, total mercury concentrations ranged from 0.005 – 0.23 mg/kg (Grigal, 2003). Plant tissue mercury data from the Peace River region were on the low end of the scale from this study in an equally remote, pristine area of boreal forest in Canada. The current data are also on the low end of the scale reported for other boreal forests in Canada (Bodaly et al., 1987; Rasmussen, 1995), Europe (Grigal, 2003) and Scandinavia (Jensen and Jensen, 1991; Steinnes and Anderson, 1991).

Although we did not measure methyl mercury concentrations, in this study, the percentage of methyl relative to total is expected to be 1%. This was well-documented by Grigal (2003) in an extensive review of the literature.

Table 8-1. QA/QC data for vegetation parameters (mg/kg dw), BC Hydro 2010.

		P49 DOGWOOD			P28 WILLOW		
	MDLs	Original 13-Jul-10	Laboratory Duplicate	RPD (%)	Original 10-Jul-10	Laboratory Duplicate	RPD (%)
TOTAL METALS (mg/kg dw)							
Aluminum	10	<10	<10	NA	15	15	0.0
Antimony	0.050	<0.050	<0.050	NA	<0.050	<0.050	NA
Arsenic	0.050	<0.050	<0.050	NA	<0.050	<0.050	NA
Barium	0.050	10.1	9.90	2.0	2.55	2.39	6.5
Beryllium	0.30	<0.30	<0.30	NA	<0.30	<0.30	NA
Bismuth	0.30	<0.30	<0.30	NA	<0.30	<0.30	NA
Cadmium	0.030	<0.030	<0.030	NA	0.046	0.045	2.2
Calcium	10	18400	17400	5.6	8300	8110	2.3
Chromium	0.50	<0.50	<0.50	NA	0.79	0.71	10.7
Cobalt	0.10	<0.10	<0.10	NA	0.34	0.34	0.0
Copper	0.050	4.67	4.44	5.0	3.06	3.03	1.0
Lead	0.10	<0.10	<0.10	NA	<0.10	<0.10	NA
Lithium	0.50	<0.50	<0.50	NA	5.56	5.53	0.5
Magnesium	3.0	3210	2990	7.1	3800	3600	5.4
Manganese	0.050	19.6	18.2	7.4	61.2	58.0	5.4
Mercury	0.0050	<0.0050	0.0054	NA	0.0093	0.0092	1.1
Molybdenum	0.050	0.315	0.275	13.6	0.181	0.162	11.1
Nickel	0.50	0.87	0.88	-1.1	1.13	1.13	0.0
Selenium	1.0	3.5	3.5	0.0	<1.0	<1.0	NA
Strontium	0.050	42.3	40.7	3.9	71.9	69.9	2.8
Thallium	0.030	<0.030	<0.030	NA	<0.030	<0.030	NA
Tin	0.20	<0.20	<0.20	NA	<0.20	<0.20	NA
Uranium	0.010	<0.010	<0.010	NA	<0.010	<0.010	NA
Vanadium	0.50	<0.50	<0.50	NA	<0.50	<0.50	NA
Zinc	0.50	15.2	14.7	3.3	133	125	6.2

Notes:

RPD = Relative Percent Difference (%) = ((original - duplicate) / (original + duplicate)/2) x 100.

Shaded RPDs exceed 25% (lab duplicates).

NA = RPDs have not been calculated for cases where one of the samples is below detection and the other is not, and in cases where both are below detection.

Concentrations are in dry weight (dw), as reported by the laboratory.

Samples were analyzed by ALS Laboratories, Burnaby, BC.

Table 8-2. Vegetation total metals (mg/kg ww), BC Hydro 2010.

Area	Peace River														Moberly River				
Station ID	P13-B	P17-E	P17-E	P24	P28	P31	P33	P33	P33	P47-A	P49-D	P49-11	P49-15	P99	M2	M2	M2	M5	M6
Species	SARSAPARILLA	ROSE	HORSETAIL	SPRUCE	WILLOW	SEDGE	REEDS	SEDGE	CATTAILS	BALSAM	ALDER	DOGWOOD	ROSE	ALDER	SPRUCE	SARSAPARILLA	DOGWOOD	ALDER	BIRCH
Lab ID	L907154-29	L909386-1	L909386-2	L909386-3	L907154-30	L907154-31	L907154-32	L907154-33	L907154-34	L909386-4	L909386-5	L909386-7	L909386-6	L909948-1	L909948-2	L909948-3	L909948-4	L909948-5	L909948-6
Date	11-Jul-10	15-Jul-10	15-Jul-10	15-Jul-10	10-Jul-10	10-Jul-10	10-Jul-10	10-Jul-10	10-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	13-Jul-10	16-Jul-10	17-Jul-10	17-Jul-10	17-Jul-10	17-Jul-10	17-Jul-10
Sampling Locations[1]																			
UTM Coordinates - Northing	6220600	6226746	6226746	6233263	6234891	6235555	6236008	6236008	6236008	6232923	6232204	6232204	6232204	6234880	6229796	6229796	6229796	6227673	6227618
UTM Coordinates - Easting	583097	590718	590718	600831	605584	606636	607166	607166	607166	616219	617475	617475	617475	614297	628026	628026	628026	625372	623701
Moisture Content (%)	NA	65.9	58.6	58.0	NA	NA	NA	NA	NA	67.3	72.4	67.6	65.3	71.2	45.2	71.7	72.6	69.5	72.7
TOTAL METALS (mg/kg ww)																			
Aluminum	3.9	7.2	<4.1	<4.2	4.6	<4.1	<4.1	<4.1	<4.1	<3.3	3.9	<3.2	3.8	6.3	37.8	5.1	6.0	5.5	6.8
Antimony	<0.015	<0.017	<0.021	<0.021	<0.015	<0.021	<0.021	<0.021	<0.021	<0.016	<0.014	<0.016	<0.017	<0.014	<0.027	<0.014	<0.014	<0.015	<0.014
Arsenic	<0.015	<0.017	<0.021	<0.021	<0.015	<0.021	<0.021	<0.021	<0.021	<0.016	<0.014	<0.016	<0.017	<0.014	<0.027	<0.014	<0.014	<0.015	<0.014
Barium	32	6.6	19.1	17.4	0.77	5.38	1.50	13.4	0.35	7.0	6.3	3.3	3.2	17.7	32.7	24.6	10.2	11.9	15.1
Beryllium	<0.091	<0.10	<0.12	<0.13	<0.091	<0.12	<0.12	<0.12	<0.12	<0.098	<0.083	<0.097	<0.10	<0.086	<0.16	<0.085	<0.082	<0.092	<0.082
Bismuth	<0.091	<0.10	<0.12	<0.13	<0.091	<0.12	<0.12	<0.12	<0.12	<0.098	<0.083	<0.097	<0.10	<0.086	<0.16	<0.085	<0.082	<0.092	<0.082
Cadmium	<0.0091	0.011	0.260	<0.013	0.014	<0.012	0.013	<0.012	0.015	0.360	<0.0083	<0.0097	<0.010	0.080	<0.016	<0.0085	0.066	<0.0092	0.044
Calcium	3767	4331	7286	1835	2522	2525	2836	1797	3416	4415	4775	5962	4962	3254	4209	3453	4137	5094	2681
Chromium	0.21	<0.17	0.78	0.38	0.24	0.31	0.39	0.63	<0.21	<0.16	<0.14	<0.16	0.18	0.16	1.00	<0.14	0.18	0.16	0.20
Cobalt	<0.030	<0.034	<0.041	<0.042	0.10	<0.041	<0.041	<0.041	0.05	0.05	<0.028	<0.032	<0.035	<0.029	<0.055	<0.028	<0.027	<0.031	<0.027
Copper	1.71	1.54	2.44	1.43	0.93	1.36	2.50	2.29	2.90	1.96	1.02	1.51	1.91	1.13	1.69	1.50	1.36	2.83	1.68
Lead	<0.030	<0.030	<0.041	<0.042	<0.030	<0.041	<0.041	<0.041	<0.041	<0.033	<0.028	<0.032	<0.035	<0.029	<0.055	<0.028	<0.027	<0.031	<0.027
Lithium	<0.15	<0.17	<0.21	<0.21	1.69	1.59	1.92	1.14	1.47	<0.16	<0.14	<0.16	<0.17	<0.14	0.62	<0.14	<0.14	<0.15	<0.14
Magnesium	1154	1279	1134	284	1154	1929	1039	741	1350	974	875	1040	1520	660	559	855	847	946	652
Manganese	24.0	12.4	4.4	6.6	18.6	88	300	43	559	7.5	6.0	6.4	10.7	4.1	17.9	11.0	6.5	3.3	17.2
Mercury	0.0032	0.0023	<0.0021	<0.0021	0.0028	0.0060	0.0064	0.0058	0.0053	0.0025	0.0023	<0.0016	0.0022	0.0016	0.0102	0.0023	0.0025	0.0022	0.0016
Molybdenum	0.200	0.222	0.484	0.082	0.055	0.679	0.139	0.173	0.396	0.059	0.182	0.102	0.082	0.097	0.367	0.100	0.048	0.274	0.086
Nickel	0.23	0.27	1.04	0.32	0.34	0.61	0.71	0.72	0.37	0.49	0.30	0.28	0.28	0.16	0.68	0.21	0.19	0.45	0.63
Selenium	<0.30	0.5	6.0	<0.42	<0.30	<0.41	<0.41	<0.41	<0.41	<0.33	<0.28	1.1	1.2	0.5	<0.55	<0.28	<0.27	<0.31	<0.27
Strontium	7.6	10.7	22.1	10.4	21.8	17.9	13.7	9.81	15.0	11.1	10.4	13.7	11.3	8.4	10.4	6.3	6.9	12.6	4.6
Thallium	<0.0091	<0.010	<0.012	<0.013	<0.0091	<0.012	<0.012	<0.012	<0.012	<0.010	<0.0083	<0.0097	<0.010	<0.0086	<0.016	<0.0085	<0.0082	<0.0092	<0.0082
Tin	<0.061	<0.068	<0.083	<0.084	<0.061	<0.083	<0.083	<0.083	<0.083	<0.065	<0.055	<0.065	<0.069	<0.058	<0.11	<0.057	<0.055	<0.061	<0.055
Uranium	<0.0030	<0.0034	<0.0041	<0.0042	<0.0030	<0.0041	<0.0041	<0.0041	<0.0041	<0.0033	<0.0028	<0.0032	<0.0035	<0.0029	<0.0055	<0.0028	<0.0027	<0.0031	<0.0027
Vanadium	<0.15	<0.17	<0.21	<0.21	<0.15	<0.21	<0.21	<0.21	<0.21	<0.16	<0.14	<0.16	<0.17	<0.14	<0.27	<0.14	<0.14	<0.15	<0.14
Zinc	10.4	6.0	7.7	20.5	40.4	13.8	21.4	22.2	12.1	61.5	4.2	4.9	4.5	6.5	31.5	6.3	6.3	10.2	45.3

[1]UTM coordinates are in NAD83 for Zone 10V.

Concentrations were converted to wet weight (ww) using moisture content for each sample or using the average moisture content of samples from similar plant types, for those without sample-specific moisture content measurements.

< DL values were also converted to wet weight using the same method as described for all other concentration measurements.

Samples were analyzed by ALS Laboratories, Burnaby, BC.

9. GENERAL SUMMARY

Together, the data collected in 2010 suggest that mercury and methyl mercury concentrations from all environmental media in the Peace River, upstream in Dinosaur Reservoir and in major tributary sources upstream of Site C are very low and characteristic of background conditions in remote, pristine systems. Chemical conditions in water and zooplankton are very similar to what has been observed in Williston Reservoir and from a mercury perspective concentrations have not changed since 2001, indicating very stable conditions. In particular, mercury concentrations in all fish species for which we have data are very low and among the lowest concentrations observed from other lakes and reservoirs in British Columbia and elsewhere in Canada. Similarly, inorganic and methyl mercury concentrations in organic soils within the forecast flood footprint of Site C are low and again, typical of pristine, remote soils removed from anthropogenic or elevated natural sources of mercury.

Notwithstanding small deficiencies in our understanding of mercury in environmental media in the Peace River (e.g., small sample size of benthic invertebrates, limited temporal extent of data) our overall conclusion is that mercury concentrations are low, spatially consistent within and between Dinosaur Reservoir and the Peace River downstream to Site C and at least for water and zooplankton, have not changed over the last 10+ years, based on Williston data. Furthermore, we do not perceive any significant gaps in our understanding that would impair or preclude mechanistic mercury modeling, using RESMERC or another similar model, to predict concentrations of mercury in environmental media within the proposed Site C reservoir. This is important because having good confidence in predicted elevations in fish mercury concentrations above baseline is important, given that exposure to mercury from fish consumption is the largest driver of potential risks to fish-eating wildlife species and to humans, especially First Nations and other domestic and sport fish fishermen.

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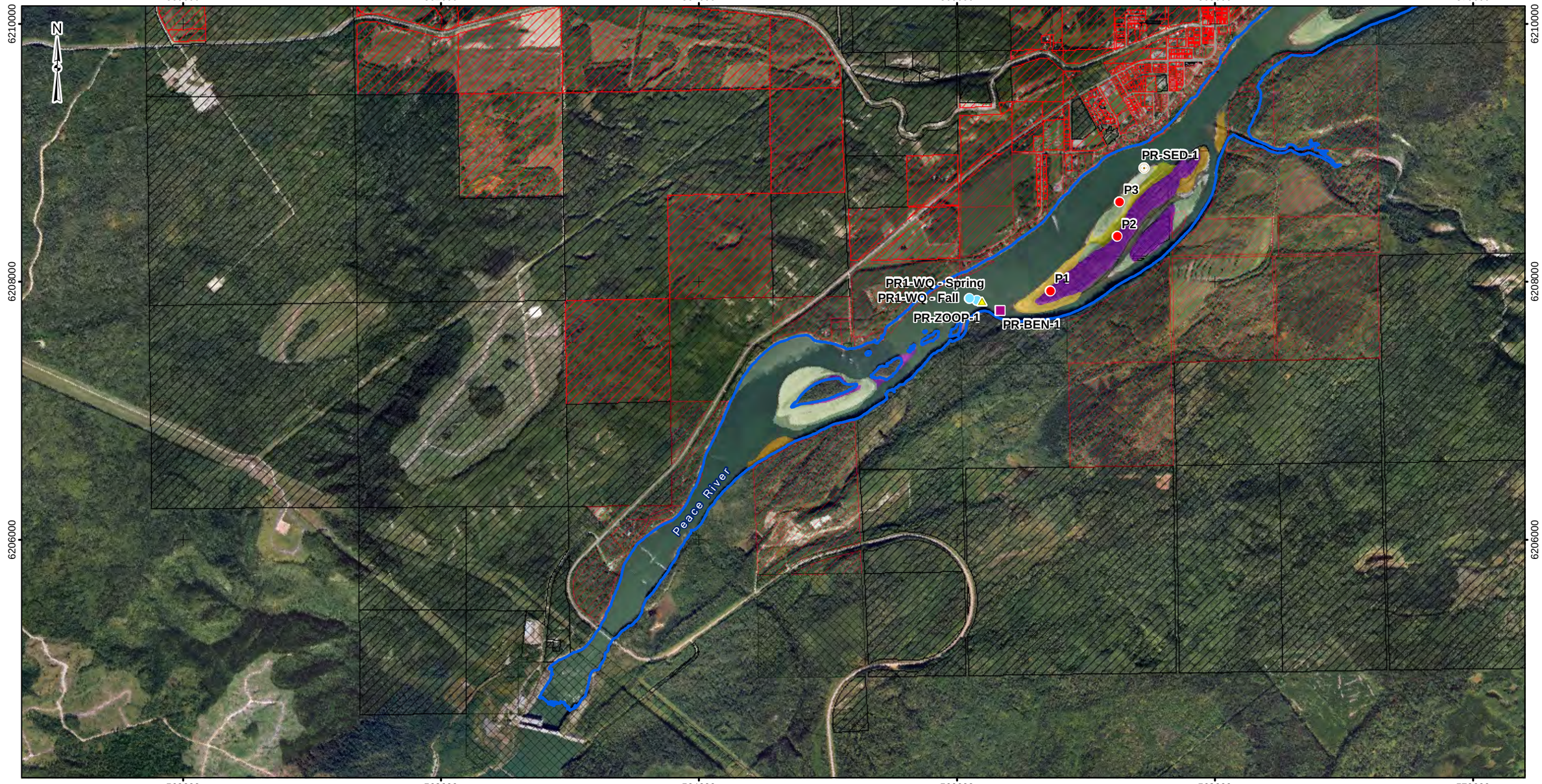
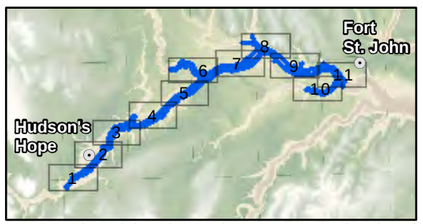
APPENDICES

APPENDIX A

PEACE RIVER MAP SERIES (MAP 1 – MAP 11)





MAP NOTES:
1. Datum: NAD83
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Proposed Reservoir

Property Status
- Crown Land
- Private Land
- BC Hydro Owned/Leased Land

Target Habitat
- BT
- CF
- Fm02
- SE
- SH
- SW
- TS
- WH

- **Soil Samples**
- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

SITE C CLEAN ENERGY PROJECT

BC hydro

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 1 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

Construction of the Site C Clean Energy Project is subject to required regulatory approvals including environmental certification.

566000 568000 570000 572000 574000 576000

6214000

6212000

6210000

N

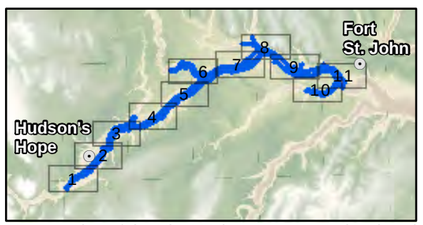
Lynx Creek

Peace River

P6

P5

P4



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- CF
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- SH
- SW
- TS
- WH

- **Soil Samples**
- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

SITE C CLEAN ENERGY PROJECT

BC hydro

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 2 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

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570000 572000 574000 576000 578000 580000

6220000

6218000

6216000

N

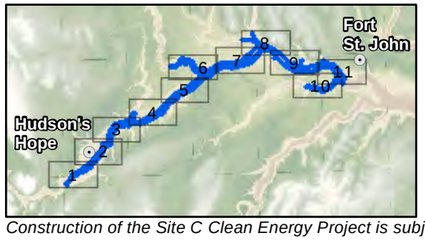
Dry Creek

Farrell Creek

Peace River

FER-WQ - Spring
FER-WQ - Fall
FER-SED

P9
P11-B
P11-A
P8



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Target Habitat
- BT
- CF
- Fm02
- SE
- SH
- SW
- TS
- WH

- **Soil Samples**
- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

SITE C CLEAN ENERGY PROJECT

BC hydro

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 3 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

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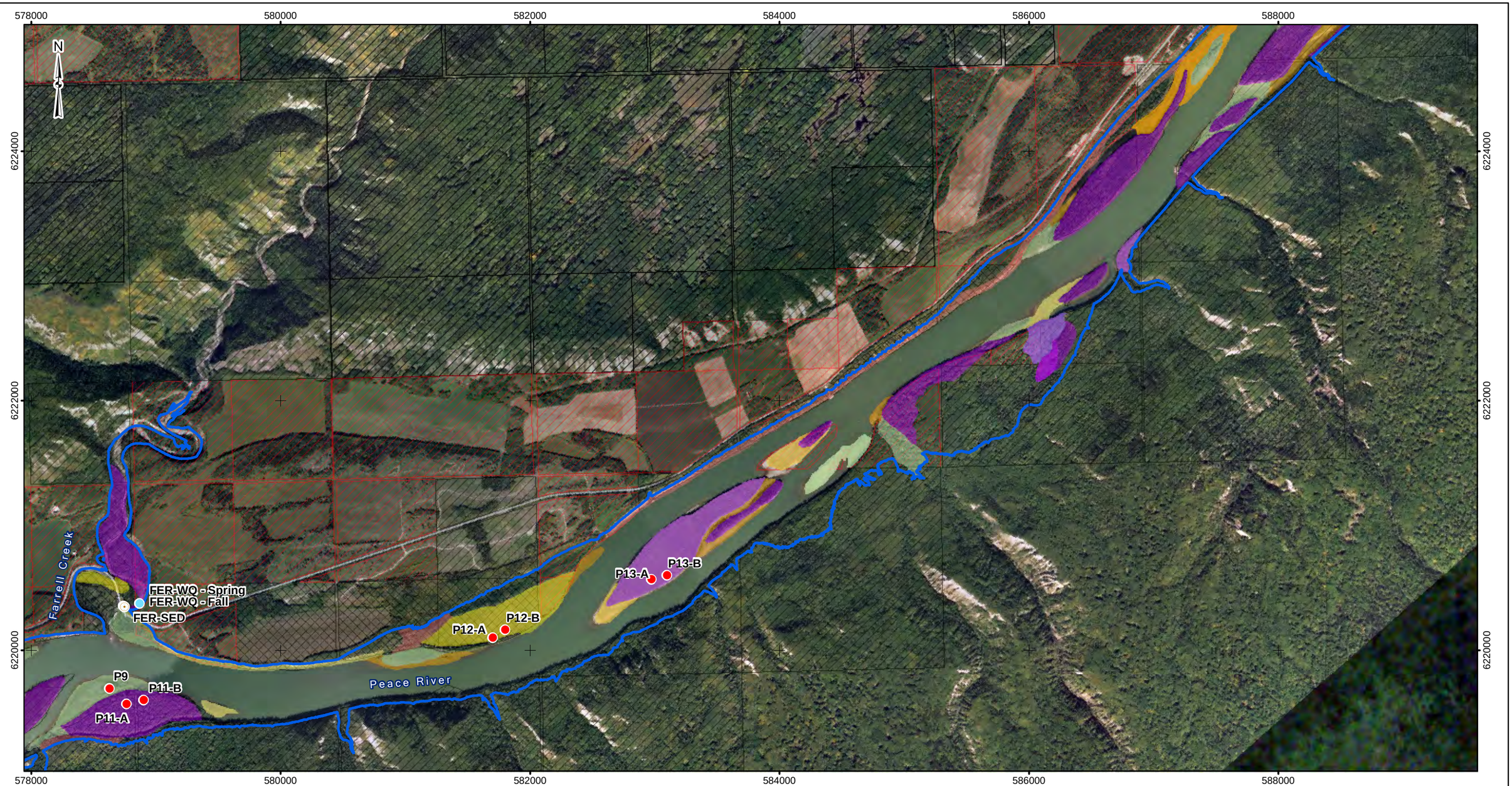

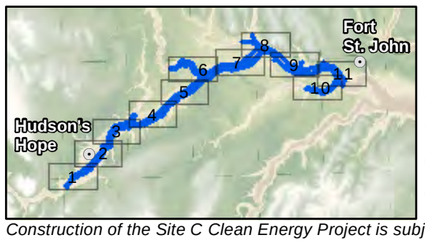

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Target Habitat
- BT
- CF
- Fm02
- SE
- SH
- SW
- TS
- WH

- **Soil Samples**
- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

SITE C CLEAN ENERGY PROJECT

BC hydro

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 4 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

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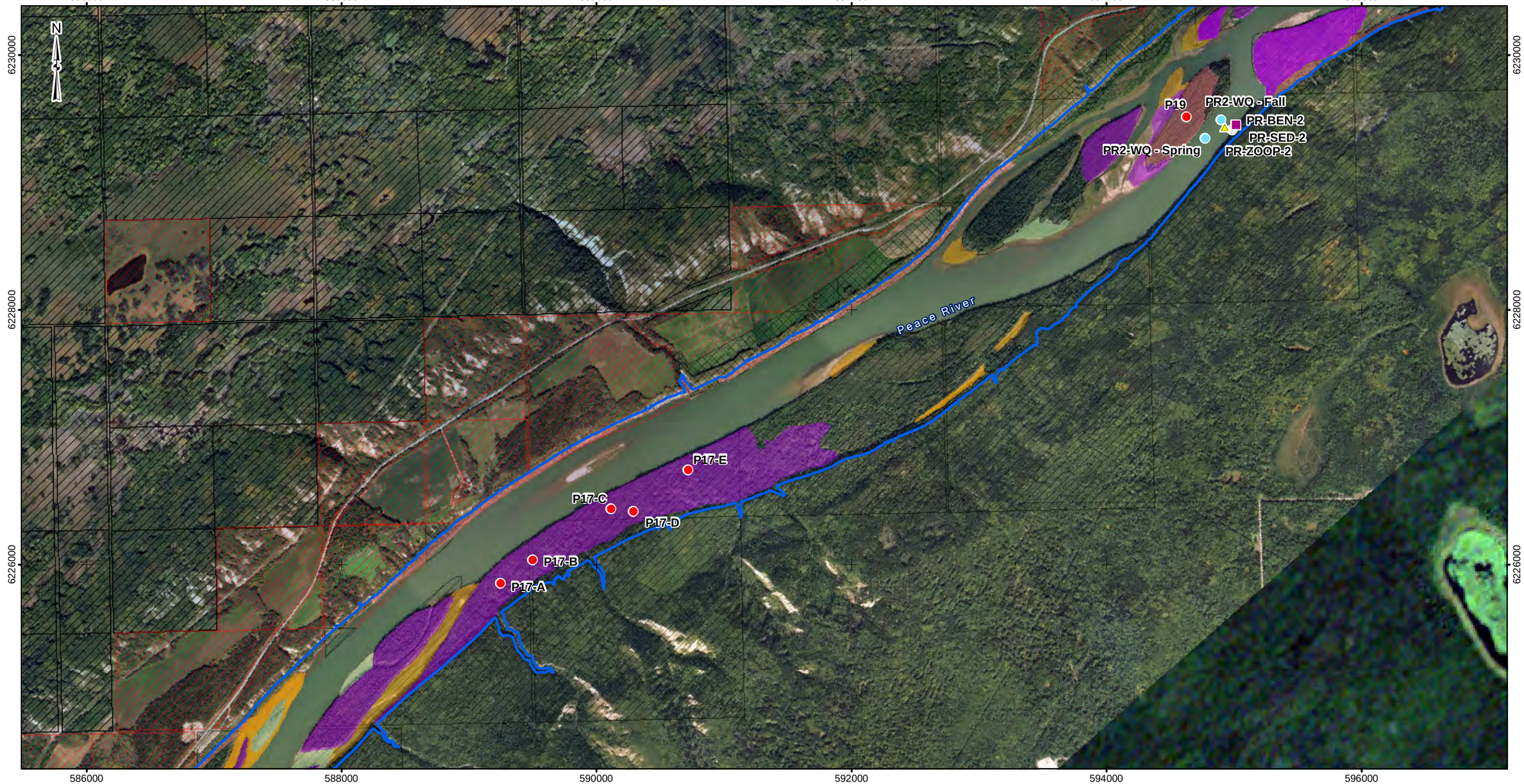

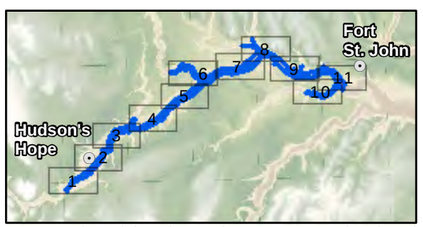

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Proposed Reservoir

Property Status
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- Private Land
- BC Hydro Owned/Leased Land

Target Habitat
- BT
- CF
- Fm02
- SE
- SH
- SW
- TS
- WH

- **Soil Samples**
- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

BC hydro

SITE C CLEAN ENERGY PROJECT

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 5 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

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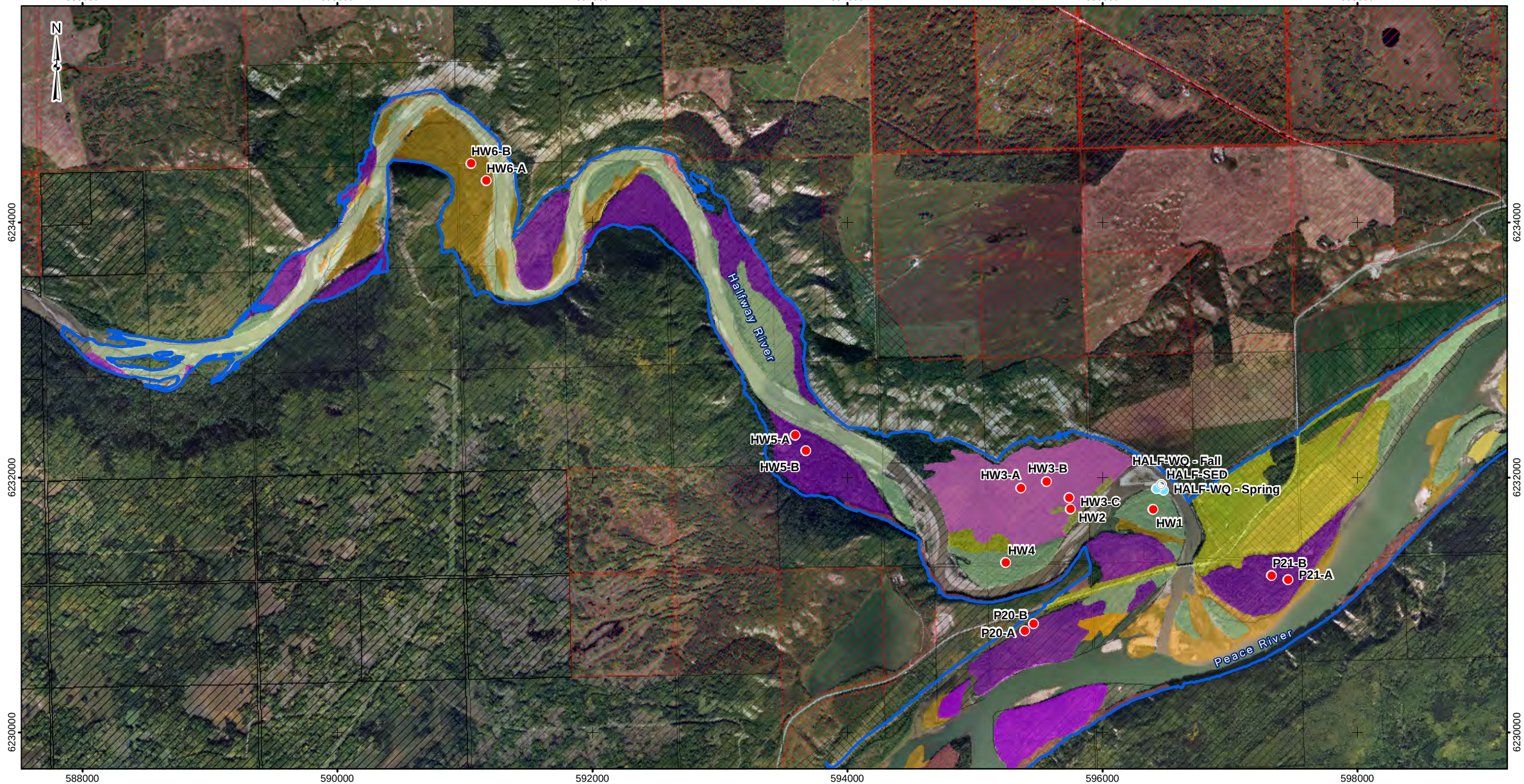

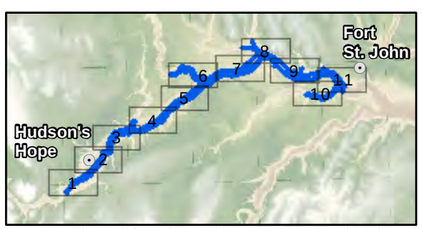

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Proposed Reservoir

Property Status
- Crown Land
- Private Land
- BC Hydro Owned/Leased Land

Target Habitat
- BT
- CF
- Fm02
- SE
- SH
- SW
- TS
- WH

- **Soil Samples**
- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

SITE C CLEAN ENERGY PROJECT

BC hydro

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 6 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

Construction of the Site C Clean Energy Project is subject to required regulatory approvals including environmental certification.

600000 602000 604000 606000 608000 610000

6236000

6234000

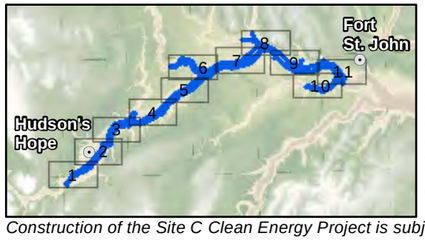
6232000

N

Watson Slough

Peace River

P38-A
P38-B
P35-C
P39
P37
P35-B
P33
P34
P35-A
P32
P31
P30
P29
P28
P25-A
P25-B
P25-C
P24
P23



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Proposed Reservoir

Property Status
- Crown Land
- Private Land
- BC Hydro Owned/Leased Land

Target Habitat
- BT
- CF
- Fm02
- SE
- SH
- SW
- TS
- WH

- **Soil Samples**
- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

BC hydro

SITE C CLEAN ENERGY PROJECT

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 7 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

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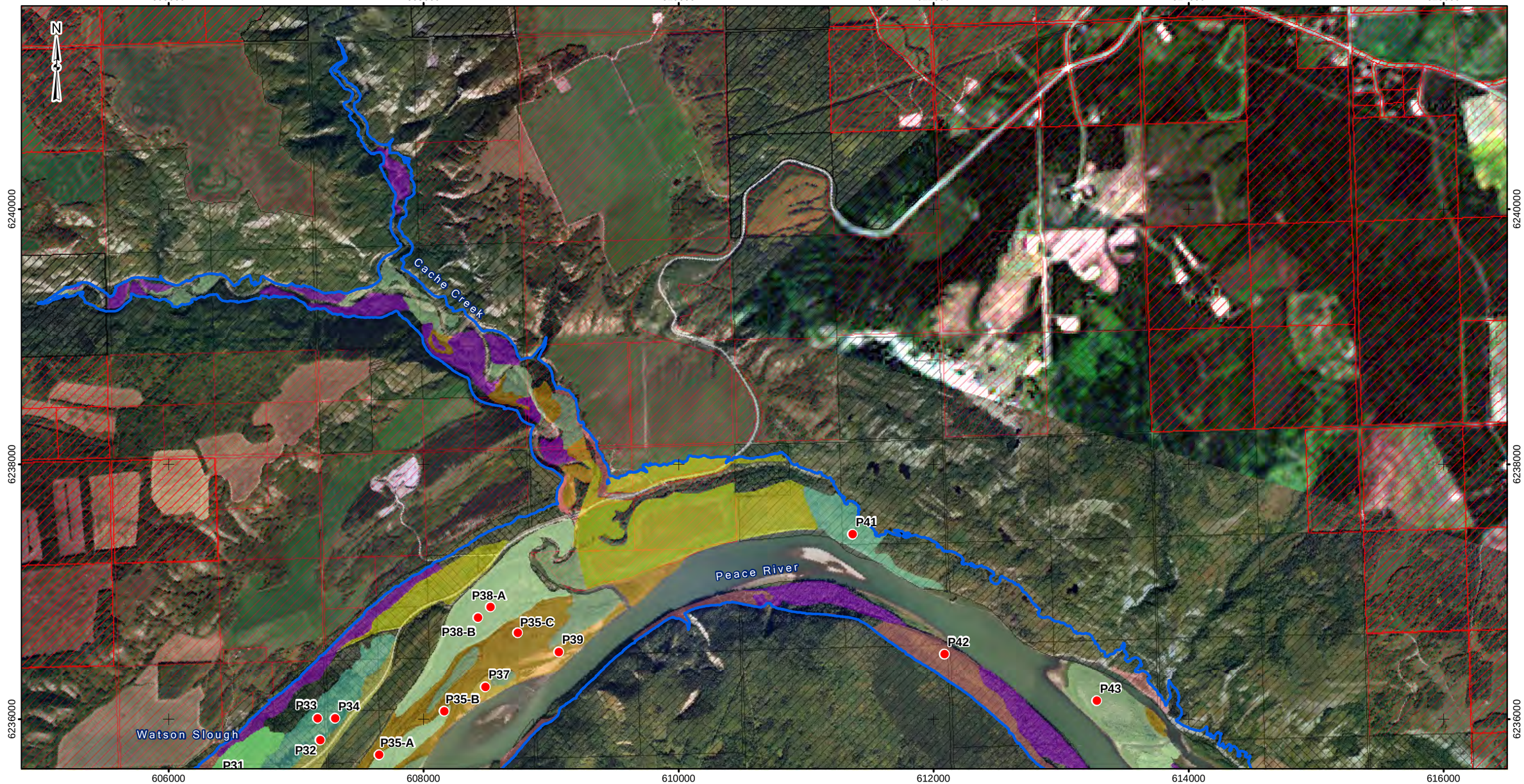

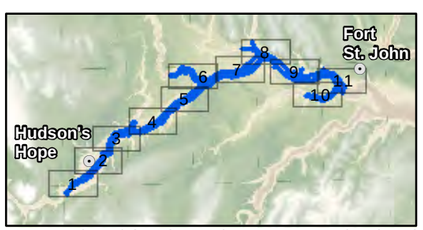

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- CF
- Fm02
- SE
- SH
- SW
- TS
- WH

- **Soil Samples**
- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

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BC hydro

SITE C CLEAN ENERGY PROJECT

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 8 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

612000 614000 616000 618000 620000 622000

6236000

6234000

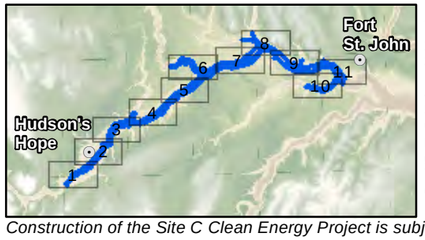
6232000

N

P12 P43 P44 P99 P46-A P46-C P46-B P48 P47-B P47-A P49-C P49-D P49-B P49-A P50 P56 P55

Peace River

Wilder Creek



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- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

BC hydro

SITE C CLEAN ENERGY PROJECT

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 9 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

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618000 620000 622000 624000 626000 628000

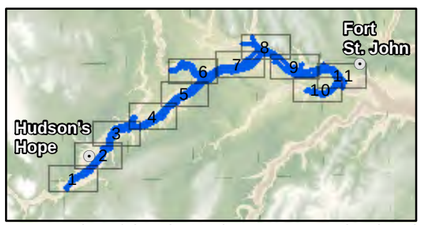
6230000

6228000

6226000

N

PR3-WQ - Fall
PR-BEN-3
PR3-WQ - Spring
PR-SED-3
PR-ZOOP-3
M1
M2
M3
M4
M5
M6
MOB-SED
MOB-WQ - Spring
MOB-WQ - Fall
Moberly River



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- CF
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- SW
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- WH

- **Soil Samples**
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- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

SITE C CLEAN ENERGY PROJECT

BC hydro

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 10 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

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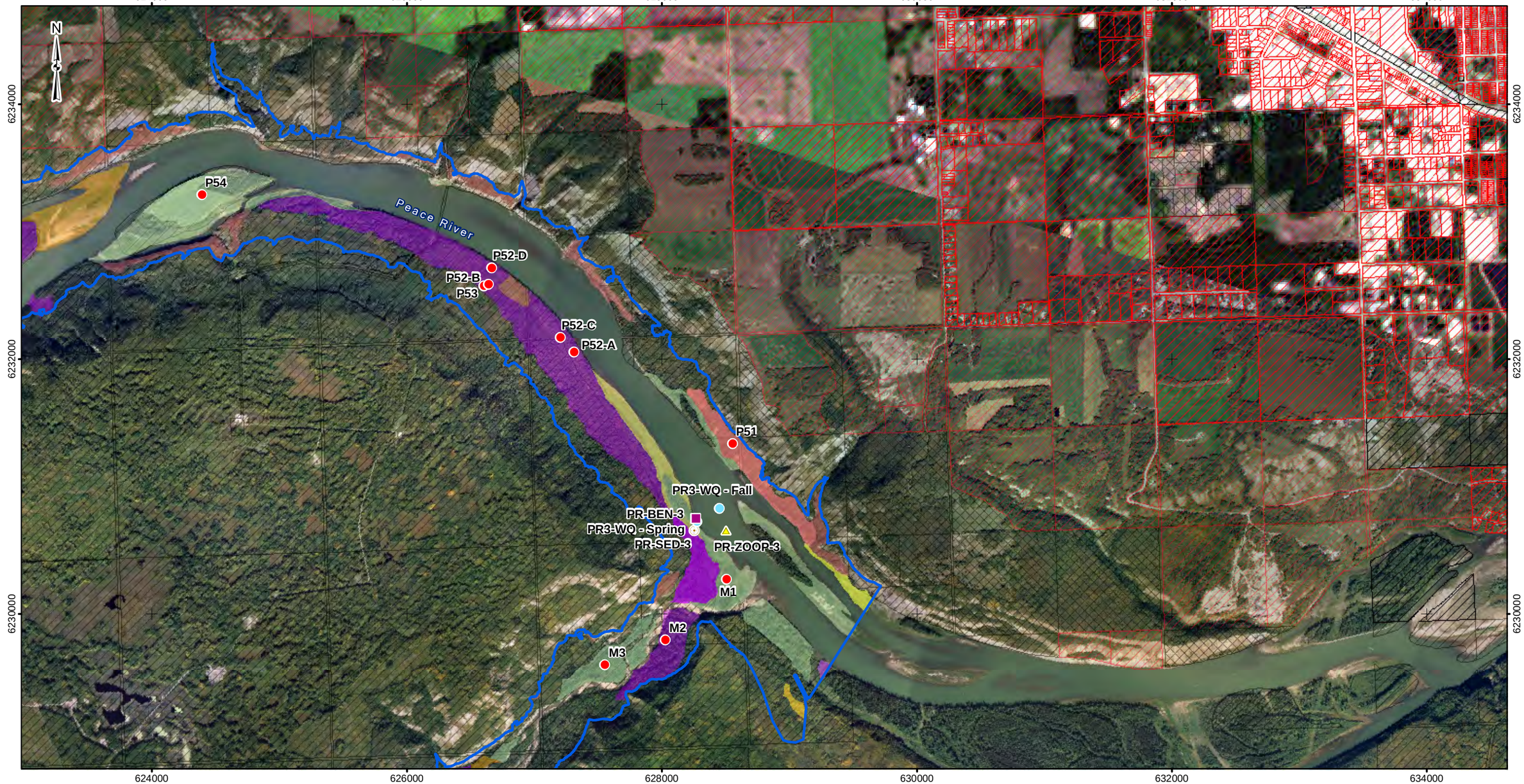

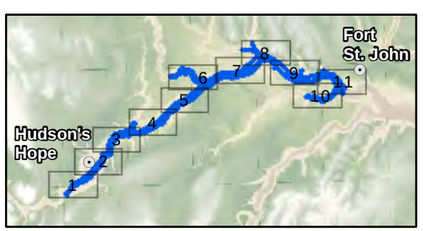

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- WH

- **Soil Samples**
- **Benthos Samples**
- **Sediment Samples**
- **Water Samples**
- **Zooplankton Samples**

BC hydro

SITE C CLEAN ENERGY PROJECT

Site C
Target Habitat Mapping for Mercury Sampling
Soil and Water Sample Plot Locations

Map 11 of 11

DATE	SEP 2011	DWG NO	1016-C14-B4134	R 0

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APPENDIX B

REQUIRED MODEL INPUTS FOR RESMERC MERCURY MODEL

Appendix B. Required Model Inputs for RESMERC Mercury Model.

Model Input Category	Model Input Parameter	Status		
		Data Already Available?	Identified by Azimuth for 2010 Field Collection	Additional Monitoring or Estimation Required
Physical	Original waterbody area	☑		
	Flooded wetland area (for each sediment zone)		Existing?	post flood
	Flooded upland area (for each sediment zone)		Existing?	post flood
	Bathymetry		Existing?	post flood
	Ice cover period	☑		post flood
	Surface water elevations	☑		post flood
Hydrologic	Monthly inflow and outflow flowrates	☑		
	Monthly precipitation	☑		
Physical/Chemical	Temperature (vertical, seasonal)	☑	pre flood	post flood
	Thermocline elevations (if relevant)	☑		post flood
	Oxygen	☑	pre flood	post flood
	pH	☑	pre flood	post flood
	Surface light exposure		pre flood	post flood
	DOC	☑	pre flood	post flood
	Selenium		pre flood	post flood
	TSS (hypo, epilimnion)	☑	pre flood	post flood
	Organic Content of TSS		pre flood	post flood
	Sulfate and Sulfide (if relevant)	☑	pre flood	post flood
	Chloride	☑	pre flood	post flood
Non-Hg Soil / Sediment Characterization	Soil porosity, density, horizon depths		☑	
	Organic carbon content, labile carbon?		☑	
Uplands, Wetlands, Sediments	Porewater chemistry: pH / DOC/ sulfate, sulfide (if relevant)			☑
	Vegetation types in flood zone		☑	☑
	Vegetation biomasses in flood zone (per m2)			☑
Biological	Zooplankton productivity / species composition	☑	☑	☑
	Benthic productivity / species composition	☑	☑	☑
	Fish species composition	☑	☑	☑
	Fish diet		☑	☑
	Fish growth rates	☑	☑	☑
	Fishing loss (harvesting)	☑	☑	☑
Mercury Data	Baseline Fish THg	☑	☑	
	Baseline MeHg in zooplankton and benthos		☑	
	Tribuary THg and MeHg (to estimate Hg loads)		☑	☑
	THg concentrations in precip	☑		☑
	THg and MeHg in soils and sediments (solids, pw useful)		☑	
	THg & MeHg in water col (ep/hypo if relevant, unfilt/particle phase)		☑	

APPENDIX C

SINLAB INTERPRETATION GUIDE

SINLAB INTERPRETATION GUIDE

Methodology

Samples in the SINLAB are analyzed for $\delta^{13}C$ and $\delta^{15}N$ using either a Thermo-Finnigan Delta Plus or Delta XP isotope-ratio mass spectrometer (Bremen, Germany) interfaced with a Carlo Erba NC2500 Elemental Analyzer (Milan, Italy) via the Conflo II or Conflo III, respectively. This is a continuous flow system using helium as a carrier gas. Samples are weighed into tin capsules, loaded into an AS128 autosampler and converted to a gaseous state via combustion.

Combustion occurs in a quartz tube filled with chromium oxide and silver cobaltous at a temperature of 1050^0C. A second quartz tube set at 780^0C is filled with copper and used for the reduction of nitrogen oxide to N2. CO_2 and N_2 peaks are separated while passing through a standard 2m GC column. A water trap of magnesium perchlorate & silica chips is located just prior to the GC column to remove water and other impurities.

Carbon and nitrogen data for animal tissues are corrected with three standards – NICOTINAMIDE, BLS, and SMB-M (See standards section below). Data for sediments and plant material are corrected with IAEA standards CH6, CH7, N1 and N2. All of these standards are calibrated against Peedee Belemnite carbonate (PDB) and atmospheric nitrogen (AIR) for carbon and nitrogen, respectively. Data are provided to clients in the form of an excel spreadsheet via email. Hard copies of the data may be obtained by request.

Column Headings

SINLAB ID = ID code assigned to the client's samples; each client is given (typically) a three letter identifier and samples numbered sequentially (starting at 001).
Date = date sample was analyzed in the lab
Position = position in the analytical "run" for that particular day; samples are weighed into 96-well ELISA trays, so a normal animal tissue run will consist of 73 client samples, 22 standards, and 1 blank
Weight = weight of the tissue analyzed; animal tissues are weighed at 0.200 ± 0.020 milligrams and plant tissues are weighed at 1.000 ± 0.200 milligrams.
CO2 amp = the amount of CO_2 gas measured on the mass spectrometer, a function of the weight of tissue used and the amount of carbon (%C) it contains
N2 amp = the amount of N_2 gas measured on the mass spectrometer, a function of the weight of tissue used and the amount of nitrogen (%N) it contains
$\boldsymbol{\delta^{13}C}$ = ratio of carbon-13 to carbon-12 in the sample according to the formula: $\delta^{13}C = [(R_{sample}/R_{standard})-1]*1000$ where R is $^{13}C/^{12}C$ and the standard is PDB (see above)
$\boldsymbol{\delta^{15}N}$ = ratio of nitrogen-15 to nitrogen-14 in the sample according to the formula: $\delta^{15}N = [(R_{sample}/R_{standard})-1]*1000$ where R is $^{15}N/^{14}N$ and the standard is AIR (see above)
%C = percent of the sample that is carbon by weight; e.g. 200 ug sample with 40% carbon has 80 ug carbon by weight
%N = percent of the sample that is nitrogen by weight; e.g. 200 ug sample with 10% nitrogen has 20 ug nitrogen by weight
C/N = Ratio of carbon to nitrogen in the sample; simple division of %C by %N

Standards

CH6 = sucrose standard issued by the International Atomic Energy Agency ($\delta^{13}C$ = -10.4‰)*
CH7 = polyethylene foil standard issued by the International Atomic Energy Agency ($\delta^{13}C$ = -31.8‰)*
N1 = ammonium sulfate standard issued by the International Atomic Energy Agency ($\delta^{15}N$ = 0.4‰)*
N2 = ammonium sulfate standard issued by the International Atomic Energy Agency ($\delta^{15}N$ = 20.3‰)*
ACETANILIDE = commercially available pure compound ($\delta^{13}C$ = -33.2‰, $\delta^{15}N$ = -1.1‰)
NICOTINAMIDE = commercially available pure compound ($\delta^{13}C$ = -34.2‰, $\delta^{15}N$ = -1.8‰)
BLS = bovine liver standard – developed by SINLAB ($\delta^{13}C$ = -18.7‰, $\delta^{15}N$ = 7.3‰)
SMB-M = smallmouth bass muscle – developed by SINLAB ($\delta^{13}C$ = -23.3‰, $\delta^{15}N$ = 12.4‰)
NIST 1547 = peach leaves ($\delta^{13}C$ = -25.7‰, $\delta^{15}N$ = 1.9‰)
NIST 8438 = wheat flour ($\delta^{13}C$ = -25.7‰, $\delta^{15}N$ = 4.4‰)
NIST 2711 = Montana soil ($\delta^{13}C$ = -17.1‰, $\delta^{15}N$ = 7.4‰)

Note: Isotope ratios for standards marked with asterisks (*) are those that are internationally accepted; others are values for the current batch measured by SINLAB.

Comment Codes

NR = no repeat; sample tissue volume too small to allow another analysis
Low amps = low amount of gas entering the mass spectrometer; normally isotope data generated with a sample that yields a value below 0.5 volts should be interpreted with caution
2nd N2 peak = likely a result of CO presence; client should consider repeating sample
Didn't drop = equipment malfunction wherein autosampler fails to turn; often leads to a "double-up" with the following sample
Double-up = two samples drop together
Drift = electronic phenomenon whereby isotope ratios shift slowly through time; this can be corrected for by using standards throughout the run
Lipid-rich = sample appeared to be oily when being weighed
Sample sticking out = material sticking out from edges of tin cup; common with feather samples
Whole bug = individual analyzed without grinding
Half bug = half of individual analyzed without grinding, normally cut in half along longitudinal plane
Double cup = two tin cups stuck together; can potentially cause interference with isotope ratio measurement
Large tin cup = necessary when sample is low in %C or %N and more tissue is required to obtain data
Max out = too much CO_2 or N_2 entering the mass spectrometer, beyond the capacity to measure; no data provided
Reduction tube chemicals = chemicals nearing exhaustion (typically changed every 500 samples); interpret data with caution
Spike = electronic malfunction that causes delta value to deviate dramatically from normal; no data provided
1/4, 1/8, 1/16, 1/32 = indicates the size of a filter paper sample that was cut into a "pie-slice" for analysis
Scraped from paper = filtered tissue was scraped from the top of filter rather than analyzed as a "pie slice"
Poor repeat = a delta value that is considerably different than when the sample was run previously; normally values within 0.5‰ are considered adequate, however certain tissue types (e.g. fish muscle) will give better repeats than others (e.g. fin clips, pooled invertebrates) due to differences in sample homogeneity

Reintegrated = computer error or sample peak wide/distorted, requiring manual adjustment; interpret data with caution
Lipid extraction = common technique to remove lipids (that have different $\delta^{13}C$ than proteins and carbohydrates) from tissues such as liver, eggs, and muscle of some marine fishes
Acid treatment = common technique to remove non-dietary carbonates (that have different $\delta^{13}C$ than organic tissue) from organisms such as shellfish

Colours

Gray shading = repeated sample as part of regular QA/QC routine (four of every 73 samples) – same day – or because problems suspected with data – different days
Red text = highlights low amps or a poor repeat (see above for definitions)

Questions about this document

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