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## BRITISH COLUMBIA - NORTHWEST TERRITORIES BILATERAL WATER MANAGEMENT AGREEMENT

# Liard and Petitot River Basins State of Knowledge Report


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REPORT


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# LIARD AND PETITOT RIVER BASINS STATE OF KNOWLEDGE REPORT

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# Executive Summary

The Northwest Territories (NWT), Canada, British Columbia (BC), Alberta, Saskatchewan, and Yukon signed the Mackenzie River Basin Transboundary Waters Master Agreement in July 1997, which created the Mackenzie River Basin Board. This agreement committed all six governments to work collaboratively to manage the water resources of the whole Mackenzie River Basin and created a framework for neighbouring jurisdictions to negotiate bilateral water management agreements to address transboundary water issues.

In October 2015, the Governments of the NWT and BC signed the Mackenzie River Basin Bilateral Water Management Agreement. The objective of this agreement is to guide management actions using a risk-informed management approach to determine what actions should be taken and when based on scientific monitoring, local and traditional knowledge, and other sources.

This report provides a summary of the state of knowledge of the Liard and Petitot Rivers Surface Water and Groundwater basins, including traditional and scientific knowledge, and identifies the existing body of knowledge, current monitoring programs, and knowledge gaps. It is anticipated that this report will guide the development of Learning Plans as required under the Mackenzie River Basin Bilateral Water Management Agreement.

## Watershed Profiles

The Groundwater Study Area as defined by the MRB BWMA, includes areas in BC, Yukon and NWT and ends at the confluence of the Liard and Nahanni rivers near the community of Nahanni Butte. The BWMA does not include the Liard River from Nahanni Butte to its confluence with the Mackenzie at Fort Simpson and therefore the Groundwater Study Area follows this delineation.

The Surface Water Study Area includes the entire portion of the Liard River basin upstream of Fort Simpson and the entire Petitot River sub-basin. For consistency with the Groundwater Study Area, the Nahanni basin was also excluded from the Surface Water Study Area because it is not a BWMA transboundary tributary.

The geographic extent of the Surface Water Study Area include NWT, BC, Yukon and Alberta and the communities of Lower Post, Fort Nelson, Trutch, and Dease Lake in BC; Watson Lake, Rancheria, and Frances Lake in Yukon; and Fort Liard in the NWT. There are no established communities in Alberta within the Study Areas.

The ecozones within the Study Areas include the Taiga Plains and the Boreal Cordillera. The Taiga Plains ecozone is dominated by Canada's largest river, the Mackenzie River, and spans the southwest corner of NWT, the northwest corner of Alberta and the northeast corner of BC. This ecozone is characterized by low precipitation and is dominated by slow-growing conifer forests of black spruce; it is the northern extension of the flat interior plains. It is underlain by horizontal sedimentary rock (limestone, shale and sandstone) and the rolling topography is predominantly covered with organic deposits. Low lying wetlands cover 25 to 50% of the ecozone. Discontinuous permafrost is present within the ecozone, with an increased coverage within the northern reach of the ecozone.

Bordered by northern BC and southern Yukon, the Boreal Cordillera ecozone makes up the rest of the Study Areas. This ecozone's vegetation ranges from open to closed canopies over much of the valley and plateau area, to sedge-dominated meadows and lichen-colonized rocks within the extensive rolling alpine tundra located at higher elevations. This ecozone has greater precipitation than the Taiga Plains due to the mountain ranges which run throughout the ecozone. Permafrost is widespread in the northern portion of the ecozone and at higher elevations.

The Study Areas can experience rainfall year-round, with the majority occurring from May to September each year. Snowfall can occur from August to June each year, with the majority of snowfall from October to April. At higher elevations, snowfall may occur throughout the year.

The Liard and Petitot River basins have severe topographic relief; this range of topographic relief is present because the Surface Water Study Area spans mountain ranges including the Northern Rocky Mountains and the Pelly Mountains, as well as low lying uplands in western NWT, northwestern Alberta and northeastern BC.

The Liard and Petitot River basins within the Surface Water Study Area have half of their surficial geology comprised of till blanket in the uplands adjacent to the Rocky Mountain and Pelly Mountain ranges. This is a result of glacial activity eroding bedrock and depositing till, sand and gravel. Till veneer and alpine complexes comprise most of the other half of surficial geology in the Surface Water Study Area. In the Ground Water Study Area, till blanket comprises just over half of the surficial geology, with another approximately fifth of the surficial geology comprised of colluvial rubble and till veneer.

Coniferous forest comprises nearly half of the Surface Water Study Area with mixed forest comprising a third and tundra comprising a tenth of the Surface Water Study Area. The primary ecoregions which host this vegetation include the Northern Alberta Uplands, Liard Basin, Boreal Mountains and Plateaus and the Northern Canadian Rocky Mountains ecosystems.

Four land and resource management plans are currently in use in the groundwater or surface water, or both, Study Areas: Fort Nelson Land and Resource Management Plan, Muskwa-Kechika Management Area, Dehcho Land Use Plan (submitted in 2006 and not yet been approved by the NWT), and Dease-Liard Sustainable Resource Management Plan. These plans are intended to specify resource values and management objectives to provide guidance on the protection of lands, management objectives and strategic development of lands.

## Historic and Current Surface Water Uses

The Study Areas are located in an area of use by multiple Aboriginal groups and partially overlaps portions of Treaty 8. The Study Areas have historically been occupied by people who speak one of the languages of the Dene (Athabaskan) or Algonquian language families. Current linguistic groups in the region include Dene K’e (Dene, Dene Tha’, Acha’otinne), (Kaska; Kaska Dena), Dane-Zaa (Beaver; Dunne-za), and Nēhiyawēwin (Cree). Traditional uses involve trapping and hunting, fishing, plant gathering, and navigation.

The following Aboriginal groups were identified as having territory used, or valued for traditional purposes, overlapping the Study Areas through use of the BC First Nations Consultative Areas Database (BC 2016) and a comparison of publicly available land use and traditional territory maps:

- Acho Dene Koe First Nation (ADK);
- Blueberry River First Nations (BRFN);
- Deh Cho First Nations (Deh Cho);
- Dene Tha First Nation (Dene Tha);
- Kaska Dena, which includes Dease River First Nation, Daylu Dena Council, Kwadacha Nation, Liard First Nation and Ross River Dena Council (Kaska Dena Council 2010);
- Fort Liard Métis (FLM);

- Fort Nelson First Nation (FNFN); and
- Members of Treaty 8 Tribal Association include Doig River First Nation (DRFN), Halfway River First Nation (HRFN), Prophet River First Nation (PRFN), and West Moberly First Nations (WMFN).

There are a variety of users in the Study Areas who currently have issued water licences pertaining to surface water allocation, including municipal and governmental water licences used for public water supply and infrastructure, private licences for both industry and private residents, as well as other licences which are unclassified. Private users account for 85% of licenced water withdrawals within the Surface Water Study Area in a worst case scenario. This water allocation is largely for mining, oil and gas exploration, hydroelectric power and private residential water supply activities.

Tourism and recreation in the Study Areas are based on large areas untouched wilderness, big-game wildlife, navigable waterways and highways. Tourism is concentrated in the summer season, when tourist attractions are open, although there are a few winter based recreational activities which draw tourists. Highlights which draw tourist and recreational activity include the following:

- Sustenance-related pursuits, including hunting, trapping, fishing, and plant gathering. Big game outfitters in the region draw international and local tourists;
- Summer-based tourism, including tourist recreational activities such as hiking, horseback riding, mountain biking, ATVing, dirt biking, fishing, swimming, hunting and canoeing, kayaking and rafting;
- Winter-based tourism, including recreational activities such as ski touring, snowmobiling, snowshoeing, and ice-fishing as well as some hunting, trapping and dog-sledding; and
- Road Travel.

Although several rivers are likely classified as navigable under the definition of the former *Navigable Waters Protection Act*, none of the water bodies in the Study Areas are identified within the current *Navigation Protection Act*. Navigation activities include the ferry crossing on Highway 1 to Fort Simpson, and private barges used on the Liard River from BC to resupply oil and gas industry projects.

## Influences on Surface Water and Groundwater Resources

The total water allocated to be removed from the Study Areas is 0.058% of annual flow, and 0.981% of winter flow, based on a worst-case scenario in which all consumptive sectors (i.e., all sectors except hydroelectric power) are considered to have zero return flow. Groundwater withdrawal quantities are not known but are considered to be negligible compared to surface water withdrawals.

The potential for point source discharges into the Liard and Petitot basins was assessed by analyzing spatial data including locations of water licences, mineral leases, oil and gas leases, forestry operations, and communities. Land use activity for these sectors tended to cluster in certain regions of the Study Areas.

Potential non-point sources of loadings of sediments, nutrients, metals, organics, and pesticides to the Liard and Petitot rivers include mining, oil and gas, forestry and agricultural activities. Due to the limited agricultural activities and linear developments in the Liard and Petitot basins, non-point source loadings to the Liard and Petitot rivers related to agricultural and linear developments are expected to be low. Mining, oil and gas, and forestry activities occur in the Liard and Petitot basins and therefore have the potential to contribute non-point source loadings to the Liard and Petitot River basins. Regulations and controls are in place to minimize non-point source loadings from these sources (e.g., BC's *Oil and Gas Activities Act* and *Forest and Range Practices Act)*. The overall low level of development and lack of industry in the Study Areas means that the effect of air emissions on the Liard and Petitot rivers is anticipated to be low.

Climate change is expected to have effects on hydrological regimes, surface water and groundwater quality, permafrost, vegetation, wildlife, fish, and the built environment.

Considering that the Land Use Plan from the Dease-Liard Basin supports oil and gas development, it is possible that oil and gas developments and pipelines may be developed in the future. Due to the presence of protected areas along the Liard River, there is little potential for the hydroelectric power sector to be developed. Areas of the Surface Water Study Area that have received protection will not be subject to future development, making these areas refugia for cumulative effects.

## Ambient Environmental Conditions

Concerns regarding the potential for contamination of water sources and the resulting effects on vegetation, wildlife, fish and people have been expressed throughout reports relevant to the region. The Treaty 8 Tribal Association (T8TA) indicated that the reduction in availability of clean water throughout their territory is a primary concern for their members (T8TA 2003; T8FN and Firelight 2012). To-date, the Kaska Dena, consider the majority of drainages and watersheds in the plan area (which overlaps with eastern portions of the Surface Water Study Area) are not experiencing changes in water quality or quantity as a result of human influence. However, the Kaska Dena have identified that appropriate management of water is key to maintaining the ecological integrity of many of the essential components of the watershed.

Water quality in the Liard and Petitot rivers are occasionally above guidelines for the protection of aquatic life and drinking water but average concentrations of most water quality parameters remained below guidelines. In the Liard River, average concentration of some metals were above guidelines but were likely adsorbed to suspended solids, reducing the availability of these metals to aquatic organisms. For most parameters, increasing concentrations were observed with distance downstream; the river shifted from an oligotrophic status in the upstream reaches to eutrophic in the downstream reaches. Seasonal patterns were also observed in the Liard River: suspended solids and parameters associated with suspended solids were highest in the springtime when flows were high and total dissolved solids (TDS) and major ions were highest during the winter when high TDS groundwater was a large component of the flow. Organics were sometimes detectable but typically below relevant aquatic life guidelines. Temporal trends in water quality in the Liard River were not observed. Water quality in the Petitot River followed similar seasonal and temporal patterns as those observed in the Liard River, however, more data for the Petitot River are needed to evaluate water quality in this river.

Flows in the Liard River peak between May and July due to snow melt and runoff; lowest flows were observed during winter conditions. In general, the only trends detected were increases in annual low flows at stations 10AA001, 10BE001, and 10BE005, and summer (open-water) low flows at station 10BE001. These stations are located in the upper half of the Liard River watershed by drainage area. Serial correlation was detected at stations 10AA001, 10BE001, and 10BE005 for low annual flows, and therefore these trends may actually be false positive results. By station 10ED001, located lower in the Liard River watershed and with a larger drainage area, trends were not detectable.

Limited groundwater quality information was identified for the Study Area. Groundwater analysis results were found for a small number of water supply wells with only limited analyses, i.e., major ions, routine parameters, some metals and nitrates.

The Study Area lies within two hydrogeological regions; predominantly in the Western Canadian Sedimentary Basin and a smaller portion in the Cordilleran Basin. Buried valley aquifers are important for their groundwater resource potential, which is applicable across the Western Canadian Sedimentary Basin. Local groundwater flow systems are typically driven by topographic variations, arising from flat-lying geological stratigraphy and bedrock heterogeneity. In the Cordilleran Basin, deeper confined and shallow unconfined surficial aquifers are both important.

In terms of recharge, permafrost mapping indicates that the Study Area is categorized as being in an area of sporadic, discontinuous permafrost, with 10% to 50% of the land area underlain by permafrost. In the context of changing permafrost conditions, permafrost within the Study Area in 2016 may be relict permafrost and the previously mapped category of ‘sporadic, discontinuous’ may have reduced to a lower category. The implications to groundwater of reduced permafrost extent will be for water tables to receive increased recharge, notably in surficial aquifers, arising from corresponding decreases in precipitation runoff, i.e., greater infiltration and contribution to water tables.

On average, Liard River suspended sediments had a higher proportion of silts and clays, compared to sands, which allows these suspended sediments to adsorb a greater proportion of metals compared to sediments mostly comprised of sands. Therefore, elevated metals concentrations in the suspended sediments and consequently in water samples with high concentrations of suspended sediments are expected. Metal and organics concentrations in suspended sediment samples were below Canadian Council of Ministers of the Environment (CCME) probable effect level (PEL) guidelines but were above the interim sediment quality guidelines (ISQGs) for some metals and organics (naphthalene, phenanthrene, fluorene and chrysene). Concentrations of PAHs were detectable in most suspended sediment samples. Because concentrations of all PAHs in the suspended sediment remained well below the CCME PEL guideline, biological effects from the observed PAH concentrations are not expected. Concentrations of total PCBs were detectable but below the CCME ISQG and PEL guidelines and the British Columbia Ministry of Environment sediment quality guideline; pesticides were not detected in suspended sediment quality samples. These results for PCBs and sediments were consistent with findings from early studies on sediment quality in the Liard River. Suspended sediment quality data were not available for the Petitot River.

Limited historical benthic invertebrate data are available from the Liard River from the early 1980s, which were compiled for the presence and absence of species in an Assessment of Ambient Conditions of the Liard River Basin in 1993. More recently, benthic macroinvertebrate data have been collected in Northeastern British Columbia to establish baseline benthic macroinvertebrate conditions for the development of a reference condition model for future water quality assessment.

Monitoring data for aquatic plants and plankton (including zooplankton, phytoplankton, and picoplankton) in the Liard or Petitot rivers were not identified.

Key fish species are identified based on presence and residency time in the Liard River, their importance as food for humans (commercial, recreational, and aboriginal use), their potential to accumulate contaminants, their place in the aquatic food chain, and their degree of sediment exposure. Key species identified were Arctic Grayling, Burbot, Inconnu, Lake Trout, Mountain Whitefish, Lake Whitefish, Northern Pike, Walleye, Longnose Sucker and Whitesucker.

Bistcho Lake, in northwestern Alberta was the only commercial fishery operating in the Liard River basin and has been closed since 2014 and as such there are no fish of commercial importance as food for humans in the Liard River basin. However, Walleye, Northern Pike, Lake Whitefish, Mountain Whitefish, Lake Trout, Arctic Grayling, and Inconnu represent popular sport fishing for the general public and sustenance species for First Nation communities in the Liard River basin.

Wildlife in the Study Areas include large mammals (caribou, moose, bison), carnivores (wolf, wolverine, black bear), mammals with a large aquatic component to their habitat (beaver, muskrat, river otter, mink), and a range of migratory and non-migratory birds (including upland birds, water birds and raptors). The Study Areas also includes species of concern, such as the grizzly bear, wood bison, rusty blackbird, horned grebe, peregrine falcon and short-eared owl.

## Risk Assessment

The potential for risk to human and ecological receptors that use or come into contact with groundwater or surface water from the Study Area was evaluated. Three components must be present for risks to exist: 1) contaminant(s) present at concentrations greater than regulatory standards or guidelines; 2) a receptor; and 3) an exposure pathway by which the receptor comes into contact with the contaminant. The other three steps in a risk assessment are: exposure assessment, toxicity assessment, and risk characterization. Summary information formed the basis of the problem formulation, including but not limited to: water uses, influence on water resources, ambient environmental conditions, traditional knowledge, and aquatic ecosystem information.

Three conceptual models for aquatic, wildlife and human receptors were used to evaluate the constituents of potential concern (COPCs) in various environmental media, potential direct and indirect (i.e., treated drinking water) exposure pathways, and human and ecological receptors. The conceptual models show that the COPCs are limited to only a few parameters, with aluminium the one parameter consistently identified as a COPC both in total and dissolved forms.

## Cumulative Effects

The sub-basins that may be of concern based on the degree of protection and cumulative effects of water licences, fire and forest include the *Petitot* and *Lower Liard – Mouth*. These two sub-basins contain no to little permanent or interim protected area in either Study Area and have a higher number of both expired and active water licenses compared to other sub-basins. Landscape change due to forest fire and forestry in the Petitot sub-basin is also higher compared to other basins.

## Knowledge Gaps

The most notable knowledge gaps are related to traditional land use and traditional knowledge, groundwater (both quality and quantity) and aquatic ecosystem (e.g., aquatic plants, benthic invertebrates). Refinements to the water and sediment quality monitoring would also help to fill in knowledge gaps in these datasets.

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**APPENDICES**

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**APPENDIX E**
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# Abbreviations and Acronyms

| Acronym | Definition |
|---|---|
| ADK | Acho Dene Koe First Nation |
| ANC | acid neutralizing capacity |
| BC | British Columbia |
| BC MOE | British Columbia Ministry of Environment |
| BRFN | Blueberry River First Nations |
| $CaCO_3$ | calcium carbonate |
| CBC | Canadian Broadcasting Corporation |
| CCME | Canadian Council of Ministers of the Environment |
| COPC | constituent of potential concern |
| COSEWIC | Committee on the Status of Endangered Wildlife in Canada |
| DFO | Fisheries and Oceans Canada |
| DGT | Diffusion Gradients in Thin-Film |
| DL | detection limit |
| DLSRMP | Dease-Liard Sustainable Resource Management Plan |
| DLUP | Dehcho Land Use Planning Committee |
| DO | dissolved oxygen |
| DOC | dissolved organic carbon |
| DRFN | Doig River First Nation |
| EC | Environment Canada |
| FLM | Fort Liard Métis |
| FNFN | Fort Nelson First Nation |
| FNLRMP | Fort Nelson Land and Resource Management Plan |
| GNWT | Government of the Northwest Territories |
| HRFN | Halfway River First Nation |
| ID | identification |
| INAC | Indian and Northern Affairs Canada |
| ISQG | Interim Sediment Quality Guidelines |
| masl | Meters above sea level |
| MKMA | Muskwa-Kechika Management Area |
| MRBB | Mackenzie River Basin Board |
| MVEIRB | Mackenzie Valley Environmental Impact Review Board |
| NEB | National Energy Board |
| NT, NWT | Northwest Territories |
| NTS | National Topographic System |
| NTU | nephelometric turbidity units |
| PAH | polycyclic aromatic hydrocarbons |
| PCB | polychlorinated biphenyl |
| PDO | Pacific Decadal Oscillation |
| PEL | Probable Effects Level |
| PRFN | Prophet River First Nation |
| RMZ | Resource Management Zone |
| RV | recreational vehicle |
| SQG | Sediment Quality Guidelines |
| T8TA | Treaty 8 Tribal Association |
| TCU | true colour unit |
| TDP | total dissolved phosphorus |

| Acronym | Definition |
|---|---|
| TK | Traditional Knowledge |
| TKN | totally Kjeldahl nitrogen |
| TLU | Traditional Land Use |
| TN | total nitrogen |
| TOC | total organic carbon |
| TSS | total suspended solids |
| UCLM | upper confidence limit of the mean |
| WMFN | West Moberly First Nations |
| WQG | Water Quality Guideline |
| YT | Yukon Territory |

# Units of Measure

| | |
|---|---|
| % | percent |
| ºC | degrees Celsius |
| < | less than |
| > | greater than |
| µeq/L | microequivalents per litre |
| µg/g | micrograms per gram |
| µS/cm | microSiemens per centimetre |
| cm | centimetre |
| km | kilometre |
| $km^2$ | square kilometre |
| m | metre |
| $m^2$ | square metre |
| $m^3/s$ | cubic metres per second |
| $m^3$/year | cubic metres per year |
| mg/L | milligrams per litre |
| mm | millimetre |

# 1.0 INTRODUCTION

## 1.1 Background

The Northwest Territories (NWT), Canada, British Columbia (BC), Alberta, Saskatchewan, and Yukon signed the Mackenzie River Basin Transboundary Waters Master Agreement in July 1997, which created the Mackenzie River Basin Board (MRBB). This agreement committed all six governments to work collaboratively to manage the water resources of the whole Mackenzie River Basin and created a framework for neighbouring jurisdictions to negotiate bilateral water management agreements to address transboundary water issues (MRBB 2015).

In October 2015 the Governments of the NWT and BC signed the Mackenzie River Basin Bilateral Water Management Agreement (MRBB 2015). The objective of this agreement is to guide management actions using a risk-informed approach to determine what actions should be taken and when based on scientific monitoring, local and traditional knowledge, and other sources.

## 1.2 Purpose of the Report

This report provides a summary of the state of knowledge of the Liard and Petitot Rivers Surface Water and Groundwater basins. It builds upon previous studies of trans-boundary waters, and supports the eventual development of Learning Plans for the basins. It includes traditional and scientific knowledge, and identifies the existing body of knowledge, current monitoring programs, and knowledge gaps.

# 2.0 WATERSHED PROFILES

This state of knowledge report summarizes information collected within two geographic study areas: the Surface Water Study Area, spanning 231,479 km$^2$ within Alberta, BC, Yukon and the NWT, and the Groundwater Study Area, spanning 81,853 km$^2$ within BC, Yukon and the NWT (Figure 1 and Appendix A, Map A-1). Collectively, these are referred to as the Study Areas.

Predominately in British Columbia, the Study Areas are situated in the physiographic regions of the Cordillera and Interior Plains and have land features characteristic of glaciated lowlands, alpine plateaus and mountains. Water within the Study Areas drains through tributaries of the Liard River, including the Petitot River, flowing north into the Mackenzie River and ultimately into the Arctic Ocean. The drainage basins include a variety of vegetation and surficial soils native to the Cordillera and Interior Plains ecosystems. They have extensive stands of boreal forests and are underlain with carboniferous palaeozoic limestone and cretaceous shale. Characterized wildlife can include but are not limited to moose, black bear, wood bison, wolf, caribou, beaver, waterfowl and other birds. Within the Study Areas there are several municipalities, land management areas associated with four first nation groups, and roadways connecting southern Canada with the arctic. Main industries include government works, natural resource exploration, mining, forestry, agriculture and tourism.

## 2.1 Groundwater and Surface Water Study Areas

### 2.1.1 Groundwater Study Area and Description

The Groundwater Study Area (Figure 1) was defined in the Mackenzie River Basin Bilateral Water Management Agreement (BC and NWT 2015). The resulting Study Area includes BC, Yukon, and the NWT. The Groundwater Study Area ends at the confluence of the Liard and Nahanni rivers near the community of Nahanni Butte, and does not include the Liard River from Nahanni Butte to its confluence with the Mackenzie at Fort Simpson.

### 2.1.2 Surface Water Study Area and Description

The Surface Water Study Area (Figure 1) was not defined in the Mackenzie River Basin Bilateral Water Management Agreement, and so was defined here based on the List of Transboundary Waters (provided in Appendix B of the Mackenzie River Basin Bilateral Water Management Agreement), water basin boundaries provided by the Water Survey of Canada, and discussion with the GNWT and BC. The resulting Surface Water Study Area includes the basin of the Liard River at the BC-NWT border, and confluences to the Liard River within the NWT (including the entire Petitot River) to its termination at the Mackenzie River confluence. For consistency with the Groundwater Study Area, the Nahanni basin was also excluded from the Surface Water Study Area.

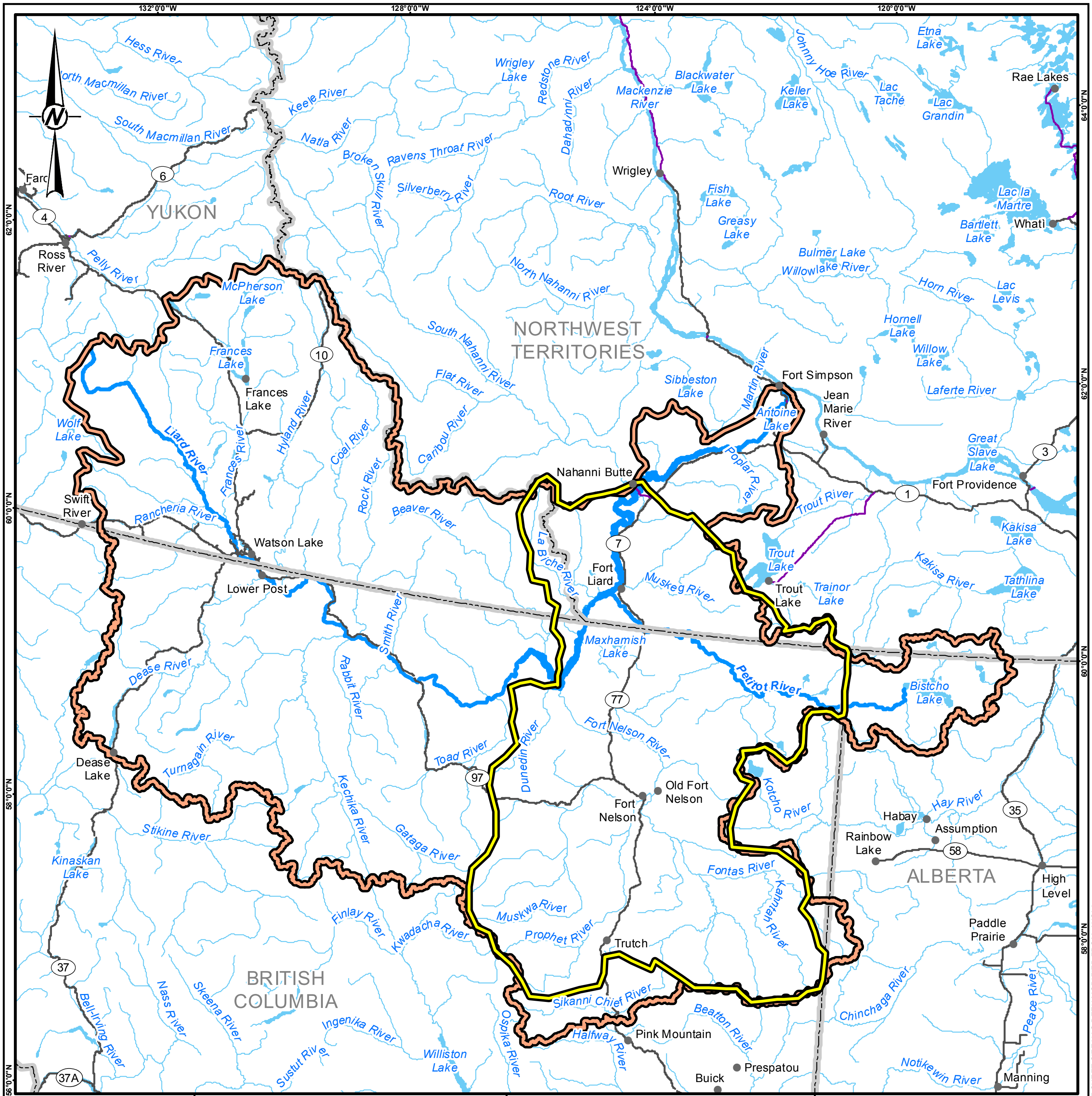
## 2.2 Liard River Overview

The Liard River originates in the Yukon's Pelly Mountains approximately 100 km southeast of Ross River, at an elevation of approximately 1500 masl, rapidly dropping to approximately 1100 masl. The river flows through alpine complexes, till blanket and till veneer in a general southeast direction, through coniferous forest approximately 300 km to Watson Lake near the Yukon-BC border. Due to the surficial geology of this area, and the high seasonal runoff, the Liard River carries a high suspended sediment load and fallen trees downriver. The river passes through a region of alluvial deposits upstream of Watson Lake, which sits at an approximate elevation of 640 masl. The river crosses into BC downstream of Watson Lake, and continues east-southeast through till blanket and glaciofluvial plain before eventually turning northward. It then flows north-northeast across the BC-NWT border toward the confluence of the Petitot River, and the community of Fort Liard. The river continues north through NWT to Nahanni Butte, then east-northeast to the confluence with the Mackenzie River at Fort Simpson.

There is very little industrial development along the Liard River, though there have been historic forest fires along its banks. The communities of Watson Lake, Fort Liard, and Nahanni Butte are located on (or very near) the Liard River, and may act as point sources for constituents of potential concern.

## 2.3 Petitot River Overview

The Petitot River headwaters are at Bistcho Lake in Alberta. The Petitot River flows generally west through deciduous forest and till blanket through the Alberta-BC border, and through a 100 km stretch of organic deposits in BC before crossing the BC-NWT border and flowing toward the confluence with the Liard River at Fort Liard. There are no communities along the Petitot River, though areas of historic forest fires and oil and gas development and mineral deposits have been documented (Appendix A).




**LEGEND**

- POPULATED PLACE
- ALL-SEASON ROAD
- WINTER ROAD
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

0 80 160

1:4,500,000 KILOMETRES

**REFERENCE(S)**

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2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT

GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**SURFACE WATER AND GROUNDWATER STUDY AREAS**

CONSULTANT

Golder Associates

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## 2.4 Liard and Petitot Rivers

### 2.4.1 Ecozones

The ecozones within the Study Areas include the Boreal Cordillera, Boreal Plains, Taiga Cordillera, and Taiga Plains (Figure 1 and Map A-2) (Ecological Stratification Working Group 1995). The Taiga Plains and Boreal Cordillera comprise most of the study areas and are described in detail below.

#### *2.4.1.1 Taiga Plains*

The Taiga Plains ecozone is dominated by Canada's largest river, the Mackenzie River, and spans the southwest corner of NWT, the northwest corner of Alberta and the northeast corner of BC. This ecozone is characterized by low precipitation and is dominated by slow-growing conifer forests of black spruce. Lodgepole pine, tamarack, dwarf birch, Labrador tea and willows are also common with understory species of bearberry, mosses and sedges. Characteristic wildlife includes moose, woodland caribou, wood bison, wolf and black bear. The Mackenzie Valley forms one of North America's most travelled migratory corridors for waterfowl breeding along the arctic coast. This ecozone is the northern extension of the flat interior plains.

#### *2.4.1.2 Boreal Cordillera*

Bordered by northern BC and southern Yukon, the Boreal Cordillera ecozone makes up the rest of the Study Areas map. This ecozone's vegetation ranges from open to closed canopies over much of the valley and plateau area, to sedge-dominated meadows and lichen-colonized rocks within the extensive rolling alpine tundra located at higher elevations. This ecozone has greater precipitation than the Taiga Plains due to the mountain ranges which run throughout the ecozone. Cryosolic, brunisols, podzols and luvisols soils are present within this region. Permafrost is widespread in the northern portion of the ecozone and at higher elevations. Characteristic wildlife includes, but is not limited to, grizzly bear, mountain goat, woodland caribou, along with a range of migratory songbirds and waterfowl. The ecozone is rich in mineral resources and hosts industry specific to forestry, hydroelectric development, localized agriculture and tourism (Ecological Stratification Working Group 1995).

### 2.4.2 Ecoregions

Within the two ecozones, the Surface Water Study Area includes twelve ecoregions (Table 1 and Map A-3), with the majority of the area being classified as Northern Alberta Uplands (17.6%), Liard Basin (14.4%), Boreal Mountains and Plateaus (13.3%), and Northern Canadian Rocky Mountains (11.6%). Within these ecoregions are varying elevations which create the distinct ecoregion characteristics, although all regions have similar attributes as described above for the Taiga Plains and Boreal Cordillera ecozones (Ecological Stratification Working Group 1995). The Groundwater Study Area covers seven ecoregions, the largest of which is the Northern Alberta Uplands.

**Table 1: Ecoregions in the Surface Water and Groundwater Study Areas**

| Ecoregions within Study Areas | Surface Water Study Area | | Ground Water Study Area | |
|---|---|---|---|---|
| | Ecoregion Areas ($km^2$) | Percentage of Total Area (%) | Ecoregion Areas ($km^2$) | Percentage of Total Area (%) |
| Northern Alberta Uplands | 40,781 | 17.6 | 28,818 | 35.2 |
| Liard Basin | 33,422 | 14.4 | - | - |
| Boreal Mountains and Plateaus | 30,800 | 13.3 | - | - |
| Northern Canadian Rocky Mountains | 26,907 | 11.6 | 9,765 | 11.9 |
| Hay River Lowland | 22,708 | 9.8 | 18,590 | 22.7 |
| Hyland Highland | 21,753 | 9.4 | 2,942 | 3.6 |
| Muskwa Plateau | 21,453 | 9.3 | 16,254 | 19.9 |
| Pelly Mountains | 13,453 | 5.8 | - | - |
| Selwyn Mountains | 11,280 | 4.9 | - | - |
| Clear Hills Upland | 5,003 | 2.2 | 3,641 | 4.4 |
| Sibbeston Lake Plain | 3,095 | 1.3 | 1,843 | 2.3 |
| Yukon Plateau-North | 824 | 0.4 | - | - |

### 2.4.3 Physiography and Topography

The Liard and Petitot River basin has severe topographic relief with a maximum elevation of 2,935 m and a minimum elevation of 120 m. The average elevation within the Surface Water Study Area is 939 m. This range of topographic relief is present because the Surface Water Study Area spans mountain ranges including the Northern Rocky Mountains and the Pelly Mountains, as well as low lying uplands in western NWT, northwestern Alberta, and northeastern BC.

Map A-4 shows the shaded relief of the Study Areas, and Map A-5 shows the sub-basin boundaries, Environment Canada Climate Stations, and Environment Canada Hydrological Stations.

The current prominent landforms in the basins are the cumulative result of glacial erosional and post-glacial sub-aerial weathering processes that acted on bedrock to varying degrees depending on its physical characteristics (i.e., strength, deformability and permeability, etc.), geological structures, and rates of post-glacial rebound. Lower Paleozoic to Lower Mesozoic carbonate, sandstone, and shale formations are exposed by folding and faulting in the highest areas of the Liard Plateau and low-dipping Cretaceous shale, sandstone, and siltstone formations underlie much of the lowland parts of the Study Areas. Folding and faulting structural processes have also formed many of the escarpments, plateaus, and tablelands from Carboniferous sandstone and limestone, and Cretaceous conglomerate, sandstone, and shale formations.

Map A-6 shows bedrock geology, made from geological GIS data composited from the four jurisdictions, then sorted by respective geological age fields after being simplified to geological period rather than epoch.

### 2.4.4 Geology and Geochemistry

The Liard and Petitot River basin within the Surface Water Study Area has 49.7% of its surficial geology composed of till blanket in the uplands adjacent to the Rocky Mountain and Pelly Mountain ranges (NRCAN 2014, Map A-7).

This is a result of glacial activity eroding bedrock and depositing till, sand and gravel. Till veneer comprises the second largest classification of surficial geology in the Surface Water Study Area, at 17.3%, and alpine complexes are the third largest classification, at 15.7%. There is a relatively small amount of surface water in the Surface Water Study Area, at 0.3% (Table 2). In the Ground Water Study Area, till blanket is the largest classification at 61.2% of the study area, with colluvial rubble and till veneer following at 11.7% and 10.5%, respectively.

**Table 2: Surficial Geology Present in Surface Water and Groundwater Study Areas**

| Surficial Geology | Area within the Surface Water Study Area ($km^2$) | Proportion of Surface Water Study Area (%)[(a)] | Area within the Ground Water Study Area ($km^2$) | Proportion of Ground Water Study Area (%) |
|---|---|---|---|---|
| Till Blanket | 114,935 | 49.7 | 50,088 | 61.2 |
| Till Veneer | 40,050 | 17.3 | 8,579 | 10.5 |
| Alpine Complexes | 36,228 | 15.7 | 3,801 | 4.6 |
| Colluvial Rubble | 18,252 | 7.9 | 9,604 | 11.7 |
| Fine Grained (Glacio)Lacustrine | 5,890 | 2.5 | 2,377 | 2.9 |
| Organic Deposits | 5,527 | 2.4 | 5,498 | 6.7 |
| Alluvial Deposits | 3,019 | 1.3 | 1,332 | 1.6 |
| Glaciofluvial Plain | 2,701 | 1.2 | 38 | <0.1 |
| Glaciofluvial Complex | 1,928 | 0.8 | - | - |
| Coarse Grained (Glacio)Lacustrine | 1,620 | 0.7 | - | - |
| Water | 749 | 1.0 | 39 | 0.05 |
| Colluvial Fines | 418 | 0.2 | 420 | <0.1 |
| Glaciers | 160 | 0.1 | 77 | <0.1 |

(a) Total is greater than 100% due to rounding

The Taiga Plains ecozone is underlain by horizontal sedimentary rock (limestone, shale and sandstone) and the rolling topography is predominantly covered with organic deposits. Low lying wetlands cover 25 to 50% of the ecozone. Low-ice content, discontinuous permafrost is present within the ecozone, with an increased coverage within the northern reach of the ecozone. Due to the ecozone having poor drainage, cryosolic, gleysolic and organic soils are most common.

## 2.4.5 Vegetation

The data displayed in Map A-8, vary with elevation, surficial geology and landscape (NRCAN 1993). Coniferous forest comprises nearly half of the Surface Water Study Area (47.3%) with mixed forest comprising 29.9% and tundra comprising 10.1% of the Surface Water Study Area (Table 3). The primary ecoregions which host this vegetation include the Northern Alberta Uplands, Liard Basin, Boreal Mountains and Plateaus and the Northern Canadian Rocky Mountains ecosystems. Common vegetation in these ecosystems includes trees such as white and black spruce, alpine fir, balsam fir, aspen, lodgepole pine; shrubs such as dwarf birch and Labrador tea; and forbs including alpine grasses, horsetail, moss, lichen, sedges and mountain avens.

**Table 3: Land Cover Classification in Surface and Groundwater Study Areas**

| Land Cover Class | Area within Surface Water Study Area ($km^2$) | Proportion of Surface Water Study Area (%)[a] | Area within Ground Water Study Area ($km^2$) | Proportion of Ground Water Study Area (%) |
|---|---|---|---|---|
| Coniferous Forest | 109,416 | 47.3 | 22,299 | 27.2 |
| Mixed Forest | 69,118 | 29.9 | 43,313 | 52.9 |
| Tundra | 23,320 | 10.1 | 1,799 | 2.2 |
| Barren Land | 13,808 | 6.0 | 2,473 | 3.0 |
| Deciduous Forest | 13,463 | 5.8 | 11,275 | 13.8 |
| Water[b] | 2,341 | 1.0 | 687 | 0.8 |
| Ice/Snow | 13 | <0.1 | 7 | <0.1 |

(a) Total is greater than 100% due to rounding

(b) Water cover includes CANVEC 50K data categories of Intermittent, Permanent and Unknown (NRCAN 2017)

Map A-9 shows the spatial coverage of forest fires between 1942 and 2012 with 35,346 $km^2$ of forest burnt over that period. Table 4 presents the top ten years with respect to the area of burnt forest and the corresponding proportion of the Study Areas.

**Table 4: Top Ten Forest Fires Years within the Study Areas between 1942 and 2012**

| Fire History (year) | Surface Area ($km^2$) | Proportion (%) |
|---|---|---|
| 1958 | 4,735 | 2.1 |
| 1982 | 4,570 | 2.0 |
| 2004 | 3,427 | 1.5 |
| 2012 | 1,881 | 0.8 |
| 1971 | 1,827 | 0.8 |
| 1961 | 1,679 | 0.7 |
| 1944 | 1,461 | <0.1 |
| 1969 | 1,383 | <0.1 |
| 1956 | 1,366 | <0.1 |
| 1981 | 1,184 | <0.1 |

## 2.5 Climate

Environment and Climate Change Canada consolidates climate data for 30 year overlapping periods of record, and calculates average annual climate data referred to as ‘climate normals’ (Environment Canada 2016a). Climate normal data for Fort Liard (NWT), Tetsa River (British Columbia), Fort Nelson (British Columbia), and Watson Lake (Yukon) locations are available for the time periods shown in Table 5 and station locations are shown in Figure 2. The most recent climate normal period of 1981 to 2010 was used for characterization and comparison purposes because it represents the most recent conditions and data were available at all stations for this interval.

**Table 5: Climate Stations with Published Normals in the Study Areas**

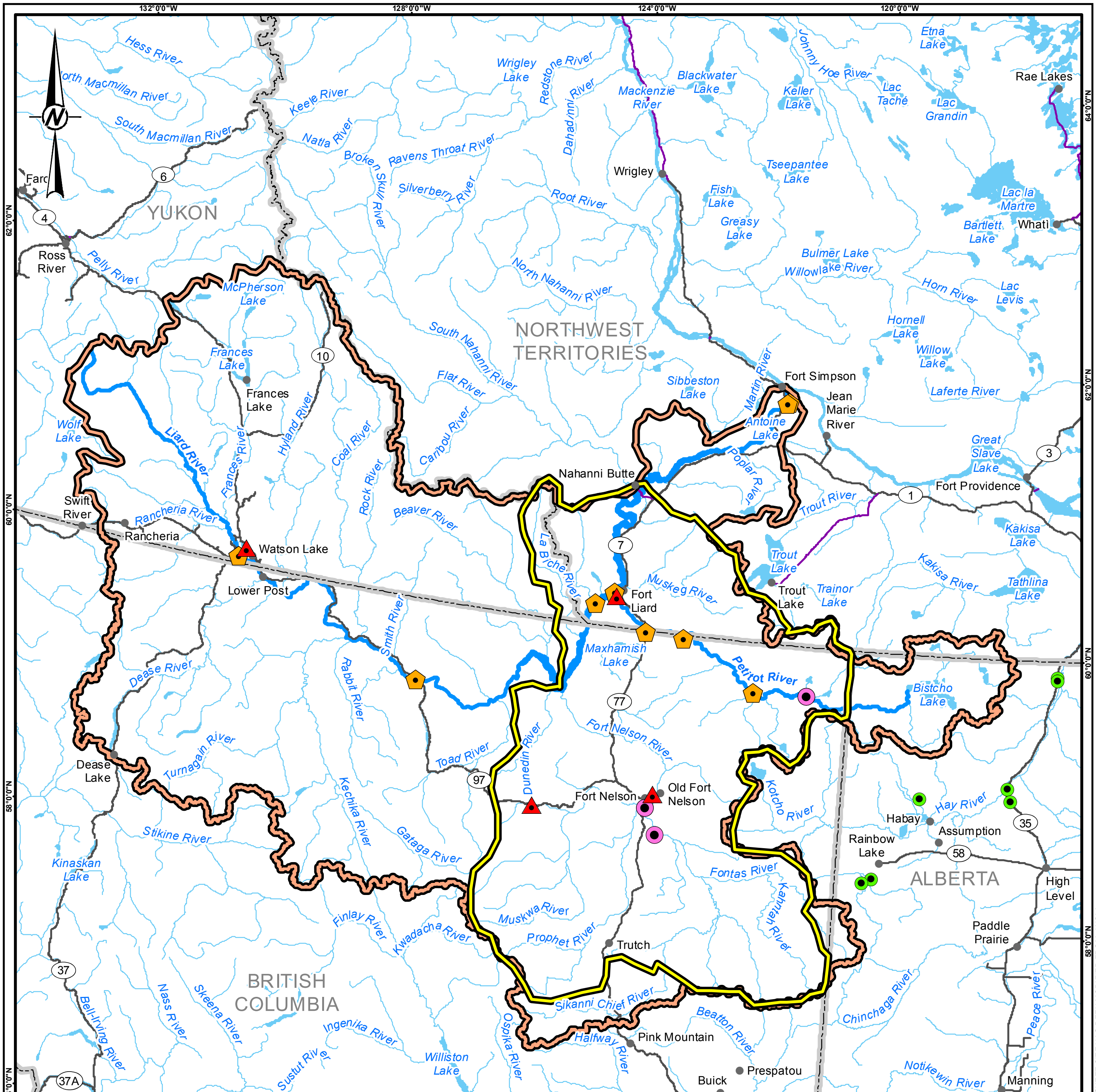
| Climate Station | Station ID | Jurisdiction | Latitude (N) | Longitude (W) | Elevation (m) | Climate Normal Period |
|---|---|---|---|---|---|---|
| Fort Liard A | 2201575 | NWT | 60°14'06" | 123°28'01" | 216 | 1971 to 2000 |
| | | | | | | 1981 to 2010 |
| Tetsa River | 1195J29 | BC | 58°39'11" | 124°14'09" | 810 | 1981 to 2010 |
| Fort Nelson A | 1192940 | BC | 58°50'11" | 122°35'50" | 382 | 1961 to 1990 |
| | | | | | | 1981 to 2010 |
| Watson Lake A | 2101200 | Yukon | 60°06'59" | 128°49'20" | 687 | 1961 to 1990 |
| | | | | | | 1981 to 2010 |

### 2.5.1 Air Temperature

Daily maximum, mean, and minimum air temperatures for the Fort Liard, Fort Nelson, Watson Lake, and Tetsa River climate stations are shown in Figures 3 to 6. Mean daily air temperatures for all stations are shown together on Figure 7.

Daily mean temperatures are generally at or below 0°C between October and March each year, rising above 0°C in April, and dropping to at or below 0°C in October. Daily mean temperatures (Figure 7) indicate that the Fort Liard, Fort Nelson, and Watson Lake climate stations exhibit very similar temperature regimes, while the Tetsa River climate station records slightly lower summer temperatures (2°C to 4°C lower) and higher winter temperatures (approximately 5°C higher) than other stations. Tetsa River is situated at an elevation of 810 masl (compared to 687 masl for Watson Lake, 382 masl for Fort Nelson, and 216 masl for Fort Liard), and is the furthest south climate station in the Study Areas, which may account for the different temperature regime compared to the other stations.

Freshet is generally expected to begin in April in the Study Areas, with break-up on the Liard River occurring in April or May.




LEGEND

- POPULATED PLACE
- ALL-SEASON ROAD
- WINTER ROAD
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA
- CLIMATE STATION
- ALBERTA CHEMISTRY WELL
- BRITISH COLUMBIA GROUNDWATER CHEMISTRY STATION
- SURFACE WATER MONITORING STATION

0 80 160

1:4,500,000 KILOMETRES

REFERENCE(S)
1. SURFACE WATER STUDY AREA CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA. GROUNDWATER STUDY AREA PROVIDED BY BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. BC DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE - BRITISH COLUMBIA
5. AB DATA OBTAINED FROM GOVERNMENT OF ALBERTA.
PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**CLIMATE, WATER QUANTITY, AND WATER QUALITY DATA COLLECTION STATION LOCATIONS**

CONSULTANT

Golder Associates

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| YYYY-MM-DD | 2017-04-07 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

PROJECT NO. 1547195 REV. 0 FIGURE **2**

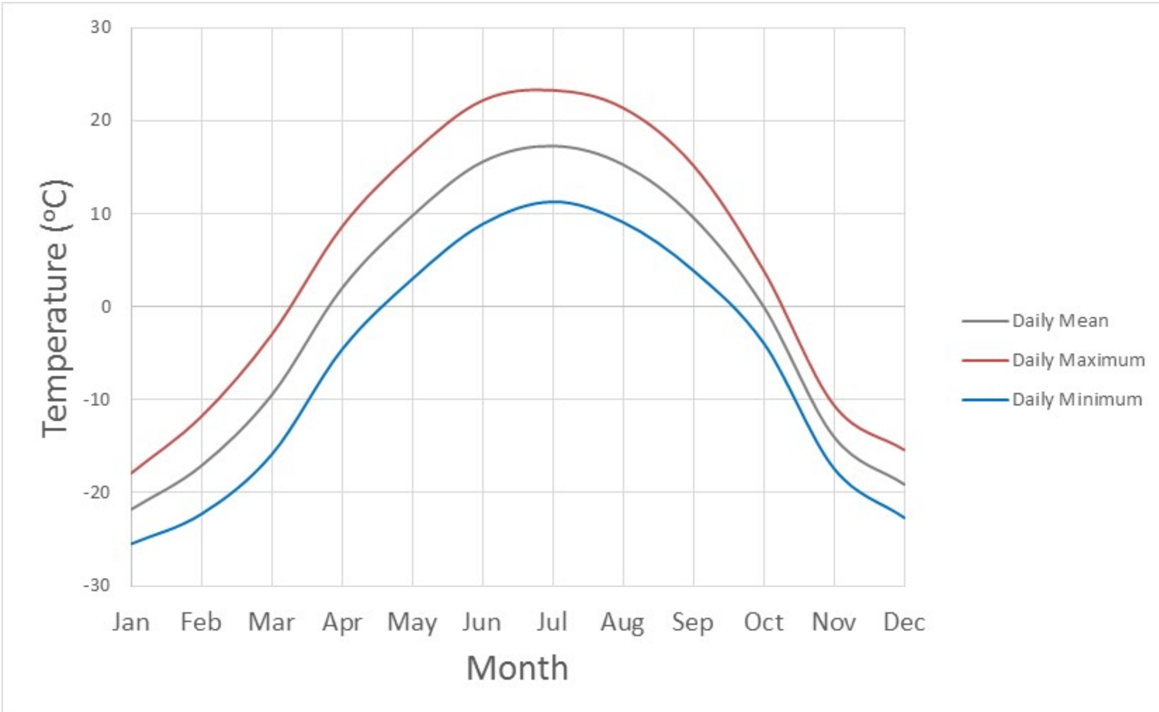


*Figure 3: Fort Liard Climate Station Monthly Temperature Normals, 1981 to 2010*

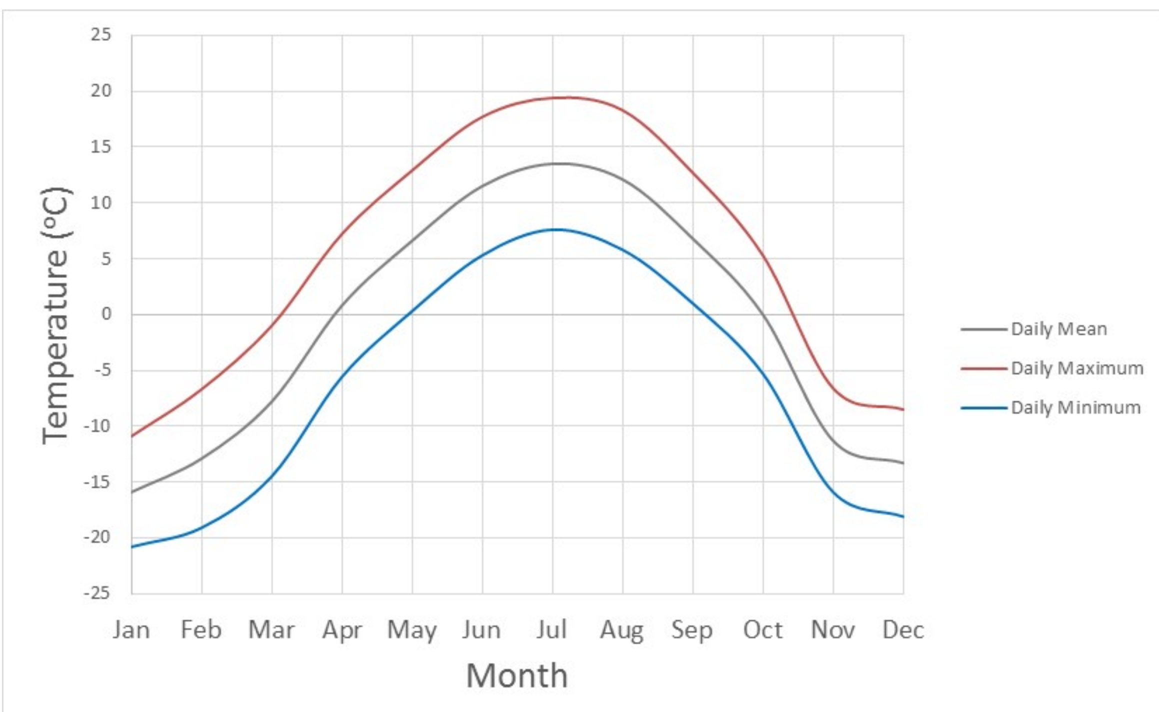


*Figure 4: Tetsa River Climate Station Monthly Temperature Normals, 1981 to 2010*

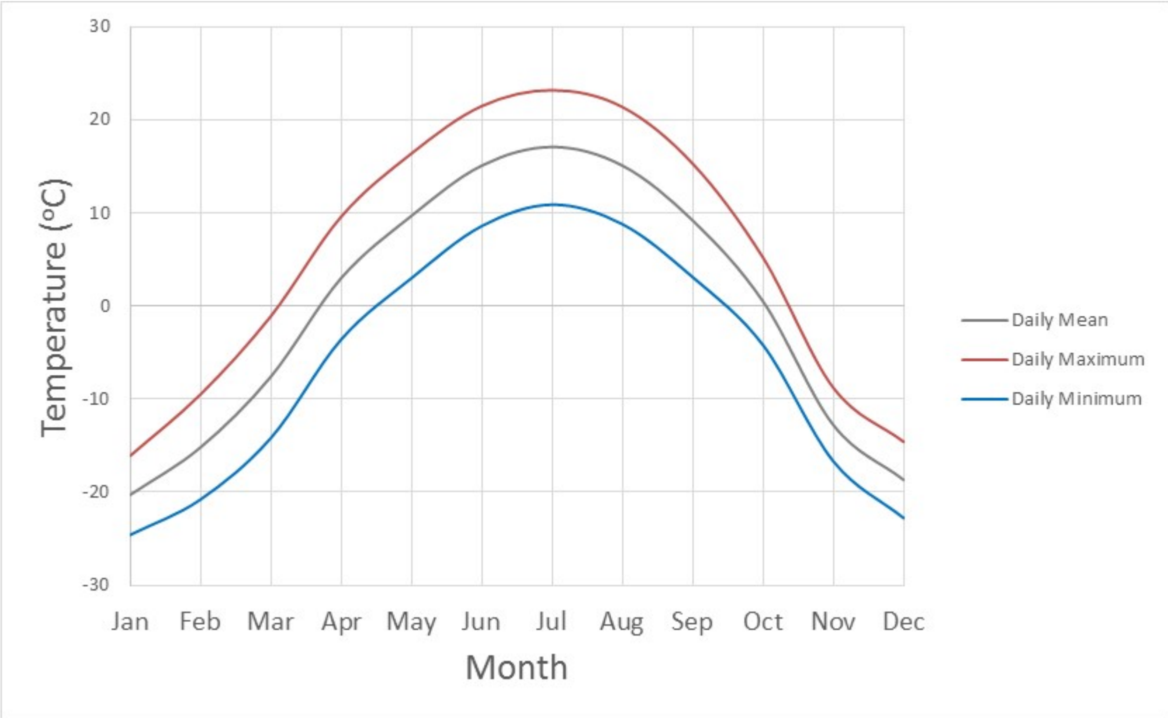


*Figure 5: Fort Nelson Climate Station Monthly Temperature Normals, 1981 to 2010*

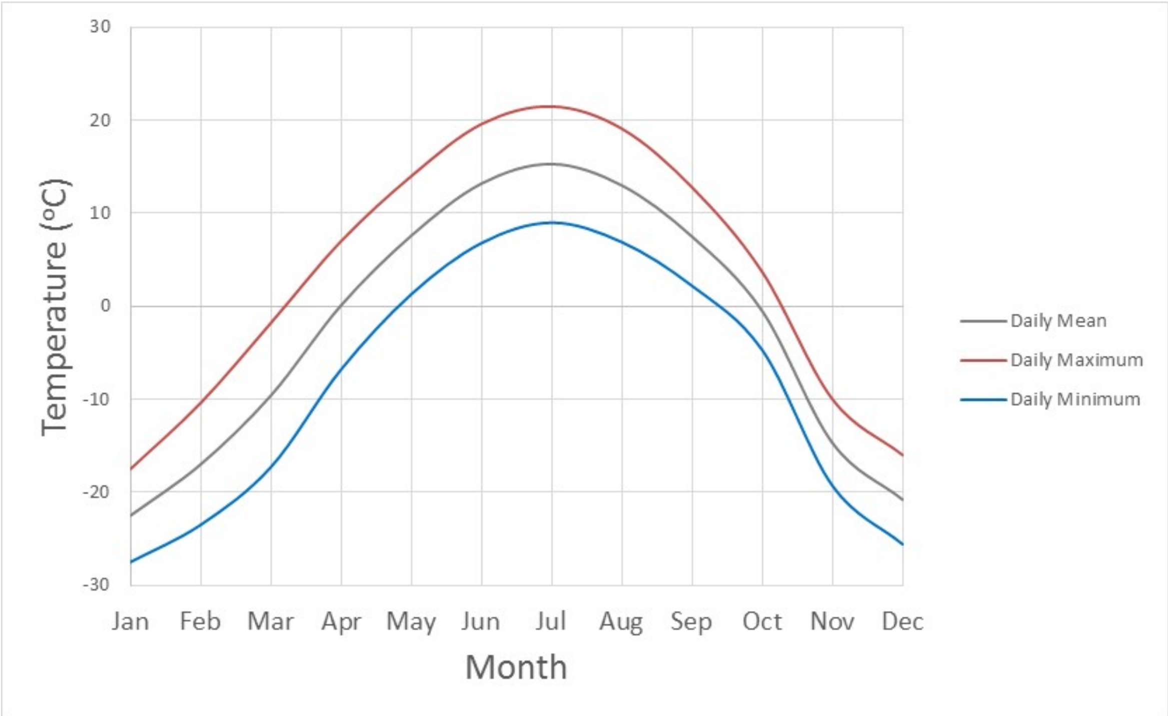


*Figure 6: Watson Lake Climate Station Monthly Temperature Normals, 1981 to 2010*

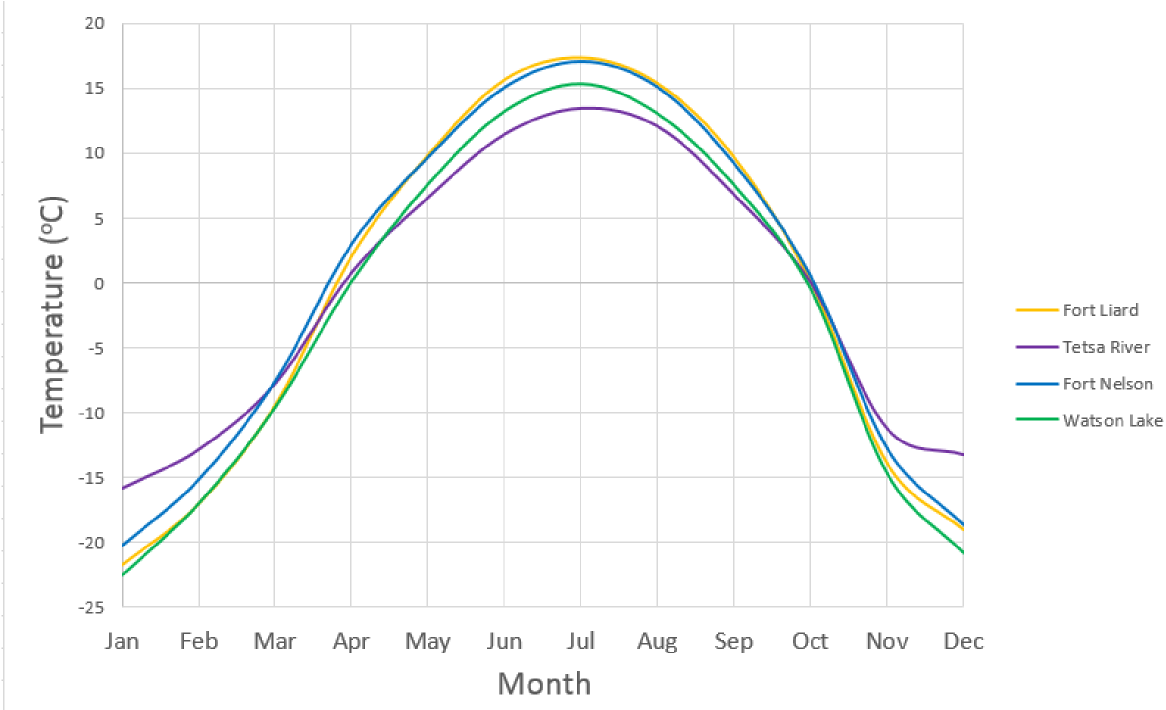


*Figure 7: Mean Daily Temperatures for Fort Liard, Tetsa River, Fort Nelson, and Watson Lake Climate Stations, 1981 to 2010*

## 2.5.2 Precipitation

Monthly climate normal for total precipitation, rainfall, and snowfall for the Fort Liard, Fort Nelson, Watson Lake, and Tetsa River climate stations are shown in Figures 8 to 10 and summarized in Table 6.

**Table 6: Annual Total Precipitation, Rainfall, and Snowfall for Fort Liard, Fort Nelson, Watson Lake, and Tetsa River Climate Stations**

| Period | Fort Liard | Tetsa River | Fort Nelson | Watson Lake |
|---|---|---|---|---|
| Rainfall | 294 | 493 | 312 | 262 |
| Snowfall | 165 | 214 | 191 | 196 |
| Total Precipitation | 459 | 707 | 503 | 458 |

### *2.5.2.1 Rainfall*

Rainfall has been measured during each month in the Study Areas, but rainfall primarily occurs between April and October (Figure 9). Tetsa River exhibits a very different rainfall regime than Fort Liard, Fort Nelson and Watson Lake, receiving between 180 mm and 230 mm more rainfall than these climate stations. The Tetsa River climate station is at a higher elevation than the other stations and may receive more orographic rainfall as a result.

#### 2.5.2.2 Snowfall

Snowfall can occur during most (or all) months of the year; only July has no recorded snowfall at any station from 1981 to 2010 (Figure 10). Most snowfall occurs between October and April at the Fort Liard, Fort Nelson, and Watson Lake climate stations. The Tetsa River climate station reports snowfall during May and September as well, and a trend of lower snowfall than other stations during November to February, and higher snowfall than other stations during March, April, May, August, September, and October. These trends are likely due to the higher elevation of the Tetsa River climate station.

### 2.5.3 Characterization of Climate

The temperature and precipitation regimes reported at the Watson Lake and Fort Liard climate stations are very similar (i.e. total precipitation and daily mean temperatures are almost identical), even though these stations have an elevation difference of nearly 600 m and are separated by nearly 300 km. Both stations are located on the Liard River proper. The similarity of climate, given the difference in elevation and distance between the stations, indicates that these stations likely reflect the approximate climatic conditions along the Liard River. The Tetsa River climate station trends, including higher snowfall and warmer winter temperatures, may be characteristic of the more mountainous regions of the Study Areas, although it is difficult to extrapolate based on data from only one station location.

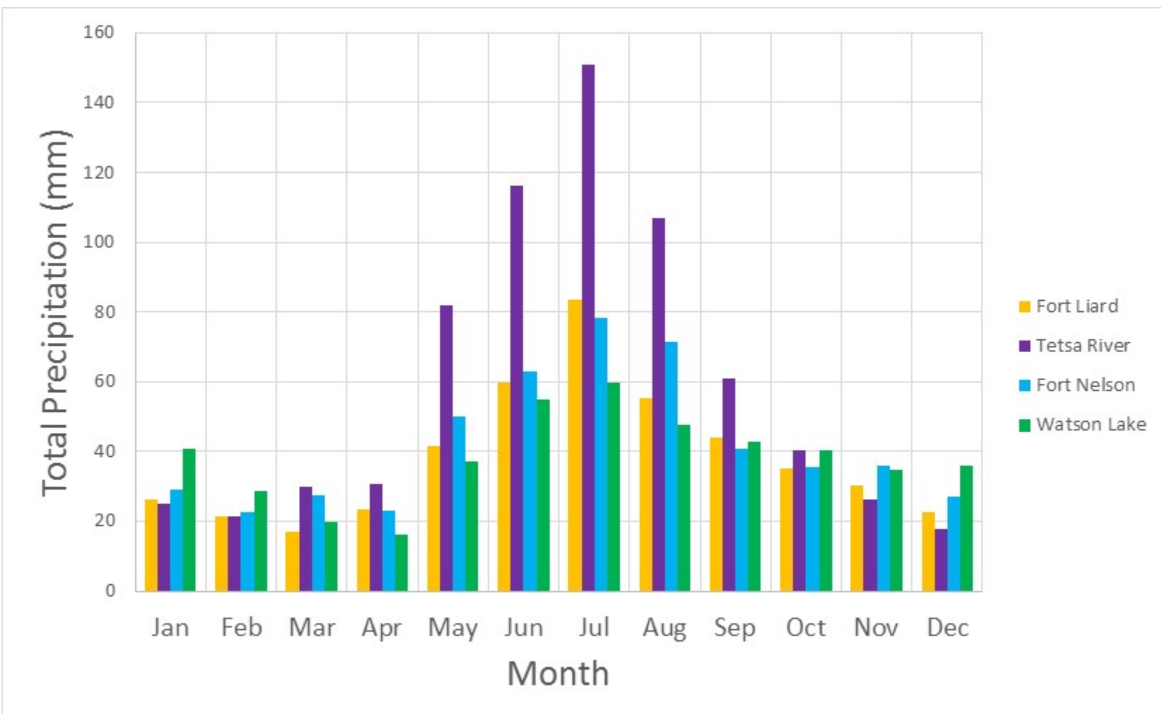


*Figure 8: Monthly Precipitation Normals in the Study Areas, 1981 to 2010*

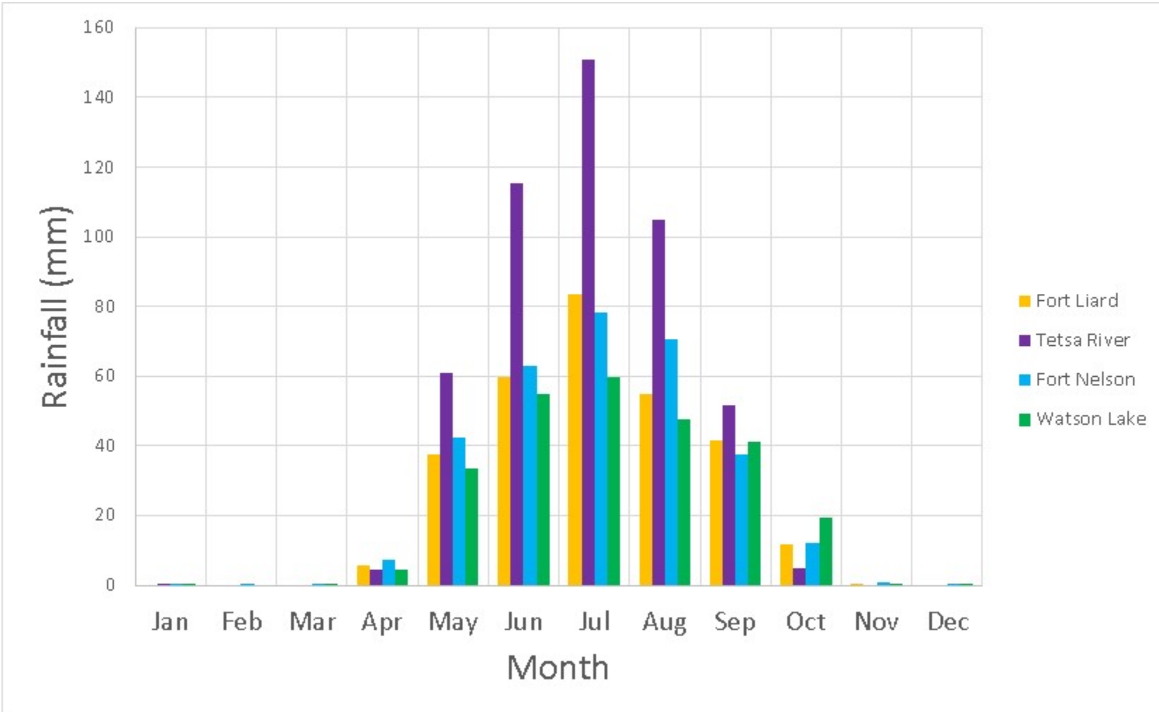


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*Figure 9: Monthly Rainfall Normals in the Study Areas, 1981 to 2010*

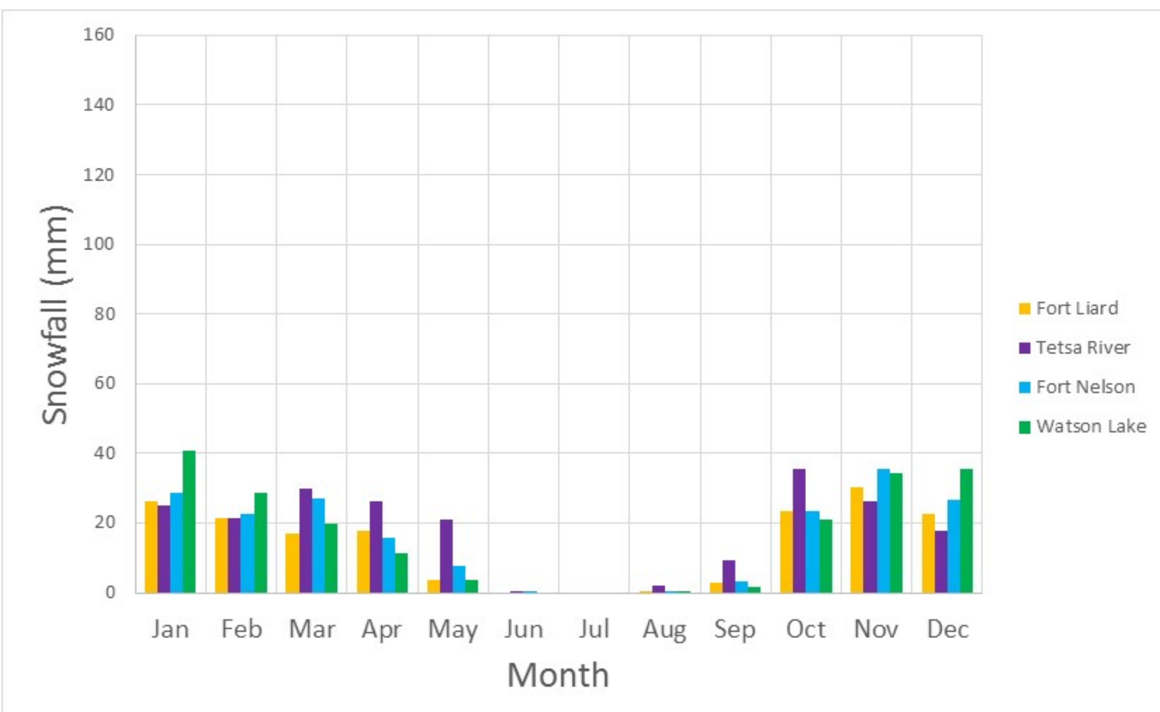



*Figure 10: Monthly Snowfall Normals in the Study Areas, 1981 to 2010*

# 3.0 HISTORIC AND CURRENT SURFACE WATER USES

## 3.1 Traditional Uses

The Study Areas are located in an area of use by multiple Aboriginal groups and partially overlaps portions of Treaty 8[1]. The Study Areas have historically been occupied by people who speak one of the languages of the Dene (Athabaskan) or Algonquian language families (FPHLCC, no date). Current linguistic groups in the region include Dene K'e (Dene, Dene Tha', Acha'otinne), (Kaska; Kaska Dena), Dane-Zaa (Beaver; Dunne-za), and Nēhiyawēwin (Cree; FPHLCC, no date).

The Aboriginal groups listed below were identified as having territory used or valued for traditional purposes overlapping the Study Areas. This assessment was conducted by consulting the BC First Nations Consultative Areas Database (BC 2016) and publicly available land use and traditional territory maps:

- Acho Dene Koe First Nation (ADK). Acho Dene Koe First Nation asserted traditional territory is located in BC, Yukon and NWT, partially overlaps the Study Areas [as mapped in ARI (no date) and DMCS (2012)].
- Blueberry River First Nations (BRFN). Blueberry River First Nations asserted traditional territory is located in BC and overlaps the southern portion of the Surface Water Study Area [as mapped in Martineau (2013a)].
- Deh Cho First Nations (Deh Cho). Deh Cho's asserted territory is located in the NWT, and, as mapped in Dehcho First Nations (no date), partially overlaps the Study Areas.
- Dene Tha First Nation (Dene Tha). Dene Tha's asserted traditional territory is located in BC, Alberta and the NWT and, as mapped in Calliou Group (2009), partially overlaps the Study Areas.
- Kaska Dena, which includes Dease River First Nation, Daylu Dena Council, Kwadacha Nation, Liard First Nation and Ross River Dena Council (Kaska Dena Council 2010). Kaska Nation's asserted traditional territory is located in BC, Yukon and the NWT and as mapped in Dena Kayeh Institute (2010) and Kaska Dena Council (2010) partially overlaps the Study Areas.
- Fort Liard Métis (FLM). The FLM have indicated in DMCS (2012) that their asserted traditional territory is the same as the ADK, therefore, FLM traditional territory is located in BC, Yukon and NWT and as mapped in DMCS (2012), partially overlaps the Study Areas.
- Fort Nelson First Nation (FNFN). Fort Nelson First Nation's asserted territory, as mapped in Martineau (2013b), is located in BC and overlaps the central majority of the Study Areas.
- Members of Treaty 8 Tribal Association[2] include Doig River First Nation (DRFN), Halfway River First Nation (HRFN), Prophet River First Nation (PRFN), and West Moberly First Nations (WMFN). Treaty 8 Tribal Association members' administration boundaries as mapped in Treaty 8 First Nations T8FN and The Firelight Group Research Cooperative (T8FN and Firelight 2012), generally overlap the southern portions of the Study Areas.

[1] Treaty 8 was signed in 1899, and is the first of the northern treaties signed between the federal government and Aboriginal groups in the region. It covers an area of 840,000 km$^2$ and overlaps portions of what is now Alberta, BC, Saskatchewan, and the NWT.

[2] Saulteau First Nations are also members of Treaty 8 Tribal Association however, the traditional territory map produced in Martineau (2013c) does not overlap with the Study Areas.

- Tahltan Central Government, including the Tahltan Band Council and Iskut Band council. Tahltan's asserted territory is located in BC and Yukon, and as mapped in (TNDC 2014) partially overlaps the western portions of the Surface Water Study Area.
- Teslin Tlingit Council. Teslin Tlingit's asserted traditional territory is located in BC and Yukon and as mapped in TTC (no date), overlaps the western portions of the Surface Water Study Area.

Data on the traditional use of the Study Areas were identified through a review of publicly available documents including those commissioned by government, Aboriginal groups and industry. In some instances, information from publicly available reports was not included because permission to reproduce the data was required from the respective Aboriginal group. Therefore, the following should not be viewed as a comprehensive overview of traditional use by all Aboriginal groups in the Study Areas. The traditional use patterns of some Aboriginal groups may be overrepresented compared to others.

The review indicated that the Study Areas have historically been used, and continue to be used, for traditional activities, including hunting, trapping, fishing, plant gathering, travel, and to practice culturally important activities at select sites and areas. Historically, Aboriginal groups in the area seasonally travelled throughout their respective territories to those areas that provided access to particular resources and culturally important sites during particular times of the year, a movement commonly referred to as a 'seasonal round' (DMCS 2012; Quicksilver Resources 2013). Particular areas within the Study Areas were relied upon as part of certain Aboriginal groups' seasonal round and continue to maintain important value for their members today.

The ADK and FLM have described how in spring, "when the frozen landscape began to thaw, families made their way to the rivers and lakes in preparation for break up" (DMCS 2012, p.7), and how sometimes this would be the time when families would construct canoes and boats that would allow them to transport their supplies to summer campsites. The lakes, creeks, and rivers of the region provide transportation routes to access hunting, trapping, fishing and other culturally important locations relied upon by Aboriginal land users. For example, A FNFN Elder (TERA 2010) described how they would use the Toad River as a winter travel route between the Toad Hot Springs and Fort Liard; the ADK and FLM have described how the Liard River is an important travel route used both when frozen and during open water seasons (DMCS 2012). The Dene Tha have described how they relied on water travel to reduce the effort involved in transporting the results of a successful harvesting trip and would "return to their camp at the end of the expedition by raft, bringing with them the game and furs harvested" (TERA 2010, p.35). The ADK and FLM have similarly noted that boats would allow for easier hunting, and that hunting by boat for moose and beaver was commonplace (DMCS 2012). In addition to the above, the Beaver River, Petitot River and La Biche River have been identified by the ADK and FLM as transportation routes (DMCS 2012).

Overland trails would often parallel watercourses and such trails have been documented along the Beaver River and the Liard River (DMCS 2012). Access to traditional use areas within the Study Areas may be conducted by truck, horseback, off-road vehicle, on foot and by using available water routes. Currently, changes in access are of importance to traditional users. New access roads from development may result in increased access to non-Aboriginal hunters and recreational users, which has the potential to increase the competition for traditional resources (e.g., furbearers) or to reduce the feelings of solitude experienced while undertaking land use activities (T8FN and Firelight 2012). Conversely, reductions in access either by interruptions to land trails or changes in the navigability of watercourses can reduce Aboriginal land user's access to traditional lands.

In addition to their importance for travel, waterbodies and watercourses provide important focal points for traditional use areas in the region including and surrounding the Study Areas. This is in part because they help support the resources relied upon for traditional land use activities, such as large and small game for hunting. The following sections summarize the use of the Study Areas by traditional activity type.

Limited information specific to the use or location of groundwater sources were identified in the literature reviewed. However, the importance of water to the overall environment was expressed: water is the key, and the Kaska are decisive that “water must be managed carefully” (Dena Kayeh Institute 2010, p.2).

### 3.1.1 Hunting and Trapping

Hunting and trapping is conducted for subsistence as well as for important utilitarian supplies, such as moose and animal hides for boats and clothing (DMCS 2012). The Study Areas have been identified as important for wildlife relied upon for traditional hunting and trapping. For example:

> *The Prophet River area has supported: high numbers of large ungulates, including moose, elk, boreal caribou, mule and white-tailed deer, mountain goat and Stone’s sheep. There are high numbers of large carnivores, such as grizzly bears, black bear and wolves, and high numbers of smaller carnivores and other furbearers, such as lynx, coyote, fox, marten, weasels, beaver and muskrat (Webster 1997, p. 80 in T8FNs and Firelight 2012, p.137).*

Aboriginal groups have recognized the interconnection of aquatic and terrestrial environments, and have expressed how changes in aquatic environments can affect traditional uses of key resources as a result. For example, Aboriginal land users have described how aquatic environments, including drainages and watercourses, provide moose, fisher, marten, wolverine and beaver habitat, all important species for hunters and trappers (TERA 2010; DMCS 2012). Hunting and trapping areas reported in the sources reviewed were often in proximity to an aquatic environment. The ADK and FLM have indicated such areas surrounding the Liard River, Beaver River, La Biche River, Celebita Lake, Maxhamish Lake and Coles Lake (DMCS 2012). Similarly, the FNFN have described the Petitot River area as having “strong habitat characteristics for a variety of preferred hunting and trapping species, especially moose, lynx, beaver, and other fur bearers, and a wide variety of migratory waterfowl” (Quicksilver Resources 2013, p.7).

### 3.1.2 Fishing

Fishing continues to be important for Aboriginal land users both for subsistence and as a way to maintain cultural traditions and pass traditional knowledge to younger generations. “Traditional fishing methods discussed include the construction of fish weirs and the use of nets, spears and hook and line. Modern methods include jigging in the winter, and angling in spring, summer and fall” (TERA 2010, p.42). Fishing occurs during multiple seasons, with winter (ice) fishing primarily focused on lakes, spring fishing focused on rivers and their confluences with other watercourses, and summer fishing focused on lakes and rivers. Fish species of importance to Aboriginal groups in the region include Northern Pike, Grayling, Walleye, Whitefish, Sucker, Pickerel, Dolly Varden (trout) and Burbot (TERA 2010; DMCS 2012). Minnows are used as bait.

Waterbodies and watercourses in the Study Areas identified as fishing locations by Aboriginal land users include the Sahtaneh River and Courvoisier Creek (FNFN; TERA 2010); Klua (or Fish) Lake continues to be the primary fishing lake for PRFN members (T8FN and Firelight 2012). Fisherman Lake, just east of Fort Liard, has been identified as an important location to harvest whitefish (DMCS 2012) by the ADK and FLM. Lede’h Ke’h (Bovie Lake), Celebita Lake, Maxhamish Lake, Coles Lake and La Biche River and surrounding areas have also been identified as fishing areas by the ADK and FLM (DMCS 2012).

### 3.1.3 Plant Gathering

Plant gathering occurs for subsistence, utilitarian, spiritual and medicinal reasons. Traditional plant harvesting has been recorded by ADK, FLM and FNFN as occurring in areas overlapping the Study Areas (TERA 2010; DMCS 2012). Specific subsistence plant gathering areas indicated include a large berry picking area around Celebita Lake, east of Fort Liard (DMCS 2012). Spruce and birch trees were used to build canoes (TERA 2010). Bogs and fens have been described as being locations where important food, utilitarian and medicinal plants such as blueberries, cloudberries, low-bush cranberry, Labrador tea, Sphagnum moss, tamarack and black spruce can be located. Aboriginal land users also indicated that muskeg can be used as a drinking water source (TERA 2010).

### 3.1.4 Culturally Important Sites and Areas

Culturally important sites and areas, such as habitation areas, burial sites and other sites of cultural significance, are often concentrated around water sources. Such sites and areas have been documented throughout the Study Areas.

> "Areas around lakes were often utilized as retirement areas for elderly community members. Unable to travel around efficiently, many Elders would permanently reside at a lake and live off of fish. This, in part, explains why there are so many burials at lakes throughout the ADK and FLM territory" (DMCS 2012, p.7)."

Cabins or camps are often used as a base from which Aboriginal land users travel out to undertake traditional activities, such as hunting, trapping and harvesting. The ADK and FLM have identified cabins at Fisherman, Celebita, and Maxhamish Lakes, and along the Beaver River. The Kotcho Lake Village Site, located at the very eastern boundary of the Study Areas, is an area of traditional settlement and resource use by the FNFN and Dene Tha (BC MOE, no date).

Sites of cultural and spiritual importance have also been documented in the Study Areas: "Fisherman Lake is both an extremely important resource procurement area and a place of cultural significance for the [ADK] people" (DMCS 2012, p.19). In addition, this area is the location of a large number (possibly as many as 100) of human burials (DMCS 2012). Lede'h Ke'h (Bovie Lake) is a place of spiritual importance to the ADK and FLM where ceremonial gatherings would occur. A spiritual site is also located around Celebita Lake and archaeological sites have been recorded around Maxhamish Lake. A FNFN gathering place and ancestral village is located at Maxhamish Lake (Quicksilver Resources 2013). The Liard River itself has also been described as "critical to the physical and cultural survival of the ADK" (DMCS 2012, p.18).

## 3.2 Water Licences and Other Authorized Water Withdrawals and Return Flows

### 3.2.1 Surface Water Withdrawals

Data on current (as of February 2016) water use were collected from active water licences throughout the Study Areas, collected from public registries and governmental offices in Yukon, NWT, Alberta and BC governments. Each issued water licence includes a location (Map A-10) and indicates a maximum annual surface water usage allocation. This volume was used to estimate the amount of surface water per year which could be withdrawn, rather than the actual withdrawals, to create a maximum-case scenario which over-estimates instead of under-estimates current water use within the Study Areas.

There are a variety of users in the Study Areas who currently have water licences for surface water allocation. The reasons for water withdrawal vary. There are municipal and governmental water licences used for public water supply and infrastructure, private licences for both industry and private residents, as well as an 'other' category which includes all unclassified licences. Private users (i.e. non-government, including industry and drinking water wells) account for 85% of licenced water withdrawals within the Surface Water Study Area (Table 7). This water allocation is largely for mining, oil and gas exploration, hydroelectric power and private residential water supply activities (Table 8).

Leading industries are power, mining and municipal works, and oil & gas which account for 89% of licenced water withdrawals within the Surface Water Study Area in a worst case scenario (Table 8). The hydro power allocation is for a single, run-of-river hydroelectric facility in the Yukon side of the Headwaters Liard sub-basin. There are no hydroelectric dams in the Surface Water Study Area (Morgan, personal communication 2016), although Yukon Energy is currently investigating hydroelectric developments upstream of Watson Lake on the Frances River (Midgard 2016).

A summary of water licences and maximum authorized withdrawals is shown in Table 9.

**Table 7: Current Surface Water Allocation Summary**

| User | Number of Licences | Maximum Use Per Year in Surface Water Study Area ($m^3$) | Allocation in Surface Water Study Area (%) |
|---|---|---|---|
| Private - Industry | 50 | 24,890,632 | 46.9 |
| Private - Personal | 28 | 20,413,251 | 38.5 |
| Municipal | 3 | 6,971,764 | 13.1 |
| Public - Government | 11 | 791,088 | 1.5 |
| Other | 2 | 3,319 | <0.1 |

**Table 8: Current Purpose of Surface Water Allocation by all Licenced Users**

| Use | Maximum Withdrawal Use ($m^3$/year) | Allocation in Study Area (%) |
|---|---|---|
| Power (Hydro) | 16,966,295 | 32.0 |
| Mining | 16,671,870 | 31.4 |
| Municipal Works | 7,026,296 | 13.2 |
| Oil and Gas | 6,286,797 | 11.8 |
| Storage | 2,778,478 | 5.2 |
| Processing | 1,972,172 | 3.7 |
| Miscellaneous | 938,415 | 1.8 |
| Road Maintenance | 258,844 | 0.5 |
| Irrigation | 141,850 | 0.3 |
| Land Improvement | 1,659 | <0.1 |
| Stockwatering | 3,319 | <0.1 |
| Work Camps | 5,808 | <0.1 |
| Domestic | 18,252 | <0.1 |

**Table 9: Surface Water Allocation Summary within Study Area by Jurisdiction**

| Jurisdiction | Licenced Annual Volume ($m^3$) | Percentage of Total |
|---|---|---|
| Northwest Territories | 474,500 | 0.9 |
| Yukon | 36,075,505 | 68.0 |
| British Columbia | 16,510,376 | 31.1 |
| Alberta | 9,672 | <0.1 |

To summarize, by jurisdiction, Yukon has licensed the most surface water withdrawal within the Surface Water Study Area (68.0%) followed by BC (31.1%), NWT (0.9%) and Alberta (<0.1%). For a spatial summary of the water licences within the Surface Water Study Area, see Map A-10. Although not specified by each jurisdiction, the water usage can be categorized as consumptive and non-consumptive. For non-consumptive licences, water is used but then returned to the source. Non-consumptive uses include run-of-river hydroelectric power generation or a proportion of municipal use that is returned to the source waterbody following treatment. Consumptive licences represent a “loss” of surface water from the natural system.

There are water licences dating back to 1996 in the Surface Water Study Area. Many water licences within the permitting records have been issued for the same location multiple times through extensions or amendments. If no extension of amendment to the water licence was completed by the user, the water licence was then closed. Historically, main users for water allocation in each jurisdiction have been municipalities, mining, oil & gas works and private industry/residents. A summary of all recorded water licences granted by category, and the associated surface water allocation percentage, is shown in Table 10.

**Table 10: Historical Water Allocation Category Proportions in the Surface Water Study Area by Jurisdiction**

| Jurisdiction | Category | Surface Water Allocation (%) |
|---|---|---|
| **Yukon** | Municipal | 86.3 |
| | Miscellaneous | 13.7 |
| **NWT** | Mining | 58.8 |
| | Oil and Gas | 21 |
| | Miscellaneous | 9 |
| | Public - Government | 6 |
| | Camps | 4.6 |
| | Power | 0.5 |
| | Industry | 0.1 |
| | Waterworks - Water Delivery | 0.1 |
| | Waterworks - Water Bottling | <0.1 |
| **Alberta** | Oil and Gas | 84.5 |
| | Construction | 15.5 |

**Table 10: Historical Water Allocation Category Proportions in the Surface Water Study Area by Jurisdiction**

| Jurisdiction | Category | Surface Water Allocation (%) |
|---|---|---|
| **British Columbia** | Oil and Gas | 51.7 |
| | Industry | 19.5 |
| | Miscellaneous | 16.1 |
| | Quarrying | 2.5 |
| | Forestry | 1.7 |
| | Fuel Storage | 1.7 |
| | Private | 1.7 |
| | Public - Government | 1.7 |
| | Camps | 0.9 |
| | Mining | 0.9 |
| | Municipal | 0.9 |
| | Power | 0.9 |

## 3.2.2 Groundwater Withdrawals

Groundwater withdrawals are also subject to water licences in all jurisdictions; however, data on groundwater wells are sparse for Alberta, Yukon and Northwest Territories. British Columbia has the most complete groundwater well records of the four jurisdictions (BC MOE 2016a). A summary of groundwater well numbers and withdrawal limits by province/territory is shown in Table 11, and although this table is by no means complete, it is a summary of publicly available information. The BC database does not include withdrawal volumes (Table 12). Most wells are privately owned followed by 'water supply' and 'unknown' uses (BC lists 'Unknown Well Use' and 'Other' as categories in data summaries; no other information is provided).

**Table 11: Groundwater Well Summary Within Study Area by Province / Territory**

| Province / Territory | Number of Wells | Total Annual Withdrawal ($m^3$) |
|---|---|---|
| Northwest Territories | 3 | 40,000[(a)] |
| Yukon | 2 | 1,690[(b)] |
| British Columbia | 190 | unknown |
| Alberta | 1 | 9,672[(b)] |

a) This value is for Fort Liard; no data were found for Nahanni Butte annual withdrawal.

b) These values were derived from active water licences in the Study Areas, but are unlikely to be complete.

**Table 12: British Columbia Groundwater Well Uses in Groundwater Study Area**

| Category | Number of Groundwater Wells | Percentage of Total Wells (%) |
|---|---|---|
| Private Domestic | 49 | 25.8 |
| Water Supply System | 41 | 21.6 |
| Unknown Well Use[(a)] | 37 | 19.5 |
| Other[(a)] | 31 | 16.3 |
| Commercial and Industrial | 26 | 13.7 |
| Abandoned | 3 | 1.6 |
| Observation Well | 2 | 1.1 |
| Test Well | 1 | 0.5 |
| **TOTAL** | **190** | **100** |

a) These are reported categories on provincial registries; no further information exists.

### 3.2.3 Community Uses

The communities of Watson Lake, Fort Liard and Nahanni Butte receive their municipal water supply from groundwater wells, and discharge to sewage lagoons and liquid waste sites. The town of Fort Nelson uses Muskwa River surface water, and returns treated effluent to the Muskwa River. Details about community water use are shown in Table 13.

**Table 13: Community Water Use in the Study Area**

| Community | Province / Territory | Drinking Water Source | Population | Approximate Annual Use ($m^3$) | Sewage | Landfill Notes |
|---|---|---|---|---|---|---|
| Town of Watson Lake | Yukon | Groundwater | 92 | 580,350 | Sewage Lagoon located 3 km from Town of Watson Lake | Landfill located 2 km from Town of Watson Lake |
| Fort Nelson | BC | Muskwa River (Surface Water) | 4,514 | 1,739,789 | Treated and discharged to Muskwa River | Located 4.5 km from For Nelson |
| Fort Liard | NWT | Groundwater | 615 | 40,000 | Sewage lagoon | - |
| Nahanni Butte | NWT | Groundwater | 92 | Not known | Liquid and Solid waste site | - |

### 3.2.4 Industrial and Commercial Uses

Water Licence registries in British Columbia, Alberta, Yukon and Northwest Territories were searched and a list of active water licences was compiled. Major users, considered to be those licenced to withdraw more than 1,000,000 $m^3$/y, were compiled into Table 14 and are shown on Map A-10. The primary water use is small-scale hydroelectric, which results in zero net withdrawals. The next largest users are community use, mining, and oil and gas.

**Table 14: Potential Point Sources: Industrial and Commercial Water Licences and Locations in Study Areas with Allotments over 1,000,000 m³/y**

| Licence Holder | Location | Province / Territory | Water Use | Details | Annual Allotment ($m^3$) | Notes |
|---|---|---|---|---|---|---|
| Denis Bouchard | Rancheria Lodge | Yukon | Small-scale hydroelectric and lodge use | - | 16,966,295 | Most water returned to river immediately |
| Yukon Zinc Corporation | Wolverine Mine (in care and maintenance as of 2015) | Yukon | Mining | Copper, lead, zinc, silver, gold | 5,277,170 | Care and maintenance (no current mining activities) |
| BMC Minerals Ltd | KZK Project | Yukon | Mining (exploration) | Copper, lead, zinc, silver, gold | 2,701,000 | Exploration phase |
| Teck Cominco | KZK Project | Yukon | Mining (exploration) | Copper, lead, zinc, silver, gold | 2,701,000 | Exploration phase |
| Sa Dene Hes Operating Corp | North of Watson Lake | Yukon | Mining (closure) | Zinc, lead | 1,493,215 | Closure Activities |
| Nexen Inc | Fort Nelson | BC | Oil and gas | Oil field injection | 5,000,000 | May not be active |
| Westcoast Energy Inc | Fort Nelson | BC | Oil and gas | Processing and manufacturing | 1,972,172 | Natural gas |

## 3.3 Other In-Situ Uses

### 3.3.1 Tourism, Recreation and Protected Areas

Tourism and recreation in the Study Areas are based on large areas of untouched wilderness, big-game wildlife, navigable waterways and highways. With tourism being a source of income for the communities and First Nation groups within the Study Areas, the Deh Cho Land Use Plan (DLUPC 2006) and Dease-Liard Management Plan (DLSRMP 2012) consider the tourism and recreation potential within the Liard and Petitot basins. Tourism is concentrated in the summer season, when tourist attractions are open, although there are a few winter based recreational activities which draw tourists. Highlights which draw tourist and recreational activity include the following:

- Sustenance-related pursuits, including hunting, trapping, fishing, and plant gathering. The Mackenzie Mountain Big Game Guide Outfitters Area in the Deh Cho Land Management Area allows for outfitters to take guests, drawn from Europe, the U.S. and Canada.
- Summer-based tourism, including tourist recreational activities such as hiking, horseback riding, mountain biking, ATVing, dirt biking, fishing, swimming, hunting and canoeing, kayaking and rafting.

- Winter-based tourism, including recreational activities such as ski touring, snowmobiling, snowshoeing, and ice-fishing as well as some hunting, trapping and dog-sledding.
- Road Travel, including RV- and camping-based road trips using all-season roads (e.g., Highway 7 to Fort Simpson or Highway 37 and 97 to Watson Lake). Service stops in communities and stops at attractions have established a tourism trade focused around food, gas and lodging.

To draw tourism and maintain the pristine wilderness, a variety of parks and protected areas exist in the Study Areas. Ranging from small parks along the highway to National Parks as well as ecological reserves and conservation areas, 7.4% of the Surface Water Study Area (17,184 km$^2$ of 231,479 km$^2$) is protected area. The largest portion of this area is territorial and provincial parks, representing 79% of the protected area (Table 15; Map A-11).

**Table 15: Protected Areas within the Surface Water Study Area**

| Protected Area Classification | Area (km$^2$) | Percentage of total (%) |
|---|---|---|
| Parks | 13,596 | 79.1 |
| Conservancy | 2,256 | 13.1 |
| Protected Area - General | 1,047 | 6.1 |
| National Park of Canada | 192 | 1.1 |
| Ecological Reserve | 89 | 0.5 |
| National Park Reserve of Canada | 4 | <0.1 |

### 3.3.2 Navigation

Within the Study Areas, there are two major rivers, the Liard and Petitot, and six major lakes, Cormac Lake (NWT), McPherson Lake (Yukon) Frances Lake (Yukon), Watson Lake (Yukon), Dease Lake (BC) and Bistcho Lake (Alberta). Bistcho Lake is the headwaters of the Petitot River which is a main tributary of the Liard River. Along with the Liard and Petitot rivers, there are many smaller tributaries within each of the respective basins, including the Dease, Muskwa, Frances and Fort Nelson rivers. None of these water bodies are identified within the *Navigation Protection Act*. Recreational activities include but are not limited to hunting, trapping, fishing, canoe tripping, motorized watercraft travel between communities and boat traffic on the Liard River. Non-recreational navigation includes the ferry crossing on Highway 1 to Fort Simpson, and private barges used on the Liard River from BC to resupply oil and gas industry projects. Refer to the Section 3.1 for traditional and cultural navigation use.

# 4.0 INFLUENCES ON SURFACE WATER AND GROUNDWATER RESOURCES

Surface water and groundwater withdrawals based on water licence data were assessed relative to discharge at the Fort Liard hydrometric station. This assessment used a 'worst-case scenario' approach that considers the maximum authorized withdrawal amounts, rather than actual withdrawals, so that effects to surface water and groundwater quantity are over-estimated rather than under-estimated. Furthermore, in addition to percentage of annual flow, the percentage of winter (defined as December, January and February) discharges was calculated. This is a very conservative approach and actual withdrawals are likely to be far below these estimates and are unlikely to be concentrated between December and February.

Water that is returned to the system from which it was withdrawn, such as water for hydroelectric facilities, which only withdraw water for a short period of time, is termed a 'return flow'. Evaluating accurate quantities for return flows is difficult because data formats vary by jurisdiction, and reporting return flows is not universally required. Alberta Environment (2007) provided descriptions of return flow by sector; however, too much uncertainty remains to determine reliable estimates for return flows.

At the current state of development in the Study Areas, a detailed return flow assessment is not required. Assuming the worst case scenario, in which all consumptive sectors (i.e., all sectors except hydroelectric power) are considered to have zero return flow, the total water allocated to be removed from the Study Areas is 0.058% of the mean annual discharge at the Fort Liard hydrometric station, and 0.981% of winter discharges as shown in Table 16. These proportions are considered overestimates, since some sectors such as municipal works may have return flows as high as 90%, many licenced users do not use their full allotment, and pumping rates may not allow for the entire annual withdrawal to be used within three (winter) months.

Groundwater withdrawal rates, as discussed in Section 3.2.2, are not well documented but are likely much lower than surface water withdrawals based on available water licence data.

**Table 16: Consumptive Water Use as a Percentage of Mean Annual Flow at Fort Liard Hydrometric Station, Surface Water Study Area**

| Use | Maximum Withdrawal Use ($m^3$/year) | Allocation of Total Use in Surface Water Study Area (%) | Percentage of Total Annual Flow at Fort Liard Hydrometric Station (%) | Percentage of Winter Flow (defined as December 1 to February 28) |
|---|---|---|---|---|
| Mining | 16,671,870 | 31.4 | 0.027 | 0.453 |
| Municipal Works | 7,026,296 | 13.2 | 0.011 | 0.191 |
| Oil and Gas | 6,286,797 | 11.8 | 0.010 | 0.171 |
| Storage | 2,778,478 | 5.2 | 0.004 | 0.076 |
| Processing | 1,972,172 | 3.7 | 0.003 | 0.054 |
| Miscellaneous | 938,415 | 1.8 | 0.002 | 0.026 |
| Road Maintenance | 258,844 | 0.5 | 0.000 | 0.007 |
| Irrigation | 141,850 | 0.3 | 0.000 | 0.004 |
| Land Improvement | 1,659 | <0.1 | 0.000 | 0.000 |
| Stockwatering | 3,319 | <0.1 | 0.000 | 0.000 |
| Work Camps | 5,808 | <0.1 | 0.000 | 0.000 |
| Domestic | 18,251 | <0.0 | 0.000 | 0.000 |
| **TOTAL** | **36,103,759** | | **0.058** | **0.981** |

## 4.1 Current Point Source Discharges

The potential for point source discharges into the Liard and Petitot basins was assessed by reviewing water licences, mineral leases, oil and gas leases, forestry operations, and communities. Land use activity for these sectors tended to cluster in certain regions of the Study Areas. A summary of the sectors and general locations within the Study Areas is given in Table 17, and specific identified point sources are shown in Map A-12 and Map A-13.

**Table 17: Land Use Sectors and Locations within Study Areas**

| | Study Area Region | | | | |
|---|---|---|---|---|---|
| **Land Use** | **Upper Liard (Liard River above Watson Lake)** | **Middle Liard (Liard River between Watson Lake and Fort Liard)** | **Lower Liard (Liard River between Fort Liard and Fort Simpson)** | **Petitot River Headwaters (Alberta)** | **Petitot River Lower (BC)** |
| Mineral Leases | • | • | | • | |
| Oil and Gas Leases | | • | | • | • |
| Forestry | • | • | • | | |
| Community of Watson Lake, Yukon | | • | | | |
| Community of Lower Post, Yukon | | • | | | |
| Community of Fort Liard, NWT | | | • | | |
| Community of Nahanni Butte, NWT | | | • | | |

### 4.1.1 Oil and Gas Activities

Most oil and gas activities in the Study Areas are in British Columbia (Map A-14), including high activity around Fort Nelson. Oil and gas activities in BC are governed by the *Oil and Gas Activities Act*, which requires that oil and gas activities must not cause an adverse effect on the quality, quantity or natural timing of flow of water into an aquifer or release deleterious materials to a stream, wetland or lake. Should an activity cross a stream, wetland or lake, fish or fish habitat cannot be damaged, fish movement cannot be prevented or impeded, and damage to riparian habitat must be mitigated. Any oil and gas activities within a wetland must maintain the natural flow of water to the wetland.

The natural gas resource potential in southwest Northwest Territories was the subject of the Liard Basin Hydrocarbon Project (2012 to 2015, inclusive), coordinated by the Northwest Territories Geological Survey, in collaboration with the British Columbia Ministry of Energy, Mines and Natural Gas, the Yukon Geological Survey and the Geological Survey of Canada. The Project studied shales of the Besa River Formation and the Golata Formation (Middle Devonian to Carboniferous), focussing on investigating these formations and also refining their stratigraphic correlation in the Liard Basin across the three jurisdictions (British Columbia, Northwest Territories and Yukon). Gas has been discovered in Devonian and Mississippian (Lower Carboniferous) shales within the Liard Basin and, as of 2013, over 400 wells have been drilled in British Columbia, 81 wells in the Northwest Territories and 13 wells in the Yukon (Fiess et al. 2013).

In 2014, the British Columbia Oil & Gas Commission produced a report detailing the existing oil and gas related disturbances in northeast British Columbia (BC Oil and Gas Commission 2014). These disturbances included wells, roads, facilities, pipelines and geophysical exploration. The areas in northeast British Columbia that roughly overlap with the Liard and Petitot Surface and Groundwater Study Areas included the Horn River basin, the Liard basin and the Cordova embayment. Landscape changes as a result of oil and gas disturbances account for approximately 3.0% of the Horn River basin, 1.3% of the Liard basin and 2.8% of the Cordova embayment (BC Oil and Gas Commission 2014). Oil and gas development is concentrated in northeast British Columbia in the Montney and Horn River Basins. In 2013, the total natural gas production was 1.5 trillion cubic feet, with the majority produced in these two basins. Exploitation of renewable energy and oil and gas in the area has been limited. There are currently no renewable energy projects and no water licenses have been issued for this purpose. Oil and gas exploration has been limited to two watersheds, the Upper Sikanni Chief and Upper Halfway River (BC Oil and Gas Commission 2014).

Constituents of potential concern from oil and gas exploration activities include pipeline and wellhead spills of oil, emissions from heavy equipment, and dust from land disturbances in the areas shown on Map A-14. Oil and gas activities have the potential to increase concentrations of metals and polyaromatic hydrocarbons (PAHs) in water and sediments.

### 4.1.2 Hydroelectric Development

Studies are currently underway in the Yukon to determine the feasibility of constructing hydroelectric infrastructure in the Watson Lake area, and connecting the Yukon electricity grid to the wider North American grid. The Yukon Development Corporation contracted Midgard Consulting Incorporated to conduct a feasibility study of potential hydroelectric projects in the Yukon, including in the Liard basin (Midgard 2016). The feasibility study identified three sites on the Frances River with hydroelectric potential and meeting other criteria (e.g. flood risk, greater than 10 megawatt potential): at Upper Canyon, False Canyon, and Middle or Lower Canyon. These locations are all upstream of Watson Lake in the Yukon portion of the Frances River.

The Rancheria Lodge in the Yukon has an active water license for small-scale hydroelectric generation for local use. It is possible that other small run-of-river hydroelectric facilities exist in the Study Areas; these have very little impact on water quality and quantity because water is returned to rivers immediately following use in turbines.

### 4.1.3 Mining

There are no active mines in the Yukon, Northwest Territories, or Alberta sections of the Study Areas. British Columbia has two mines that are potentially active (Table 18), but limited information could be found regarding these operations. Mineral leases are shown in Map A-15.

**Table 18: Point Sources: Mines listed as Active**

| Company | Mine | Province / Territory | Years of Operation | Minerals | Notes |
|---|---|---|---|---|---|
| Cassiar Jade | Cassiar Jade | BC | unknown | Jade | Project referenced by British Columbia Ministry of Energy and Mines (2016) but no further information was found |
| Fireside Minerals | Fireside Mine | BC | 1997 - present | Barite | - |

There are several mineral exploration sites and past producers in the Study Areas, primarily in the Yukon and BC. Although it is beyond the scope of this Project to evaluate each mineral exploration activity in the Study Areas, it is possible to identify constituents of potential concern based on mining activities. These are:

- Copper;
- Zinc;
- Lead;
- Silver;
- Gold; and
- Low-pH water associated with acid-rock drainage.

The highest concentration of past mineral exploration activity is in the Dease Lake area of British Columbia.

### 4.1.4 Forestry

Forestry activities in all parts of the Study Areas are subject to regulations. For example, forestry activities in BC are governed by the *Forest and Range Practices Act*, which requires that all forestry operations maintain non-merchantable vegetation within 5 m of any stream, wetland or lake. Ground based equipment must not be operated within 5 m of a stream, wetland or lake. Trees must be felled away from the stream, wetland or lake so as to not introduce sediment or debris or restrict natural water patterns or fish passage. Current forestry activities are very limited in scale (Map A-16) and are considered unlikely to act as point sources for contaminants in the Study Areas, although large-scale forestry operations can result in increased transportation of suspended sediments to waterways.

### 4.1.5 Pulp and Paper

There are currently no pulp and paper mills in the Study Areas.

### 4.1.6 Agriculture

Other than near Fort Nelson BC, there is no agricultural industry in the Study Areas (Agriculture and Agri-Food Canada 2017a). Agricultural activities in Fort Nelson involve livestock including cattle, pigs and chickens, and crops including oats, hay, barley, wheat and rye.

Agriculture can result in increased runoff of nutrients including nitrogen and phosphorous (Agriculture and Agri-Food Canada 2017b) and pesticides; however, the small scale of agriculture around Fort Nelson likely does not result in a potential point source of contamination.

### 4.1.7 Communities

The only community in the Study Area that discharges into a water body is Fort Nelson; the other communities discharge to sewage lagoons or liquid waste sites. There is a water treatment plant in Fort Nelson and therefore it is unlikely that Fort Nelson is a point source of constituents of potential concern in effluent.

Community landfills have the potential to act as sources for constituents of potential concern, including metals.

Sewage lagoons and liquid waste sites have the potential to act as sources for constituents of potential concern, including nutrients.

## 4.2 Current Non-Point Source Loadings and Air Emissions

Potential non-point sources of loadings of sediments, nutrients, metals, organics, and pesticides to the Liard and Petitot rivers include mining, oil and gas, forestry and agricultural activities. Disturbances of the lands from these activities near rivers may accelerate streambank erosion and convey additional sediment loadings, as well as loadings of any contaminants (e.g., metals or organics) adsorbed to the soil, during runoff events. Chemicals applied to the land, such as nutrients in fertilizers or pesticides for agricultural purposes, may also enter the Liard and Petitot rivers through runoff events. Linear developments, such as roads and pipelines, may also contribute non-point source loadings to the Liard and Petitot rivers through streambank erosion where the development crosses the rivers and, in case of roads, from the application of salts and sands to roads.

Due to the limited agricultural activities and linear developments in the Liard and Petitot basins, non-point source loadings to the Liard and Petitot rivers related to agricultural and linear developments are expected to be low.

Mining, oil and gas, and forestry activities occur in the Liard and Petitot basins and therefore have the potential to contribute non-point source loadings of suspended solids, metals, acid-rock drainage, and PAHs to the Liard and Petitot River basins. Regulations and controls are in place to minimize non-point source loadings from these sources (e.g., BC's *Oil and Gas Activities Act* and *Forest and Range Practices Act*, see Section 4.1.3*)*.

Other than limited localized development, such as oil and gas extraction in the Fort Nelson area, the overall level of development in the Study Areas is low. Therefore, the current effect of air emissions on the Liard and Petitot rivers is considered to be low.

### 4.2.1 Long-Range Transport of Compounds in the Atmosphere

The overall level of development in the Study Areas is low, and the associated long-range transport of compounds from the Study Areas is considered to be low.

### 4.2.2 Surface Water Runoff

The overall level of development in the Study Areas is low, and therefore surface water runoff is not considered a substantial source of constituents of potential concern.

### 4.2.3 Linear Development

An analysis of the MKMA (MKMA 2016) indicated that there was a relatively low level of linear development in this area; the development that was present was concentrated (Crane Management Consultants 2008). Total linear development density of the area is approximately 0.1 km per km$^2$ with the total distance equally approximately 7,000 km. Unimproved roads and cutlines accounted for 77% of this total distance. The Upper Sikanni River had one of the highest concentrations of linear development, approximately 0.4 km per km$^2$. There are currently no active mines or mineral developments in the MKMA; however, approximately 11.6% of the management area has been rated as having a high potential of containing mineral deposits that would be of interest. Watersheds within the MKMA that had low levels of linear development included the Coal River, Upper Liard River, Lower Kechika River, and Turnagain River. Renewable energy and oil and gas in the area has been limited. There are currently no renewable energy projects and no water licenses have been issued for this purpose. Oil and gas exploration has been limited to two watersheds, the Upper Sikanni Chief and Upper Halfway River.

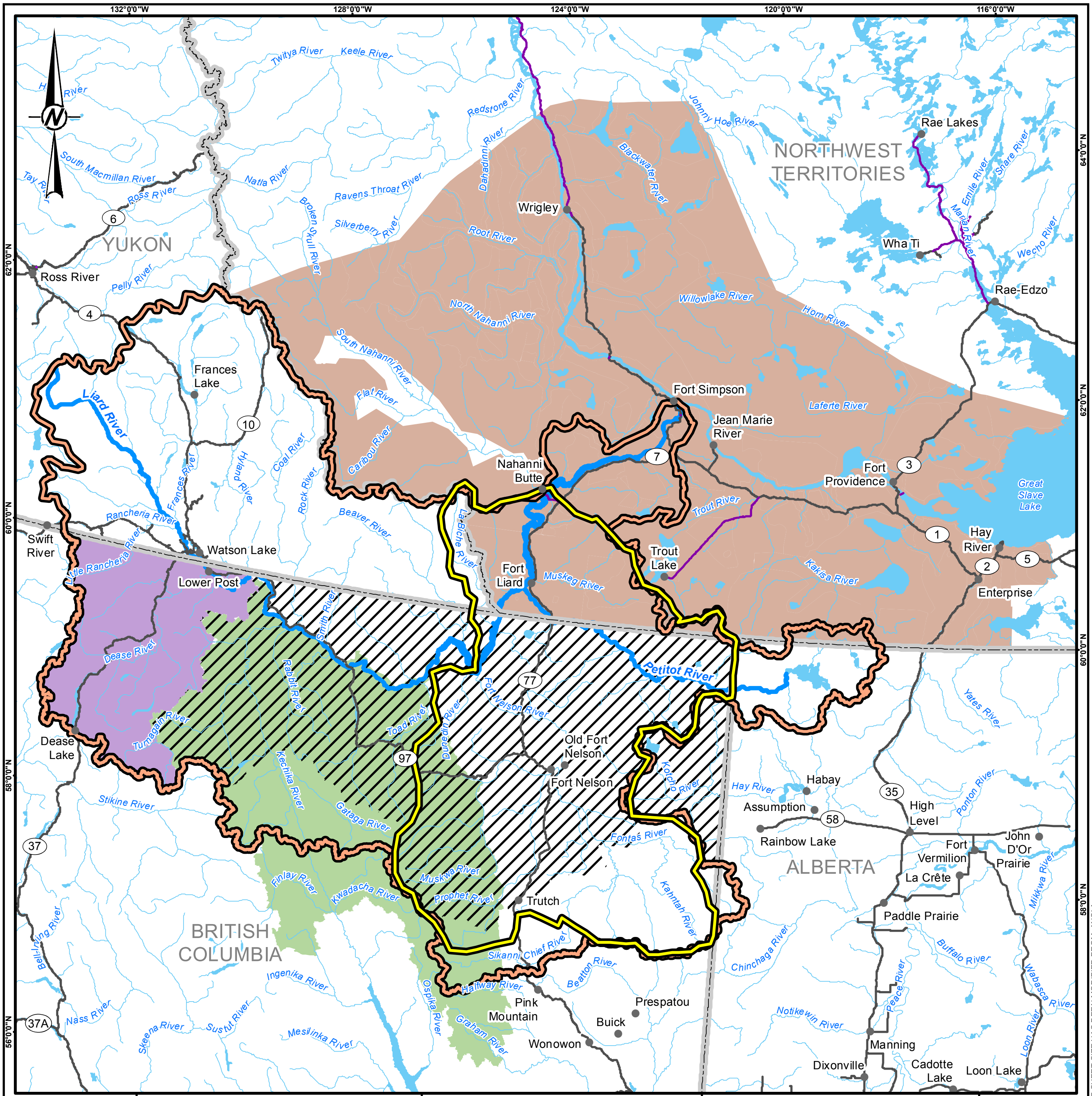
## 4.3 Land Use Plans

There are three land and resource management plans in use in both the groundwater and surface water Study Areas (Figure 11).

- Fort Nelson Land and Resource Management Plan (FNLRMP), approved by BC in 1997.
- Muskwa-Kechika Management Area, approved by BC in 1997 and overlapping with the FNLRMP.
- Dehcho Land Use Plan, submitted in 2006 and not yet been approved by the NWT.

In addition, a fourth land use and resource management plan is in use in the Surface Water Study Area, but not the Groundwater Study Area:

Dease-Liard Sustainable Resource Management Plan (DLSRMP) area, approved by BC in 2004.




**LEGEND**

- POPULATED PLACE
- ALL-SEASON ROAD
- WINTER ROAD
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA
- DEASE-LIARD SUSTAINABLE RESOURCE MANAGEMENT PLAN
- DEHCHO LAND USE PLAN
- FORT NELSON LAND AND RESOURCE MANAGEMENT PLAN
- MUSKWA-KECHIKA MANAGEMENT PLAN

0 100 200

1:5,000,000 KILOMETRES

**REFERENCE(S)**

1. SURFACE WATER STUDY AREA CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA. GROUNDWATER STUDY AREA PROVIDED BY BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. BC DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE - BRITISH COLUMBIA
5. DEHCHO LAND USE PLAN OBTAINED FROM THE DEHCHO LAND USE PLANNING COMMITTEE

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

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CLIENT

GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**LAND AND RESOURCE MANAGEMENT PLAN AREAS**

CONSULTANT

Golder Associates

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| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

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The FNLRMP has been accepted by the BC government and provides land use management for most of the BC portion represented in the Study Areas (FNLRMP 2007). The FNLRMP considers sectors of activity including forestry, oil and gas, tourism, transportation, agriculture, and trapping. Forestry is the dominant sector, representing 40% of the economy, followed by oil and gas (10 to 20%) and tourism (10%). There are also significant mineral resources present, but exploration has been limited in that area. Agriculture is mostly concentrated around Fort Nelson and represents only 1% of the economy, but there is potential for that sector to grow (FNLRMP 2007). Due to the presence of protected areas along the Liard River, there is little potential for the hydroelectric power sector to be developed (FNLRMP 2007).

The FNLRMP is divided into 37 Resource Management Zones (RMZs). Each RMZ contains specific resource values, management objectives, and strategic development, which set out the types of activities and level of intensity permitted. These RMZs fall into four categories of land use:

1) Enhanced Resource Development, representing approximately 36% of the FNLRMP area. The management intent is to provide for intensive development of resources such as timber, natural gas, and minerals, with an emphasis on the recreation and tourism resources along the highway corridor.

2) General Resource Development, representing approximately 24% of the FNLRMP area. The intent for this category is to provide for a wide array of resource values and uses and all the development sectors will be site-specific. The long-term objective is to return the lands to their natural state after activities are completed.

3) Muskwa-Kechika Special Management, representing approximately 29% of the FNLRMP area. Resource development can proceed but impacts on other resource values must be minimal. Wilderness characteristics and wildlife habitat must be maintained over time during resource development, including roaded resource development.

4) Protected Area, representing approximately 11% of the FNLRMP area. Logging, mining, energy and hydroelectric exploration and development are prohibited in these areas.

Most of the Muskwa-Kechika Management Area (MKMA) is within the FNLRMP area (FNLRMP 2007, MKMA 2016). The covered area is largely undeveloped and contains a wide range of resources. Wildlife is abundant, the northern portion has considerable timber value, and there is a well-defined potential for mineral and gas resources (MKMA 2016). About 30% of the MKMA has been designated as protected areas. There is interest in natural resource development in the MKMA, and guidelines are provided in the MKMA for minimizing impacts on other resource values and ensuring that the wilderness characteristics and wildlife habitat are maintained over time.

The DLSRMP (included in the surface water study area only) includes, and extends beyond the western end of the Study Areas in BC (DLSRMP 2012). Historically, the mining and forestry sectors have been active in this area, and there is still ongoing development. The DLSRMP provides guidelines for economic opportunity for the sustainable development of the oil and gas, mining, forestry, and tourism sectors, and with respect to aboriginal culture. In January 2012, a major protected area was created (Ne'ah Protected Area) that covers about 10% of the total area (DLSRMP 2012).

The NWT portion of the Study Areas are located in the Dehcho First Nation Territory which still does not have an agreement with the NWT government. In 2006, the Dehcho Land Use Planning Committee submitted a final draft land use plan, which was rejected by the NWT government. Negotiations between the two parties are still on-going (CBC 2015). The aim of this land use plan is to guide the future conservation, development and utilization of the land, water and other resources in the Dehcho Territory (DLUPC 2006). Following consultations with communities, a total of 36 zones have been classified in five categories of land use. Each zone falls under one of the following categories, and would allow the development of the associated sector of activity:

1) Protected Areas Strategy Zones – Tourism permitted only.

2) Conservation Zones – Tourism permitted only.

3) General Use Zones – Oil and gas, mining, forestry, tourism, and agriculture permitted.

4) Special Management Zones – 15 zones with limited development recommended, zone-specific criteria.

5) Special Infrastructure Corridor – The zones falling under this category overlay, or float over, the underlying zones for pipeline development.

## 4.4 Cumulative Effects

### 4.4.1 Approach

The Mackenzie Valley Environmental Impact Review Board (MVEIRB 2004) and the Canadian Environmental Assessment Agency (CEA Agency 2013) define cumulative effects as the effects from the proposed project in combination with environmental effects of other past, present, and reasonably foreseeable activities. As such, the cumulative effects described here includes all identified impacts within the Study Areas that result from human development; natural processes (such as forest fires) are excluded.

While the definition of cumulative effects includes both current and past impacts, the impacts of closed developments diminish with time and are not documented as well as current developments. Emphasis is placed on identifying current impacts over impacts from historic developments.

The cumulative effects summary is a narrative description of the nature and extent of development within the Study Areas, both current and historic, to a level of detail appropriate to the information available and relevance to the State of Knowledge Report and risk assessment.

Information was gathered from compiled sources only (such as land use plans and government agency cumulative effects summaries). Primary information from specific developments was not included. The summary was aided by the map book (Appendix A), where sufficient geospatial information is available.

Where sufficient data are available, a qualitative summary of potential cumulative effects within the watershed is provided using the following approach.

- Cumulative effects in the Liard and Petitot basins is assessed qualitatively by sector; primarily oil and gas, mining, forestry, municipal, and hydroelectric. Other water users such as outfitting, mineral exploration, and winter road construction are also documented.

- Development is summarized by sub-basin (as defined by Water Survey of Canada), to further identify areas of concern. For example, some sub-basins have more industry than others. Some industry sectors are exclusive to specific sub-basins (i.e., forestry, oil and gas, and mining occur in some areas and not others).
- To document past activity, this report describes the level of activity for each industry sector that may contribute to current water quality and quantity. However, sufficient data are absent to clearly identify historic water quality and quantity trends.
- To forecast future impacts, forecasts of increased activity, decreased activity, and business as usual are used to guide development of the conceptual model and the risk assessment, which could be used to indicate if a particular sub-basin is reaching a to-be-defined threshold.

### 4.4.2 Findings

The Petitot and Dease sub-basins contain the most active water licenses in both the Surface and Groundwater Study Areas. The area of, forest fires, active and expired water licences, permanent and interim protection, and forestry activities was documented for each sub-basin (Tables 19 and Table 20; Maps A-7, A-9, A-10, and A-16).

**Table 19: Summary of Sub-Basin Area, Protection, Water Licences, Fires and Forestry for the Surface Water Study Area**

| Sub-Basin | Sub-Basin Area ($km^2$) | Permanent Protection (%) | Interim Protection (%) | Expired Water Licences | Active Water Licences | Fires 2000 to 2009 (%) | Fires 2010 to 2012 (%) | Active Forestry (%) | Retired Forestry (%) |
|---|---|---|---|---|---|---|---|---|---|
| Beaver (Y.T.-B.C.) | 10,511 | 0.3 | 0.0 | 1 | 0 | 4.8 | 1.1 | 0.0 | 0.0 |
| Central Liard - Toad | 27,970 | 8.5 | 0.0 | 0 | 3 | 1.8 | 0.0 | 0.0 | 0.2 |
| Coal | 9,350 | 1.7 | 0.2 | 2 | 2 | 7.8 | 0.1 | 0.0 | 1.6 |
| Dease | 14,364 | 7.8 | 0.0 | 23 | 21 | 0.2 | 3.3 | 0.0 | 0.0 |
| Fontas | 7,381 | 0.5 | 0.0 | 26 | 0 | 1.3 | 0.8 | 0.2 | 0.2 |
| Frances | 12,700 | 0.0 | 45.5 | 9 | 6 | 6.0 | 0.0 | 0.0 | 0.0 |
| Headwaters Liard | 23,737 | 0.1 | 13.1 | 7 | 6 | 2.1 | 0.4 | 0.0 | 0.4 |
| Hyland | 9,191 | 0.0 | 13.3 | 0 | 2 | 4.4 | 0.0 | 0.0 | 0.0 |
| Kechika | 15,192 | 34.0 | 0.0 | 0 | 0 | 1.0 | 0.6 | 0.0 | 0.0 |
| Lower Fort Nelson | 7,798 | 0.0 | 0.0 | 30 | 7 | 0.3 | 0.8 | 0.2 | 1.2 |
| Lower Liard - La Biche | 7,410 | 0.6 | 0.0 | 24 | 5 | 0.1 | 1.6 | 0.1 | 0.2 |
| Lower Liard - Mouth | 18,774 | 0.0 | 0.0 | 95 | 11 | 0.1 | 0.1 | 0.0 | 0.1 |
| Muskwa | 19,552 | 36.2 | 0.0 | 6 | 12 | 0.2 | 0.2 | 0.0 | 0.3 |
| Petitot | 22,210 | 2.0 | 0.0 | 50 | 38 | 8.4 | 5.8 | 0.0 | 0.0 |
| Sahtaneh | 3,995 | 0.0 | 0.0 | 3 | 6 | 0.2 | 0.1 | 0.0 | 0.4 |
| Sikanni Chief | 10,754 | 1.3 | 0.0 | 1 | 7 | 0.6 | 0.0 | 0.1 | 0.3 |
| Turnagain | 6,871 | 4.4 | 0.0 | 0 | 1 | 4.2 | 0.4 | 0.0 | 0.0 |
| Upper Fort Nelson | 3,718 | 7.3 | 0.0 | 0 | 0 | 0.1 | 1.5 | 0.0 | 0.2 |

**Table 20: Summary of Sub-Basin Area, Protection, Water Licences, Fires and Forestry for the Groundwater Study Area**

| Sub-Basin | Sub-Basin Area (km$^2$) | Permanent Protection (%) | Interim Protection (%) | Expired Water Licences | Active Water Licences | Fires 2000 to 2009 (%) | Fires 2010 to 2012 (%) | Active Forestry (%) | Retired Forestry (%) |
|---|---|---|---|---|---|---|---|---|---|
| Beaver (Y.T.-B.C.) | 75 | 0.0 | 0.0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Central Liard - Toad | 3,451 | <0.1 | 0.0 | 0 | 0 | 0.1 | <0.1 | 0.3 | 1.6 |
| Finlay | 77 | 0.6 | 0.0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Fontas | 5,793 | 0.0 | 0.0 | 0 | 0 | 0.2 | 0.9 | 0.2 | 0.3 |
| Kakisa | 106 | 0.0 | 0.0 | 0 | 0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Lower Fort Nelson | 7,798 | 0.0 | 0.0 | 30 | 7 | 0.3 | 0.8 | 0.2 | 1.2 |
| Lower Liard - La Biche | 7,249 | <0.1 | 0.0 | 24 | 5 | 0.1 | 1.7 | 0.1 | 0.1 |
| Lower Liard - Mouth | 9,334 | 0.0 | 0.0 | 84 | 9 | 0.2 | <0.1 | 0.0 | 0.0 |
| Lower South Nahanni | 193 | 0.4 | 0.0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Muskwa | 19,173 | 0.4 | 0.0 | 6 | 12 | 0.2 | 0.3 | <0.1 | 0.3 |
| Petitot | 13,712 | <0.1 | 0.0 | 18 | 34 | 2.6 | 1.1 | <0.1 | <0.1 |
| Sahtaneh | 3,894 | 0.0 | 0.0 | 3 | 6 | 0.2 | <0.1 | <0.1 | 0.4 |
| Sikanni Chief | 6,432 | <0.1 | 0.0 | 0 | 0 | 0.5 | <0.1 | <0.1 | 0.4 |
| Trout | 505 | 0.0 | 0.0 | 0 | 0 | 4.1 | 2.4 | 0.0 | 1.6 |
| Upper Fort Nelson | 3,706 | <0.1 | 0.0 | 0 | 0 | 0.1 | 1.5 | 0.0 | <0.1 |
| Upper Hay | 306 | 0.0 | 0.0 | 0 | 0 | 0.0 | <0.1 | 0.0 | 0.0 |

<= less than. Table excludes sub basins with less than 30 km$^2$ represented in the Groundwater Study Area.

Federal Contaminated Sites are included in Map A-17 and are available through the Federal Contaminated Sites Inventory (Treasury Board of Canada 2016).

In the Surface Water Study Area sub-basins, the percent of permanently protected area varies from 0.0% to 36.2% (Muskwa sub-basin) while the minimum and maximum percent of interim protection is 0.0% and 45.5% (Frances sub-basin, Table 19). The Frances, Hyland, Lower Fort Nelson, Lower Liard – Mouth, and Sahtaneh sub-basins all have no permanent protection. Sub-basins with the most expired water licenses include Lower Fort Nelson, Petitot and Lower Liard – Mouth with 30, 50 and 95, respectively. Sub-basins with the most active water licenses include Lower Liard – Mouth, Muskwa, Dease, and Petitot with 11, 12, 21 and 38, respectively. Landscape changes due to forest fires were most prevalent in the Frances (6.0%), Coal (7.8%) and Petitot (8.4%) sub-basins from 2000 to 2009 (Table 19). The Petitot continued to have the most fire damage from 2010 to 2012, with an additional burned area of 5.8% (Table 19). Active forestry in the Surface Water Study Area appears to be minimal with the 0.2% of landscape harvested. The area of retired forestry is slightly higher, varying from zero to 1.6% of the sub-basin area (Table 19).

Permanently protected area in the sub-basins within the Groundwater Study Area varies from 0.0% to 0.6% (Finlay sub-basin) and none have interim protected land (Table 20). The Sahtaneh, Muskwa, Petitot, Lower Fort Nelson, Lower Liard – La Biche, and Lower Liard – Mouth all contain expired and active water licenses while all the other sub-basins found in the Groundwater Study Area have had no recorded water license applications. The Lower

Liard - Mouth Sub-basin contains the most expired water licenses (84) while the Petitot sub-basin contains the most active water licenses (34). Petitot and Trout sub-basins contain the highest percentages of landscape change due to fire from 2000 to 2009 with 2.6% and 4.1%, respectively. From 2010 to 2012, the Trout sub-basin had the highest percentage of land damaged from fire at 2.4%. Similarly to the Surface Water Study Area, sub-basins in the Groundwater Study Area had minimal land cover changes due to active and retired forestry. Percentage of change due to active forestry varies from 0.0% to 0.3%. Percentage of change for retired forestry was slightly higher but still considered low at 0.0% to 1.6% (Table 20).

Sub-basins that may be of concern from the cumulative effects of the landscape changes outlined in Table 19 and Table 20 include the Petitot and Lower Liard – Mouth. These two sub-basins contain no to little permanent or interim protected area in either Study Area and have a higher number of both expired and active water licenses compared to other sub-basins. Landscape change due to forest fire and forestry in the Petitot sub-basin is also higher compared to other basins.

## 4.5 Climate Change

### 4.5.1 Direct Effects to Surface Water and Groundwater

The Liard River basin is representative of a northern high alpine and boreal hydrological regime (Burn et al. 2004a; 2004b). It has little natural storage (i.e., no large lakes) and has not been subject to major or minor water impoundments or diversions (e.g., dams, canals).

The Liard River drainage basin is 275,000 km$^2$, representing 16% of the total drainage area of the Mackenzie River basin. Average annual flow of the Liard River is 2440 m$^3$/s. It contributes the largest proportion of flow (27%) to the Mackenzie River (Burn et al. 2004a; 2004b) of all tributaries, and therefore affects freshwater inputs to the Arctic Ocean (Prowse et al. 2009). The Liard River is characterized by low flows in winter, a rising hydrograph starting in late April and May with peak flow generally occurring in June, and a secondary peak occurring in fall (typically October).

Average precipitation over the basin is 490 mm per year, with 60% falling as rain. Trend analysis of meteorological measurements in the Liard basin for 1971 to 2000 indicates significant increases in air temperatures for the months of March through May (Burn et al. 2004a). There were fewer significant trends for precipitation, and significant differences among the trends observed at meteorology stations within the basin. In general, there was no consistent increase or decrease in annual precipitation, but a consistent decrease in spring and fall snowfall, and corresponding increases in spring and fall rainfall.

Analysis of the relationship between meteorological and hydrological variables indicates the following relationships (Burn et al. 2004a; 2004b):

- Increasing winter flows related to more frequent occurrences of rain instead of snow in October;
- Increasing April flow and earlier onset of the spring freshet related to both April temperature and spring temperatures; and
- A decrease in the coefficient of variation in daily flows (related to increases in minimum winter flows).

Because minimum annual flows occur in winter, and these flows appear to be increasing, this results in increasing minimum annual flows, and is potentially related to decreasing flows in summer months, though this trend was not statistically significant (Burn et al. 2004b).

There are also significant correlations between meteorology and hydrology variables as a result of large-scale atmospheric and oceanic processes, namely the Pacific Decadal Oscillation (PDO). During warm PDO phases, annual maximum and spring maximum flows shift towards spring; during cold PDO phases, the maxima shift towards summer (Burn et al. 2004a). PDO phase also influences annual minimum flow and date of its occurrence, with lower and earlier minimum flows during the cold PDO phases (i.e., during lower winter temperatures and more snowfall).

Hydrological modelling of the Liard River basin under a range of climate change scenarios tend to confirm the trends observed in meteorological and hydrological measurements (Thorne 2011). The magnitude of the change is uncertain due to differences in future projections of air temperature and precipitation among climate models. Projections include the following:

- 6% to 18% increase in annual precipitation for a 2°C increase in temperature, resulting in -3% to +15% increase in total annual discharge;
- Earlier onset of the spring freshet with 19% to 41% increase in maximum flows;
- Reductions in summer flow of up to 22% in some scenarios, but increases in evaporation and increases in precipitation resulting in little change to total summer flow in other scenarios;
- 1% to 28% increase in fall maximum flows due to increased rain versus snow occurring in fall; and
- 4% to 12% increase in winter low flow due to increased rain versus snow occurring in fall.

### 4.5.2 Indirect Effects to Surface Water and Groundwater

Changing weather patterns due to climate change can affect surface water and groundwater directly by altering the local and regional water balance. Other ecosystem level responses to a changing climate can indirectly affect the local and regional water quantity and quality through a variety of feedback mechanisms. Here we discuss potential feedbacks in the context of: the physical landscape; vegetation and wildlife communities; fish and fisheries; and, the built environment.

#### *4.5.2.1 Permafrost Degradation and the Physical Landscape*

Three terrestrial ecozones are located within the Liard River watershed. These include the Boreal and Taiga Cordillera, and the Taiga Plains. The Boreal Cordillera is characterized by subdued mountains with flat rolling plateaus. The Taiga Cordillera is characterized by steep terrain with sharply etched ridges and narrow valleys. The Taiga Plains are characterized by broad lowlands, gently rolling plains, and meandering streams with rivers and wetlands.

Arctic and sub-Arctic regions globally are undergoing a system-wide response to an altered climatic state including impacts to permafrost, hydrology, as well as biological, and social systems (Hinzman et al. 2005). Changes to the physical environment in the Liard-Petitot system will affect valued components of the terrestrial, aquatic, and man-made environments. For example:

1) Melting permafrost could increase the probability of rock falls and landslides in the steep mountainous terrain of the upper Liard watershed (Gruber and Haeberli 2007).

2) Loss of permafrost-rich forests through their conversion to permafrost-free wetlands has been observed in the lower Liard River valley (Connon et al. 2014).

3) In some permafrost areas, wetland polygons are combining to create thermokarst ponds or lakes (Jorgenson et al. 2006). In other permafrost areas, the number of closed-basin ponds or lakes is decreasing (Riordan et al. 2006).

4) Changes to the physical landscape due to melting permafrost can occur quickly (Jorgenson et al. 2006), radically altering the local landscape (Rowland et al. 2010) and water chemistry (Kokelj et al. 2009).

Of particular concern to the Liard-Petitot hydrological system is the impact of climate change on forest fires and permafrost melt. Early modelling studies (Stocks et al. 1998) and recent updates (Wotton et al. 2009) predict higher probabilities and larger extents of boreal forest fires due to climate change. Fire-induced permafrost degradation is well documented in lowland and upland black spruce forests like those found in the Liard-Petitot system (Jafarov et al. 2013). Other studies have shown that tundra fires can also induce relatively rapid thaw subsidence of permafrost in this type of terrain (Jones et al. 2015). These types of physical changes will affect both local hydrology and water chemistry.

Existing maps of permafrost in the Liard-Petitot region are based on data collected in the late 1970’s to the mid 1980’s (NRCAN 2017). These sources indicate extensive (50-90%) and sporadic (10-50%) discontinuous permafrost is common throughout all three of the Liard-Petitot ecozones and that soils are approximately 10% ice by volume. The resolution of the existing NRCan maps are too coarse to estimate regional or local variability in permafrost extent and volume.

A recent satellite and vegetation cover based estimate of the extent of permafrost was undertaken in the Mackenzie Delta (Nguyen et al. 2009). The study results predict continuous permafrost to be common in the Mackenzie Delta, a region formerly predicted to be dominated by extensive discontinuous permafrost (NRCan 2017). This has potential implications for the Liard-Petitot system as it is also classified by NRCan as being dominated by extensive discontinuous permafrost.

A recent analysis of permafrost probability was carried out using observations in the Wolf Creek area approximately 250 km west of the headwaters of the Liard sub-basin (Lewkowicz and Ednie 2004). The results found that uniformly deep snow is predicted to reduce permafrost extent and raise the continuous permafrost elevation contour by about 100 m. Conversely, widespread shallow snow cover is predicted to increase permafrost extent and reduce the continuous permafrost elevation by about 300 m. These effects are predicted based on changes in snow accumulation only and are independent of any changes in air temperature. Furthermore, localized microclimate such as downslope cold air drainage, elevation, and slope aspect (e.g., north versus south facing) can result in marked differences in the probability of permafrost occurrences over short distances.

Where permafrost occurs, the thickness of the active layer in the Mackenzie Delta and the Liard-Petitot system will vary locally based on soil characteristics, especially soil organic matter content and volumetric water content (Burn and Kokelj 2009). Ground temperatures differ between uplands and lowlands due to the presence or absence of ponds and lakes, creeks and rivers, and different soil and vegetation types. Above the tree line, ground temperatures are expected to decrease with increasing latitude and altitude, and decreasing snow thickness. A study of active-layer characteristics in the Mackenzie Delta included sampling locations in the Hay River Lowlands

(Smith et al. 2009). Their observations of progressively deeper thaw depths show contemporary permafrost degradation between frozen peatlands and unfrozen fens. Shallowest thaw depths occurred in organic rich soils under the shade of conifer canopies in unburned forests (Smith et al. 2009).

Permafrost degradation in the Liard-Petitot system could affect surface and ground water quantity and quality. Risks are highest for the Taiga Plains and the Cordillera valleys containing most human activities. These locations are underlain by a mixture of tills, glaciofluvial and alluvial deposits, and organic soils. Sporadic permafrost may be less extensive, and discontinuous or continuous permafrost more extensive, than predicted by the NRCan maps, but will depend on local geography, micro-climate, and local soil and vegetation types.

#### 4.5.2.2 Vegetation

Changes to surface water and groundwater quantity and quality affect vegetation directly. However, changes to vegetation can also indirectly affect ground and surface waters. For example, loss of local vegetation can result in permafrost degradation and/or soil erosion that can increase the concentrations of suspended solids in surface waters. Similarly, increases in the prevalence of shrubs can trap wind-blown snow, potentially altering local patterns of runoff and/or infiltration and therefore surface and groundwater quantity and quality. Feedbacks between these valued ecosystem components are an active area of research. Here we discuss potential changes to vegetation as a result of climate change, the effects of which may or may not affect surface and ground waters at local or regional scales in the Liard-Petitot system.

Composition of vegetation communities in the cordillera is dependent on elevation. At high elevation, lichens, sedges, and mosses inhabit the snow and ice-free regions of the alpine tundra, upland plateaus, and mountain slopes. The subalpine transition region includes fir, willow, and shrub birch. These species transition to spruce, pine, poplar, and birch in cordillera valleys. Wetlands are common along flat river valleys. In the Taiga Plains, climate, extensive permafrost, and forest fires lead to poor soil conditions. Trees, often stunted, are dominated by spruce, tamarack, birch, aspen, and poplar. Low shrubs are abundant and include heathers and a wide variety of berry-producing species including cranberries, currents, and blueberries.

Due to climate change, it is generally assumed that plant species will migrate north; and locally, they will also migrate uphill (ACIA 2005). These effects will occur at the ecosystem level and will likely lead to a northward expansion of the boreal treeline into the taiga. Early modelling studies in Norway (Holten, 1990; Holten and Carey 1992) predicted blueberry heath could move upslope by up to 400 m as a result of climate change. Whether plant communities can actually adapt to soils found at higher latitudes or elevations, whether they will cease to exist at lower latitudes and elevations, and the time scales for this to occur, will depend on local geography and climate. Local vegetation responses to climate change will be heterogeneous and can be expected to produce both positive and negative impacts to highly valued ecosystem components.

Plant productivity in Arctic and boreal ecosystems has shown positive increases with increased temperatures, growing season length, snow season length, light availability, enhanced soil decomposition, and nitrogen availability (Kimball et al. 2007; Euskirchen et al. 2009; Hill et al. 2011). Elevated $CO_2$ concentrations can also lead to greater plant productivity (i.e., increased biomass) and changes to soil composition (e.g., type/abundance of mycorrhizal fungi) (Rey and Jarvis 1997).

Climate change influences plant composition, particularly shrub abundance in the tundra and taiga, which is increasing with warming temperature (Sturm et al. 2001; Lantz et al. 2010). Alpine vegetation changes have been shown to be rapid and flexible in responding to climate change (Cannone et al. 2007; Tape et al. 2006). Increase in shrub or tree cover, height or their regional distribution has the potential to alter ecosystem structure and therefore interactions between species (Miller and Smith 2012; Myers-Smith et al. 2011; Tape et al. 2006).

#### 4.5.2.3 Wildlife

Changes to surface water and groundwater quantity and quality affect wildlife directly. However, changes to wildlife can also indirectly affect ground and surface waters, with changes to wildlife often associated with changes to vegetation. For example, beavers may become more prevalent in areas where they were previously absent due to the establishment of new birch and poplar forest. Building of lodges and dams on smaller tributaries of the Liard-Petitot system could have profound effects on permafrost and local hydrology. Similarly, patterns of human land-use may change in response to changes to wildlife (e.g., higher prevalence of deer, moose and caribou could attract hunters), this can put additional demands on local surface and ground water resources for use as drinking water, or as receiving waters for wastewaters. Feedbacks between these valued ecosystem components are an active area of research. Here we discuss potential changes to wildlife as a result of climate change, the effects of which may or may not affect surface and ground waters at local or regional scales in the Liard-Petitot system.

Wildlife in the cordillera region include alpine species (e.g., Hoary Marmot, American Pika, Dall Sheep, Mountain Goat, Woodland Caribou, and Grizzly Bears) as well as boreal species (e.g., Canadian Geese, Bald Eagle, Willow Ptarmigan, Moose, Wolverine, Fox, Lynx, and Wolves). Birds visit the cordillera region seasonally to breed but there are no reptiles and there are few species of amphibians. The Taiga Plains are inhabited by boreal species but also include a rich diversity of tundra species (e.g., Barren-ground Caribou, Snowshoe Hare, Black Bear, Marten, Mink, River Otter, Porcupine, Muskrats, and Beaver) especially waterfowl (e.g., ducks, geese, and swans) and predator birds (e.g., eagle, falcon, and osprey).

As landscapes change and vegetation communities shift to higher latitudes and elevations, wildlife will need to adapt. Success or failure of local animal populations will be heterogeneous and dependent on the degree of change occurring to the physical landscape in their habitat, and positive and negative impacts of climate change on their food sources.

Changes to local meteorology can also affect wildlife directly. For example, icing or rain-on-snow events have been shown to affect reindeer and caribou (Vors and Boyce 2009; Tyler 2010) and may affect rodent populations (Korslund and Steen 2005). If icing and rain-on-snow events become more prevalent in April and October, it may negatively affect ungulates and other prey, and therefore predators in the Liard-Petitot system. The significance of these episodic events compared to the effects of enhanced plant productivity and longer growing seasons on predator and prey is a topic of active research.

#### 4.5.2.4 Fish and Fisheries

Although species diversity and productivity in the region is generally low (Bodaly et al. 1989), the aquatic environment of the Liard-Petitot system includes species well adapted to the cold, nutrient-poor streams, rivers and lakes of the region (e.g., Lake Trout, Lake and Mountain Whitefish, Arctic Grayling, Dolly Varden, Burbot, Walleye, and Northern Pike). Common anadromous fish in the Mackenzie River System undertake complex migrations between the Beaufort Sea and the upper reaches of the Mackenzie system, including the Liard River. Many of the above species are known to have spawning grounds in the Liard, and Pink salmon have been reported historically in the Mackenzie River Delta (McLeod and O'Neil 1983). It is not clear whether improved reporting or climate change is responsible for recent reports of Pacific salmonids in the Arctic (Babaluk et al. 2000; Stephenson 2005). However, potential effects of new colonization by non-native species could lead to: introduction of new diseases or parasites; competition for critical resources; increased predation; or, increased hybridization among closely related taxa (ACIA 2005).

#### *4.5.2.5 Built Environment*

Direct and indirect effects of climate change on the Liard-Petitot system could have a series of potential consequences for the built environment and the stakeholders that depend upon these systems for their social and economic well-being. Examples of potential interactions induced by a changing climate may include the following:

- Abrupt changes to the physical landscape (e.g., rockfalls, landslides, flooding) could endanger public health, safety, and the environment.
- Gradual changes to the physical landscape due to permafrost melt could affect the stability and integrity of expensive long-lived engineered structures such as roads, railways, bridges, buildings, oil and gas pipelines, and drinking water and waste water treatment systems.
- More frequent and intense forest fires can endanger public health and safety, can affect regional air quality, and reduce economic opportunities in the forestry sector.
- Changes to the physical landscape induced by permafrost degradation can affect surface and ground water quality needed to support local communities and industries.
- Failure to plan for climate-related contingencies can affect long-term economic opportunities in the region, for example by reducing the attractiveness of the region to industries such as resource development and tourism.
- Changes to local flora and fauna can affect the livelihoods of aboriginal people and their cultural and spiritual connections to the natural environment.

These challenges are not unique to the Liard-Petitot system, but adaptation plans should be developed by authorities familiar with both the local stakeholder needs and potential effects of climate changes on the region. Federal, provincial, and territorial authorities should encourage the development of vulnerability assessments and then rank and seek to mitigate potential risks through the development of adaptation plans. These efforts should extend beyond analysis of risks posed to public health, safety, the environment, and engineered structures, to include mapping of potential hazards (Kaab 2008) and analysis of potential economic liabilities (e.g., depth and breadth of insurance coverage in the event of disaster.

Steps should be taken to determine potential risks to public and private engineered structures that were most likely designed to accommodate historic climate conditions, not predictions of future climate. Engineers Canada has already developed their *Public Infrastructure Engineering Vulnerability Committee Protocol* (PIEVC 2017) to "assess the vulnerability of infrastructure to extreme weather events and future changes in climate to enable better planning and design of safe and climate-resilient infrastructure".

## 4.6 Future Developments and Potential Impacts

A recent study that has been released from major actors in the oil and gas sector estimates that the Dease-Liard Basin contains one of the largest gas resources in the world (NEB 2016). About 219 trillion cubic feet of natural gas is trapped in layers of shale, 3 to 4 km deep, spanning the boundaries of BC, Yukon, and the NWT, and hydraulic fracturing would be the only way to access the resource (CBC 2016). The Liard Basin in northeastern British Columbia continues to be a highly prospective area for unconventional gas and oil development. Regionally-continuous unconventional reservoirs may be present with a potential for long-term development, as indicated by increased numbers of horizontal wells being completed, compared to vertical.

To develop unconventional reservoirs, industry will need large quantities of water for hydrofracturing injection and stimulation of reservoirs. Hydrofracturing injectants include additives (at several percent concentrations), blended according to the characteristics of the injected water and shale formation being fractured (https:/fracfocus.org/). Additives generally include water friction-reducers and solids (proppants) to facilitate injection to target zones at higher rates under reduced pressures. Other additives typically include biocides to minimize biofouling of fractures and oxygen scavengers and stabilizers to minimize metal pipe corrosion. Aquifer options appear to be available to industry for using to deep groundwater, to avoid surface water conflicts and possible negative environmental impacts. Given the remoteness and absence of support infrastructure, the only current water disposal option is the use of deep aquifers, to avoid potentially contaminating shallow groundwater and surface water (Hayes and Costanzo 2014).

Other potential environmental impact risks to the Liard Basin may be posed by hydrofracturing-injection well failures. Statistical information for such rates in Canada are not readily available. A study of the industry-reported failures of hydrofracturing-injection wells in the Pennsylvanian Marcellus Shale area (Ingraffea 2012), analyzed on the number of well failure incidents involving: (1) the migration of gas and fluids outside the casing, (2) the loss of integrity of casing or cement and (3) improper casing designs leaving open formations with shallow gas. Of the over 4,500 wells evaluated, the study concluded that failures by loss of structural integrity occurred at rates of 6.9% (2010), 7.2% (2011) and 6.6% (2012), with implications for contaminating shallow groundwater and surface water.

Due to the presence of protected areas along the Liard River, there is little potential for the hydroelectric power sector to be developed (FNLRMP 2007) along the river itself, though smaller rivers in the region (e.g. Frances River) are being investigated for possible hydroelectric projects (Midgard 2016).

Areas of the Surface Water Study Area that have received protection will not be subject to future development, making these areas refugia for cumulative effects. Interim and permanent protection within the sub-basins ranges from none (Sahtaneh, Lower Liard – Mouth, Lower Fort Nelson) to over 30% (Kechika, Frances, Muskwa) (Table 21). This does not include areas with interim protection under the Dehcho Land Use Plan process.

**Table 21: Permanent and Interim Protection by Sub-Basin in the Surface Water Study Area**

| Sub-Basin | Sub-Basin Area ($km^2$) | Permanent Protection (%) | Interim Protection (%) |
|---|---|---|---|
| Muskwa | 19,552 | 36.2 | 0.0 |
| Kechika | 15,192 | 34.0 | 0.0 |
| Central Liard - Toad | 27,970 | 8.5 | 0.0 |
| Dease | 14,364 | 7.8 | 0.0 |
| Upper Fort Nelson | 3,718 | 7.3 | 0.0 |
| Turnagain | 6,871 | 4.4 | 0.0 |
| Petitot | 22,210 | 2.0 | 0.0 |
| Coal | 9,350 | 1.7 | 0.2 |
| Sikanni Chief | 10,754 | 1.3 | 0.0 |
| Lower Liard - La Biche | 7,410 | 0.6 | 0.0 |
| Fontas | 7,381 | 0.5 | 0.0 |
| Beaver (Y.T.-B.C.) | 10,511 | 0.3 | 0.0 |
| Headwaters Liard | 23,737 | 0.1 | 13.1 |
| Frances | 12,700 | 0.0 | 45.5 |
| Hyland | 9,191 | 0.0 | 13.3 |
| Lower Fort Nelson | 7,798 | 0.0 | 0.0 |
| Lower Liard - Mouth | 18,774 | 0.0 | 0.0 |
| Sahtaneh | 3,995 | 0.0 | 0.0 |

# 5.0 AMBIENT ENVIRONMENTAL CONDITIONS

## 5.1 Traditional Knowledge related to Aquatic Ecological Health and Groundwater

A review of sources included in Section 3.0 was conducted for Traditional Knowledge (TK) related to aquatic health and groundwater conditions. Traditional Knowledge considered to be indicative of aquatic health conditions includes information pertaining to the following:

- Water quality and confidence in watersources;
- Water quantity;
- Changes in animals, fish, and vegetation health and availability due to changes in water and riparian areas; and
- Importance of water to biodiversity and ecosystem function.

Traditional Knowledge considered to be indicative of groundwater conditions, includes:

- ‘Underground springs’ or ‘underground rivers’;
- Reaches of the Liard or Petitot Rivers, or their main tributaries, that have minimal or no ice-up in winter, related to warmer groundwater discharge;

- Spring-fed lakes;
- Springs or seeps discharging groundwater to surface, via overburden or bedrock; and
- Wildlife ‘salt lick’ areas.

To date, searches for TK related to groundwater have not identified relevant information in the Groundwater Study Area; limited TK related to aquatic health was identified relevant to the Surface Water Study Area.

Concerns regarding the potential for contamination of water sources and the resulting effects on vegetation, wildlife, fish, and people have been expressed throughout reports relevant to the region. For example, a HRFN member stated “our water is always dirty now, not like it used to be. We could drink water anywhere and now we cannot do that. This is hard on our food we take from the waters” (T8TA 2003; T8FN and Firelight 2012). Similarly, members of FNFN also reported concerns about water withdrawals by industry and have observed oily substances in standing water at locations in the Study Areas (Quicksilver Resources 2013). While not specifically expressed in regard to the Study Areas, the Treaty 8 Tribal Association (T8TA) indicated that the reduction in availability of clean water throughout their territory is a primary concern for their members (T8TA 2003; T8FN and Firelight 2012).

The Kaska Dena have identified certain aspects of the ecosystem as “especially important and essential in maintaining biological diversity. These include wetlands, water bodies, the alluvial forests around the major waterways, and special fish and wildlife habitats. Water is the key, and the Kaska are decisive that water must be managed carefully” (Dena Kayeh Institute 2010, p.2). As part of the Kaska Dena Land Use Framework (Dena Kayeh Institute 2010), the Kaska Dena have noted that they consider the majority of drainages and watersheds in the plan area (which overlaps with eastern portions of the Surface Water Study Area) are not experiencing changes in water quality or quantity as a result of human influence.

## 5.2 Assessment of Existing Surface Water Quality Conditions

### 5.2.1 Data Sources

A description of existing surface water quality conditions was based on a review and summary of available water quality data from identified stations within the Liard and Petitot river basins (Table 22; Figure 2; Map A-18) and a review of existing reports that described water quality conditions within, and proposed site-specific water quality guidelines for, the Liard River (Table 23). Data are summarized in Appendix B, and data sources are listed in Appendix C. Water quality data for the Liard and Petitot river basins included sample results for a variety of water quality parameters including conventional parameters (e.g., turbidity, pH), major ions (e.g., chloride), nutrients (e.g., ammonia, total phosphorus), metals (e.g., total aluminum, total arsenic), organics (e.g., naphthalene), and pesticides (e.g., aldrin, dieldrin) (Table 22).

**Table 22: Surface Water Quality Station Monitoring Location, Duration, Frequency, and Parameter Groups**

| Watershed | Station ID | Station Description | Data Source | Location | | Monitoring Period | Parameter Monitoring Groups[a] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Latitude | Longitude | | Conventional Parameters and Major Ions | Nutrients | Metals | Organics | Pesticides |
| Liard | YT10AA0005 | Liard River at Upper Crossing - Westbank | EC | 60° 03' 03" | 128° 54' 25" | 1983 to 1994 | yes | yes | yes | - | - |
| | YT10AA0001 | Liard River at Upper Crossing | EC | 60° 03' 03" | 128° 54' 25" | 1991 to 2015 | yes | yes | yes | - | - |
| | BC10BE0001 | Liard River at Lower Crossing | EC | 59° 24' 45" | 126° 05' 50" | 1984 to 1994 | yes | yes | yes | - | - |
| | No Station ID | Liard River upstream of Kotaneelee River | AANDC/ GNWT | 60° 8' 56" | 123° 44' 6" | 1991 to 2015[b] | yes | yes | yes | yes | yes |
| | NW10ED0001 | Liard River at Fort Liard | EC NWT region | 60° 14' 29" | 123° 28' 31" | 1960 to 2015[c] | yes | yes | yes | yes | yes |
| | NW10ED0002 | Liard River at Fort Simpson | EC NWT region | 61° 44' 33" | 121° 12' 40" | 1960 to 2015 | yes | yes | yes | yes | yes |
| | LIARD-SIMP-01 | Liard River at Fort Simpson – upstream of Ferry | EC NWT region | 61° 43' 57" | 121° 14' 19" | 2013 to 2015 | yes | yes | yes | - | - |
| Petitot | E290871 | Petitot River downstream of Tsea River | BC MOE - website | 59° 38' 20" | 121° 21' 11" | 2013 to 2015 | yes | yes | - | - | - |
| | E290869 | Fortune Creek upstream of Petitot River | BC MOE - website | 59° 58' 19" | 122° 25' 16" | 2013 to 2015 | yes | yes | - | - | - |
| | E282116 | Petitot River downstream of Highway No. 77 | BC MOE - website | 59° 59' 20" | 122° 57' 22" | 2013 to 2015 | yes | yes | - | - | - |

a) Additional descriptions of parameters are provided in 5.2.2.4.

b) 1991 to 1994 data available in non-digital format only; digital data available: 2001 to 2015 for conventional parameters, major ions, nutrients, and metals; 2013 to 2015 for organics; 2001 to 2014 for pesticides.

c) no data from 1974 to 1984.

- = no available data; AANDC = Aboriginal Affairs and Northern Development Canada; GNWT = Government of the Northwest Territories; EC = Environment Canada; NWT = Northwest Territories; BC MOE = British Columbia Ministry of Environment.

**Table 23: List of Reviewed Technical Reports with Water Quality Information Used in this Report**

| Citation | Summary |
|---|---|
| MacDonald (1993) | This report provides a summary of water quality monitoring within the Liard River basin, including a review of data collected by Indian and Northern Affairs Canada (INAC) and Environment Canada (EC) (data to the early 90's) and reference to other reports and studies. At the time of the report publication, there was only a single study on sediment quality for the Liard River basin. |
| Taylor et al. (1998) | This report provides a summary of an environmental monitoring program for the Liard River basin. Samples were collected from the Liard River above Kotaneelee River for analysis of water (1991 to 1994) and suspended sediments (1992 to 1994). The study provides an overview of seasonality of water quality, and a comparison of water quality and sediment quality results to protection of aquatic life guidelines. |
| MRBB (2004) | This report is a status of the Mackenzie River basin aquatic ecosystem. This is a high-level report that provides indicators of environmental quality for the Liard River sub-basin, including water quality and potential environmental stressors. |
| Tri-Star (2005) | This report presents proposed site-specific water quality guidelines for the Liard River as based on the status of water quality, known stressors, and known users at the time of the report. |

### *5.2.1.1 Liard River*

Water quality samples have been collected by Environment Canada at six stations in the Liard River from upstream near Watson Lake to the confluence with the Mackenzie River at Fort Simpson (Figure 2, Map A-18), through several monitoring programs conducted since 1960. Samples have been collected from the Liard River above the Kotaneelee River station by GNWT (formerly AANDC) as part of the transboundary monitoring program since 1991. Data from this site were not available in digital format until 2001, therefore data collected from 1991 to 1994 and 1998 were qualitatively reviewed and compared to the 2001 to 2015 data when relevant. The range of water quality parameters, annual monitoring periods, and the frequency of monitoring, has varied for each monitoring station (Tables 22 and 24).

Most of the water samples (i.e., more than 80%) in the Liard River were collected from three main stations (Table 24):

- Upper Crossing (including Upper Crossing-West Bank);
- Fort Liard; and
- Fort Simpson.

Water samples were generally collected at these three stations in every month of the year; however, more samples were collected during the open-water period (i.e., May to October) compared to the ice-covered period (i.e., November to April) (Table 24). Water samples from upstream of Kotaneelee River and at the Lower Crossing were collected during the open-water period only.

**Table 24: Number of Samples Collected at the Liard River Water Quality Stations, 1960 to 2015**

| Month | Upper Crossing | Upper Crossing-West Bank | Lower Crossing | Upstream of Kotaneelee River[(a)] | Fort Liard | Fort Simpson | Fort Simpson-Upstream of Ferry | Monthly Total |
|---|---|---|---|---|---|---|---|---|
| January | 25 | 4 | 0 | 0 | 22 | 26 | 0 | 77 |
| February | 32 | 5 | 0 | 0 | 28 | 22 | 0 | 87 |
| March | 33 | 3 | 0 | 0 | 10 | 27 | 0 | 73 |
| April | 24 | 6 | 2 | 0 | 23 | 16 | 0 | 71 |
| May | 35 | 8 | 12 | 0 | 27 | 34 | 0 | 116 |
| June | 36 | 11 | 17 | 4 | 30 | 40 | 2 | 140 |
| July | 34 | 8 | 16 | 17 | 35 | 28 | 5 | 143 |
| August | 43 | 10 | 8 | 15 | 25 | 29 | 2 | 132 |
| September | 34 | 8 | 8 | 13 | 34 | 26 | 0 | 123 |
| October | 33 | 10 | 9 | 0 | 24 | 29 | 0 | 105 |
| November | 21 | 7 | 0 | 0 | 8 | 19 | 0 | 55 |
| December | 21 | 4 | 0 | 0 | 16 | 7 | 0 | 48 |
| **TOTAL** | **371** | **84** | **72** | **49** | **282** | **303** | **9** | **1,161** |

a) Includes samples for which digital data were available.

Two types of water samples were analyzed from the Liard River upstream of Kotaneelee River: grab water samples and centrifugate water samples. Centrifugate water was collected from the outflow of the centrifuge. The centrifuge is a device that separates the suspended sediments from the raw surface water. Centrifugate water samples were prepared by centrifuging a water sample with a portable centrifuge on site during the open-water season when suspended solids concentrations were high. A portable field centrifuge was used to remove suspended sediment from surface river water at the Liard River upstream of Kotaneelee River sampling location, providing both centrifugate water samples and suspended sediment samples. Detailed field sampling procedures for the centrifuge are included in Puznicki (1993). The sampler was shown to collect all particle sizes, including the very fine particles most prone to adsorb chlorinated organic compounds (Swanson et al. 1993). The concentrations of organics were measured from centrifugate samples only. The concentrations of non-organics were measured from both grab water and centrifugate water samples. The organics concentrations measured from the centrifugate water samples and the non-organics concentrations measured from the grab samples were used in the data analysis. Concentrations of non-organics were assessed using grab samples to allow comparisons to other Liard River stations, where only grab samples were collected. Organic concentrations in the Liard River were measured only upstream of the Kotaneelee River, at Fort Liard, and at Fort Simpson. Organic substances comprise of pesticides and PAHs.

Water samples were collected at the Fort Simpson upstream of the Ferry station using grab samples, and two types of passive sampling devices that measure time-weighted concentrations: Diffusion Gradients in Thin-Film (DGTs) for dissolved metals concentrations and Polyethylene Membrane Devices (PMDs) for PAHs (Dion 2016; NWT Water Stewardship 2016). Only the concentrations in the grab samples are summarized in this report.

#### *5.2.1.2 Petitot River*

Water quality data have been collected by BC MOE at two stations along the Petitot River: upstream of Tsea River and downstream of Highway No.77, and one station in Fortune Creek, which is a tributary to the Petitot River (Table 25; Figure 2, Map A-18). Samples were collected at each station from 2013 to 2015, typically between May and October (Table 25). Monitored parameters included conventional parameters, major ions, and nutrients.

**Table 25: Number of Samples Collected at the Petitot River and Fortune Creek Water Quality Stations, 2013 to 2015**

| Month | Petitot River | | Fortune Creek | Monthly Total |
|---|---|---|---|---|
| | Downstream of Tsea River | Downstream of Highway No. 77 | | |
| January | 0 | 0 | 0 | 0 |
| February | 1 | 1 | 2 | 4 |
| March | 2 | 1 | 2 | 5 |
| April | 0 | 0 | 0 | 0 |
| May | 4 | 1 | 2 | 7 |
| June | 0 | 0 | 0 | 0 |
| July | 2 | 2 | 2 | 6 |
| August | 3 | 4 | 3 | 10 |
| September | 0 | 0 | 0 | 0 |
| October | 2 | 4 | 2 | 8 |
| November | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 |
| **TOTAL** | **14** | **13** | **13** | **40** |

## 5.2.2 Water Quality Characterization Approach

### *5.2.2.1 Summary of Data and Comparisons to Guidelines*

Water quality data collected from the Liard and Petitot rivers were summarized by calculating the median, 25th and 75th percentiles, minimum, and maximum concentrations for parameters for each monitoring station. When calculating the percentile and median concentrations, values less than the detection limit were replaced with values at the detection limit, but were ranked below values at the detection limit. The measured parameter concentrations of each sample were compared to water quality guidelines for the protection of freshwater aquatic life (BC MOE 2016b; CCME 1999) and human health (i.e., drinking water quality) (Health Canada 2014), where guidelines existed (Table 26). Canadian Council of Ministers of the Environment (CCME) and BC MOE aquatic life guidelines were used because the water quality sampling stations were located in the Northwest Territories and British Columbia. Acute or maximum aquatic life guidelines are protective of aquatic life for short-term exposure; chronic or average aquatic life guidelines are protective for long-term exposure. Water quality data were not compared to livestock or irrigation guidelines, which are typically less stringent than aquatic life and drinking water guidelines. Comparisons to drinking water guidelines are provided for context; water from the Liard River would be treated prior to use as drinking water.

Ammonia concentrations were compared to the ammonia guideline calculated based on the measured pH and temperature of the corresponding sample, if available. Metals concentrations with hardness-dependent guidelines were compared to guidelines calculated using the hardness in the corresponding sample. Nitrite concentrations were compared to the BC MOE nitrite guideline grouped based on the concentration of chloride of corresponding sample. If pH, temperature, hardness, or chloride results were not available for the corresponding sample, the monthly median value from the station for the missing parameter was used to calculate the guideline.

**Table 26: Water Quality Guidelines for the Protection of Aquatic Life and Drinking Water**

| Parameter | Units | Aquatic Life | | | | Drinking Water |
|---|---|---|---|---|---|---|
| | | CCME | | BC MOE | | Health Canada[e] |
| | | Acute[a] | Chronic[b] | Maximum[c] | Average[d] | |
| **Field Measured** | | | | | | |
| Dissolved oxygen | mg/L | - | 6.5 | 5.0 | 8.0 | - |
| **Conventional** | | | | | | |
| pH | - | - | 6.5 - 9.0 | -[f] | -[f] | 6.5 - 8.5 |
| **Major Ions** | | | | | | |
| Chloride | mg/L | 640 | 120 | 600 | 150 | - |
| Sulphate[g] | mg/L | - | - | - | 128 - 429 | - |
| Fluoride | mg/L | - | 0.12[h] | 0.73 - 1.7 | - | 1.5 |
| **Nutrients** | | | | | | |
| Nitrate | mg-N/L | 124 | 2.9 | 33 | 3.0 | 10 |
| Nitrite | mg-N/L | - | 0.06 | 0.06 - 0.6 | 0.02 - 0.2 | 1.0 |
| Total Ammonia[i] | mg-N/L | - | 0.041 - 19 | 0.75 - 23 | 0.1 - 2.1 | - |

**Table 26: Water Quality Guidelines for the Protection of Aquatic Life and Drinking Water**

| Parameter | Units | Aquatic Life | | | | Drinking Water |
|---|---|---|---|---|---|---|
| | | CCME | | BC MOE | | Health Canada[e] |
| | | Acute[a] | Chronic[b] | Maximum[c] | Average[d] | |
| **Total Metals** | | | | | | |
| Aluminum | µg/L | - | 100 | - | - | 100 |
| Antimony | µg/L | - | - | - | 9.0 | 6.0 |
| Arsenic | µg/L | - | 5.0 | - | 5.0 | 10 |
| Barium | µg/L | - | - | - | 1,000 | 1,000 |
| Beryllium | µg/L | - | - | - | 0.13 | - |
| Boron | µg/L | 29,000 | 1,500 | - | 1,200 | 5,000 |
| Cadmium[g] | µg/L | 0.11 - 5.3 | 0.04 - 0.34 | - | - | 5.0 |
| Chromium[j] | µg/L | - | 1.0 | - | 1.0 | 50 |
| Cobalt | µg/L | - | - | 110 | 4.0 | - |
| Copper[g] | µg/L | - | 2.0 - 4.0 | 4.1 - 25 | 2.0 - 9.9 | - |
| Iron | µg/L | - | 300 | 1,000 | - | - |
| Lead[g] | µg/L | - | 1.0 - 7.0 | 3 - 260 | 3.8 - 13 | 10 |
| Manganese[g] | µg/L | - | - | 544 - 3,279 | 607 - 1,699 | - |
| Mercury | µg/L | - | 0.026 | - | 0.01 | 1.0 |
| Molybdenum | µg/L | - | 73 | 2,000 | 1,000 | - |
| Nickel[g] | µg/L | - | 25 - 150 | - | 25 - 150 | - |
| Selenium | µg/L | - | 1.0 | - | 2.0 | 50 |
| Silver[g] | µg/L | - | 0.25 | 0.1 - 3.0 | 0.05 - 1.5 | - |
| Thallium | µg/L | - | 0.8 | - | 0.8 | - |
| Uranium | µg/L | 33 | 15 | - | 8.5 | 20 |
| Zinc[g] | µg/L | - | 30 | 33 - 152 | 7.5 - 126 | - |
| **Dissolved Metals** | | | | | | |
| Aluminum | µg/L | - | - | 100 | 50 | - |
| Cadmium[g] | µg/L | - | - | 0.13 - 1.5 | 0.07 - 0.41 | - |
| Iron | µg/L | - | - | 350 | - | - |
| **Polycyclic aromatic hydrocarbon** | | | | | | |
| Acenaphthene | µg/L | - | 5.8 | - | 6.0 | - |
| Anthracene | µg/L | - | 0.012 | - | 0.1[k] | - |
| Benzo(a)anthracene | µg/L | - | 0.018 | - | 0.1 | - |
| Benzo(a)pyrene | µg/L | - | 0.015 | - | 0.01 | 0.01 |
| Fluoranthene | µg/L | - | 0.04 | - | 0.2[k] | - |
| Fluorene | µg/L | - | 3.0 | - | 12 | - |
| Naphthalene | µg/L | - | 1.1 | - | 1.0 | - |

**Table 26: Water Quality Guidelines for the Protection of Aquatic Life and Drinking Water**

| Parameter | Units | Aquatic Life | | | | Drinking Water |
|---|---|---|---|---|---|---|
| | | CCME | | BC MOE | | Health Canada[e] |
| | | Acute[a] | Chronic[b] | Maximum[c] | Average[d] | |
| Phenanthrene | µg/L | - | 0.4 | - | 0.3 | - |
| Pyrene | µg/L | - | 0.025 | - | 0.02[k] | - |

Note: Guidelines for some parameters were calculated based on the water quality conditions (e.g., pH, temperature, or hardness) of corresponding samples. The range of guidelines presented in the table represent the guideline range of the water quality samples summarized in this report.

a) CCME acute aquatic life guideline (CCME 1999).

b) CCME chronic aquatic life guideline (CCME 1999).

c) BC MOE long-term average (30-day mean) water quality guidelines (BC MOE 2016b).

d) BC MOE short-term maximum water quality guidelines (BC MOE 2016b).

e) Guidelines for Canadian Drinking Water Quality (Health Canada 2014).

f) The BC MOE aquatic life guidelines for pH are based on the background pH of the waterbody. For waterbodies less than 6.5, no significant decrease; for waterbodies greater than 9.0 no significant increase from background; for waterbodies 6.5 to 9.0, unrestricted change, but with some caution (BC MOE 2016b).

g) Guidelines ranges indicate the guideline is hardness-dependent; the guideline range is based on the hardness range of the samples summarized in this report (22 to 249 mg/L as $CaCO_3$).

h) Interim guideline.

i) Total ammonia guideline is dependent on pH and water temperature; the guideline range is based on the pH and temperature range from the samples summarized in this report that resulted in the minimum and maximum total ammonia guideline (i.e., pH values 5.5 to 9.1 and temperature values -1 to 26.2ºC).

j) Hexavalent chromium guideline.

k) The freshwater phototoxic guideline was selected because either a long-term average guideline was not available or the phototoxic guideline was more stringent than the long-term average guideline.

- = no guideline; µg/L = micrograms per litre; BC MOE = British Columbia Ministry of Environment; CCME = Canadian Council of Ministers of the Environment.

### *5.2.2.2 Spatial Patterns*

Spatial patterns in the rivers were evaluated by comparing median parameter concentrations from upstream and downstream water quality monitoring stations that had long sampling monitoring periods with no discernable temporal trends, but similar sampling frequencies. In the Liard River, upstream conditions were characterized using water quality at the Upper Crossing station and downstream conditions were characterized using water quality from the Fort Liard and Fort Simpson stations. Organic data were collected using different sampling techniques at upstream (centrifugate samples) and downstream (grab samples) stations; the differences in sampling techniques likely influenced results. Therefore, organic results were not evaluated for spatial patterns because notable differences between upstream and downstream samples could have been related to differences in sampling technique or spatial patterns. Spatial patterns on the Petitot River could not be discerned based on the limited data available from the river (i.e., three years of data from two stations); however, notable differences in concentrations between Fortune Creek and the Petitot River were identified where corresponding data were present.

#### 5.2.2.3 Temporal Trends and Seasonal Patterns

Trends of water quality parameters over time in the Liard River were qualitatively identified by visually reviewing temporal plots for a subset of parameters. Qualitative review of temporal trends was considered appropriate given the broad scale of the study and the large number of parameters and stations reviewed; statistical trend analyses should be completed on targeted datasets for parameters of concern to avoid large numbers of tests that can result in false positives (i.e., identifying a trend that is not real).

Seasonal patterns in the Liard River were identified by comparing the time series plots showing seasonal data at downstream stations. Data from the two downstream stations (Liard and Fort Simpson) were combined for the purposes of providing a larger dataset for seasonal analyses; the median values were similar between these two downstream stations; therefore, seasonal differences were expected to be greater than spatial differences. Values below detection limits were plotted at the detection limit as open data points (i.e., data point not shaded in). The seasonal data were grouped according to hydrograph periods and based on the month of sample collected:

- Spring: May 1 to June 30;
- Summer: July 1 to August 31;
- Fall: September 1 October 31; and
- Winter: November 1 to April 30.

Water quality data from the Petitot River were also plotted over time, but were not evaluated for temporal trends or seasonal patterns because of the limited data. Three years of water quality results from the Petitot River and Fortune Creek, mostly collected between May and October, did not provide sufficient data to identify temporal trends or seasonal patterns.

### 5.2.3 Liard River Water Chemistry Results and Discussion

#### 5.2.3.1 pH

The pH is the negative logarithmic value, defined on a scale of 0 to 14, of the activity (i.e. effective concentration) of dissociated hydrogen ions in a water solution. The pH of water is a direct measure of acidity and a useful indicator of the acid-base buffering capacity of an aquatic system. Pure water at 25°C is neutral with a pH value of 7. A solution with a pH less than 7 is acidic whereas greater than 7 is basic. A decrease of one pH unit signifies a tenfold increase in the activity of dissociated hydrogen ions in water and vice versa.

The pH of natural waters is largely controlled and determined by atmospheric deposition and the geology of the watershed. Photosynthesis, respiration, and decomposition are common natural processes that affect pH fluctuations in an aquatic system. Anthropogenic activities can alter the natural pH of a water body via point source input such as municipal and industrial wastewater effluent discharges or non-point source input such as agricultural and urban runoffs, spills and emissions (Michaud 1991; BC MOE 1998). The pH of water is a critical index of aquatic ecosystem health in that it controls vital processes such as the solubility and availability of metals and nutrients in water. Changes in pH can have negative impacts on aquatic ecosystems from effects such as metal toxicity and eutrophication.

The pH of the Liard River is typically basic or above the neutral pH value of 7. The pH of water samples collected from the Liard River was generally between 7.5 and 8.5; the median pH varied minimally between stations (i.e., from 8.0 to 8.2) and remained within guidelines (Table 27). Measured pH in the Liard River was occasionally above the Canadian drinking water guideline of 8.5; the CCME chronic guideline for pH of 9 was exceeded in two samples (one each at Fort Liard and Fort Simpson). These two high pH values appear to be outliers (Figure 12) and not representative of typical pH values in the Liard River. Clear temporal trends in pH values in the Liard River were not observed (Figure 12).

**Table 27: Summary of Water Quality in the Liard River at Upper Crossing, Fort Liard, and Fort Simpson Stations, 1960 to 2015**

| | Unit | Upper Crossing | | | | Fort Liard | | | | Fort Simpson | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960-2015 | | | | | | | | | | | |
| | | Min | Median | Max | Count | Min | Median | Max | Count | Min | Median | Max | Count |
| Conventional Parameters | | | | | | | | | | | | | |
| Dissolved inorganic carbon | mg/L | 15 | 22 | 34 | 261 | 20 | 27 | 40 | 7 | 9.6 | 20 | 42 | 19 |
| Dissolved organic carbon | mg/L | 0.4 | 1.5 | 7.6 | 258 | 1.0 | 4.0 | 26 | 70 | 0.1 | 3.7 | 32 | 237 |
| Hardness, as $CaCO_3$ | mg/L | 69 | 106 | 160 | 369 | 22 | 151 | 235 | 247 | 57 | 149 | 249 | 254 |
| Total dissolved solids | mg/L | 90 | 125 | 195 | 66 | 19 | 190 | 305 | 162 | 33 | 194 | 400 | 121 |
| pH | - | 7.7 | 8.1 | 8.6[(D)] | 344 | 7.5 | 8.1 | 9.0[(D)] | 249 | 5.5[(C, D)] | 8 | 9.1[(C, D)] | 295 |
| Specific conductivity | µS/cm | 141 | 206 | 273 | 365 | 21 | 278 | 446 | 281 | 120 | 284 | 510 | 295 |
| Stability Index (Calcd.) | - | - | - | - | - | 6.9 | 8.5 | 12 | 58 | 6.6 | 8.1 | 17 | 171 |
| Total Alkalinity, As $CaCO_3$ | mg/L | 62 | 96 | 131 | 367 | 19[(Mn)] | 116 | 191 | 253 | 63 | 116 | 210 | 286 |
| Total Inorganic Carbon | mg/L | 15 | 22 | 32 | 75 | - | - | - | - | 0.64 | 18 | 46 | 37 |
| Total Organic Carbon | mg/L | <0.5 | 1.2 | 10 | 75 | <0.5 | 4.4 | 29 | 83 | <0.5 | 5.0 | 46 | 203 |
| Total suspended solids | mg/L | <1.0 | <10 | 190 | 109 | <1.0 | 59 | 2490 | 204 | <1.0 | 40 | 3627 | 249 |
| Turbidity | NTU | 0.09 | 0.95 | 110 | 359 | <0.1 | 12 | 3900 | 252 | 0.6 | 28 | 2872 | 282 |
| Magnesium | mg/L | - | - | - | - | 1.4 | 11 | 18 | 158 | 5.6 | 11 | 19 | 252 |
| Calcium | mg/L | - | - | - | - | 6.7 | 41 | 78 | 192 | 12 | 41 | 68 | 292 |
| Sodium | mg/L | 1.7 | - | 1.8 | 2 | 0.41 | 2.9 | 12 | 194 | 0.68 | 2.6 | 13 | 288 |
| Potassium | mg/L | - | - | - | - | 0.13 | 0.78 | 2.4 | 192 | 0.2 | 0.78 | 3.8 | 288 |
| Sulphate | mg/L | 7.1 | 14 | 19 | 364 | 4.6 | 35 | 300 | 272 | 2.6 | 37 | 71 | 292 |
| Chloride | mg/L | <0.05 | 0.29 | 0.9 | 365 | 0.15 | 0.8 | 9.6 | 272 | 0.1 | 1.3 | 15 | 292 |
| Fluoride | mg/L | <0.01 | 0.08 | 0.2[(C)] | 365 | 0.02 | 0.09 | 0.23[(C)] | 230 | 0.02 | 0.09 | 0.3[(C)] | 283 |
| Silica | mg/L | 2.7 | 3.4 | 5.0 | 147 | 0.69 | 4.5 | 21 | 159 | 2.3 | 5.3 | 7.8 | 169 |
| Nutrients and Biological Indicators | | | | | | | | | | | | | |
| Dissolved Ortho Phosphate | mg/L | 0.004 | <0.05 | <0.1 | 156 | <0.002 | 0.007 | 0.05 | 9 | <0.002 | <0.002 | 0.031 | 27 |
| Dissolved Phosphorous | mg-P/L | 0.0008 | <0.002 | 0.004 | 4 | <0.002 | <0.01 | 0.11 | 77 | <0.002 | 0.006 | 0.5 | 234 |
| Nitrate | mg-N/L | <0.002 | 0.036 | 0.36 | 294 | <0.002 | 0.13 | 3.6[(C, Mn)] | 77 | 0 | 0.13 | 0.5 | 46 |
| Nitrate + nitrite | mg-N/L | <0.002 | 0.044 | 0.17 | 53 | <0.005 | 0.057 | <2.0 | 155 | <0.001 | 0.067 | <2.0 | 173 |
| Nitrite | mg-N/L | <0.005 | <0.005 | 0.009 | 196 | <0.005 | <0.01 | 0.03[(Mn)] | 61 | <0.01 | <0.01 | 1.3[(C, D, Mn, Mx)] | 41 |
| Particulate Organic Nitrogen | mg/L | - | - | - | - | - | - | - | - | 0.13 | 0.15 | 0.15 | 4 |
| Particulate Phosphorous (Calcd.) | mg-P/L | - | - | - | - | <0.004 | 0.035 | 1.4 | 36 | 0 | 0.038 | 2.4 | 174 |
| Total Ammonia | mg-N/L | <0.001 | - | <0.005 | 2 | <0.001 | <0.01 | 0.7 | 79 | 0.002 | 0.0085 | 0.3 | 94 |
| Total Kjeldahl Nitrogen | mg-N/L | - | - | - | - | <0.5 | - | <0.5 | 2 | <0.1 | <0.5 | 2.3 | 30 |
| Total Nitrogen | mg-N/L | 0.07 | 0.13 | 0.5 | 83 | 0.056 | 0.23 | 4.0 | 69 | 0.08 | 0.25 | 44 | 212 |
| Total Phosphorous | mg-P/L | 0.0016 | 0.007 | 0.17 | 362 | 0.0003 | 0.044 | 2.7 | 198 | <0.002 | 0.049 | 2.5 | 268 |
| Total Metals | | | | | | | | | | | | | |
| Aluminum | µg/L | <2.0 | 39 | 2,150[(C, D)] | 334 | 11 | 517[(C, D)] | 21,400[(C, D)] | 152 | 7.0 | 570[(C, D)] | 65,100[(C, D)] | 130 |

**Table 27: Summary of Water Quality in the Liard River at Upper Crossing, Fort Liard, and Fort Simpson Stations, 1960 to 2015**

| | Unit | Upper Crossing | | | | Fort Liard | | | | Fort Simpson | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960-2015 | | | | | | | | | | | |
| | | Min | Median | Max | Count | Min | Median | Max | Count | Min | Median | Max | Count |
| Antimony | µg/L | 0.023 | 0.065 | 0.19 | 156 | 0.001 | 0.1 | 0.33 | 65 | 0.079 | 0.13 | 0.37 | 70 |
| Arsenic | µg/L | 0.1 | 0.44 | 2.3 | 209 | <0.1 | 0.6 | 20(C, D, Mx) | 174 | 0.16 | 0.89 | 8.0(C, Mx) | 65 |
| Barium | µg/L | 40 | 61 | 105 | 352 | 18 | 90 | 1,050(D, Mn) | 158 | 46 | 93 | 773 | 213 |
| Beryllium | µg/L | <0.001 | <0.05 | 0.14(Mn) | 354 | <0.001 | 0.051 | 1.3(Mn) | 158 | <0.001 | <0.05 | 1.6(Mn) | 131 |
| Bismuth | µg/L | <0.001 | 0.001 | 0.047 | 158 | <0.001 | 0.0035 | 0.087 | 34 | <0.001 | 0.011 | 0.11 | 39 |
| Boron | µg/L | <0.5 | 1.4 | 3.6 | 159 | 2.0 | 8.3 | 22 | 65 | 5.6 | 9.0 | 16 | 70 |
| Cadmium | µg/L | <0.001 | <0.1 | 0.9(C) | 349 | 0.016 | 0.1 | 17(A, C, D) | 160 | 0.012 | 0.1 | 11(A, C, D) | 217 |
| Cesium | µg/L | <0.005 | 0.014 | 0.27 | 77 | <0.005 | 0.051 | 1.5 | 65 | 0.005 | 0.13 | 1.3 | 70 |
| Chromium | µg/L | 0.067 | <0.2 | 3.8(C, Mn) | 338 | <0.02 | 1.1(C, Mn) | 8,530(C, D, Mn) | 151 | 0.05 | 0.8 | 32(C, Mn) | 131 |
| Cobalt | µg/L | 0.019 | 0.1 | 2.0 | 355 | 0.025 | 0.65 | 22(Mn) | 158 | 0.017 | 0.8 | 22(Mn) | 217 |
| Copper | µg/L | <0.2 | 0.52 | 4.6(C, Mn) | 322 | 0.3 | 2.0 | 54(C, Mn, Mx) | 160 | <0.2 | 2.0 | 132(C, Mn, Mx) | 217 |
| Iron | µg/L | 38 | 100 | 3,990(C, Mx) | 334 | 1.0 | 870(C) | 57,600(C, Mx) | 207 | 1.0 | 1,120(C, Mx) | 93,500(C, Mx) | 131 |
| Lead | µg/L | 0.013 | <0.2 | 3.3(C) | 351 | <0.005 | 0.91 | 33(C, D, Mn) | 160 | 0.012 | <1.0 | 33(C, D, Mn) | 217 |
| Lithium | µg/L | 1.3 | 1.9 | 4.8 | 355 | 1.0 | 7.1 | 32 | 158 | 4.5 | 7.9 | 69 | 131 |
| Magnesium | mg/L | - | - | - | - | 1.4 | 13 | 16 | 16 | 7.0 | 14 | 26 | 61 |
| Manganese | µg/L | 4.4 | 8.7 | 133 | 335 | 1.7 | 31 | 1040 | 207 | 0.9 | 35 | 1,300(Mn) | 131 |
| Mercury | µg/L | - | - | - | - | - | - | - | - | - | 0.057(C, Mn) | - | 1 |
| Molybdenum | µg/L | 0.2 | 0.7 | 1.4 | 350 | <0.1 | 1.1 | 3.0 | 158 | 0.1 | 1.4 | 5.6 | 131 |
| Nickel | µg/L | <0.2 | 0.7 | 6.5 | 334 | 0.4 | 2.8 | 62 | 158 | 0.7 | 2.9 | 65 | 216 |
| Rubidium | µg/L | 0.64 | 0.75 | 3.5 | 159 | 0.12 | 0.94 | 26 | 65 | 0.66 | 1.6 | 22 | 70 |
| Selenium | µg/L | <0.1 | 0.23 | 0.9 | 210 | <0.1 | 0.6 | 12(C, Mn) | 168 | <0.05 | 0.62 | 1.1(C) | 65 |
| Silver | µg/L | <0.001 | 0.009 | 0.1 | 264 | <0.001 | 0.038 | 0.55(C) | 83 | <0.001 | 0.047 | 0.9(C) | 91 |
| Sodium | mg/L | - | - | - | - | 0.35 | 2.0 | 3.1 | 16 | 0.64 | 2.2 | 6.2 | 61 |
| Strontium | µg/L | 92 | 132 | 216 | 355 | 25 | 172 | 400 | 158 | 119 | 187 | 284 | 131 |
| Thallium | µg/L | <0.001 | 0.003 | 0.036 | 158 | <0.001 | 0.009 | 0.42 | 65 | 0.004 | 0.022 | 0.34 | 70 |
| Tin | µg/L | <0.005 | <0.005 | 0.021 | 74 | <0.005 | <0.005 | 0.09 | 65 | <0.005 | <0.005 | 0.074 | 70 |
| Uranium | µg/L | 0.75 | 0.95 | 1.2 | 159 | 0.7 | 1.4 | 4.4 | 59 | 0.4 | 1.5 | 3.1 | 65 |
| Vanadium | µg/L | 0.08 | 0.19 | 3.8 | 331 | 0.078 | 1.4 | 44 | 158 | 0 | 1.2 | 68 | 217 |
| Zinc | µg/L | <0.2 | 1.0 | 15(Mn) | 318 | <0.05 | 9.1 | 209(C, Mn, Mx) | 160 | 0.8 | 8.6 | 388(C, Mn, Mx) | 217 |
| Dissolved Metals | | | | | | | | | | | | | |
| Aluminum | µg/L | - | - | - | - | 4.6 | 36 | 803(Mn, Mx) | 44 | 6.8 | 40 | 196(Mn, Mx) | 53 |
| Antimony | µg/L | - | - | - | - | 0.093 | 0.15 | 0.43 | 42 | 0.11 | 0.16 | 0.37 | 49 |
| Arsenic | µg/L | - | - | - | - | 0.1 | 0.3 | <5.0 | 66 | <0.1 | 0.37 | 13 | 250 |
| Barium | µg/L | - | - | - | - | 31 | 61 | 104 | 42 | 40 | 57 | 103 | 49 |
| Beryllium | µg/L | - | - | - | - | <0.001 | 0.006 | 0.064 | 42 | 0.001 | 0.007 | 0.018 | 49 |

**Table 27: Summary of Water Quality in the Liard River at Upper Crossing, Fort Liard, and Fort Simpson Stations, 1960 to 2015**

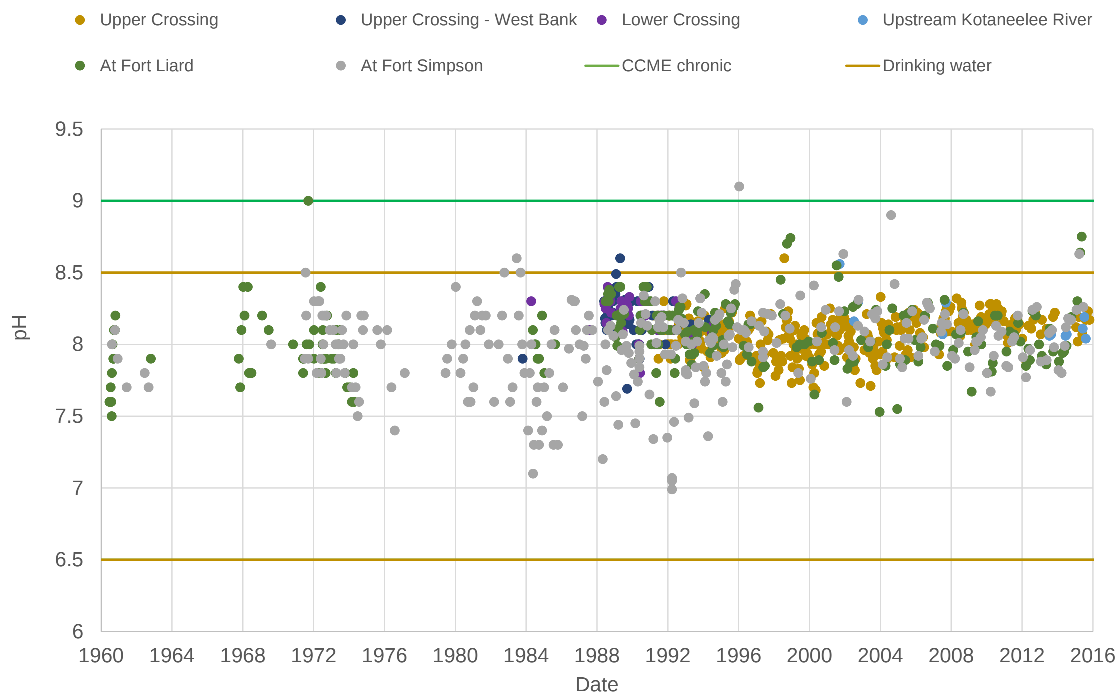
| | Unit | Upper Crossing | | | | Fort Liard | | | | Fort Simpson | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960-2015 | | | | | | | | | | | |
| | | Min | Median | Max | Count | Min | Median | Max | Count | Min | Median | Max | Count |
| Bismuth | µg/L | - | - | - | - | <0.001 | 0.001 | 0.015 | 42 | <0.001 | 0.001 | 0.005 | 49 |
| Boron | µg/L | - | - | - | - | 2.2 | 8.1 | 30 | 44 | 4.7 | 40 | 580 | 133 |
| Cadmium | µg/L | - | - | - | - | 0.012 | 0.023 | <1.0$^{(DL>Mn)}$ | 49 | 0.014 | 0.026 | 0.067 | 49 |
| Cesium | µg/L | - | - | - | - | 0.004 | 0.007 | 0.26 | 42 | 0.003 | 0.007 | 0.055 | 49 |
| Chromium | µg/L | - | - | - | - | 0.068 | 0.15 | 1.7 | 42 | 0.07 | 0.12 | 0.32 | 49 |
| Cobalt | µg/L | - | - | - | - | 0.025 | 0.072 | 0.94 | 42 | 0.021 | 0.064 | 0.2 | 49 |
| Copper | µg/L | - | - | - | - | 0.35 | 1.5 | <64 | 57 | 0.37 | 1.3 | 6.0 | 53 |
| Iron | µg/L | - | - | - | - | <1.0 | 76 | 1,980$^{(Mx)}$ | 62 | <10 | 60 | 350 | 61 |
| Lead | µg/L | - | - | - | - | 0.011 | 0.11 | <50 | 57 | 0.012 | 0.068 | 6.0 | 53 |
| Lithium | µg/L | - | - | - | - | 1.9 | 4.8 | 7.4 | 42 | 2.8 | 4.8 | 8.6 | 50 |
| Manganese | µg/L | - | - | - | - | <1.0 | 8.0 | 116 | 62 | 0.49 | 5.1 | 17 | 60 |
| Molybdenum | µg/L | - | - | - | - | 0.49 | 1.1 | 1.6 | 42 | 0.71 | 1.5 | 1.8 | 49 |
| Nickel | µg/L | - | - | - | - | 0.74 | 1.2 | 3.5 | 42 | 0.97 | 1.8 | 3.4 | 50 |
| Niobium | µg/L | - | - | - | - | <0.001 | 0.002 | 0.027 | 42 | <0.001 | 0.002 | 0.018 | 49 |
| Platinum | µg/L | - | - | - | - | <0.001 | <0.001 | 0.004 | 42 | <0.001 | <0.001 | 0.002 | 49 |
| Silver | µg/L | - | - | - | - | <0.001 | 0.0015 | 0.038 | 42 | <0.001 | 0.001 | 0.007 | 49 |
| Strontium | µg/L | - | - | - | - | 77 | 166 | 408 | 42 | 96 | 173 | 285 | 50 |
| Thallium | µg/L | - | - | - | - | 0.001 | 0.0055 | 0.028 | 42 | 0.003 | 0.007 | 0.051 | 49 |
| Tin | µg/L | - | - | - | - | <0.005 | <0.005 | 0.021 | 42 | <0.005 | 0.005 | 0.13 | 49 |
| Uranium | µg/L | - | - | - | - | 0.46 | 1.1 | 1.9 | 42 | 0.39 | 1.3 | 1.9 | 50 |
| Vanadium | µg/L | - | - | - | - | 0.091 | 0.24 | 2.5 | 42 | 0.086 | 0.27 | 0.7 | 49 |
| Zinc | µg/L | - | - | - | - | 0.6 | 1.2 | 23 | 57 | 0.5 | 1.3 | 140 | 53 |
| Organics | | | | | | | | | | | | | |
| Acenaphthylene | µg/L | - | - | - | - | <0.0065 | <0.0065 | <0.016 | 22 | <0.01 | <6.5 | <16 | 48 |
| Anthracene | µg/L | - | - | - | - | <0.0061 | <0.0061 | 0.034$^{(C)}$ | 22 | <5.0$^{(DL>C, DL>Mn)}$ | <6.1$^{(DL>C, DL>Mn)}$ | <20$^{(DL>C, DL>Mn)}$ | 38 |
| Benzo(a)anthracene | µg/L | - | - | - | - | <0.01 | <0.01 | <0.02$^{(DL>C)}$ | 22 | <5.0$^{(DL>C, DL>Mn)}$ | <10$^{(DL>C, DL>Mn)}$ | <20$^{(DL>C, DL>Mn)}$ | 38 |
| Benzo(a)pyrene | µg/L | - | - | - | - | <0.006 | <0.0094 | <0.069$^{(DL>C, DL>D, DL>Mn)}$ | 21 | <0.03$^{(DL>C, DL>D, DL>Mn)}$ | <9.4$^{(DL>C, DL>D, DL>Mn)}$ | <69$^{(DL>C, DL>D, DL>Mn)}$ | 45 |
| Chrysene | µg/L | - | - | - | - | <0.003 | 0.0086 | 0.03 | 22 | <3.0 | <20 | 54 | 38 |
| Dibenzothiophene | µg/L | - | - | - | - | <0.0052 | <0.0082 | 0.029 | 15 | <5.2 | <8.2 | 73 | 22 |
| Fluoranthene | µg/L | - | - | - | - | <0.0041 | 0.0078 | 0.028 | 22 | <0.015 | 4.4$^{(C, Mn)}$ | 17$^{(C, Mn)}$ | 48 |
| Fluorene | µg/L | - | - | - | - | <0.0064 | 0.012 | 0.044 | 22 | <0.015 | 8.5$^{(C)}$ | 68$^{(C, Mn)}$ | 48 |
| Indene | µg/L | - | - | - | - | <0.0051 | <0.0051 | <0.015 | 22 | <0.01 | <5.1 | 84 | 48 |
| Naphthalene | µg/L | - | - | - | - | <0.0058 | 0.02 | 0.16 | 22 | <5.8$^{(DL>C, DL>Mn)}$ | <20$^{(DL>C, DL>Mn)}$ | 131$^{(C, Mn)}$ | 38 |
| Perylene | µg/L | - | - | - | - | <0.009 | 0.02 | 0.12 | 21 | <9.0 | 18 | 230 | 35 |

**Table 27: Summary of Water Quality in the Liard River at Upper Crossing, Fort Liard, and Fort Simpson Stations, 1960 to 2015**

| | Unit | Upper Crossing | | | | Fort Liard | | | | Fort Simpson | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960-2015 | | | | | | | | | | | |
| | | Min | Median | Max | Count | Min | Median | Max | Count | Min | Median | Max | Count |
| Phenanthrene | µg/L | - | - | - | - | <0.0062 | <0.034 | 0.24 | 22 | <0.015 | 30(C, Mn) | 177(C, Mn) | 47 |
| Pyrene | µg/L | - | - | - | - | <0.0039 | <0.0078 | 0.059(C, Mn) | 22 | <0.015 | 7.2(C, Mn) | 148(C, Mn) | 48 |
| Aldrin | µg/L | - | - | - | - | <0.00017 | <0.00027 | <0.00077 | 22 | <0.0021 | <0.27 | <0.61 | 40 |
| Alpha-Benzenehexachloride | µg/L | - | - | - | - | <0.0002 | <0.00035 | <0.0011 | 22 | <0.0023 | <0.35 | <0.35 | 40 |
| Alpha-Chlordane | µg/L | - | - | - | - | <0.00031 | <0.0006 | <0.0006 | 22 | <0.0029 | <0.6 | <0.6 | 40 |
| Alpha-Endosulfan | µg/L | - | - | - | - | <0.00022 | <0.00062 | <0.00064 | 22 | <0.0031 | <0.62 | <0.62 | 40 |
| Beta-Endosulfan | µg/L | - | - | - | - | <0.00036 | <0.00059 | <0.00088 | 22 | <0.0059 | <0.59 | <0.88 | 40 |
| Beta-HCH | µg/L | - | - | - | - | <0.00085 | <0.0016 | <0.0016 | 17 | <1.0 | <1.6 | <1.6 | 27 |
| Cis-Nonachlor | µg/L | - | - | - | - | <0.0006 | <0.0011 | <0.0011 | 17 | <0.68 | <1.1 | <1.1 | 27 |
| Dieldrin | µg/L | - | - | - | - | <0.00035 | <0.0011 | <0.0013 | 22 | <0.0068 | <1.1 | <1.1 | 40 |
| Endrin | µg/L | - | - | - | - | <0.00055 | <0.0013 | <0.0013 | 22 | <0.0073 | <1.3 | <1.3 | 40 |
| Gamma-Chlordane | µg/L | - | - | - | - | <0.00019 | <0.00031 | <0.00041 | 22 | <0.0028 | <0.31 | <0.33 | 40 |
| Heptachlor | µg/L | - | - | - | - | <0.00035 | <0.00056 | <0.00082 | 22 | <0.0043 | <0.56 | <0.82 | 40 |
| Heptachlor Epoxide | µg/L | - | - | - | - | <0.00017 | <0.00033 | <0.0006 | 22 | <0.0032 | <0.33 | <0.33 | 40 |
| Hexachlorobutadiene | µg/L | - | - | - | - | <0.00025 | <0.00041 | <0.00053 | 17 | <0.25 | <0.41 | <0.41 | 27 |
| Methoxychlor (P,P'-Methoxychlor). | µg/L | - | - | - | - | <0.0032 | <0.0051 | <0.0079 | 22 | <0.048 | <5.1 | <7.9 | 40 |
| Mirex | µg/L | - | - | - | - | <0.00051 | <0.00082 | <0.0014 | 22 | <0.0044 | <0.82 | <1.4 | 40 |
| O,P'-DDD | µg/L | - | - | - | - | <0.00048 | <0.00078 | <0.00094 | 17 | <0.48 | <0.78 | <0.78 | 27 |
| O,P'-DDE | µg/L | - | - | - | - | <0.00074 | <0.0012 | <0.0013 | 17 | <0.74 | <1.2 | <1.2 | 27 |
| O,P'-DDT | µg/L | - | - | - | - | <0.00035 | <0.00056 | <0.0018 | 22 | <0.0094 | <0.56 | <0.75 | 40 |
| Oxychlordane | µg/L | - | - | - | - | <0.00045 | <0.001 | <0.001 | 17 | <0.64 | <1.0 | <1.0 | 27 |
| P,P'-DDD (TDP) | µg/L | - | - | - | - | <0.00055 | <0.00088 | <0.0022 | 22 | <0.017 | <0.88 | <2.2 | 40 |
| P,P'-DDE | µg/L | - | - | - | - | <0.0004 | <0.00065 | <0.0013 | 22 | <0.0064 | <0.65 | <1.3 | 40 |
| P,P'-DDT | µg/L | - | - | - | - | <0.00072 | <0.0012 | <0.0016 | 22 | <0.0093 | <1.2 | <1.3 | 40 |
| PCB-TOTAL | µg/L | - | - | - | - | <0.00034 | - | <0.00034 | 2 | <0.21 | <0.34 | <11 | 6 |
| Pentachloroanisole | µg/L | - | - | - | - | <0.00017 | <0.00028 | <0.00048 | 17 | <0.17 | <0.28 | 0.81 | 27 |
| Pentachlorobenzene | µg/L | - | - | - | - | <0.00021 | <0.00034 | <0.0008 | 18 | <0.0027 | <0.34 | <0.8 | 31 |
| Trans-Nonachlor | µg/L | - | - | - | - | <0.00046 | <0.00074 | <0.00074 | 17 | <0.46 | <0.74 | <0.74 | 27 |

Note: Values in shaded cells are above guidelines.
(A) = concentration higher than the relevant acute aquatic life guideline or beyond the recommended pH range.
(C) = concentration higher than the relevant chronic aquatic life guideline or beyond the recommended pH or total alkalinity concentration range.
(D) = concentration higher than the relevant drinking water guideline or beyond the recommended pH range.
(Mn) = concentration higher than the relevant 30-day mean aquatic life guideline or beyond the recommended pH range.
(Mx) = concentration higher than the relevant maximum aquatic life guideline or beyond the recommended pH range.
(DL>C) = analytical detection limit was higher than the relevant chronic aquatic life guideline.
(DL>D) = analytical detection limit was higher than the relevant drinking water guideline.
(DL>Mn) = analytical detection limit was higher than the relevant 30-day mean aquatic life guideline.
Water quality data and guidelines shown in this table were rounded to reflect laboratory or field instrument precision after comparisons to guidelines. Therefore, values slightly above guidelines may be displayed as being equal to the guidelines and identified as exceedances. Measured concentrations equal to the guideline values were not identified as exceedances.
- = no data.

The assessment of pH in the Liard River was based on laboratory measurements of pH in samples collected from the river. Collection of field measurements of pH are recommended instead of laboratory pH measurements because of the short holding time for laboratory pH measurements (i.e., typically 24 to 48 hours). Values of pH in a sample can change over time depending on the constituents in the sample; therefore, instantaneous instream measurements of pH are recommended. Measurements of field pH should be collected routinely at all sampling locations in the Liard River.




Note: The lower pH drinking water and CCME chronic guidelines overlap.

*Figure 12: pH in the Liard River, 1960 to 2015*

### *5.2.3.2 Total Dissolved Solids and Conductivity*

Classification of solids in water are commonly carried out via gravimetric analysis, a technique of separating suspended and dissolved constituents by weight using methods of filtration and evaporation at controlled temperatures. Total dissolved solids (TDS) refers to all dissolved organic and inorganic constituents in water measured after a solution is filtered through a 2 micron filter and evaporated at 180˚C to completely remove water from the solids. In most natural waters, the concentrations of TDS are often similar to the total major ion concentrations or the total dissolved salt content of the water and is directly correlated with electrical conductivity and salinity. Concentrations of TDS is an indicator for hardness, alkalinity and the aesthetic quality of drinking water. For the protection of freshwater aquatic life, concentrations of TDS above 1,000 mg/L could become harmful to aquatic organisms (Hart et al. 1990; Mitchell and Prepas 1990). Although freshwater systems in different geological regions have different natural ranges of TDS concentrations, elevated concentrations of TDS is commonly observed in urban watersheds due to contaminant loadings from sources such as road salt and municipal wastewater discharge.

Conductivity is the ability of a substance to conduct an electrical current. Specific conductivity is the conductivity of a unit volume substance at a specified temperature. The conductivity of water measures the ability of an aqueous solution to transmit electrical current under the influence of temperature and the types of dissolved species, their concentrations, mobility, and valence. It is a numerical expression useful for approximating the amount of total dissolved ionic species in a solution and is strongly correlated with salinity. Conductivity depends on the level of dissolved ionic species in natural waters and varies depending on the geology of the watershed. Natural waters inherit distinct chemical characteristics from the weathering process of parent geological materials. Waters in igneous bedrocks, such as granite, typically have lower amount of total dissolved solids than those in carbonate bedrock such as limestone.

Specific conductance of most natural surface waters range from 50 to 1,500 µS/cm (McNeely et al. 1979). Impacts from anthropogenic sources such as road salt, urban runoff, and industrial wastewater inputs could also significantly alter the natural chemistry of the water (LCRA 2011). Changes in the natural chemistry of an aqueous system can often be detected in the conductivity of the water, making it a useful diagnostic indicator of deviations from the natural chemical state of the system.

A generic classification of TDS and conductivity values is provided in Table 28.

**Table 28: Scale of Total Dissolved Solids and Specific Conductivity**

| Description | Total Dissolved Solids (mg/L) | Specific Conductivity (µS/cm) |
|---|---|---|
| Low | ≤100 | ≤165 |
| Moderate | 101 to 500 | 166 to 830 |
| High | >500 | >830 |

Note: The categories in this table were operationally defined to facilitate description of water quality in this document in a standardized format.
µS/cm = microSiemens per centimetre.

Liard River has moderate concentrations of TDS and values of specific conductivity. Clear temporal trends in specific conductivity or concentrations of TDS in the Liard River were not observed (Figures 13 to 14).

Specific conductivity values in the Liard River ranged from about 100 to 500 µS/cm, with a clear spatial pattern between upstream and downstream stations (Figure 13). The median specific conductivity of water samples increased from approximately 200 µS/cm at upstream stations to near 300 µS/cm at downstream stations (see Table 28). The same spatial pattern of higher concentrations in TDS at downstream stations relative to upstream stations in the Liard River was observed (see Table 27); however, this spatial pattern was less definitive due to the variability in concentrations and the shorter sampling period at some locations (Figure 14). Specific conductivity and concentrations of TDS may be increasing as the river flows downstream due to natural dissolution of material from geological formations into the water, inputs from natural, agricultural, and urban runoff, and point sources, such as municipal wastewater discharges.

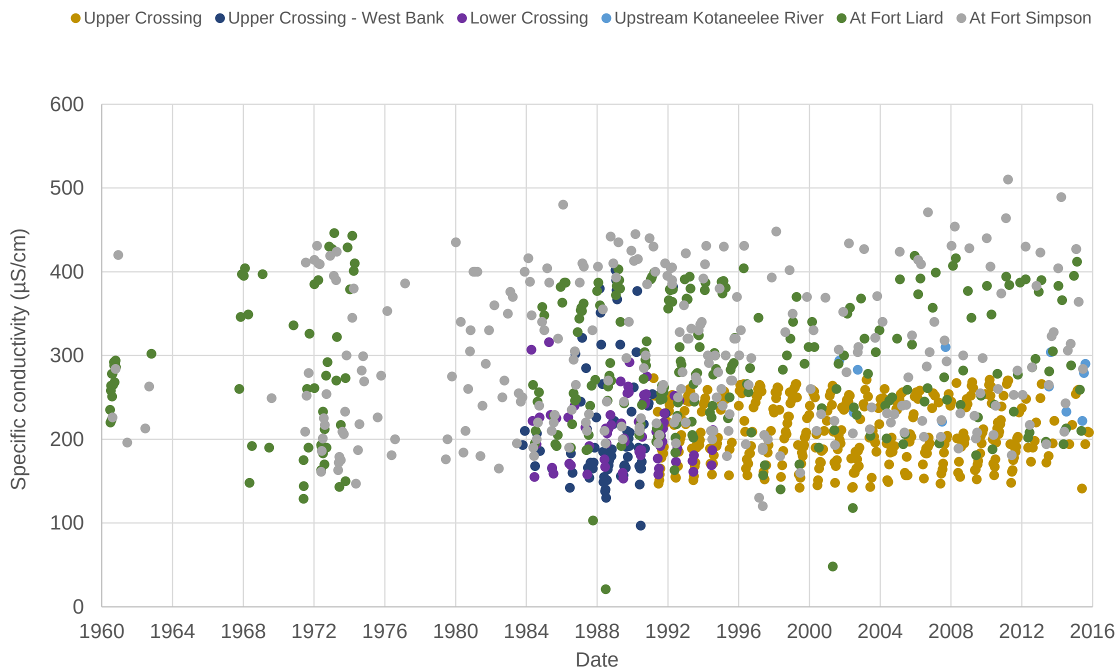



*Figure 13: Specific Conductivity in the Liard River, 1960 to 2015*

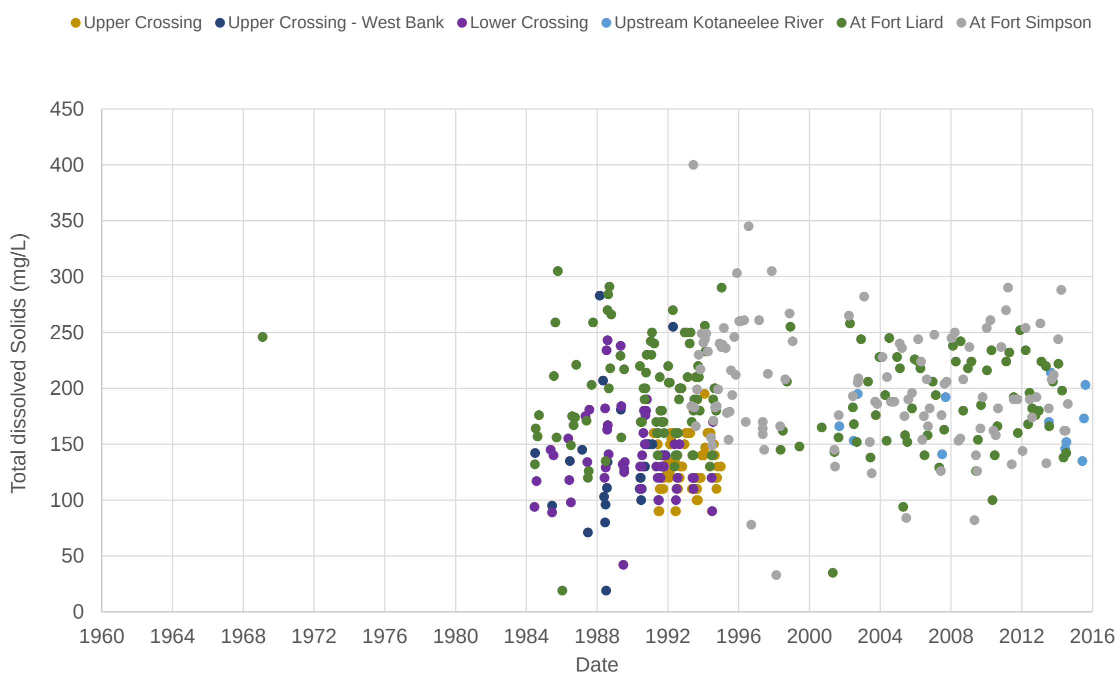



*Figure 14: Total Dissolved Solids Concentrations in the Liard River, 1969 to 2015*

Seasonal patterns in conventional parameters of specific conductivity and TDS were observed in the Liard River. Specific conductivity and concentrations of TDS were lower during spring/freshet conditions and then increased from summer to winter (Figures 15 and 16). Concentrations of TDS were lowest during spring/freshet conditions, when a greater proportion of water from ice melt and surface water runoff, which are typically lower in TDS relative to groundwater, flow into the Liard River. Concentrations of TDS were highest during the winter when the source of flows in the Liard River is predominantly groundwater, which typically has higher TDS concentrations than surface waters. The exclusion of salts from ice as it forms in the Liard River during the winter also increases the concentrations of salts in Liard River during the ice-covered period. The seasonal patterns identified for specific conductivity and TDS are consistent with those seasonal patterns identified in Taylor et al. (1998).

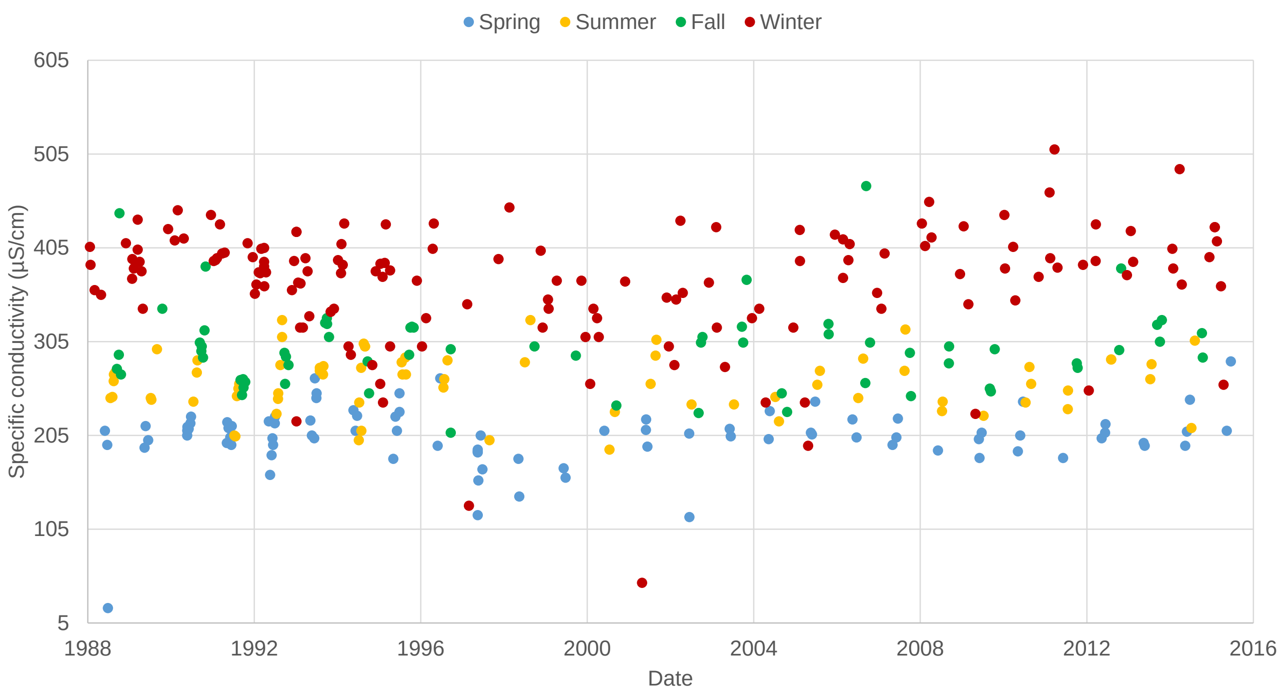



*Figure 15: Seasonal Conductivity in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

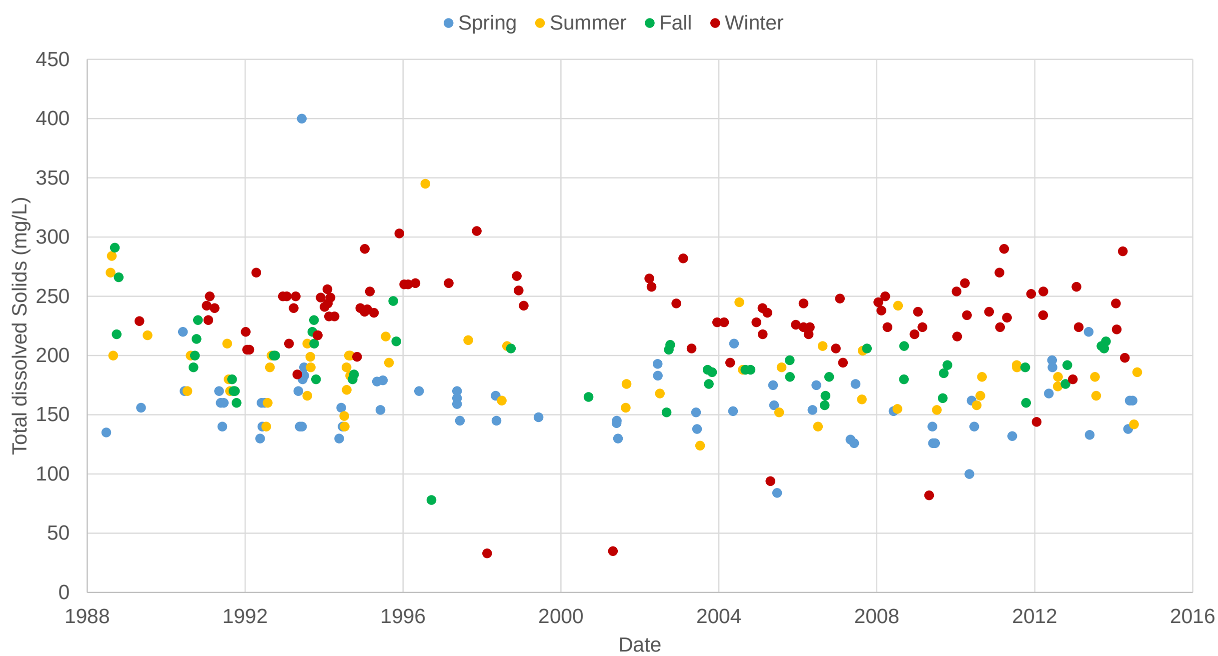


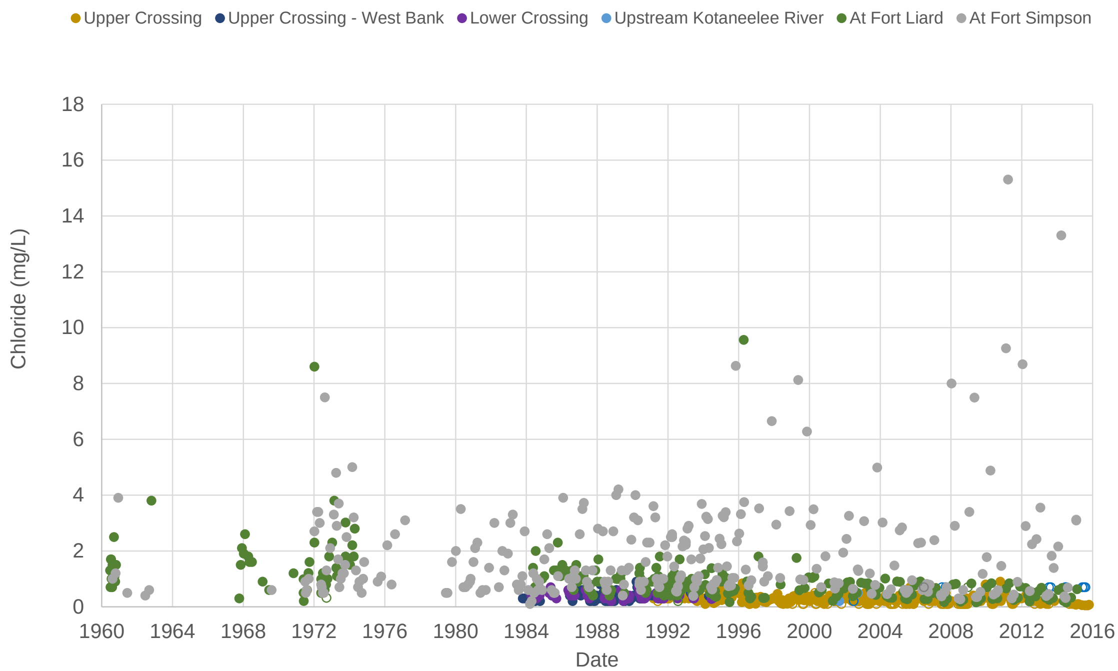

*Figure 16: Seasonal Total Dissolved Solids Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

Concentrations of TDS in the upstream reaches of the Liard River have not been measured consistently since 1996. Specific conductivity and TDS concentrations are recommended to be collected routinely at all sampling locations in the Liard River.

### 5.2.3.3 Major Ions

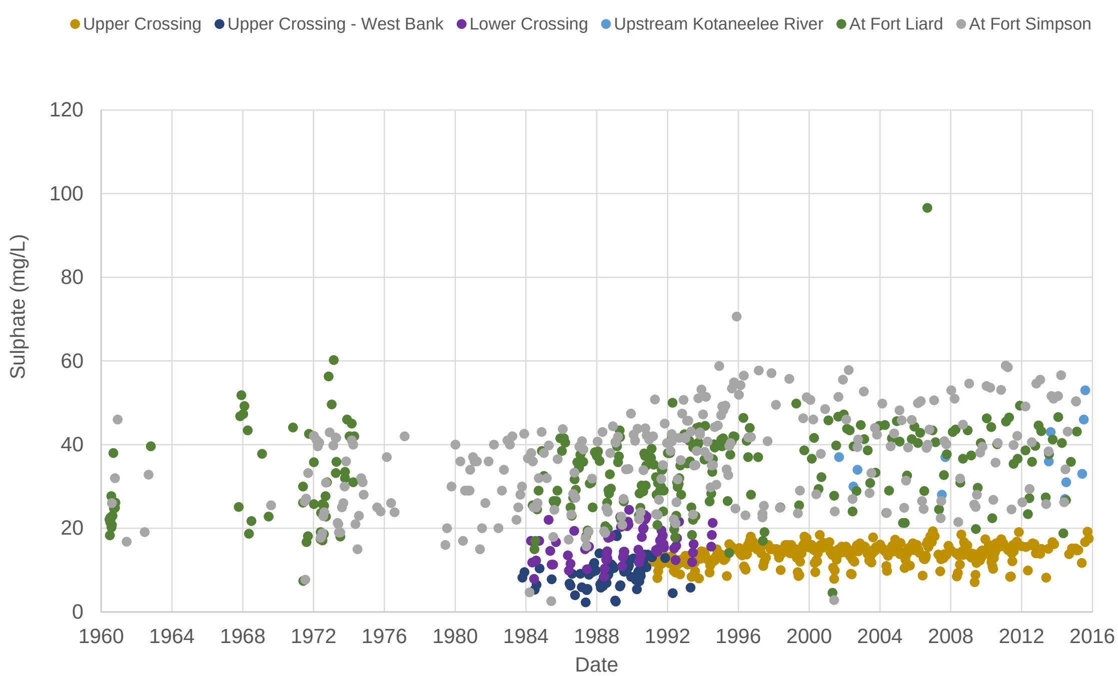
Major ions are ionically dissociated inorganic chemical species in water and the major constituent of the total dissolved solids in solution. Dissolved ionic species in water carry either positive charges (cations) or negative charges (anions) that balance up to a net charge of zero. Water-rock interactions through weathering have a direct influence on the concentrations of major ions in freshwater systems. The major ions calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), sodium ($Na^{+}$), potassium ($K^{+}$), bicarbonate ($HCO_3^{-}$), sulphate ($SO_4^{2-}$), and chloride ($Cl^{-}$) are the common major ions of most natural freshwater chemistry. The major ions become incorporated as a part of the water chemistry mainly through mineral weathering and dissolution. In addition to geological sources of major ions in surface waters, anthropogenic inputs can also alter the natural major ion chemistry of waters via discharge of municipal and industrial wastewater effluents, and agricultural and urban runoffs. In particular, the application of road salt in urban areas can substantially increase chloride concentrations in runoff, and within receiving waters (CCME 1999).

Concentrations of major ions in the Liard River were typically below aquatic life and drinking water guidelines, with the exception of the interim CCME chronic guideline for fluoride (Table 27). Individual fluoride concentrations in the Liard River were occasionally above the interim CCME chronic guideline for the protection of aquatic life (0.12 mg/L) at both upstream and downstream stations; less than 10% of concentrations were above the interim chronic guideline at all stations. Median fluoride concentrations in the Liard River (0.08 to 0.09 mg/L) were below the interim CCME chronic guideline. Clear temporal trends in concentrations of major ions in the Liard River were not observed (Figures 17 to 23).




Note: For the purposes of visually reviewing the data: CCME acute (640 mg/L), CCME chronic (120 mg/L), BC MOE maximum (600 mg/L) and BC MOE 30-day mean (150 mg/L) guidelines are not shown.

*Figure 17: Chloride Concentrations in the Liard River, 1960 to 2015*




Note: For the purposes of visually reviewing the data, one data point was removed: 300 mg/L at Fort Liard on December 16, 1999.

*Figure 18: Sulphate Concentrations in the Liard River, 1960 to 2015*

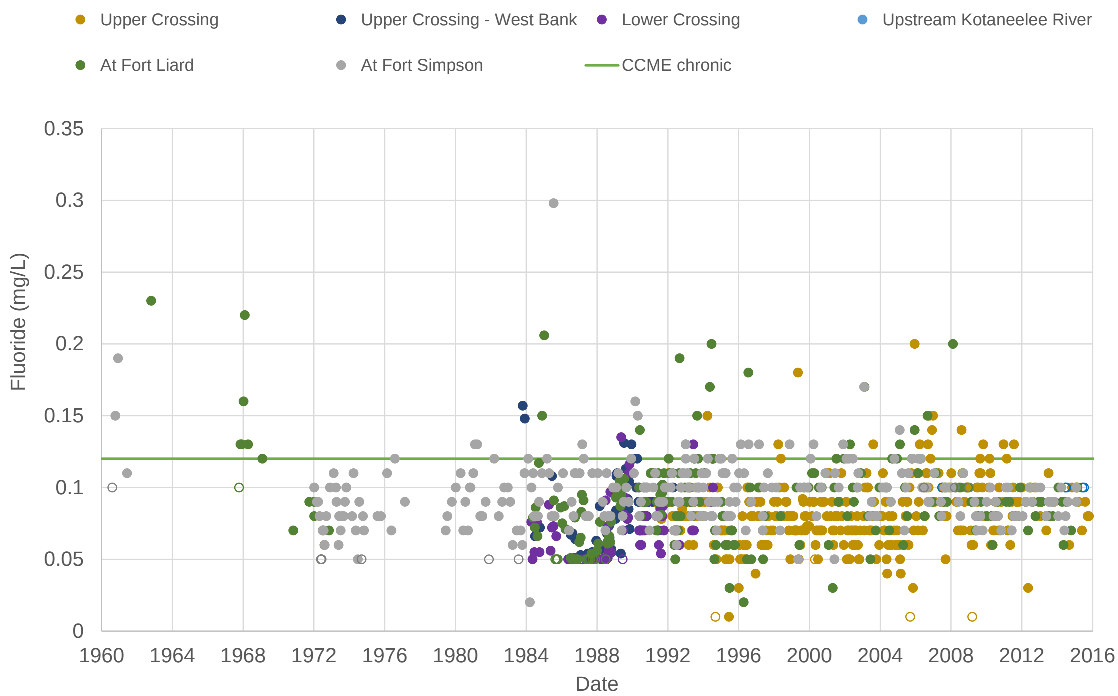



*Figure 19: Fluoride Concentrations in the Liard River, 1960 to 2015*

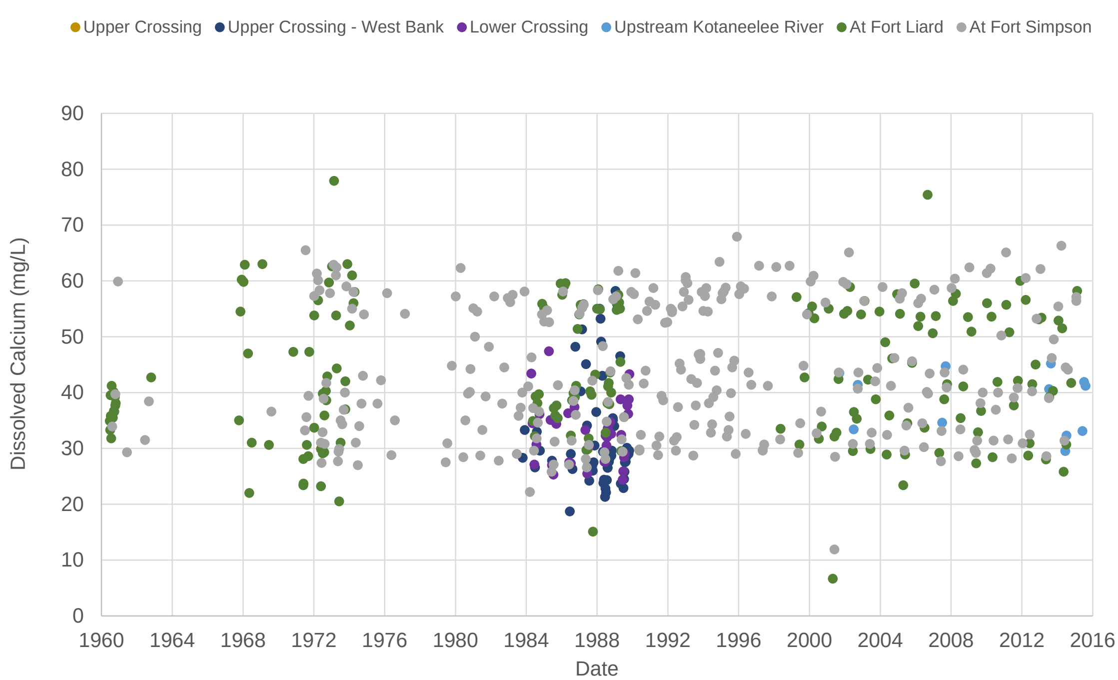



*Figure 20: Calcium Concentrations in the Liard River, 1960 to 2015*

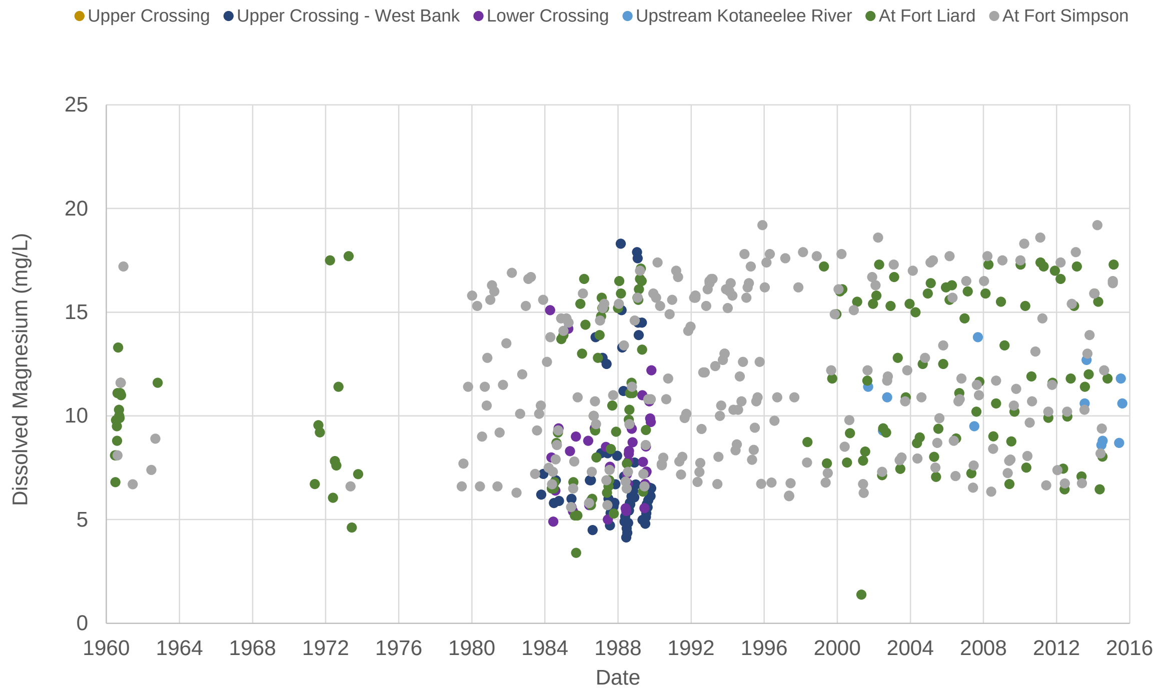



*Figure 21: Magnesium Concentrations in the Liard River, 1960 to 2015*

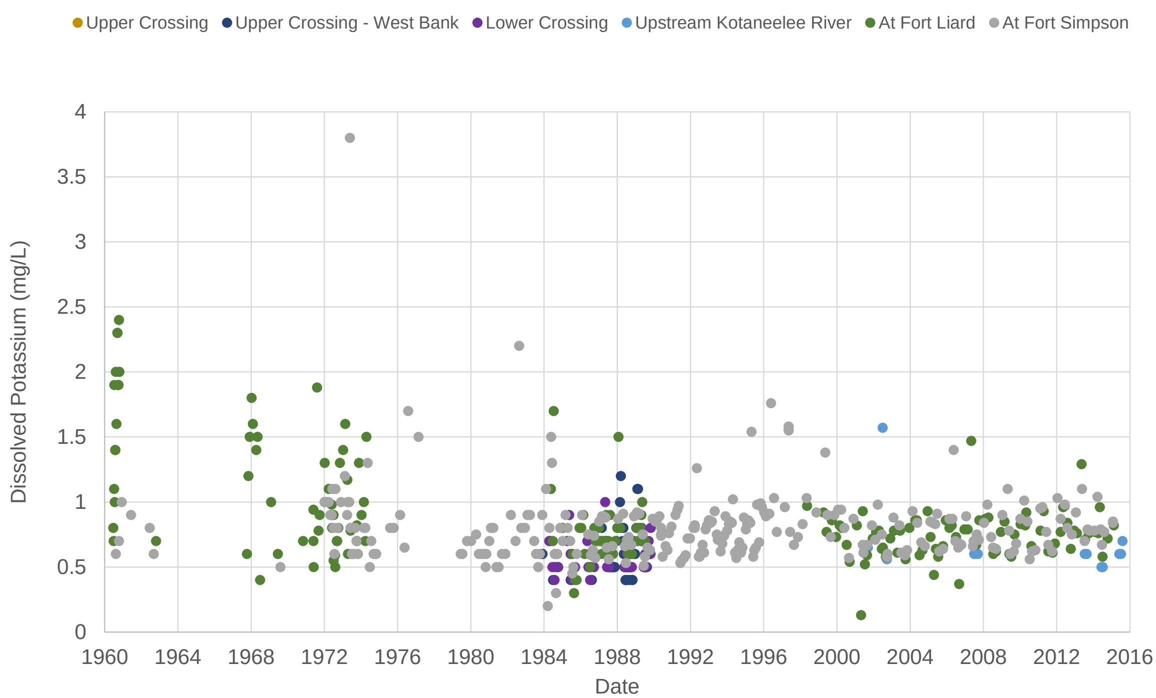



*Figure 22: Potassium Concentrations in the Liard River, 1960 to 2015*

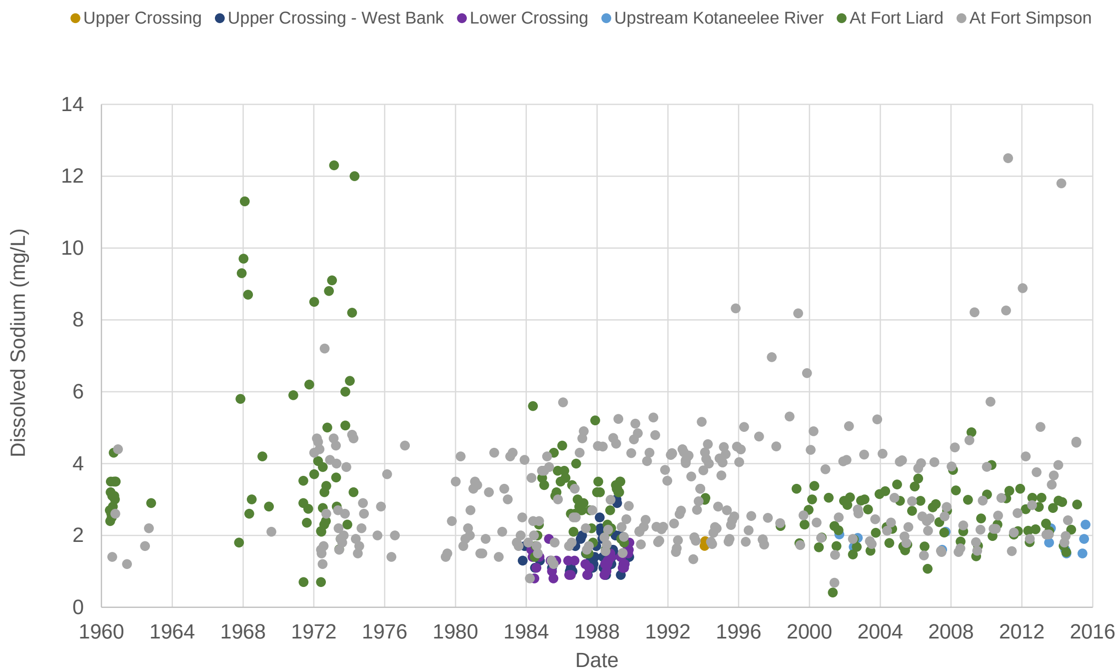



*Figure 23: Sodium Concentrations in the Liard River, 1960 to 2015*

Spatial patterns for some major ions were similar to those observed for measured TDS and specific conductivity. Median chloride, fluoride, sulphate, and silica concentrations increased from upstream to downstream stations (from upstream: 0.29, 0.08, 14, and 3.4 mg/L to downstream: 1.3, 0.09, 37, and 5.3 mg/L, respectively), when comparing stations sampled during the same time period (i.e., Upper Crossing, Fort Liard, and Fort Simpson stations) (see Table 27). However, for some of these major ions (e.g., fluoride and silica), the variation in median concentrations was small.

The concentrations of chloride, sulphate, calcium, magnesium, and sodium the Liard River were typically highest during winter and lowest during spring (Figures 24 to 28), which is consistent with the seasonal patterns observed for TDS concentrations. Similar to TDS concentrations, concentrations of these major ions were lowest during spring/freshet conditions, when a greater proportion of water from ice melt and surface water runoff, which are typically lower in major ions relative to groundwater, flow into the Liard River. Concentrations of these major ions were highest during the winter when the source of flows in the Liard River is predominantly groundwater, which typically has higher major ions concentrations. The exclusion of salts from ice as it forms in the Liard River during the winter also increases the concentrations of salts in Liard River. Clear seasonal patterns in potassium and fluoride concentrations were not observed, which may be related to the overall lower concentrations of these major ions observed in the Liard River (Figures 29 and 30).

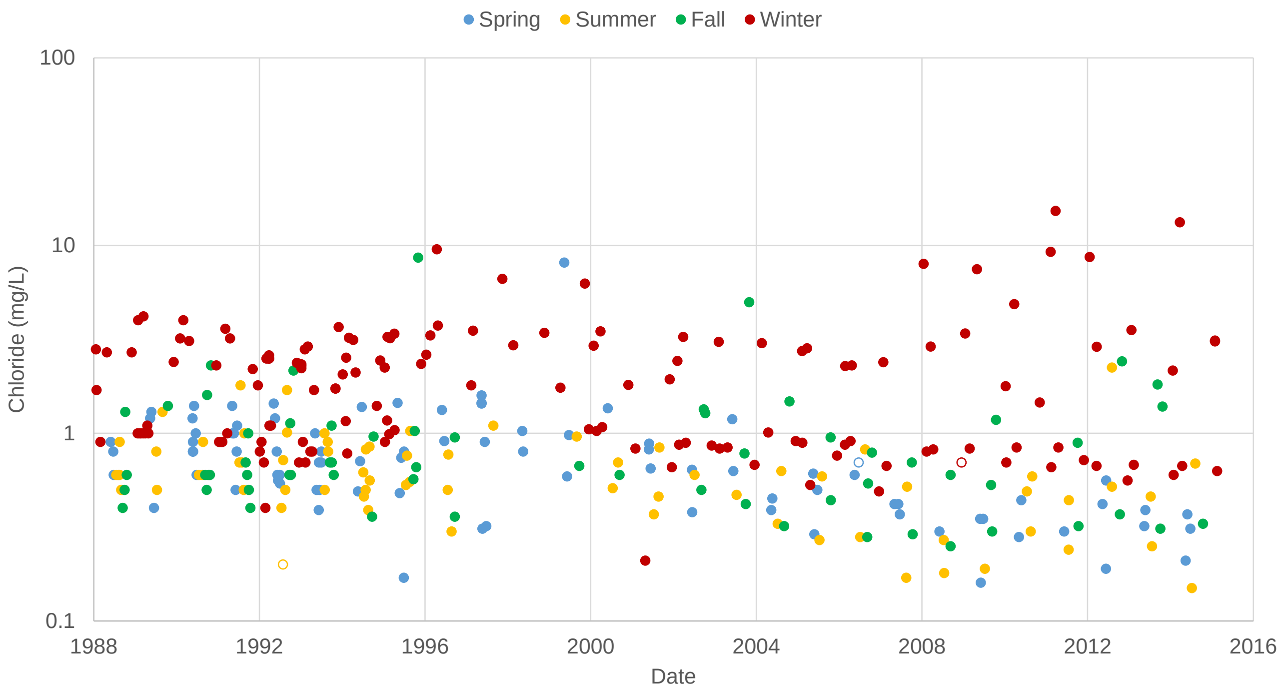



*Figure 24: Seasonal Chloride Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

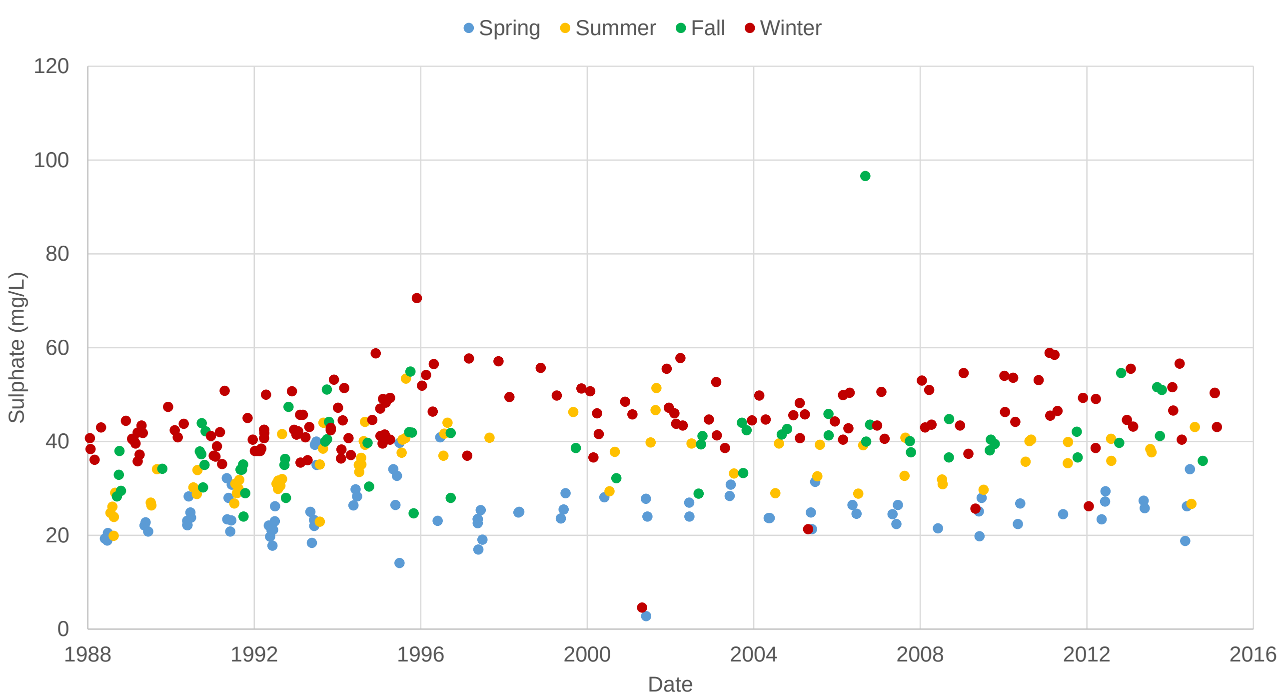



*Figure 25: Seasonal Sulphate Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

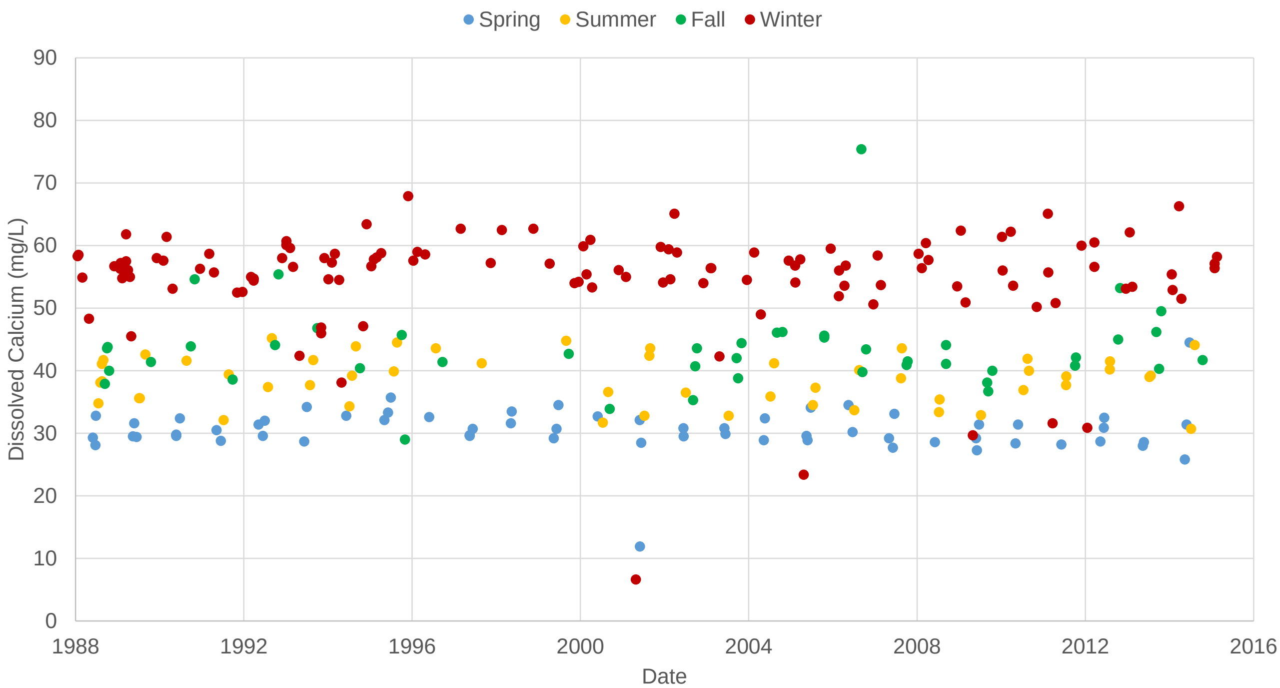



*Figure 26: Seasonal Calcium Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

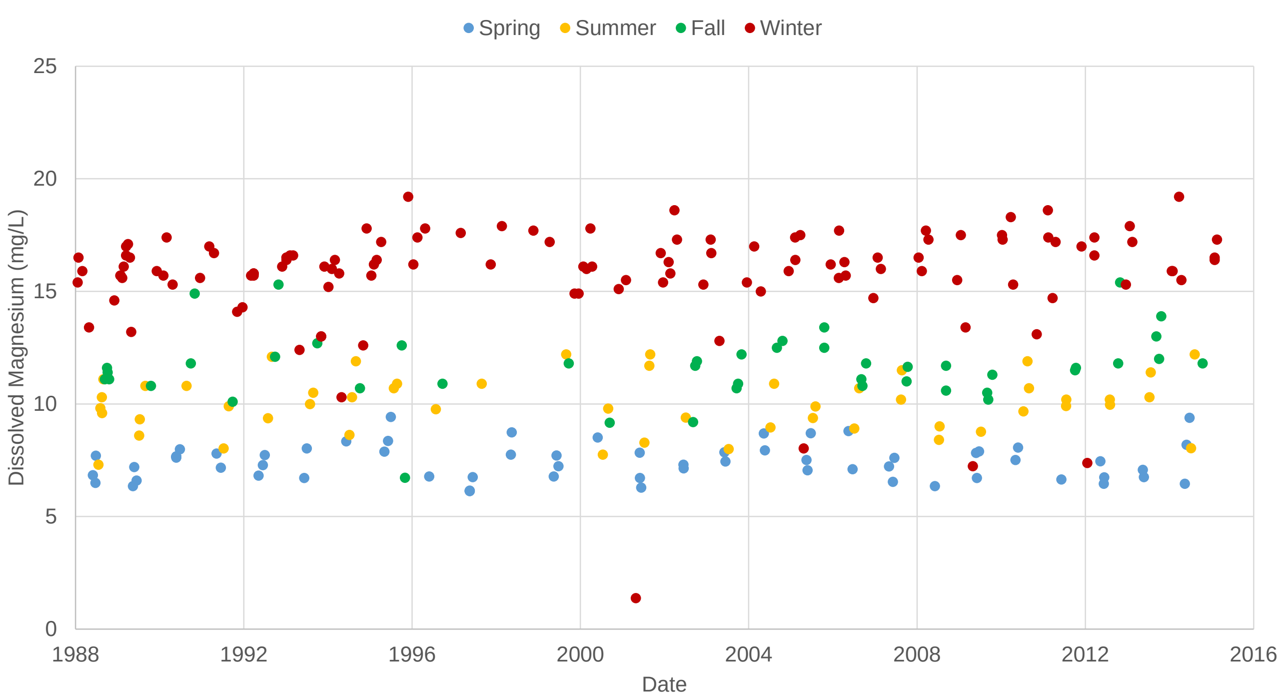



*Figure 27: Seasonal Magnesium Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

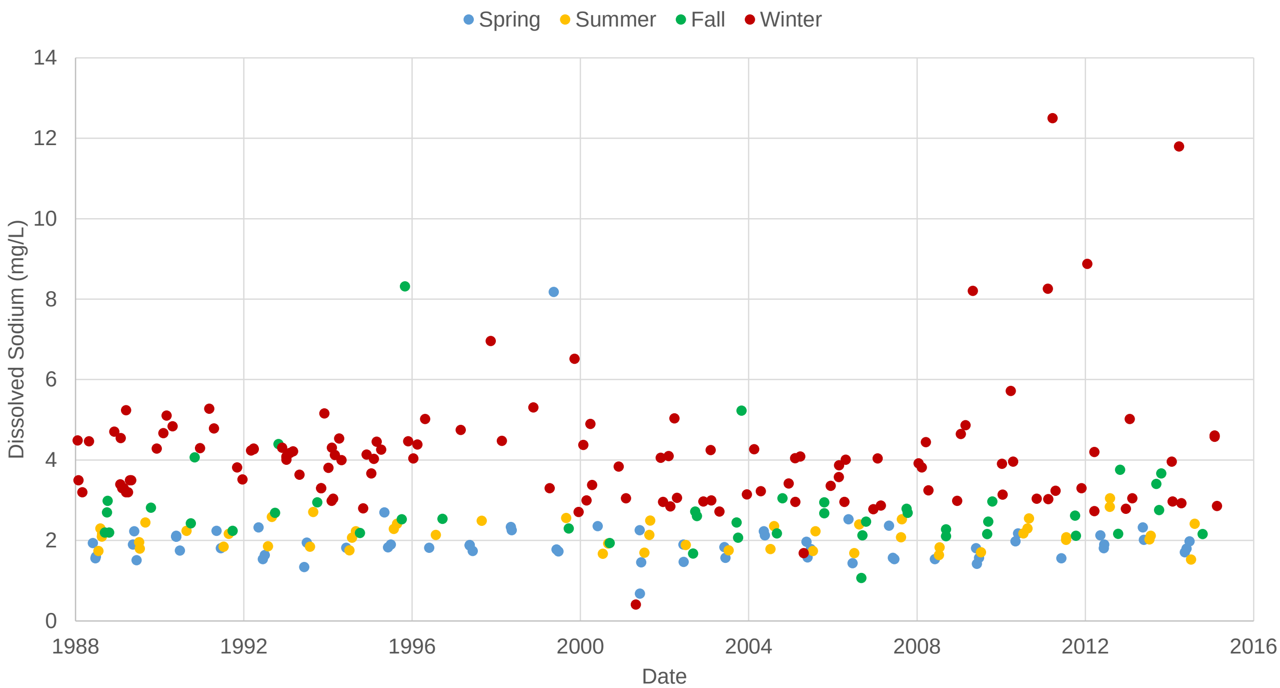



*Figure 28: Seasonal Sodium Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

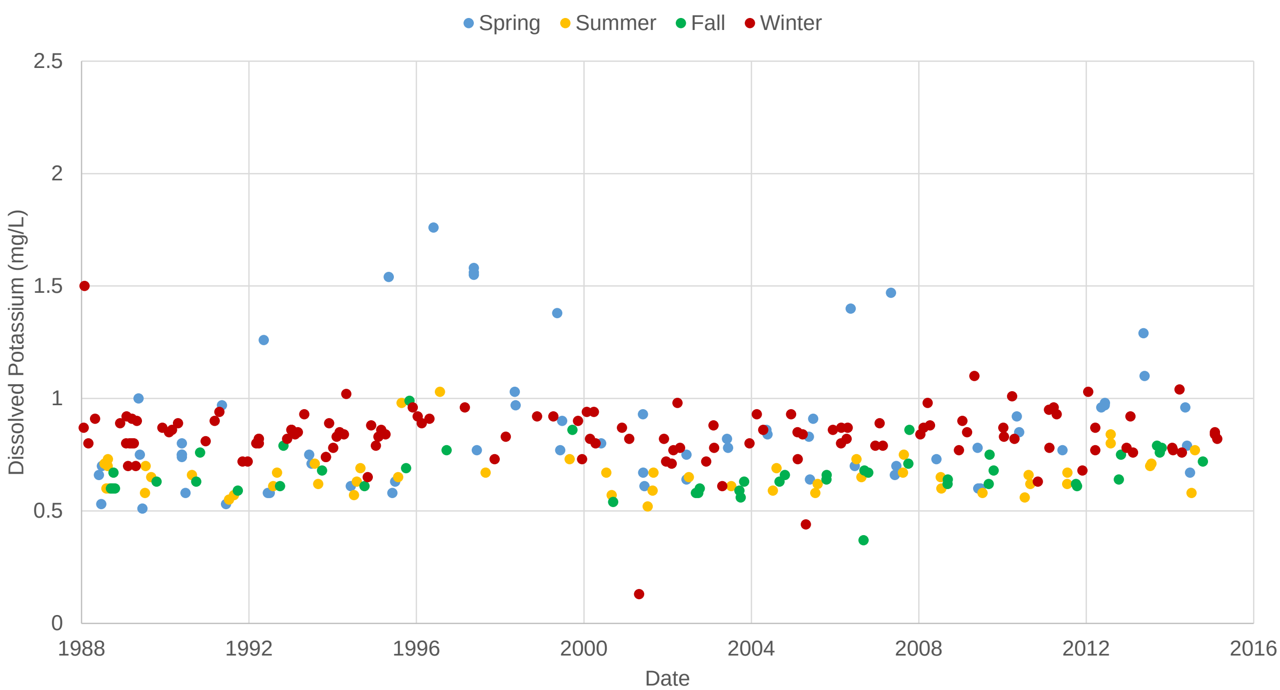



*Figure 29: Seasonal Potassium Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

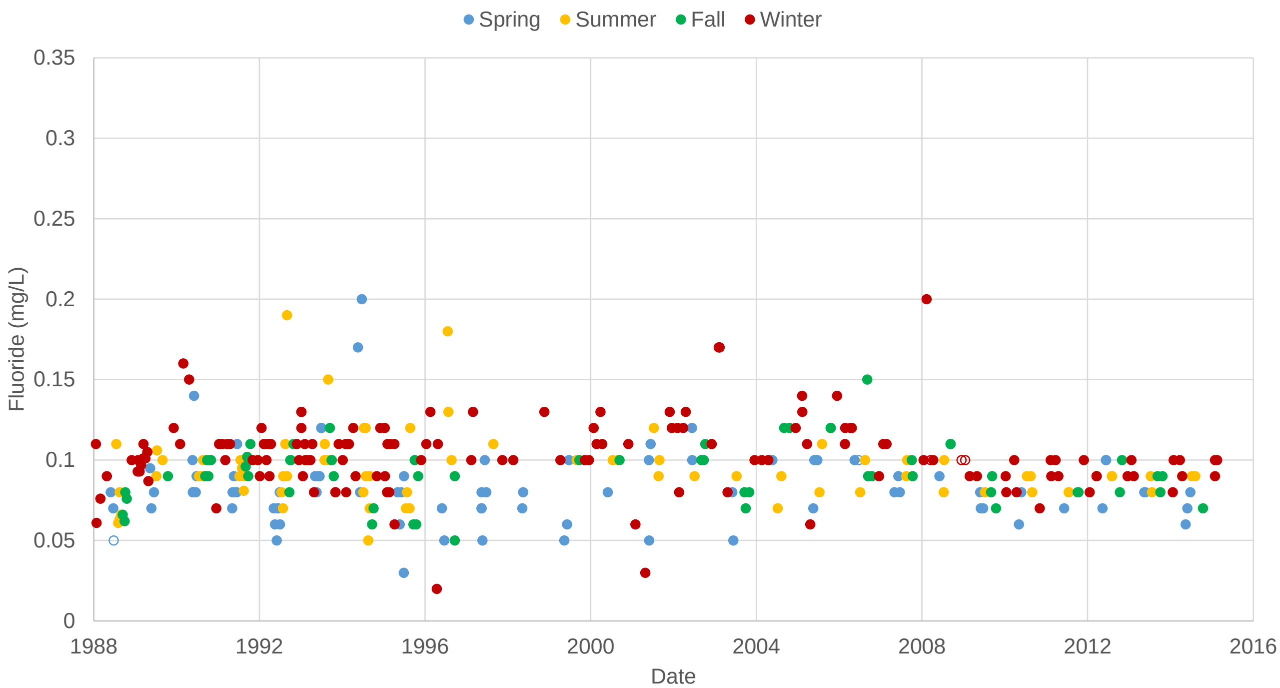



*Figure 30: Seasonal Fluoride Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

Concentrations of major ions were not consistently measured at all stations in the Liard River, particularly Lower Crossing and upstream of the Kotaneelee River. Routine monitoring of major ions concentrations at all sampling stations in the Liard River is recommended.

#### *5.2.3.4 Alkalinity*

Alkalinity is defined as the capacity of a solution to buffer and neutralize acid and is a useful measure of an aquatic system's acid neutralizing capacity (ANC). Alkalinity is produced by ionic/molecular species of not fully dissociated weak acids above a pH of 4.5. For most natural waters, alkalinity is contributed by bicarbonate, carbonate, and hydroxide species. The relative concentrations of the carbonate species in water is pH dependent. Anthropogenic activities could reduce a system's natural buffering capacity against acid by reducing the alkalinity of the system. Acid mine drainage, acid deposition, and industrial effluent discharge are examples of anthropogenic inputs that can reduce the alkalinity in waterbodies.

In natural waters, alkalinity does not usually exceed 500 mg/L (CCREM 1987). Saffran and Trew (1996) presented a scale of lake sensitivity to acidification based on alkalinity and acid neutralizing capability (Table 29), which was used to provide context to the alkalinity values in the Liard and Petitot watersheds.

**Table 29: Scale of Acid Sensitivity Based on Alkalinity in Lakes**

| Acid Sensitivity | Alkalinity or Acid Neutralizing Capacity | |
|---|---|---|
| | (mg/L as $CaCO_3$) | (μeq/L) |
| High | 0 to 10 | 0 to 200 |
| Moderate | >10 to 20 | >200 to 400 |
| Low | >20 to 40 | >400 to 800 |
| Least | >40 | >800 |

Source: Saffran and Trew (1996).

μeq/L = microequivalents/litre.

Water in the Liard River ranged from moderately hard to hard water, which did not classify as sensitive to acidification based on minimum alkalinity values. Clear temporal trends in alkalinity in the Liard River were not observed (Figure 31).

Alkalinity in the Liard River has a clear seasonal pattern; alkalinity is typically highest during winter and lowest during spring (Figure 32), which is consistent with the spatial patterns observed for the major ions and TDS concentrations.

Alkalinity has not consistently been measured at all stations in the Liard River, particularly Lower Crossing and upstream of the Kotaneelee River. Routine monitoring of alkalinity at all sampling stations in the Liard River is recommended.

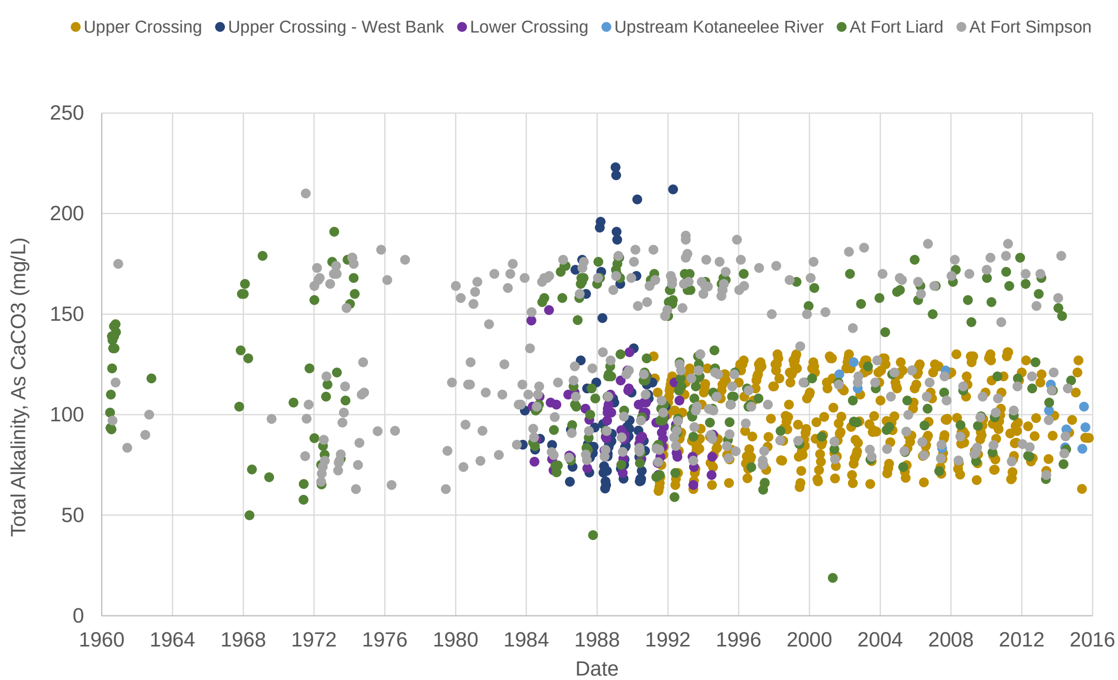



*Figure 31: Total Alkalinity in the Liard River, 1960 to 2015*

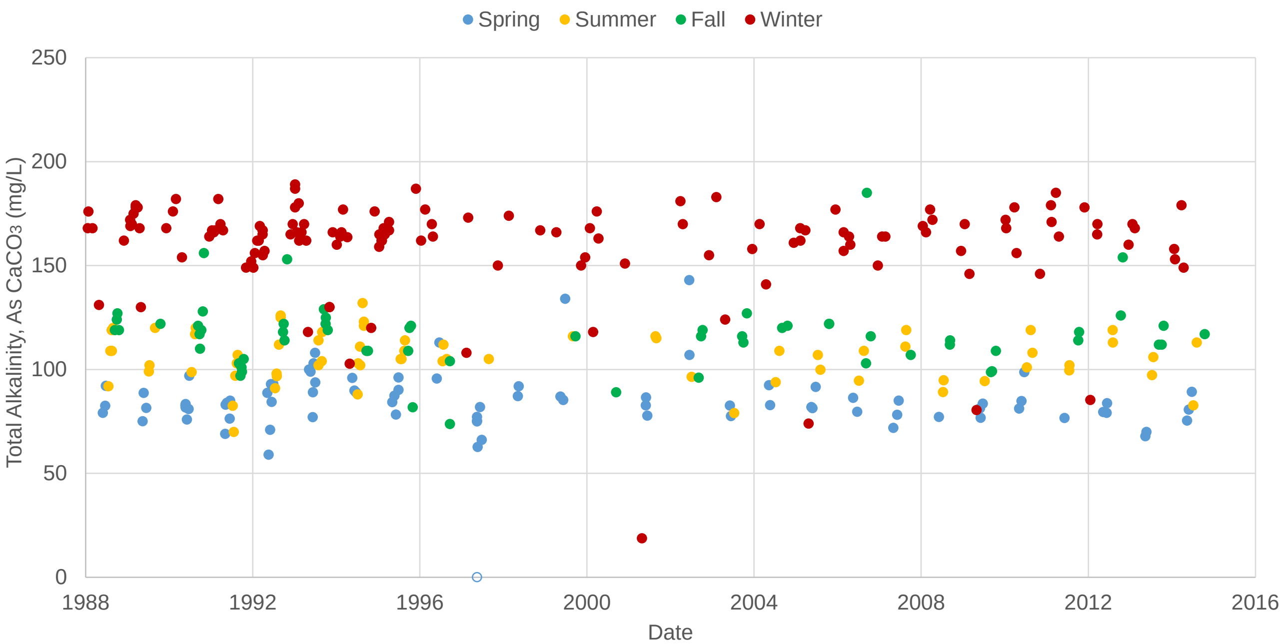



*Figure 32: Seasonal Alkalinity in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

### 5.2.3.5 Total Suspended Solids

Total suspended solids (TSS) is a measure of all the particulate material (silt, clay and sand particles) suspended in the water column that remain after filtration and evaporation of the water sample. Suspended solids can be made up of both inorganic and organic material, such as plankton, bacteria, and detritus.

Natural erosion of underlying geological formations is the most common source of suspended sediments to a water body (CCME 1999). Erosion rates are affected by flows in the river; therefore, natural increases in springtime flows typically result in higher TSS concentrations in rivers. Increased rates of erosion can occur due to anthropogenic activities that increase disturbed areas (e.g., clearing of land due to agriculture, forestry, urbanization, or mining), which lead to decreases in vegetative cover and high runoff rates. Anthropogenic sources of sediment to water bodies include forestry, road construction, navigation dredging, agriculture, wastewater discharges, mining activities, and other land disturbances (CCME 1999).

Some parameters, such as phosphorus, metals and organics, can be adsorbed to suspended solids; therefore, higher concentrations of these parameters are often associated with higher concentrations of TSS. Phosphorus and metals adsorbed to TSS are typically not always biologically available; however, high TSS concentrations that flow downstream can transport adsorbed parameters long distances downstream from the origin source where changes in water quality conditions may cause some adsorbed parameters to transition into solution (e.g., decreases in pH or DO may cause certain metals to become more soluble).

High TSS concentrations can cause stress to aquatic life depending on both the TSS concentration and the duration of exposure (Newcombe and Jensen 1996). Examples of stresses include physical effects to fish, such as clogging of fish gills, and impairment of fish habitat, such as smothering gravel areas where fish spawn (US EPA 2012). Concentrations of TSS below 25 mg/L are generally not considered harmful to aquatic life (DFO and DOE 1983; EIFAC 1965; US EPA 1973). Aquatic organisms can withstand low levels of TSS for long periods and higher levels for shorter periods (Newcombe and MacDonald 1991). In this report, TSS is characterized by the following concentrations:

- Low: less than 10 mg/L;
- Moderate: between 10 and 25 mg/L; and
- High: greater than 25 mg/L.

Turbidity is the optical property of suspended particulates in water to scatter light; increases in turbidity are typically associated with increases in TSS concentrations. Turbidity reflect both the amount of suspended material in the water and its nature; fine clay particles, for example, create higher turbidity levels than an equal mass of coarser-grained (e.g., sandy silt) particles (Taylor et al. 1998). Higher turbidity reduces the amount of light penetrating the water, which can reduce photosynthesis and the production of DO (US EPA 2012).

Increases in TSS concentrations or turbidity values due to anthropogenic activities are of greater concern than naturally elevated TSS concentrations or turbidity; CCME guidelines for TSS and turbidity are based on changes from background levels and not absolute values (CCME 1999).

Concentrations of TSS varied widely in the Liard River (<1 mg/L to 3,627 mg/L), ranging from low to high on an annual basis at all stations; median values ranged from <10 mg/L to 90 mg/L from Upper Crossing to Fort Simpson (Table 27). The downstream reaches of the Liard River are highly turbid; higher TSS concentrations and turbidity were typically observed at downstream locations compared to upstream locations, which is typical for most rivers. Higher concentrations in TSS appear to be due to natural causes because no clear temporal trends in concentrations of TSS in the Liard River were observed (Figure 33). A slight increase in turbidity values was observed between 1992 and 2014 at Upper Crossing; however, increases were not observed in turbidity at other locations in the Liard River (Figure 34).

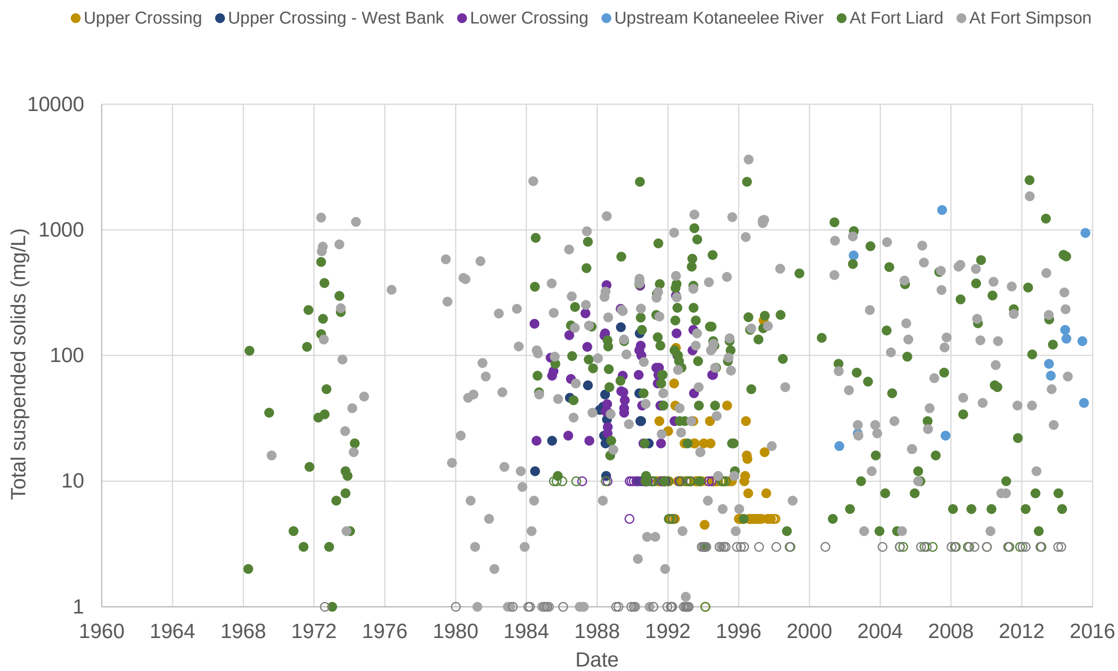



*Figure 33: Total Suspended Solids Concentrations in the Liard River, 1968 to 2015*

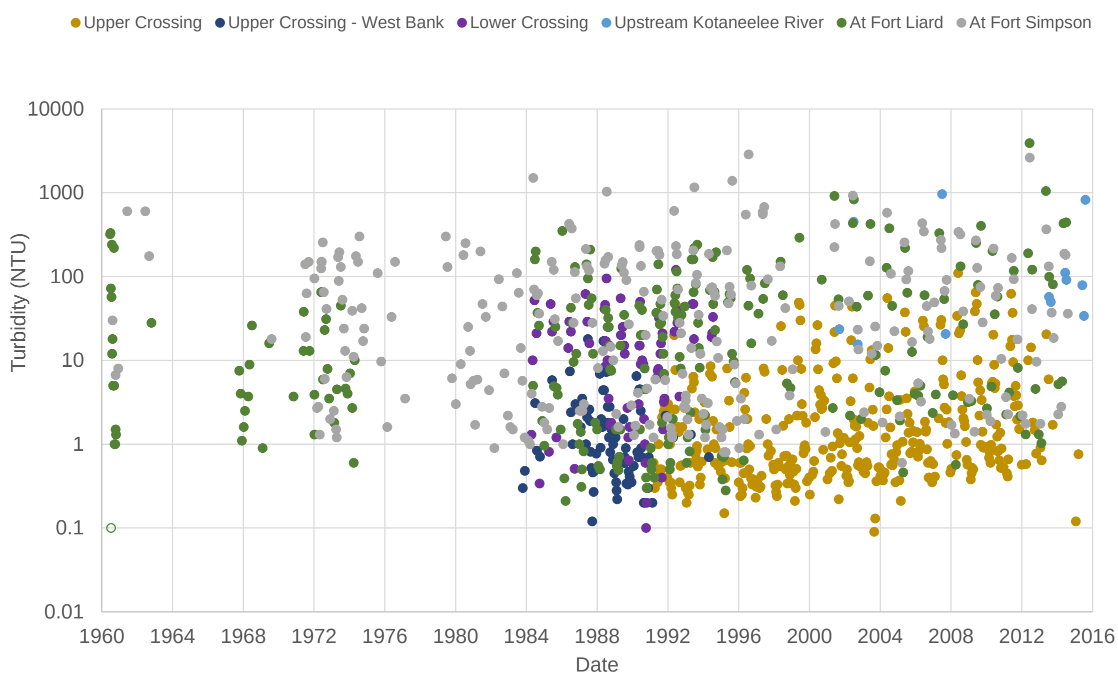



*Figure 34: Turbidity in the Liard River, 1968 to 2015*

Seasonal patterns in turbidity and concentrations of TSS were observed in the Liard River. Maximum turbidity and concentrations of TSS were typically observed during spring conditions (e.g., Figures 35 and 36) likely due to naturally higher flow conditions, which cause increased erosion within the river and higher surface runoff loads of TSS. The seasonal patterns identified for TSS are consistent with those seasonal patterns identified in Taylor et al. (1998).

Turbidity and concentrations of TSS have not consistently been measured at all stations in the Liard River, particularly Lower Crossing and upstream of the Kotaneelee River. Routine monitoring of turbidity and TSS concentrations at all sampling stations in the Liard River is recommended to evaluate trends in turbidity and TSS at all sampling locations in the Liard River. Correlations of TSS and turbidity with flows are recommended to confirm the observed causes of higher TSS concentrations and turbidity during spring conditions.

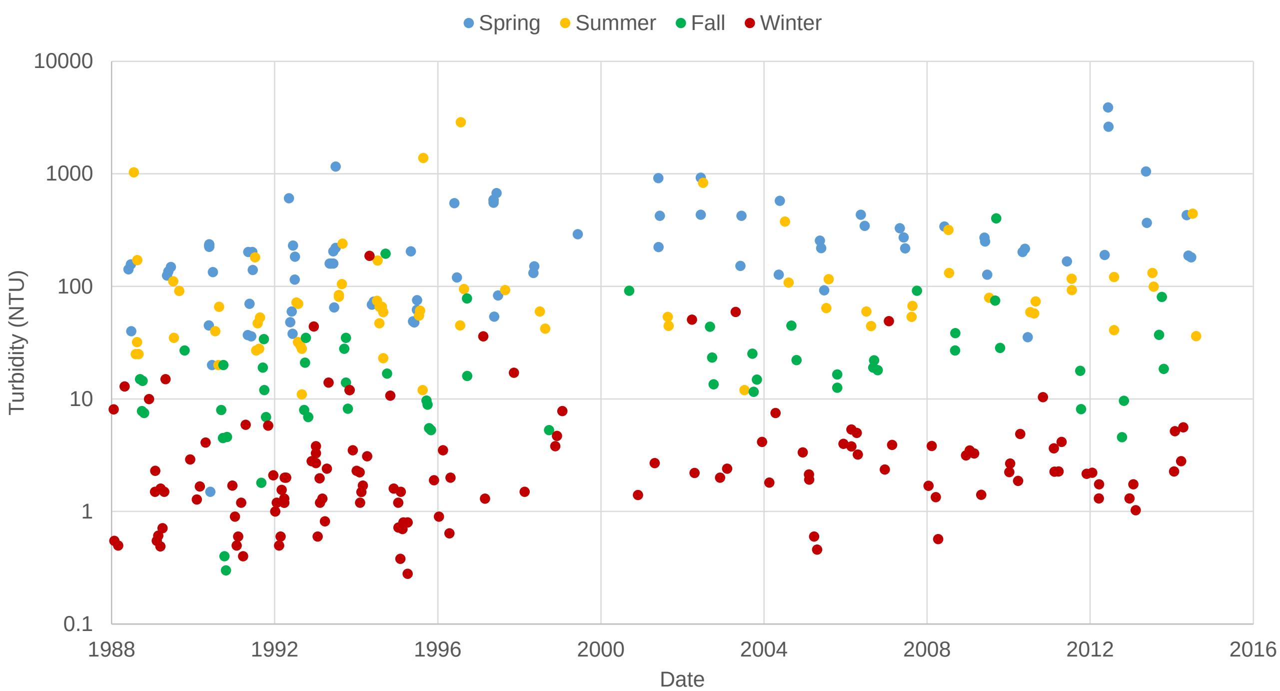



*Figure 35: Seasonal Turbidity Values in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

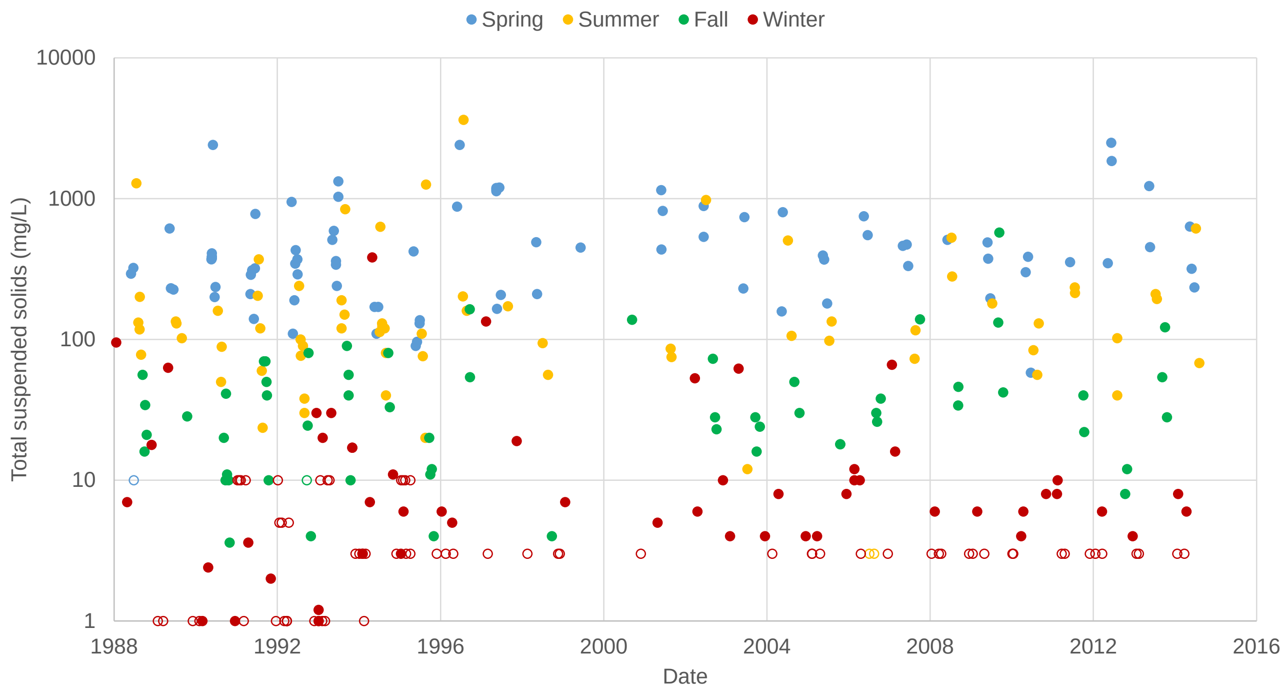



*Figure 36: Seasonal Total Suspended Solids Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

### 5.2.3.6 Organic Carbon

Total organic carbon (TOC) is comprised of particulate and dissolved organic carbon (DOC). Natural waters can have concentrations that vary from 1 to 30 mg/L (McNeely et al. 1979). Naturally occurring “brown water” lakes and ponds, which are common in boreal forest areas, generally have higher TOC concentrations. Most TOC is derived from humic substances and partly degraded plant and animal materials. In this report, TOC is characterized by the following concentrations:

- Low: less than 5 mg/L;
- Moderate: between 5 and 20 mg/L; and
- High: greater than 20 mg/L.

Water in the Liard River had low concentrations of TOC based on the median concentration of TOC measured at each station; however the upper range of TOC concentrations indicated high concentrations of TOC (Table 27). Clear temporal trends in concentrations of TOC in the Liard River were not observed (Figure 37). Seasonal patterns in TOC were observed in the Liard River; maximum concentrations of TOC were typically observed during spring conditions (Figure 38), likely due to high flow conditions which carry higher loads of TSS.

Concentrations of total organic carbon have not been measured in the Liard River since 2008; routine monitoring of TOC concentrations should recommence at all sampling locations in the Liard River.

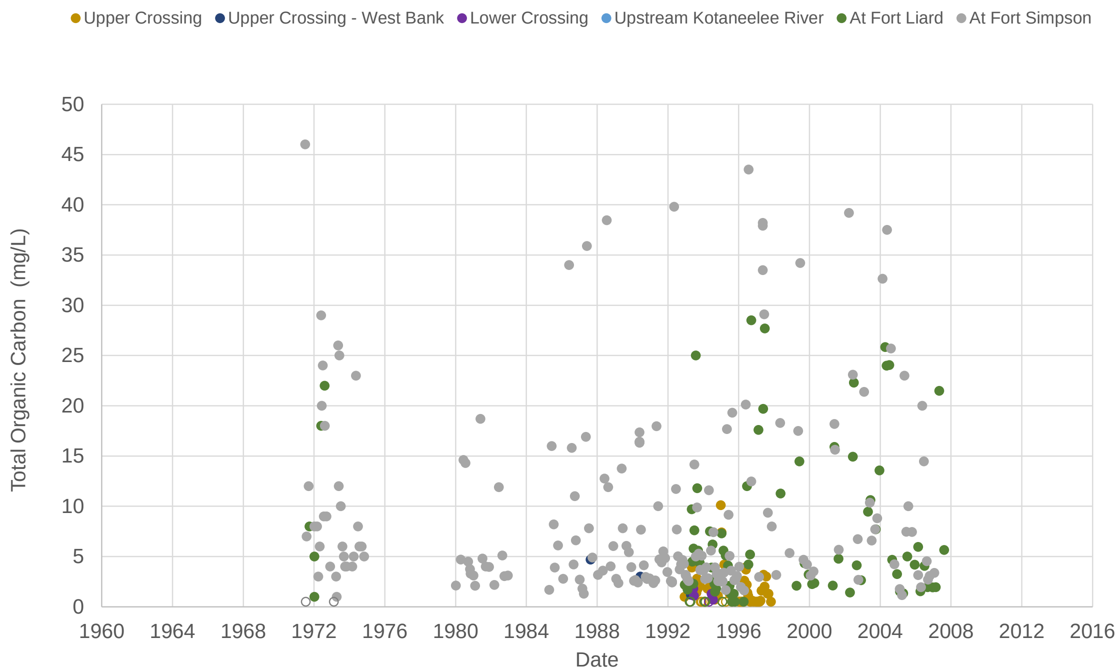



*Figure 37: Concentrations of Total Organic Carbon in the Liard River, 1971 to 2008*

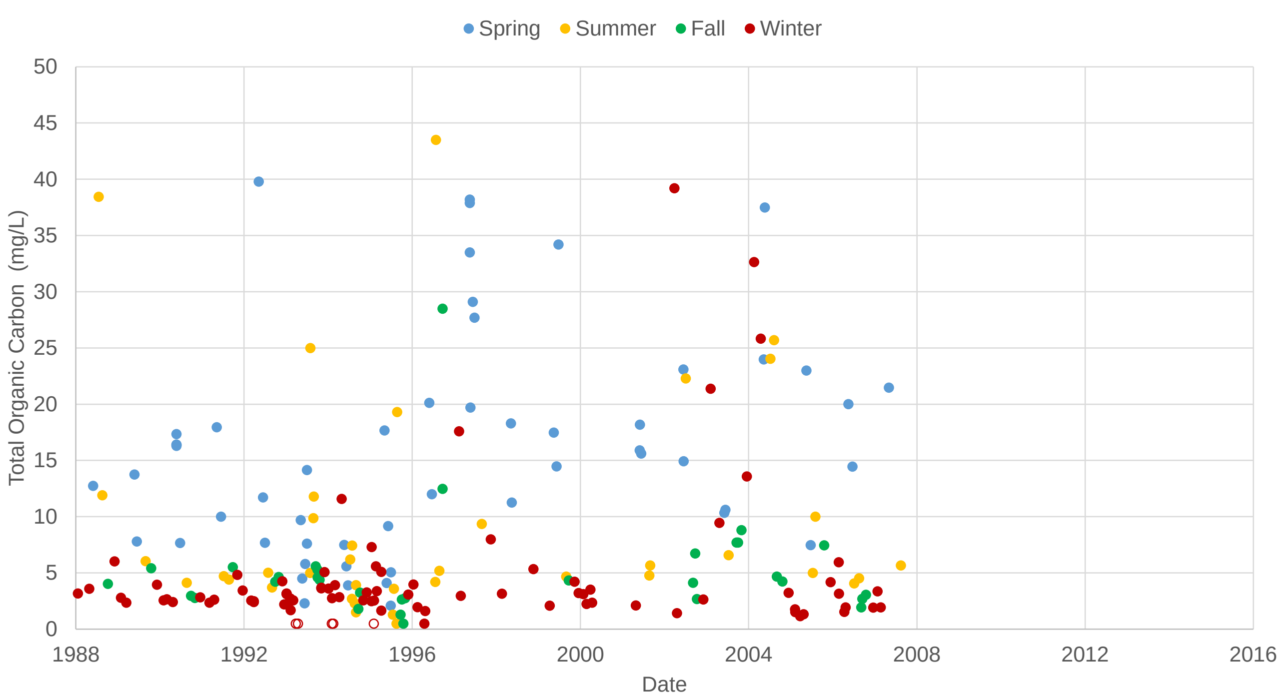



*Figure 38: Seasonal Total Organic Carbon Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2008*

### 5.2.3.7 Nutrients

The main nutrients of concern in most surface waters are nitrogen and phosphorus. Both are required for plant growth in small amounts. Total nitrogen is the sum of all forms of nitrogen, including TKN (which is a measure of ammonia and organic nitrogen in water), nitrate, and nitrite. The TKN concentrations in rivers that are not influenced by excessive organic inputs typically range from 0.1 to 0.5 mg/L (McNeely et al. 1979). Naturally occurring nitrate levels in Canadian lakes and rivers rarely exceed 1 mg/L (as N) and are typically below 0.01 mg/L (as N) in oligotrophic streams (CCME 1999). In this report, TN is characterized by the following concentrations:

- Low: less than 0.1 mg/L;
- Moderate: between 0.1 and 0.5 mg/L; and
- High: greater than 0.5 mg/L.

The speciation of nitrogen in water to different redox states, such as ammonia, nitrate, and nitrite, depend on multiple factors such as temperature, pH, dissolved oxygen, and the presence of nitrifying/denitrifying bacteria. The toxicity of nitrogen increases when conditions favour the conversion to nitrite under low pH conditions or unionized ammonia under high pH conditions. In most freshwater systems, nitrate is the dominant form of soluble inorganic nitrogen in the water. It is a highly soluble and non-particle reactive anion compound. Nitrate in aquatic ecosystems may be produced from nitrification of reduced nitrogen species or removed by denitrification and assimilated into the aquatic biomass. Municipal wastewater discharges and agriculture runoff (containing manure and/or fertilizers) are common sources of nitrogen loading to rivers.

Phosphorus in freshwater systems exists in inorganic and organic compounds and in both particulate and dissolved forms; the latter two forms make up the total phosphorus (TP) content of the water (BC MOE 1998). Dissolved phosphorus is a measure of the amount of phosphorus that will pass through a 0.45 µm porosity filter and is the fraction that is most readily bioavailable for plant growth.

Phosphorus is found in soils, plants, and microorganisms in a number of organic and inorganic forms. In natural waters, phosphorus is likely to be present as phosphate anions, complexes with metal ions, and colloidal particulate matters. The major natural source of phosphorus to the aquatic environment is through the weathering of phosphorus-bearing rock (Glozier et al. 2010), which can be chemically and biologically transformed to the bioavailable form of phosphorus: phosphate. Effluent from municipal (i.e., human waste and detergents) and industrial wastewater, as well as runoff from agricultural areas (e.g., manure and fertilizers), are the largest non-natural sources of phosphorus to the environment (BC MOE 1998).

Phosphorus is not commonly toxic to humans, animals or fish (McNeely et al. 1979); however, increases in phosphorus can result in adverse impacts to aquatic systems. Biological productivity of waterbodies and watercourses can be described in terms of trophic classification, especially in the context of the concentration of total phosphorus (Table 30). The trophic status is determined by the amount of available nutrients. Phosphorus is frequently the limiting nutrient (i.e., the nutrient in shortest supply); therefore, increased input of phosphorus to freshwater systems can cause excessive algal growth and eutrophication (BC MOE 1998). Excessive algal growth and eutrophication can result in decreases in concentrations of dissolved oxygen that are harmful to fish and other aquatic life.

**Table 30: Total Phosphorus Trigger Ranges for Canadian Lakes and Rivers**

| Trophic Status | Trigger Ranges (mg/L)[(a)] |
|---|---|
| Ultra-oligotrophic (very nutrient-poor) | <0.004 |
| Oligotrophic (nutrient-poor) | 0.004 to 0.01 |
| Mesotrophic (containing a moderate level of nutrients) | 0.01 to 0.02 |
| Meso-eutrophic (containing moderate to high level of nutrients) | 0.02 to 0.035 |
| Eutrophic (nutrient rich) | 0.035 to 0.1 |
| Hypereutrophic (very nutrient rich) | >0.1 |

a) CCME (2004).

Concentrations of nitrogen nutrients were moderate at all stations in the Liard River and below water quality guidelines, with the exception of nitrite (Table 27). Individual nitrite concentrations were occasionally above BC MOE's average guideline for the protection of aquatic life at Fort Liard and Fort Simpson (i.e., in less than 5% of samples); however, median nitrite concentrations remained below all guidelines at all stations in the Liard River. No clear temporal trends in concentrations of nitrogen and phosphorus parameters were observed in the Liard River (Figures 39 to 43). However, the presence or absence of temporal trends was more difficult to identify for some nutrients, particularly nitrite, ammonia, and dissolved phosphorus, due to inconsistent detection limits and limited data (Figures 40, 41 and 43).

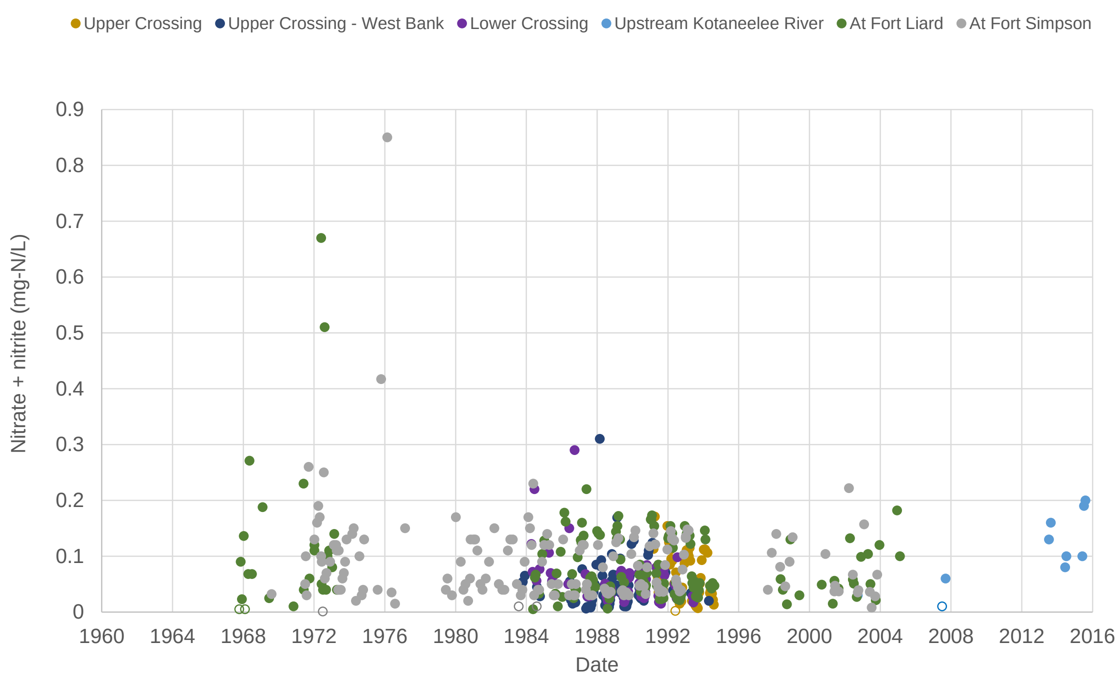
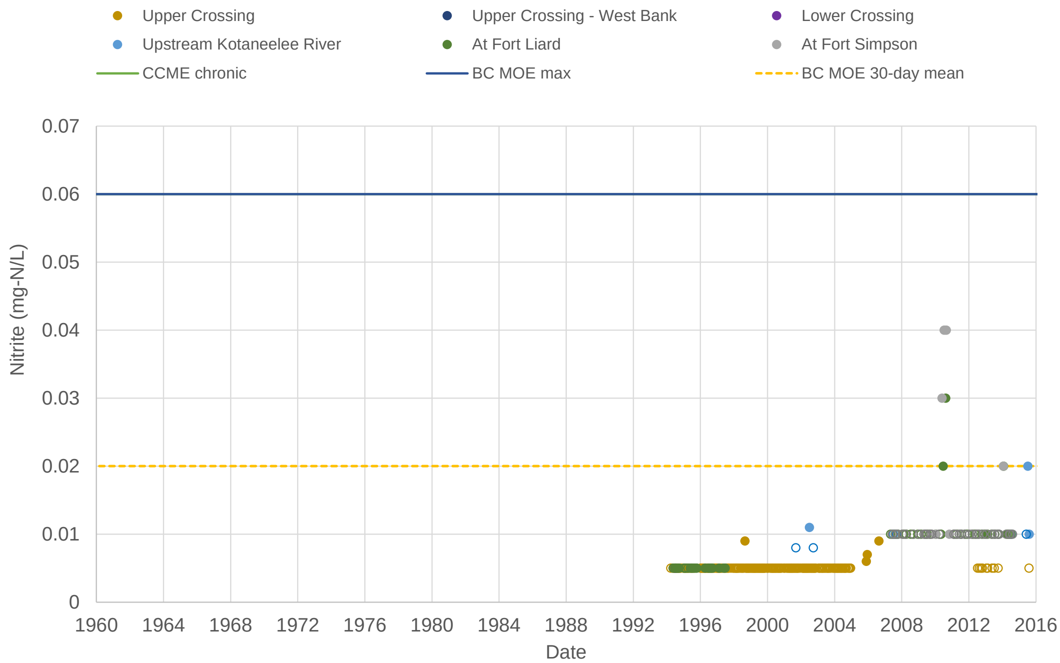



*Figure 39: Concentrations of Nitrate + Nitrite in the Liard River, 1968 to 2015*

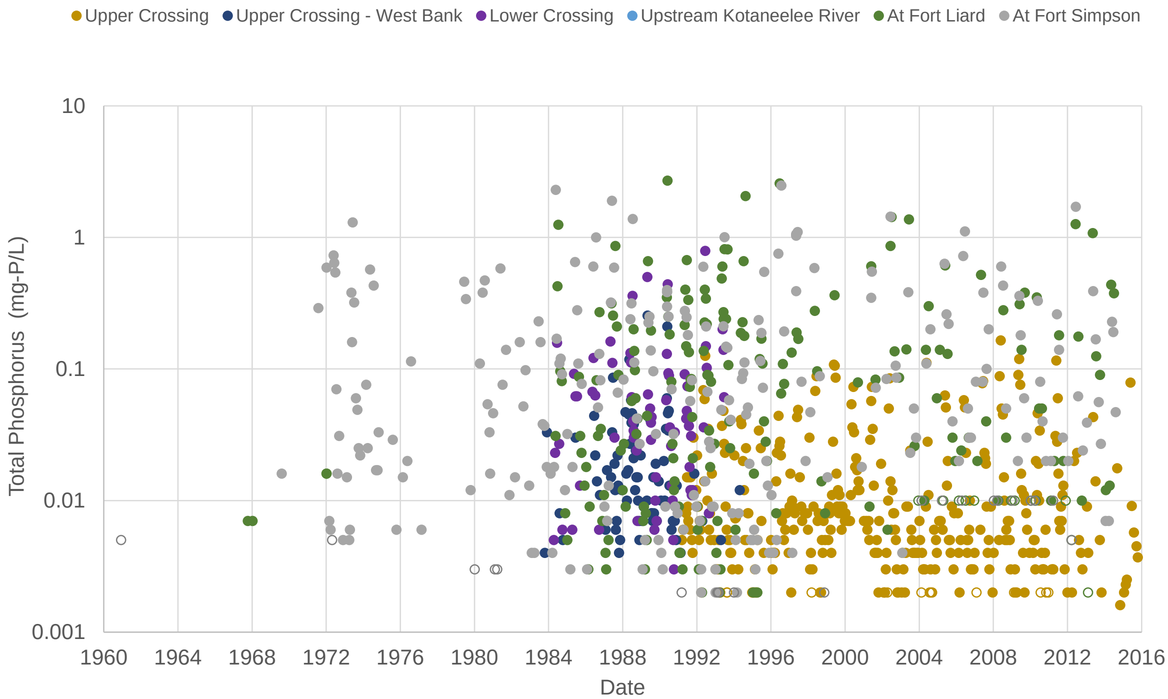



Notes: For the purposes of visually reviewing the data, the drinking water guideline (1 mg/L) is not shown and two data points were removed: 1.2 and 1.3 mg/L at Fort Simpson on June 3 and July 10, 2008, respectively. The CCME chronic guideline is the same as the BC MOE's maximum guideline.

*Figure 40: Concentrations of Nitrite in the Liard River, 1994 to 2015*


Note: For the purposes of visually reviewing the data, BC MOE's maximum guideline (4.8 *mg*/L) is not shown.

*Figure 41: Concentrations of Total Ammonia in the Liard River, 1960 to 2015*




Note: For the purposes of visually reviewing the data, one data point was removed: 0.0003 mg/L at Fort Liard on February 14, 1994.

*Figure 42: Concentrations of Total Phosphorus in the Liard River, 1994 to 2015*

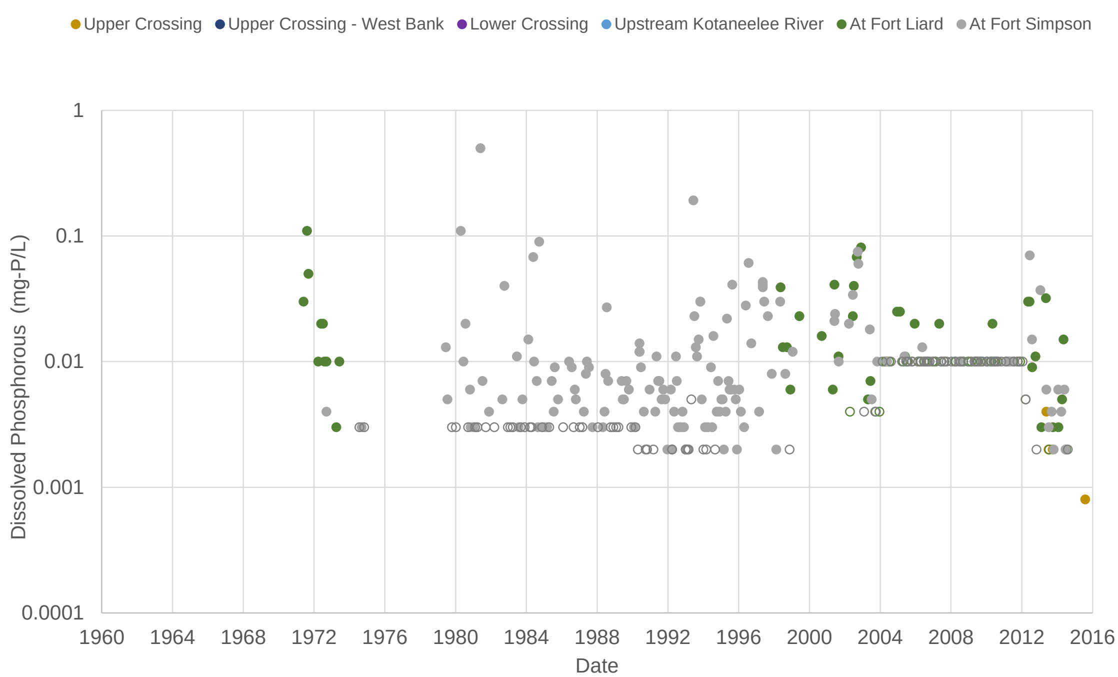



*Figure 43: Concentrations of Dissolved Phosphorus in the Liard River, 1994 to 2015*

Median concentrations of nitrate+nitrite, nitrite, and total nitrogen, increased from upstream to downstream stations (from upstream: 0.044, <0.005, and 0.13 mg/L to downstream 0.067, <0.01, and 0.25 mg/L, respectively) (Table 27). The observed spatial variation in nitrite concentrations was slight; nitrite is less stable than other forms of nitrogen and therefore concentrations are generally low in the Liard River. Spatial patterns in total ammonia concentrations were not evaluated due to data limitations (i.e., total ammonia data were only available at downstream stations, with the exception of two results from the Upper Crossing station).

The trophic status of the Liard River shifted from oligotrophic at the upstream station (median total phosphorus concentration was 0.007 mg/L) to eutrophic at the downstream stations (median total phosphorus concentrations ranged from 0.044 to 0.059 mg/L). The higher total phosphorus concentrations with distance downstream is likely related to the increases in downstream TSS concentrations; median dissolved phosphorus concentrations remained relatively low in the Liard River (<0.002 mg/L to 0.006 mg/L). Therefore, although downstream total phosphorus concentrations increased to the range of potentially eutrophic conditions, the amount of phosphorus that is likely to be biologically available remains low throughout the Liard River.

Concentrations of total nitrogen and total phosphorus were generally highest during spring and lowest during winter (e.g., Figures 44 to 47), consistent with the seasonal patterns observed for TSS concentrations. The low concentrations of nitrite and total ammonia in the Liard River made it difficult to discern a clear seasonal pattern in the concentrations of these two nitrogen parameters (Figures 48 and 49).

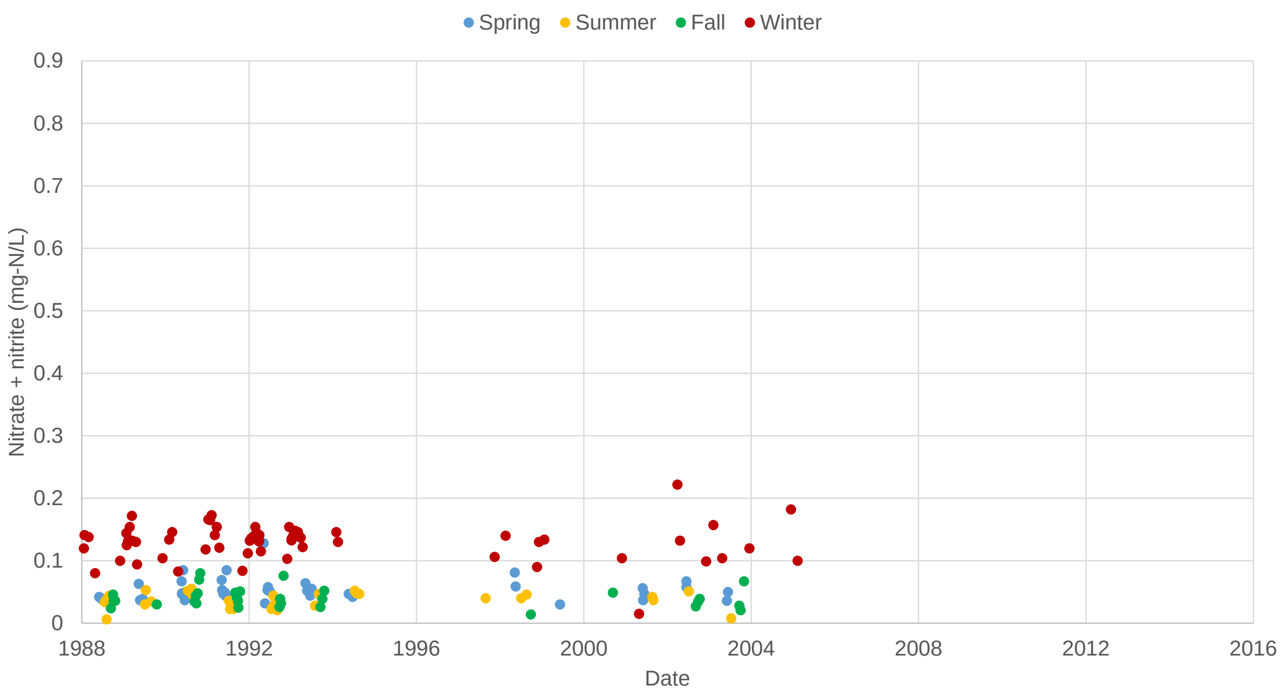



*Figure 44: Seasonal Nitrate+Nitrite Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2005*

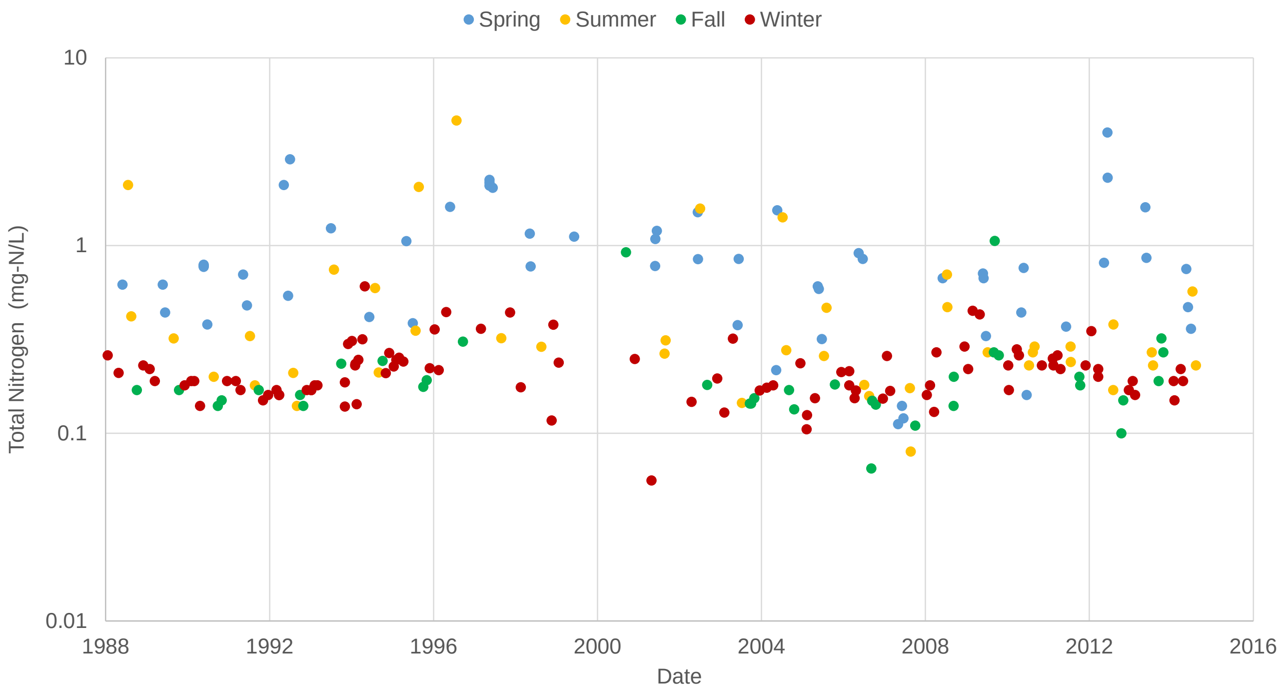



*Figure 45: Seasonal Total Nitrogen Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

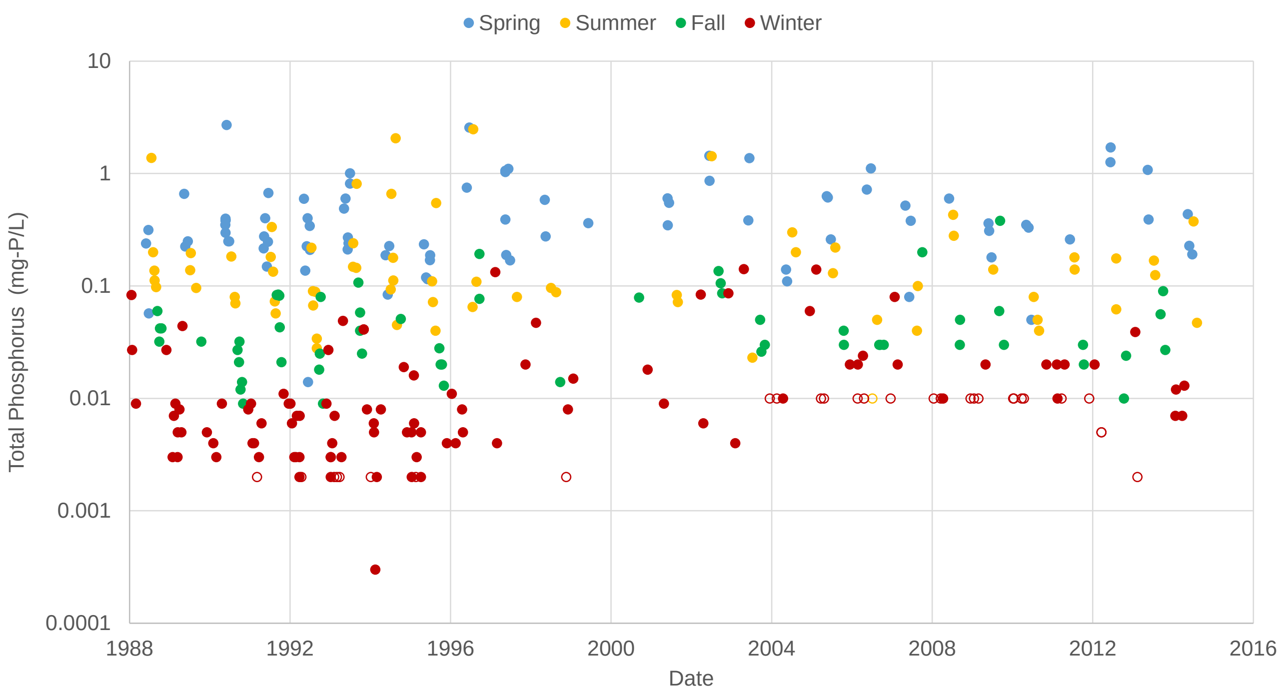



*Figure 46: Seasonal Total Phosphorus Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

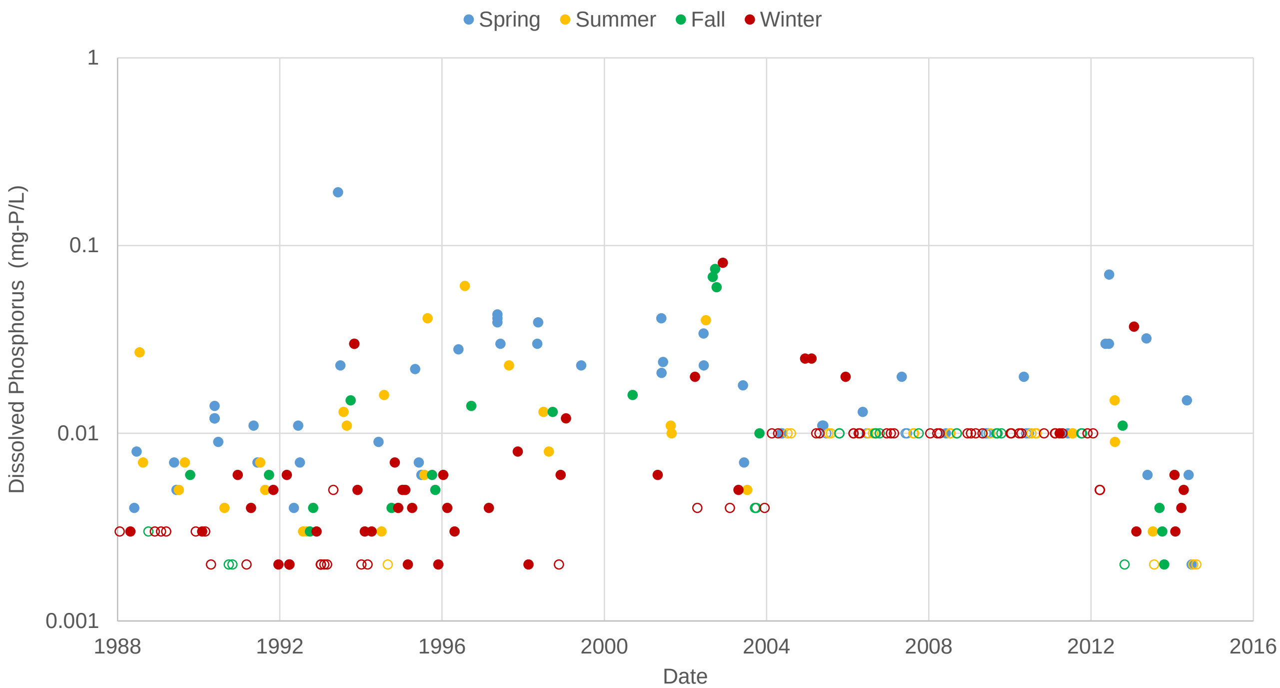



*Figure 47: Seasonal Dissolved Phosphorus Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

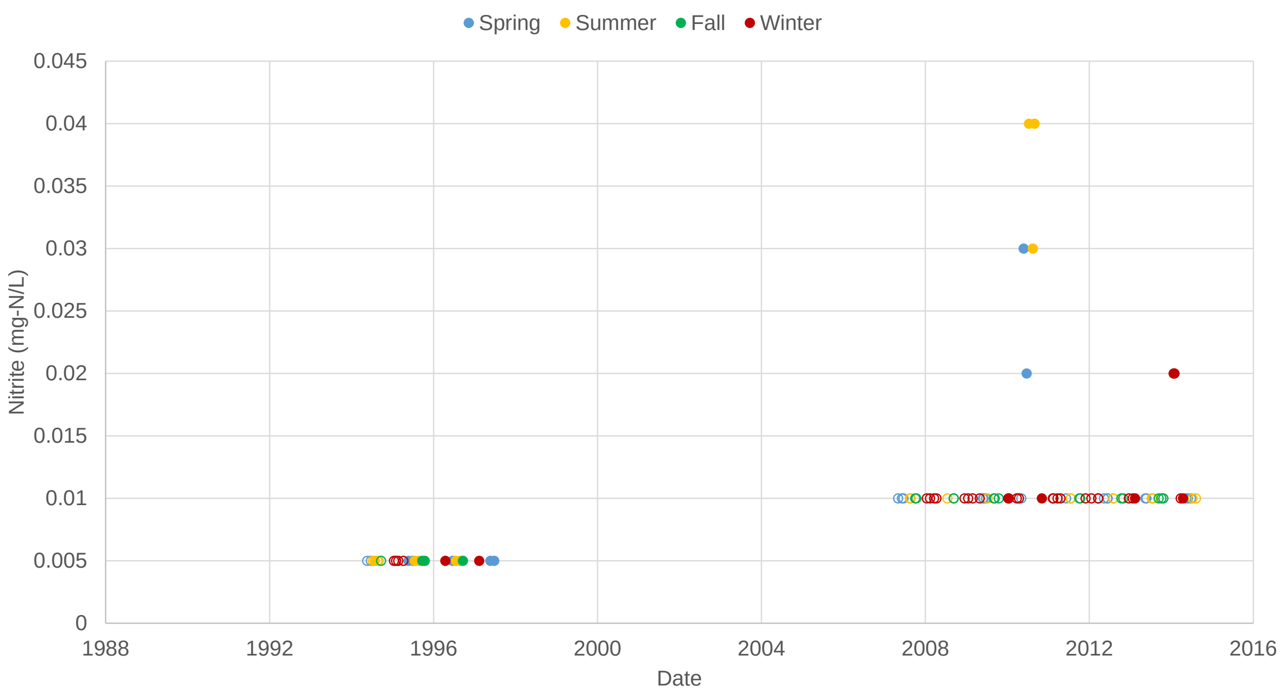



*Figure 48: Seasonal Nitrite Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1993 to 2015*

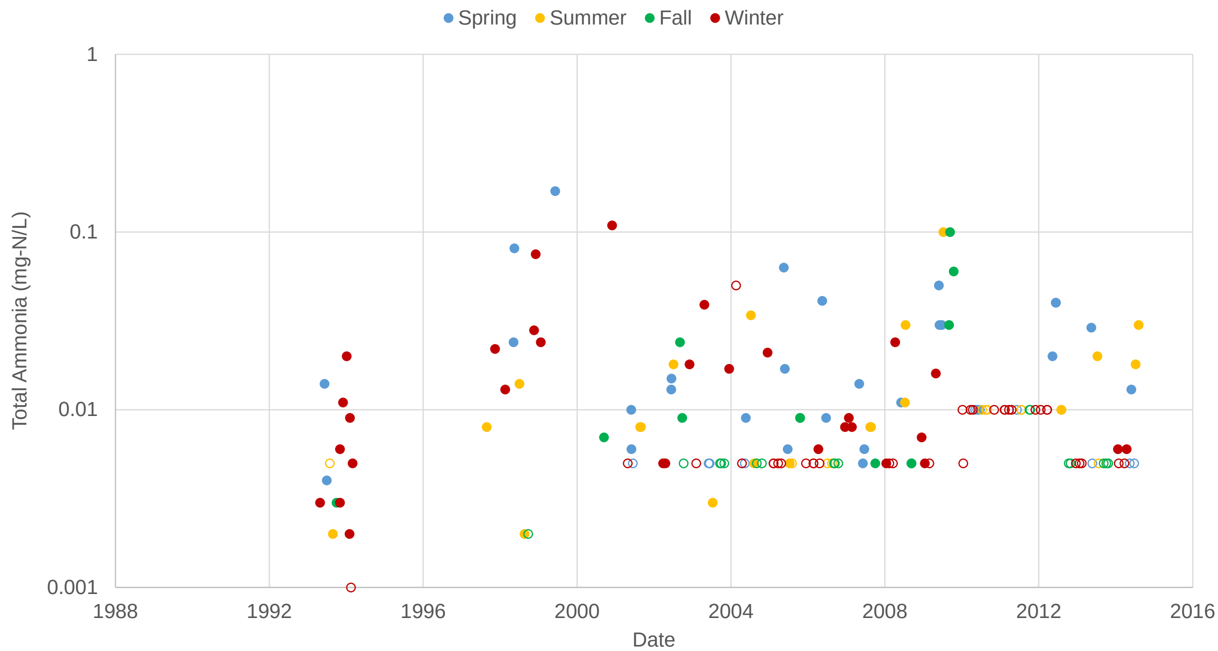



*Figure 49: Seasonal Total Ammonia Concentrations in the Liard River downstream stations (Fort Liard and Fort Simpson), 1993 to 2015*

The nutrient parameters monitored in the Liard River have differed between stations and over time. Routine monitoring of TKN, nitrate+nitrite, nitrite, total phosphorus, and dissolved phosphorus concentrations at consistent detection limits at all sampling stations in the Liard River is recommended. Additionally, the collection of field measurements of dissolved oxygen is recommended at all sampling locations in the Liard River; continuous measurements of dissolved oxygen are recommended to capture diurnal fluctuations in concentrations of dissolved oxygen. Correlations of total phosphorus and TSS are also recommended to confirm a relationship between total phosphorus and TSS concentrations.

### 5.2.3.8 Metals

Metals naturally occur in surface waters in small quantities (i.e., usually at concentrations below 1 mg/L for clear flowing waters); higher concentrations of metals are typical of sediment-laden rivers such as the Liard River. Aquatic organisms can show effects associated with high metal concentrations; however, the level at which metals are toxic varies by metal. The toxicity of some metals is also dependent on toxicity modifying factors, such as the hardness of the water; as hardness increases, toxicity of certain metals decreases. Often metals are associated with TSS and therefore tend to settle out of the water column, rendering them biologically unavailable. In this report, metal concentrations are discussed relative to aquatic life and drinking water guidelines.

Concentrations of total metals in the Liard River were often high relative to water quality guidelines; guideline exceedances were observed at every monitoring station for a variety of metals. Median concentrations of total aluminum, beryllium, cadmium, chromium, copper, and iron were above guidelines at one or more monitoring stations (Table 27; Appendix B, Table B1). Concentrations of 15 total metals (i.e., aluminum, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, selenium, silver, zinc) exceeded guidelines in one or more samples. Occasional exceedances of metals guidelines are typical of many freshwater systems, and are more likely to occur in sediment-laden rivers such as the Liard River.

A summary of total metal concentrations that exceeded relevant guidelines were:

- Median concentrations of total aluminum, beryllium, cadmium, chromium, copper, iron, and selenium above the CCME chronic or BC MOE's average guidelines for the protection of aquatic life at one or more stations;
- Maximum concentrations of total cadmium, copper, iron, lead, and zinc above the CCME acute or BC MOE's maximum guidelines for the protection of aquatic life at one or more stations; and
- Maximum concentrations of total aluminum, antimony, arsenic, barium, cadmium, chromium, and lead above drinking water guidelines at one or more stations.

Based on the high TSS concentrations measured in the Liard River, a large fraction of these total metals are likely adsorbed to TSS; therefore, in this form they are not readily bio-available to aquatic organisms, and would be removed in drinking water treatment systems. Guideline exceedances for metals associated with the high TSS concentrations in the Liard River have been noted in previous reports (Taylor et al. 1998; MRBB 2004; Tri-Star 2005). Clear temporal trends were not observed for metals concentrations in the Liard River (Appendix B, Figures B2[1] to B2[17])

Concentrations of dissolved metals, which were only measured at downstream stations, were notably lower relative to their respective total fraction measured at the same stations. However, concentrations of dissolved aluminum were occasionally above the BC MOE's average and short-term maximum guidelines at all downstream stations. Concentrations of dissolved iron were generally low in the Liard River, with only one exceedance of BC MOE's maximum guideline measured at Fort Liard. Concentrations of dissolved cadmium were below the BC MOE's water quality guideline at all the monitoring stations.

Additional assessment of the relevance of the observed metal guideline exceedances to human health and aquatic biota are provided in Appendix D.

Median concentrations of most metals measured at downstream stations were higher relative to median concentrations at upstream stations. The increased metals concentrations with distance downstream are likely due to the higher TSS concentrations at the downstream stations.

Concentrations of most total metals were highest during spring and lowest during winter (e.g., aluminum concentrations in Figure 50; Figures B1[1] to B1[17]), which was likely due to the same seasonal pattern observed in TSS concentrations as reported in Taylor et al. (1998). However, for some metals, clear seasonal patterns were not clear (e.g., total barium, molybdenum, selenium [Figure 51], and uranium) or not consistently observed at all stations. For example, higher spring total barium concentrations were only observed at downstream stations (Figure 52). These metals may be more influenced by groundwater or geochemical inputs relative to concentrations of TSS.

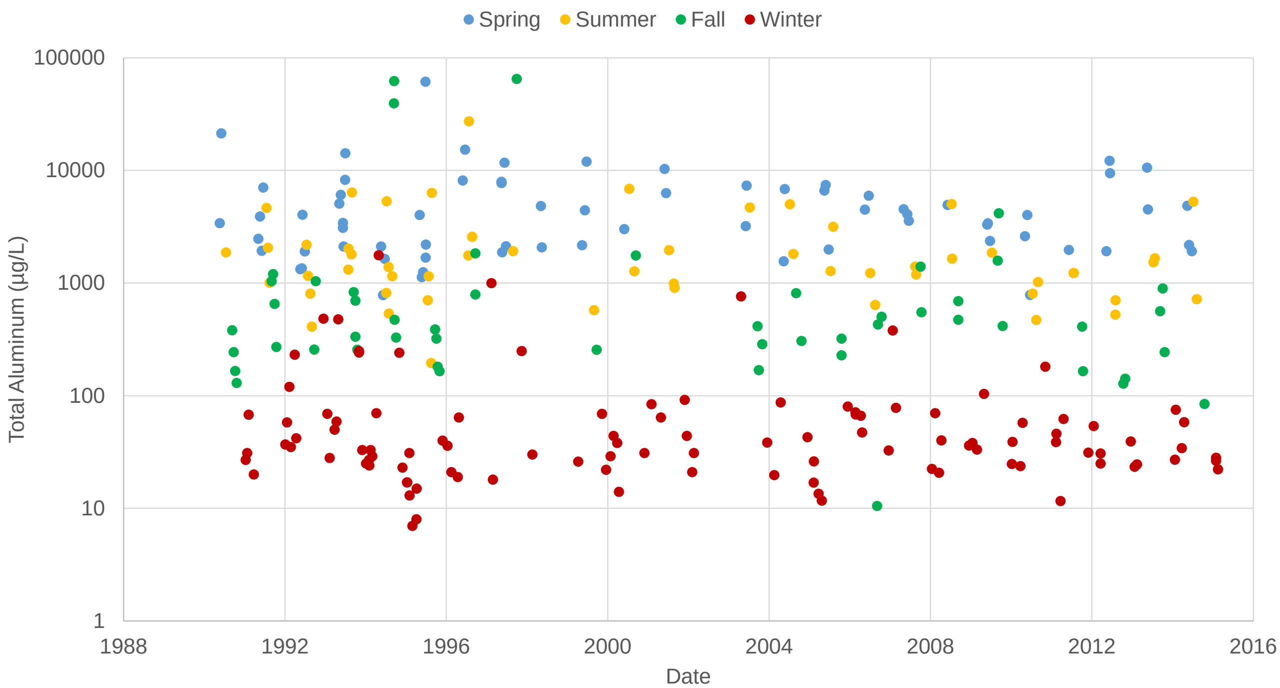



*Figure 50: Seasonal Total Aluminum Concentrations in the Liard River (Fort Liard and Fort Simpson), 1990 to 2015*

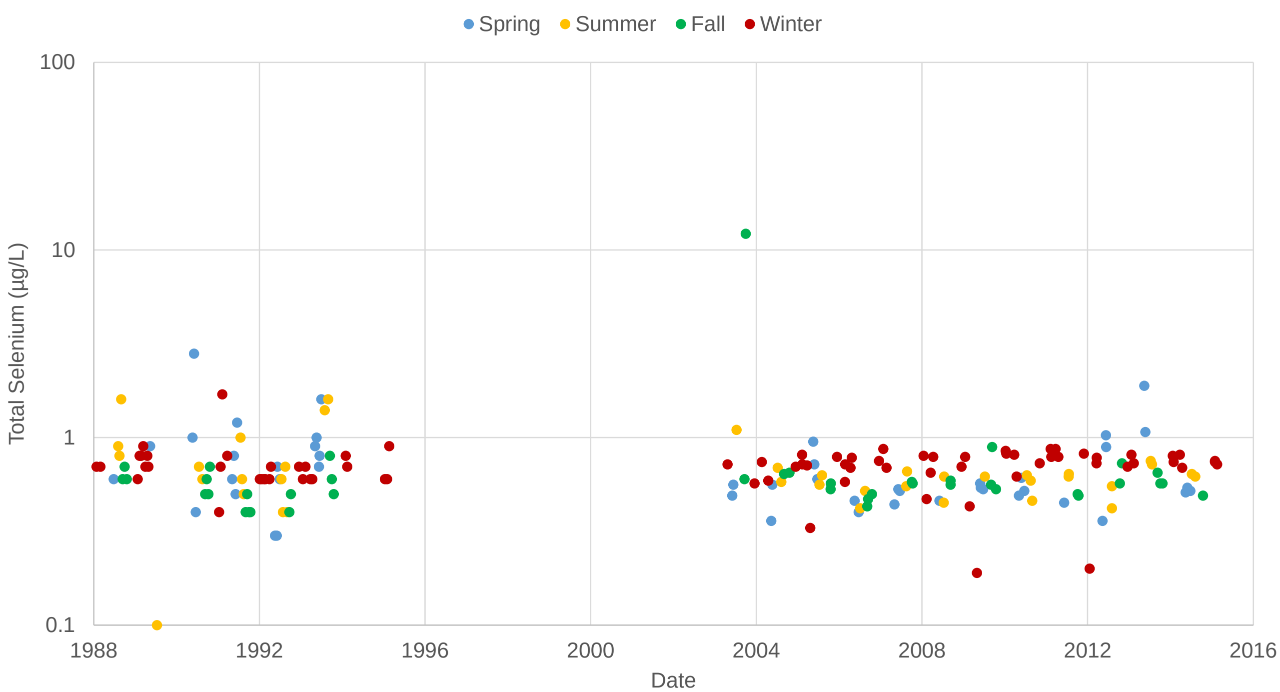



*Figure 51: Seasonal Total Selenium Concentrations in the Liard River (Fort Liard and Fort Simpson), 1988 to 2015*

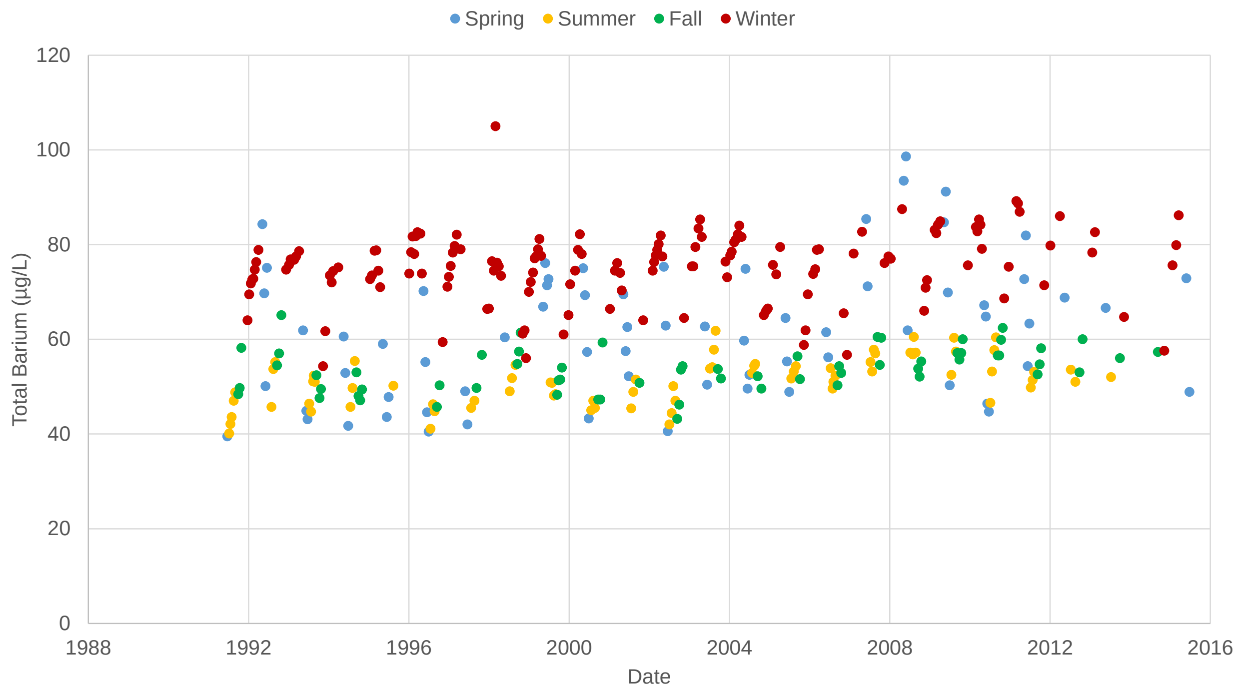



*Figure 52: Seasonal Total Barium Concentrations in the Liard River (Upper Crossing), 1991 to 2015*

Total and dissolved metals have not consistently been measured at all stations in the Liard River. Routine monitoring of total and dissolved metals concentrations at consistent detection limits at all sampling stations in the Liard River is recommended. Correlations of metals and TSS are recommended to confirm a relationship between metals and TSS concentrations.

### 5.2.3.9 Organic Compounds and Pesticides

Organic compounds (organics) include chemicals consisting of chains or rings of carbon atoms, such as herbicides, solvents, hydrocarbons, phenols, polycyclic aromatic hydrocarbons (PAHs), and other petroleum products. Polycyclic aromatic hydrocarbons are a group of organic compounds that contain two or more benzene rings in their structure (CCME 1999). These compounds may originate from natural sources (e.g., forest fires) and inhabited areas (solvents, coolants), or may be released from industrial sources (e.g., vehicle exhaust, wastewater discharges); anthropogenic sources of PAHs are typically higher than natural sources (Blumer 1976). Guidelines for PAHs have been developed for aquatic life and drinking water.

Pesticides are beneficial in controlling weeds, insects, fungus, or other organisms but can be unintentionally released into natural waterbodies through surface runoff from agriculture or urban areas. Examples of pesticides include organochloride compounds, cholinesterase inhibitors, organophosphorus compounds, and carbamates (Stephensen and Solomon 1993). Pesticides are synthetic compounds and therefore the natural background concentrations of pesticides in waterbodies are expected to be zero.

Elevated concentrations of PAHs and pesticides may be harmful to aquatic organisms; however, toxicity, persistence, degradation and fate varies widely by chemical. In this report, concentrations of PAHs and pesticides are discussed in terms of which substances are detectable in the Liard River and how concentrations compare to relevant aquatic life and drinking water guidelines.

Concentrations of pesticides and PAHs were measured in the samples collected from the Liard River upstream of Kotaneelee River, Fort Liard, and Fort Simpson. Pesticides were not detected in any of the water samples collected from these three stations (Table B-1).

Measureable median and maximum concentrations of PAHs in grab samples from the Liard River at Fort Liard and Fort Simpson were reported for chrysene, fluoranthene, fluorene, naphthalene, and perylene (Table 27). Concentrations of PAHs at downstream stations in the Liard River were below guidelines, with some exceptions. Maximum concentrations of anthracene, fluoranthene, and pyrene at the Fort Liard or Fort Simpson stations were above the CCME chronic and/or BC MOE's average guidelines for the protection of aquatic life; however, median concentrations of all PAHs remained below guidelines. The guidelines for PAHs are based on chronic exposure; therefore, concentrations that occasionally exceed the chronic guideline are not likely to be harmful to aquatic biota.

Organics were sampled more intensively in the Liard River upstream of the Kotaneelee River; guideline exceedances were not found for PAHs or pesticides in any of the centrifugate water samples collected from this station. Concentrations of PAHs measured in centrifugate samples collected in the Liard River upstream of the Kotaneelee River are not directly comparable to those concentrations measured in grab samples at Fort Liard and Fort Simpson due to sample collection differences. Higher concentrations of sediment in grab samples relative to centrifugate samples may have contributed to differences in concentrations of organics. Measureable median and maximum concentrations of PAHs in the Liard River upstream of Kotaneelee River were reported for chrysene, fluoranthene, fluorene, naphthalene, perylene, phenanthrene, and pyrene; this list is similar to the list of PAHs detected at median concentrations at Fort Liard and Fort Simpson.

Clear temporal trends were not identified for PAHs in the Liard River (Figures B2[18] to B2[23]; insufficient data were available to review seasonal patterns in PAH concentrations.

The measurement of pesticides and PAHs in the Liard River has been inconsistent; different collection methods (i.e., passive samplers, grab samples and centrifugate samples) and different detection limits limit the ability to compare results for temporal trends or spatial patterns. Routine monitoring for pesticides and PAHs, using a consistent method and detection limits, is recommended at select locations, such as upstream of the Kotaneelee River, where historical data exists, and at one or two downstream locations (i.e., Fort Liard and Fort Simpson).

### *5.2.3.10 Characterization of Water Quality in the Liard River*

Water quality in the Liard River has high pH and moderate levels of specific conductivity and concentrations of TDS. Alkalinity measured in the Liard River indicates that the river is not sensitive to effects of acidification. Concentrations of TDS and related parameters (i.e., specific conductivity, alkalinity, and major ions) were typically higher during the winter, when the proportion of groundwater with higher TDS concentrations in the river flow is higher, and ice exclusion may occur; concentration of TDS and related parameters were typically lower during the spring during freshet. Turbidity levels and concentrations of TSS in the Liard River ranged from low to high; lower reaches of the river were highly turbid during spring conditions when higher flows and runoff cause more sediment load to enter the river. A slight increase in turbidity levels in the upper reaches (Upstream Crossing) was observed between 1992 and 2014 but an increase in TSS concentrations at this location or turbidity levels or TSS concentrations at other locations were not observed. Concentrations of major ions and nitrogen parameters were typically below guidelines for aquatic life and drinking water. Total phosphorus concentrations in the Liard River indicates oligotrophic conditions in upstream reaches and the potential for eutrophic conditions in downstream reaches; however, the more biologically available form of phosphorus (i.e., dissolved phosphorus) remained low throughout the river, suggesting a strong correlation between TSS and phosphorus during seasonal flow events. Metal concentrations were frequently above water quality guidelines for aquatic life and drinking water. The guideline exceedances for metals are generally associated with periods of high TSS concentrations observed in the Liard River indicating that much of the metal concentrations are not bio-available, and therefore do not necessarily indicate toxic effects to aquatic biota. Concentrations of pesticides and PAHs were generally lower in the Liard River and typically below water quality guidelines. Increasing trends in water quality concentrations, with the exception of turbidity levels at one upstream location, were not observed. Additional assessment of water quality related risks to human health and aquatic biota for the Liard River is provided in Appendix D.

### 5.2.4 Petitot River Water Chemistry Results and Discussion

Summarized water quality data for Petitot River and Fortune Creek, collected between 2013 and 2015, are provided in Table 31. Time series plots of selected parameters are presented in Appendix B, Figures B3[1] to B3[14]). The water quality data from the Petitot River and Fortune Creek were limited to three years of mostly open-water monitoring; therefore, the evaluation of data was limited to a general characterization of water quality in these watercourses.

**Table 31: Summary of Water Quality in the Petitot River and Fortune Creek, 2013 to 2015**

| Parameter | Unit | Petitot River Downstream of Tsea River | | | | Fortune Creek Upstream of Petitot River | | | | Petitot River Downstream of Highway No. 77 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2013-2015 | | | | | | | | | | | |
| | | Min | Median | Max | Count | Min | Median | Max | Count | Min | Median | Max | Count |
| **Field Measured** | | | | | | | | | | | | | |
| pH | - | 7.3 | - | 8.2 | 2 | 7.7 | 8.0 | 8.1 | 5 | - | 7.3 | - | 1 |
| Specific conductivity | µS/cm | 247 | - | 310 | 2 | 192 | 208 | 224 | 4 | - | 337 | - | 1 |
| Temperature | °C | 0 | 8.2 | 22 | 14 | 0 | 7.1 | 18 | 13 | 0 | 12.4 | 19.5 | 12 |
| **Conventional Parameters** | | | | | | | | | | | | | |
| pH | - | 7.5 | 7.9 | 8.1 | 12 | 7.5 | 7.9 | 8.0 | 13 | - | 7.3 | - | 1 |
| Specific conductivity | µS/cm | 169 | 239 | 322 | 14 | 82 | 196 | 226 | 13 | - | 337 | - | 1 |
| Hardness, as $CaCO_3$ | mg/L | 76 | 118 | 158 | 14 | 39 | 97 | 116 | 13 | 66 | 128 | 173 | 13 |
| Total alkalinity, as $CaCO_3$ | mg/L | 55 | 90 | 122 | 14 | 29 | 73 | 91 | 13 | 53 | 101 | 136 | 13 |
| Total dissolved solids | mg/L | 124 | 164 | 222 | 14 | 88 | 144 | 218 | 13 | 128 | 186 | 260 | 13 |
| Total suspended solids | mg/L | 1.6 | 4.5 | 243 | 14 | <1.0 | <2.0 | 55 | 13 | 1.3 | 4.8 | 42 | 13 |
| Dissolved organic carbon | mg/L | 13 | 18 | 22 | 12 | 17 | 24 | 27 | 13 | 0.82 | 18 | 24 | 13 |
| Colour | TCU | 30 | 65 | 80 | 10 | 60 | 100 | 198 | 11 | 30 | 80 | 100 | 11 |
| Turbidity | NTU | 2.3 | 5.1 | 22 | 11 | 1.2 | 3.3 | 13 | 11 | 2.1 | 5.7 | 10 | 11 |
| Bromide, extractable | mg/L | 0.01 | 0.01 | 0.013 | 7 | 0.01 | 0.01 | 0.012 | 7 | 0.01 | 0.013 | 0.016 | 8 |
| Dissolved inorganic carbon | mg/L | 13 | 19 | 30 | 12 | 5.8 | 15 | 22 | 13 | 11 | 23 | 33 | 13 |
| Total carbon | mg/L | 32 | 39 | 47 | 12 | 25 | 42 | 47 | 13 | 30 | 42 | 53 | 13 |
| Total dissolved carbon | mg/L | 31 | 38 | 47 | 12 | 23 | 41 | 47 | 13 | 28 | 42 | 50 | 13 |
| Total inorganic carbon | mg/L | 12 | 19 | 30 | 12 | 5.8 | 16 | 22 | 13 | 12 | 22 | 33 | 13 |
| Total organic carbon | mg/L | 13 | 19 | 22 | 12 | 20 | 25 | 28 | 13 | 15 | 20 | 23 | 13 |
| Total solids | mg/L | 128 | 197 | 254 | 14 | 143 | 188 | 220 | 13 | 170 | 214 | 261 | 13 |
| Salinity | g/L | 0.08 | 0.11 | 0.15 | 11 | 0.04 | 0.09 | 0.11 | 12 | 0.07 | 0.12 | 0.17 | 13 |
| **Major Ions** | | | | | | | | | | | | | |
| Chloride | mg/L | 1.1 | 1.3 | 1.7 | 14 | 0.84 | 1.5 | 2.5 | 13 | 1.2 | 1.4 | 1.9 | 13 |
| Fluoride | mg/L | 0.039 | 0.069 | 0.088 | 14 | 0.033 | 0.059 | 0.09 | 13 | 0.035 | 0.07 | 0.099 | 13 |
| Sulphate | mg/L | 17 | 26 | 47 | 14 | <0.5 | 23 | 31 | 13 | 19 | 30 | 44 | 13 |
| Sulphur | mg/L | 5.9 | 10 | 16 | 14 | <3.0 | 7.8 | 11 | 13 | 5.9 | 10 | 16 | 13 |
| Calcium | mg/L | 22 | 34 | 46 | 14 | 12 | 29 | 35 | 13 | 20 | 38 | 51 | 13 |
| Magnesium | mg/L | 4.8 | 7.8 | 10 | 14 | 2.2 | 5.8 | 7.0 | 13 | 4.1 | 8.1 | 11 | 13 |
| Potassium | mg/L | 0.33 | 0.97 | 3.3 | 14 | 0.16 | 0.55 | 0.79 | 13 | 0.26 | 0.76 | 1.2 | 13 |
| Sodium | mg/L | 2.7 | 4.1 | 6.7 | 14 | 1.4 | 5.6 | 8.1 | 13 | 2.0 | 4.5 | 8.2 | 13 |
| **Nutrients and Biological Indicators** | | | | | | | | | | | | | |
| Nitrite | mg-N/L | 0.002 | 0.002 | 0.004 | 10 | 0.002 | 0.0024 | 0.02 | 13 | 0.002 | 0.002 | 0.02 | 13 |
| Nitrate + nitrite | mg-N/L | 0.004 | 0.064 | 0.47 | 8 | 0.004 | 0.016 | 0.19 | 11 | 0.005 | 0.0095 | 0.36 | 8 |
| Total ammonia | mg-N/L | 0.005 | 0.015 | 0.23 | 12 | 0.005 | 0.023 | 0.27 | 13 | 0.006 | 0.019 | 0.051 | 13 |
| Total Kjeldahl nitrogen | mg-N/L | 0.48 | 0.77 | 1.3 | 12 | 0.59 | 0.77 | 0.98 | 13 | 0.45 | 0.66 | 0.82 | 13 |
| Total dissolved nitrogen | mg-N/L | 0.59 | 0.7 | 1.2 | 12 | 0.6 | 0.8 | 1.2 | 13 | 0.59 | 0.67 | 1.1 | 13 |
| Dissolved phosphorus | mg-P/L | 0.0066 | 0.028 | 0.055 | 11 | 0.0083 | 0.017 | 0.044 | 10 | 0.0061 | 0.0086 | 0.067 | 11 |
| Nitrate | mg/L | 0.002 | 0.0038 | 0.46 | 10 | 0.002 | 0.0053 | 0.2 | 13 | 0.002 | 0.0033 | 0.36 | 13 |
| Dissolved Kjeldahl nitrogen | mg-N/L | 0.49 | 0.7 | 1.1 | 12 | 0.6 | 0.8 | 1.0 | 13 | 0.49 | 0.66 | 0.76 | 13 |
| Dissolved organic nitrogen | mg-N/L | 0.48 | 0.68 | 0.85 | 12 | 0.53 | 0.73 | 0.87 | 13 | 0.48 | 0.62 | 0.74 | 13 |
| Total organic nitrogen | mg-N/L | 0.47 | 0.76 | 1.0 | 12 | 0.52 | 0.75 | 0.82 | 13 | 0.45 | 0.63 | 0.81 | 13 |
| Total nitrogen | mg-N/L | 0.62 | 0.81 | 1.4 | 11 | 0.59 | 0.8 | 1.2 | 12 | 0.6 | 0.67 | 1.0 | 13 |

- = no available data; < = less than.

#### 5.2.4.1 Conventional Parameters

Water in the Petitot River and Fortune Creek ranged from moderately hard to hard waters, which were not sensitive to acidification based on minimum alkalinity values. Concentrations of TSS were generally low; however, high TSS concentrations were occasionally observed in the early open-water season, which may be due to naturally higher flows during the spring. Concentrations of TOC ranged from moderate to high, with a median concentration of 20 mg/L. The Petitot River and Fortune Creek have moderate concentrations of TDS and high pH. Values of pH in the Petitot River and Fortune Creek were within aquatic life and drinking water guidelines in Petitot River.

Concentrations of TOC were lower in the Petitot River relative to Fortune Creek; higher concentrations of TDS, TSS, hardness, and alkalinity were noted in the Petitot River relative to Fortune Creek. Additional data are needed to determine whether these differences occur over a longer time period or whether they are reflecting natural variation in the limited dataset.

#### 5.2.4.2 Major Ions

Concentrations of major ions in Petitot River and Fortune Creek were below aquatic life and drinking water guidelines. Higher concentrations of sulphate, dissolved sulphur, calcium, and magnesium were observed in Petitot River relative to Fortune Creek (e.g., sulphate concentrations in Figure 53). Additional data are needed to determine whether these differences occur over a longer time period or whether they are reflecting natural variation in the limited dataset.

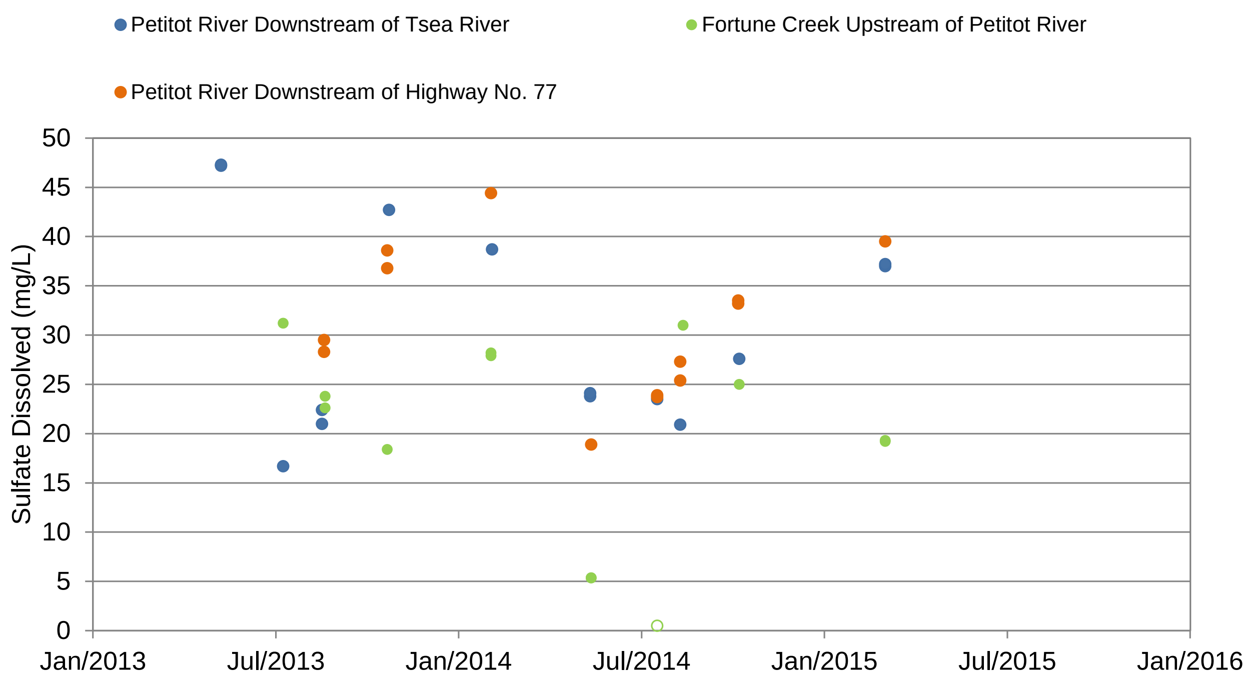



*Figure 53: Sulphate Concentrations in the Petitot River, 2013 to 2015*

### 5.2.4.3 Nutrients

Concentrations of TN measured in the Petitot River and Fortune Creek during the monitoring period of 2013 to 2015 were always above 0.5 mg/L, indicating that TN concentrations were high (Figure 54). Concentrations of ammonia, nitrate, and nitrite were relatively low and remained below guidelines. Total phosphorus concentrations were not measured so could not be used to assess the trophic status of Petitot River and Fortune Creek. However, dissolved phosphorus concentrations in the Petitot River and Fortune Creek (median ranged from 0.0086 to 0.017 mg/L) were typically higher than dissolved phosphorus concentrations in the Liard River (median ranged from <0.002 to 0.006 mg/L), indicating that the Petitot River may have a potential for eutrophic conditions similar to the downstream reaches of the Liard River (based on the ratio of total phosphorus to dissolved phosphorus concentrations observed in the Liard River data).

Differences between nutrient concentrations in the Petitot River and Fortune Creek were not identified due to the small number of samples for nutrients.

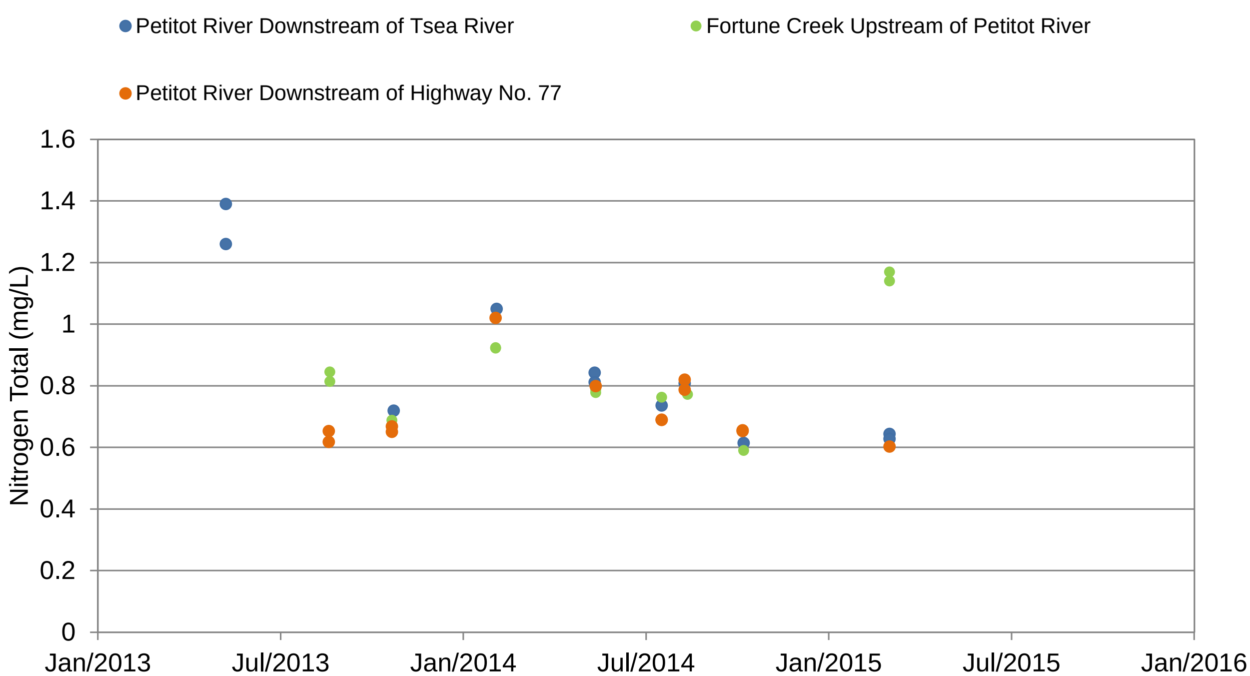



*Figure 54: Total Nitrogen Concentrations in the Petitot River, 2013 to 2015*

### 5.2.4.4 Gaps and Recommendations for Petitot River Water Quality

Water quality data for the Petitot River and Fortune Creek are limited to three years of data for selected conventional parameters, major ions, and nutrients. Data should continue to be collected, preferably during all seasons, to lengthen the data set, and additional parameters should collected to provide a more comprehensive assessment of water quality in these watercourses. Additional parameters should include all conventional parameters measured in the Liard River, field pH and dissolved oxygen, total phosphorus, phosphate, and total and dissolved metals. The need for monitoring of organics, such as PAHs or pesticides, should be evaluated but is not recommended for general characterization of water quality in these watercourses.

### 5.2.5 Approach to Identifying Constituents of Potential Concern

An objective of the State of Knowledge Report is to evaluate the potential for risk to human and ecological receptors that use or come into contact with groundwater or surface water from the Study Area. Three components must be present for risks to exist: 1) contaminant(s) present at concentrations greater than regulatory standards or guidelines; 2) a receptor; and 3) an exposure pathway by which the receptor comes into contact with the contaminant. To determine whether these conditions are present, the first step of a risk assessment, the problem formulation, is conducted. The other three steps in a risk assessment following the problem formulation are: exposure assessment, toxicity assessment, and risk characterization.

A risk assessment approach including problem formulation and conceptual models is presented in Appendix D of this report for the Liard and Petitot River Basin. Information summarized by other State of Knowledge Report components form the basis of the problem formulation, including but not limited to: water uses, influence on water resources, ambient environmental conditions, traditional knowledge, and aquatic ecosystem information. The results from the problem formulation related to COPC identification is presented below along with the approach taken.

## 5.3 Existing Surface Water Quantity Conditions

Water Survey of Canada (Environment Canada 2016b) data were available for four active Liard River stations, three deactivated Liard River stations, and one active Petitot River station, as shown in Figure 2 and described in Table 32. Hydrographs are shown in Appendix E.

**Table 32: Water Survey of Canada Stations on Liard and Petitot Rivers**

| Station Name | Station Number | Province or Territory | Latitude (N) and Longitude (W) | Gross Drainage Area ($km^2$) | Active / Inactive | Data Years[a] | Data Collected[b] |
|---|---|---|---|---|---|---|---|
| Liard River at Upper Crossing | 10AA001 | YT | 60° 03’ 03” 128° 54’ 25” | 32,600 | Active | 1960 – 2016 | Flow and Level |
| Liard River above Kechika River | 10BE006 | BC | 59° 42’ 04” 127° 13’ 39” | 61,600 | Inactive | 1969 – 1995 | Flow |
| Liard River at Lower Crossing | 10BE001 | BC | 59° 24’ 45” 126° 05’ 50” | 104,000 | Active | 1944 – 2016 | Flow and Level |
| Liard River above Beaver River | 10BE005 | BC | 59° 44’ 33” 124° 28’ 35” | 119,000 | Inactive | 1968 – 1995 | Flow |
| Liard River at Fort Liard | 10ED001 | NT | 60° 14’ 29” 123° 28’ 31” | 222,000 | Active | 1942 – 2016 | Flow and Level |
| Liard River at Lindberg Landing | 10ED008 | NT | 61° 07’ 05” 122° 51’ 35” | n/a | Inactive | 1991 – 1996 | Flow |
| Liard River near Mouth | 10ED002 | NT | 61° 44’ 33” 121° 12’ 40” | 275,000 | Active | 1972 – 2016 | Flow and Level |
| Petitot River below Highway 7 | 10DA001 | BC | 59° 59’ 20” 122° 57’ 23” | 22,400 | Active | 1995 – 1996 2012 – 2016 | Flow and Level |

a) Includes years for which data are missing

b) Indicates that flow and level were collected at this station; however, flow and level were often collected during different time periods.

n/a = not available from Water Survey of Canada; value is between 222,000 and 275,000 $km^2$.

Data downloaded from the Water Survey of Canada website were screened for data qualifiers and only final, processed data were used for analyses. Annual and seasonal trend analyses were performed using the Mann-Kendall test (Helsel and Hirsch 2002) and frequency analyses were performed using numerical methods described in Section 5.3.2. Analyses were not performed at Liard River station 10ED008 (Liard River at Lindberg Landing) and Petitot River station 10DA001 (Petitot River below Highway 7) because these stations had only five years of data, which is insufficient for meaningful trend and frequency analyses.

### 5.3.1 Regional and Basin-Wide Water Quantity Trends

The *State of the Aquatic Ecosystem Report* (MRBB 2004) described a decreasing trend in mean annual stream flows for the Liard River at stations 10AA001 (Liard River at Upper Crossing), 10BE001 (Liard River at Lower Crossing), and 10ED001 (Liard River at Fort Liard) using Water Survey of Canada stream flow data from 1960 to 1995. These trends were detected using a trend-line analysis tool such as the one available in Microsoft Excel. However, the updated data set for Station 10AA001, incorporating data from 1960 to 2014, shows the opposite trend (increasing discharge). Trend-line analysis is generally not considered a robust tool for detecting trends in this type of data set, as illustrated by this inconsistency in results when applied to different time periods of the same data set, and real trends can remain hidden by the effect of a few extreme data points.

For this report, water quantity trends in the Liard and Petitot Rivers were assessed by applying the Mann-Kendall test (Helsel and Hirsch 2002) to processed and validated Water Survey of Canada discharge data (Environment Canada 2016b). The Mann-Kendall test measures the strength of the monotonic relationship between two variables and is rank-based, which means that it is resistant to the skewing effect of a small number of extreme data points (Helsel and Hirsch 2002). Therefore, it is more effective for detecting long term trends than a simple trend-line analysis, and is more likely to provide consistent results over different sub-sets of a data set than a trend-line analysis.

The Mann-Kendall test was performed for maximum annual discharge, minimum annual discharge, minimum summer discharge, and mean annual discharge. For all tests, $\alpha$ was set to 0.05, which corresponds to a 95% confidence level that a trend will be detected by the analysis. The period of record used to assess trends was the longest set of complete data years available; some years at the beginning of the period of record were only partially recorded and were therefore truncated from the trend assessment data set.

Data sets with detected trends were run through a serial correlation test using SYSTAT software. Serial correlation can cause false positives in the Mann-Kendall test. Data sets with detected trends and showing serial correlation were flagged for potential false positive results.

### 5.3.2 Frequency and Severity of Floods and Droughts

Discharge data from the Water Survey of Canada were analyzed and the maximum and minimum annual flows, and the minimum summer (open-water) flow extracted from the data sets. Summer (open-water) flows were defined as taking place between June and September.

These extreme data were then processed using different probability distributions to determine the best-fit relationship for high and low return periods of 2, 5, 10, 20, 50, and 100 years.

The probability distributions used to determine the return periods were:

1) Three-parameter log-normal distribution (Pilon and Harvey 1994);

2) Extreme value distribution (Stephens 1974; Pilon and Harvey 1994);

3) Log-Pearson III distribution (Kite 1999); and

4) Weibull distribution (Condie and Cheng 1982).

For each frequency analyses, the number of bootstraps (Burn 2003) was set to 2000 and the confidence level (α) was set to 0.025 (Pilon and Harvey 1994). The best-fit curve for each data set was chosen as the set of return period flows.

The results of these analyses are shown in Tables 33 to 38.

**Table 33: Frequency Analysis of Flows at Station 10AA001 (Liard River at Upper Crossing)**

| Parameter | Return Period (years) | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 |
| Maximum Flow ($m^3/s$) | 1,792 | 2,402 | 2,785 | 3,139 | 3,578 | 3,892 |
| Minimum Winter Flow ($m^3/s$) | 68 | 56 | 50 | 45 | 40 | 36 |
| Minimum Summer Flow ($m^3/s$) | 313 | 259 | 235 | 218 | 201 | 191 |

**Table 34: Frequency Analysis of Flows at Station 10BE001 (Liard River at Lower Crossing)**

| Parameter | Return Period (years) | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 |
| Maximum Flow ($m^3/s$) | 5,261 | 6,518 | 7,206 | 7,790 | 8,467 | 8,927 |
| Minimum Winter Flow ($m^3/s$) | 216 | 178 | 163 | 154 | 146 | 142 |
| Minimum Summer Flow ($m^3/s$) | 164 | 153 | 149 | 145 | 141 | 138 |

**Table 35: Frequency Analysis of Flows at Station 10BE005 (Liard River above Beaver River)**

| Parameter | Return Period (years) | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 |
| Maximum Flow ($m^3/s$) | 6,584 | 7,717 | 8,255 | 8,673 | 9,117 | 9,400 |
| Minimum Winter Flow ($m^3/s$) | 252 | 212 | 195 | 183 | 172 | 167 |
| Minimum Summer Flow ($m^3/s$) | 1,222 | 1,025 | 933 | 863 | 789 | 743 |

**Table 36: Frequency Analysis of Flows at Station 10BE006 (Liard River above Kechika River)**

| Parameter | Return Period (years) | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 |
| Maximum Flows ($m^3/s$) | 3,377 | 4,154 | 4,601 | 4,992 | 5,461 | 5,787 |
| Minimum Winter Flows ($m^3/s$) | 124 | 103 | 92 | 82 | 72 | 65 |
| Minimum Summer Flows ($m^3/s$) | 593 | 502 | 454 | 414 | 368 | 338 |

**Table 37: Frequency Analysis of Flows at Station 10ED001 (Liard River at Fort Liard)**

| Criteria | Return Period (years) | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 |
| Maximum Flow ($m^3/s$) | 8,971 | 11,277 | 12,506 | 13,533 | 14,706 | 15,491 |
| Minimum Winter Flow ($m^3/s$) | 277 | 227 | 210 | 198 | 188 | 184 |
| Minimum Summer Flow ($m^3/s$) | 1,663 | 1,397 | 1,278 | 1,187 | 1,093 | 1,034 |

**Table 38: Frequency Analysis of Flows at Station 10ED002 (Liard River near Mouth)**

| Criteria | Return Period (years) | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 50 | 100 |
| Maximum Flow ($m^3/s$) | 11,099 | 13,805 | 15,225 | 16,390 | 17,688 | 18,544 |
| Minimum Winter Flow ($m^3/s$) | 370 | 300 | 267 | 242 | 218 | 204 |
| Minimum Summer Flow ($m^3/s$) | 2,237 | 1,812 | 1,602 | 1,435 | 1,252 | 1,135 |

### 5.3.3 Water Quantity Trends

Water quantity trend detection was performed as described in Section 5.3.1. A summary of the results of the trend analysis is included in Table 39 and a discussion of the results is included in this section.

**Table 39: Trends in Water Quantity for Liard River**

| Station Name | Station Number | Data Years | Trend in Mean Annual Flows | Trend in Peak Annual Flows | Trend in Low Annual Flows | Trend in Low Summer (Open-Water) Flows | Trend in Timing of Peak Flows |
|---|---|---|---|---|---|---|---|
| Liard River at Upper Crossing | 10AA001 | 1961 to 2014 | - | - | Increasing[(a)] | - | - |
| Liard River above Kechika River | 10BE006 | 1970 to 1995 | - | - | - | - | - |
| Liard River at Lower Crossing | 10BE001 | 1946 to 2014 | - | - | Increasing[(a)] | Increasing | - |
| Liard River above Beaver River | 10BE005 | 1969 to 1994 | - | - | Increasing[(a)] | - | - |
| Liard River at Fort Liard | 10ED001 | 1965 to 2014 | - | - | - | - | - |
| Liard River near Mouth | 10ED002 | 1973 to 2014 | - | - | - | - | - |

a) Serial correlation exists; result may be a false positive.

'-' = no trend detected

In general, the only trends detected were increases in annual low flows at stations 10AA001, 10BE001, and 10BE005, and summer (open-water) low flows at station 10BE001. These are the four most upstream stations on the Liard River. Serial correlation was detected at stations 10AA001, 10BE001, and 10BE005 for low annual flows, and therefore these trends may actually be false positive results. By station 10ED001, located lower in the Liard River watershed and with a larger drainage area, possible trends are no longer detectable which could mean that the trend is attenuated by one of the following:

1) An increasing but undetectable trend in the lower portion of the Liard River, that is rendering the overall trend undetectable by reducing the overall significance of the upstream trend;
2) No trend in the lower portion of the Liard River, that is rendering the upstream increasing trend undetectable by reducing its significance; or
3) An opposite (decreasing) trend in the lower portion of the Liard River, which is resulting in an undetectable overall trend.

The small increasing low-flow trends at stations 10AA001, 10BE001, and 10BE005 are not significant enough to cause a resulting overall increase in mean annual flows.

The timing of peak flows was analyzed for trends; however, all stations on the Liard River exhibited a tendency toward multiple annual peaks occurring between May and July. Therefore, a more detailed analysis (beyond the scope of this project) of the timing of peak flows accounting for temperature-driven freshet flows and precipitation-driven flows would be required for a more robust analysis of peak flow timing trends.

### 5.3.4 Flow and Water Quality

Flows influence the water quality in the Liard River; high springtime flows due to increased rainfall result in an increase of sediment loads from surface runoff and instream erosion. Concentrations of parameters associated with or adsorbed to sediments, such as phosphorus and many metals (e.g., aluminum and iron), increase as flows increase in the spring. During low flow conditions, either later in the summer or winter, when rainfall and consequently surface runoff is minimal, the proportion of flow sourced from groundwater increases, and concentrations of parameters that are higher in groundwater (salts and some dissolved metals, such as barium and strontium) increase in the Liard River. Salt exclusion during ice formation in winter (Pieters and Lawrence 2009) and evaporation during the open-water season also concentrate dissolved parameters in the river.

### 5.3.5 Flow and Biology

Flow in the Liard River has ranged from an historic low of 205 $m^3/s$ to an historic high of 19,400 $m^3/s$ at station 10ED002 (hydrograph provided in Appendix E). Freshet peaks occur in late spring or early summer. Higher flows and associated higher water levels inundate river banks during freshet peaks, potentially creating more littoral habitat. This littoral habitat is, however, seasonal and disappears when flows and water levels decrease in late summer and early fall. The high minimum flows provide consistent habitat for aquatic organisms, and the potential trend of increased low open water flows at station 10BE001 is not anticipated to have an impact on aquatic organisms because water depth remains several metres throughout the winter.

Flow in the Petitot River has ranged from an historic low of 0.67 $m^3/s$ to an historic high of 1030 $m^3/s$ at station 10DA001 (hydrograph provided in Appendix E). The low winter flows may represent a seasonal loss of habitat to aquatic organisms because river cross sections are shorter; however freshet flows cause an increase in water levels and therefore habitat. There were not enough data available to conduct a trend analysis on Petitot River flows.

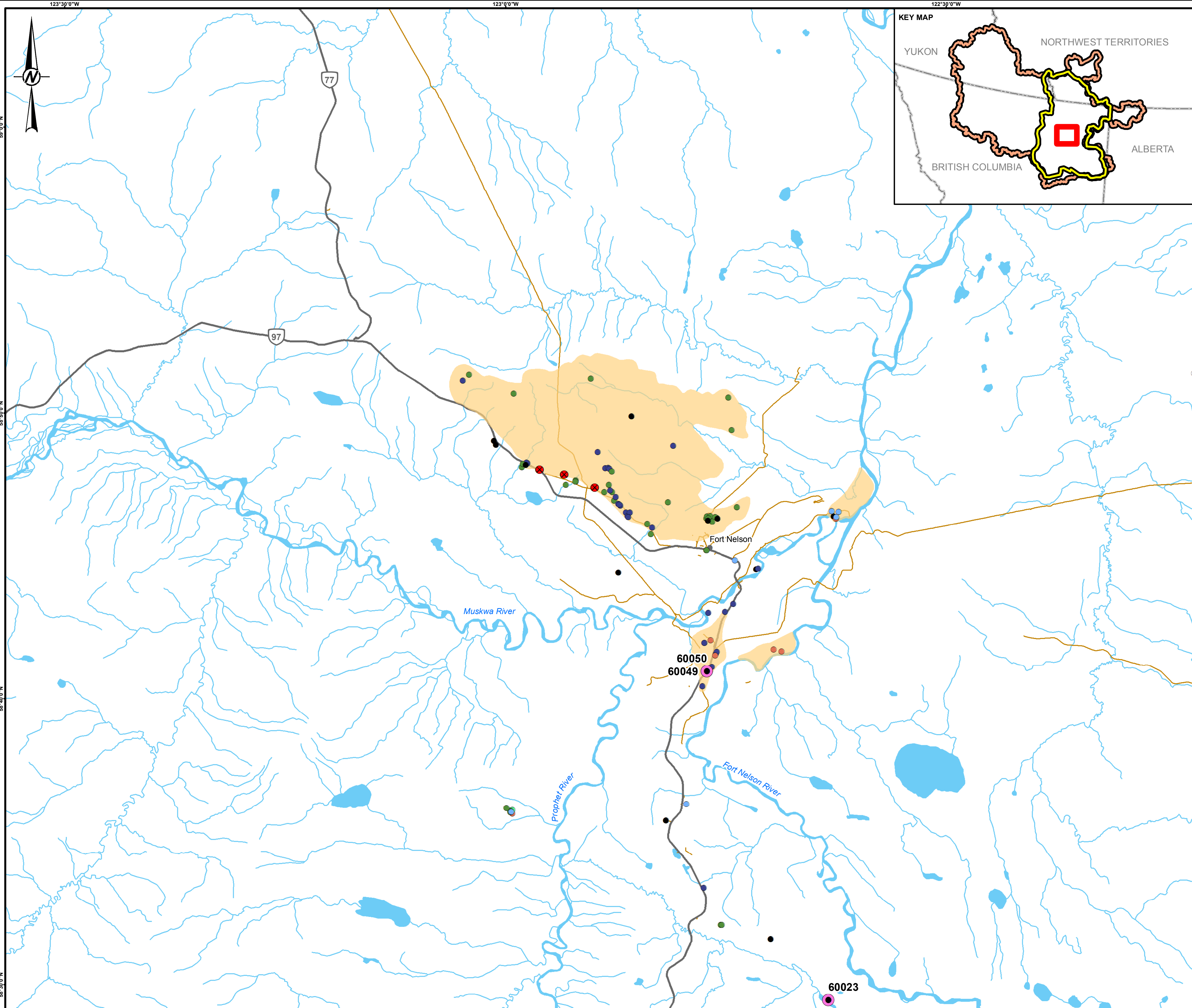
## 5.4 Existing Groundwater Conditions

The Study Area lies within two hydrogeological regions; predominantly in the Western Canadian Sedimentary Basin and a smaller portion in the Cordilleran Basin. Buried valley aquifers are important for their groundwater resource potential, which is applicable across the Western Canadian Sedimentary Basin. Local groundwater flow systems are typically driven by topographic variations, arising from flat-lying geological stratigraphy and bedrock heterogeneity (GIN 2016). In the Cordilleran Basin, deeper confined and shallow unconfined surficial aquifers are both important (GIN 2016).

Four aquifers have been identified and mapped in the Groundwater Study Area, as shown in Figure 55 (Government of BC 2016). Each of the four aquifers occur in the Fort Nelson area and are summarized in Table 40. Groundwater quantity was also assessed by reviewing the groundwater well licences in the Study Area (Map A-18). There are 191 groundwater wells in the Groundwater Study Area. The depths of these wells ranged from approximately 5 m to 375 m, with an average of 71 m. Recorded water levels range from zero to 108 m below ground surface. Well yields (well flow rating) range up to 1,000 litres per minute (Government of BC 2016).

**Table 40: Summary of Known Aquifers in the Groundwater Study Area**

| Aquifer Location | Aquifer Type | Lithology | Productivity | Area ($m^2$) |
|---|---|---|---|---|
| Highland area north of Fort Nelson | Bedrock | Fort St. John Group | Low | 124,766,366 |
| Industrial area 6 km south of Fort Nelson | Sand and Gravel | Glaciofluvial gravels and sands | High | 5,547,956 |
| East side of Fort Nelson River | Sand and Gravel | Glaciofluvial sands and gravel | Moderate | 4,216,631 |
| 7 km SE of Fort Nelson | Sand and Gravel | Fluvial gravel and sands | High | 3,190,907 |




**LEGEND**

- POPULATED PLACE
- PRIMARY HIGHWAY
- LOCAL ROAD
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA
- BRITISH COLUMBIA CHEMISTRY STATION

**BRITISH COLUMBIA GROUNDWATER WELLS**

- OTHER
- COMMERCIAL AND INDUSTRIAL
- OBSERVATION WELL
- PRIVATE DOMESTIC
- TEST
- UNKNOWN WELL USE
- WATER SUPPLY SYSTEM
- LICENSED SPRING
- AQUIFER

0 5 10

1:250,000 KILOMETRES

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: NATIONAL TOPOGRAPHIC DATA BASE (NTDB) DATA: © DEPARTMENT OF NATURAL RESOURCES CANADA, 250K SCALE.
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. BC DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE - BRITISH COLUMBIA

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT

GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**AQUIFERS IDENTIFIED IN THE FORT NELSON AREA**

CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-10-26 |
| DESIGNED | TG |
| PREPARED | LMS |
| REVIEWED | DP |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
|---|---|---|---|
| 1547195 | 3000 | A | 55 |

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25mm

PATH: I:\2015\1547195\Figures\ReportFigures\FIG21 - 1547195 Water Monitoring Stations.mxd

### 5.4.1 Groundwater Aquifer Mapping

The most recent status availability of aquifer mapping in British Columbia (2013) was reviewed. For the most north-east area of British Columbia as generally applicable to the Groundwater Study Area, i.e., Canadian National Topographic System (NTS) mapsheet areas 094O and 094P (1:250,000 scale), approximately ten 1:50,000 scale maps within each of these mapsheets are identified as ‘areas where aquifers will be mapped in the future’. No actual areas of mapped aquifers are shown within mapsheets NTS 094O and 094P, as of 2013.

Hydrogeological mapping (2005) is available for the north-west portion of Alberta, corresponding to NTS 084L and 084M, specifically Alberta Map 163 (Hydrogeological Map of the Zama-Bistcho Lakes Area, Alberta). The Zama-Bistcho Lakes map area shares common boundaries with British Columbia to the west and with the Northwest Territories to the north. The main discharge area is Zama-Hay Lakes lowland. Groundwater potential in the surficial sediments, in terms of quantity and quality, is fair to excellent. Poor quality aquifers are present with respect to Upper Cretaceous shale bedrock (low permeability) and Lower Cretaceous and Paleozoic formations with saline porewaters (low water quality).

Groundwater or hydrogeological mapping was not identified for the Northwest Territories or the Yukon Territory portions of the Groundwater Study Area.

### 5.4.2 Groundwater Quality - Fort Nelson, Andy Bailey Regional Park and Petitot River Areas

Groundwater analysis results were found for a small number of water supply wells, located in Fort Nelson, Andy Bailey Regional Park and the Petitot River near the Thinahtea South Protected Area, as summarized in Table 41, Figure 2 and on Map A-18. The available groundwater quality data identified to date is limited to these locations with only limited analyses, i.e., major ions, routine parameters, some metals and nitrates.

**Table 41: Groundwater Quality - Fort Nelson, Andy Bailey Regional Park and Petitot River Areas**

| Location | Fort Nelson (Well 1) | | Fort Nelson (Well 2) | Andy Bailey Regional Park | Petitot River Near Thinahtea South Protected Area (Well 1) | Petitot River Near Thinahtea South Protected Area (Well 2) | |
|---|---|---|---|---|---|---|---|
| **Water Portal ID** | **60050** | | **60049** | **60023** | **60763** | **60762** | |
| **Owner** | **BC Rail** | | **BC Rail** | **Andy Bailey Regional Park** | **Spectra Energy (Mid-Winter Gas Plant)** | **Spectra Energy (Mid-Winter Gas Plant)** | |
| **Network** | **Northern Health Authority** | | **Northern Health Authority** | **Northern Health Authority** | **Northern Health Authority** | **Northern Health Authority** | |
| **Description** | **Raw Supply, Shallow Well** | | **Shallow Well** | **Andy Bailey Regional Park Well** | **Deep Well** | **Distribution System, Deep Well** | |
| Sample Date | 24/Jan/95 | 5/Nov/99 | 5/Nov/99 | 20/Aug/08 | 12/Jul/06 | 3/Nov/09 | 1/Dec/09 |
| **Parameters** | | | | | | | |
| Alkalinity (mg/L) | - | 360 | 461 | - | - | - | - |
| Aluminum (mg/L) | 1.95 | <0.03 | 0.176 | 39.7 | - | - | - |
| Antimony (mg/L) | <0.02 | - | - | 0.05 | - | - | - |
| Arsenic (mg/L) | 0.0026 | <0.0005 | 0.0007 | 0.14 | 0.00035 | 0.00041 | 0.00072 |
| Barium (mg/L) | 0.4 | 0.17 | 0.148 | 75.5 | <0.01 | 0.018 | <0.1 |
| Boron (mg/L) | <0.04 | <0.3 | <0.3 | 78 | - | - | - |
| Cadmium (mg/L) | 0.0008 | <0.001 | <0.001 | 0.058 | - | - | - |
| Calcium (mg/L) | 255 | 148 | 53.1 | 194 | 0.686 | 83.5 | 94.9 |
| Chloride (mg/L) | - | 61.1 | 5.8 | - | - | - | - |
| Chromium (mg/L) | - | 61.1 | 5.8 | - | - | - | - |
| Colour (TCU) | - | <5 | <5 | - | - | - | - |
| Copper (mg/L) | 0.028 | 0.074 | 0.039 | 6.55 | - | - | - |
| Electrical Conductivity (Conductance (us/cm) | - | 1000 | 1040 | - | - | - | - |
| Fluoride (mg/L | - | 0.3 | 0.24 | - | - | - | - |
| Hardness (mg/L) | 835 | 494 | 208 | - | 2.2 | 377 | 378 |
| Iron (mg/L) | 67.6 | <0.03 | 0.12 | 865 | <0.03 | 1.45 | 4.42 |
| Lead (mg/L) | 0.037 | <0.005 | <0.005 | 1.4 | - | - | - |
| Magnesium (mg/L) | 48.1 | 30.3 | 18.2 | 48.4 | 0.12 | 40.9 | 34.3 |
| Manganese (mg/L) | 48.1 | 30.3 | 18.2 | 48.4 | 0.12 | 40.9 | 34.3 |
| Mercury | - | <0.00005 | <0.00005 | - | - | - | - |

**Table 41: Groundwater Quality - Fort Nelson, Andy Bailey Regional Park and Petitot River Areas**

| Location | Fort Nelson (Well 1) | | Fort Nelson (Well 2) | Andy Bailey Regional Park | Petitot River Near Thinahtea South Protected Area (Well 1) | Petitot River Near Thinahtea South Protected Area (Well 2) | |
|---|---|---|---|---|---|---|---|
| **Water Portal ID** | **60050** | | **60049** | **60023** | **60763** | **60762** | |
| **Owner** | **BC Rail** | | **BC Rail** | **Andy Bailey Regional Park** | **Spectra Energy (Mid-Winter Gas Plant)** | **Spectra Energy (Mid-Winter Gas Plant)** | |
| **Network** | **Northern Health Authority** | | **Northern Health Authority** | **Northern Health Authority** | **Northern Health Authority** | **Northern Health Authority** | |
| **Description** | **Raw Supply, Shallow Well** | | **Shallow Well** | **Andy Bailey Regional Park Well** | **Deep Well** | **Distribution System, Deep Well** | |
| Mercury (mg/L) | <0.00005 | - | - | - | - | - | - |
| Molybdenum (mg/L) | <0.004 | - | - | 0.88 | - | - | - |
| Nickel (mg/L) | 0.11 | - | - | 5.39 | - | - | - |
| Nitrogen - Nitrite ($NO_2$) (mg/L) | - | <0.1 | 0.336 | - | - | - | - |
| Nitrogen - Nitrate ($NO_3$) (mg/L) | - | 0.8 | 0.4 | - | - | - | - |
| pH (units) | - | 7.81 | 8.24 | - | - | - | - |
| Phosphorus (mg/L) | 1.44 | - | - | - | - | - | - |
| Potassium (mg/L) | 3.7 | 4 | 2.5 | - | - | - | - |
| Selenium (mg/L) | <0.0005 | <0.005 | 7.25 | <0.04 | - | - | - |
| Silver (mg/L) | <0.0001 | | - | 0.005 | - | - | - |
| Sodium (mg/L) | 9.8 | 20.5 | 172 | - | - | - | - |
| Solids - Dissolved (mg/L) | - | 636 | 626 | - | <689 | <1080 | 1050 |
| Sulphate (mg/L) | - | 110 | 112 | - | - | - | - |
| Turbidity (NTU) | - | 0.2 | 0.2 | - | 0.73 | 12.3 | 37.3 |
| Uranium (mg/L) | - | 0.0061 | 0.00054 | 4.19 | - | - | - |
| Zinc (mg/L) | 0.94 | <0.03 | 0.18 | 3470 | - | - | - |

Source: BC Oil and Gas Commission. 2015. Water Information - Northeast Water Tool (NEWT). Available at: https://www.bcogc.ca/public-zone/water-information. Accessed: February 2016.

Note: exact well locations were not available.

'-' = no data available

### 5.4.3 Groundwater Quality – Fort Liard Area

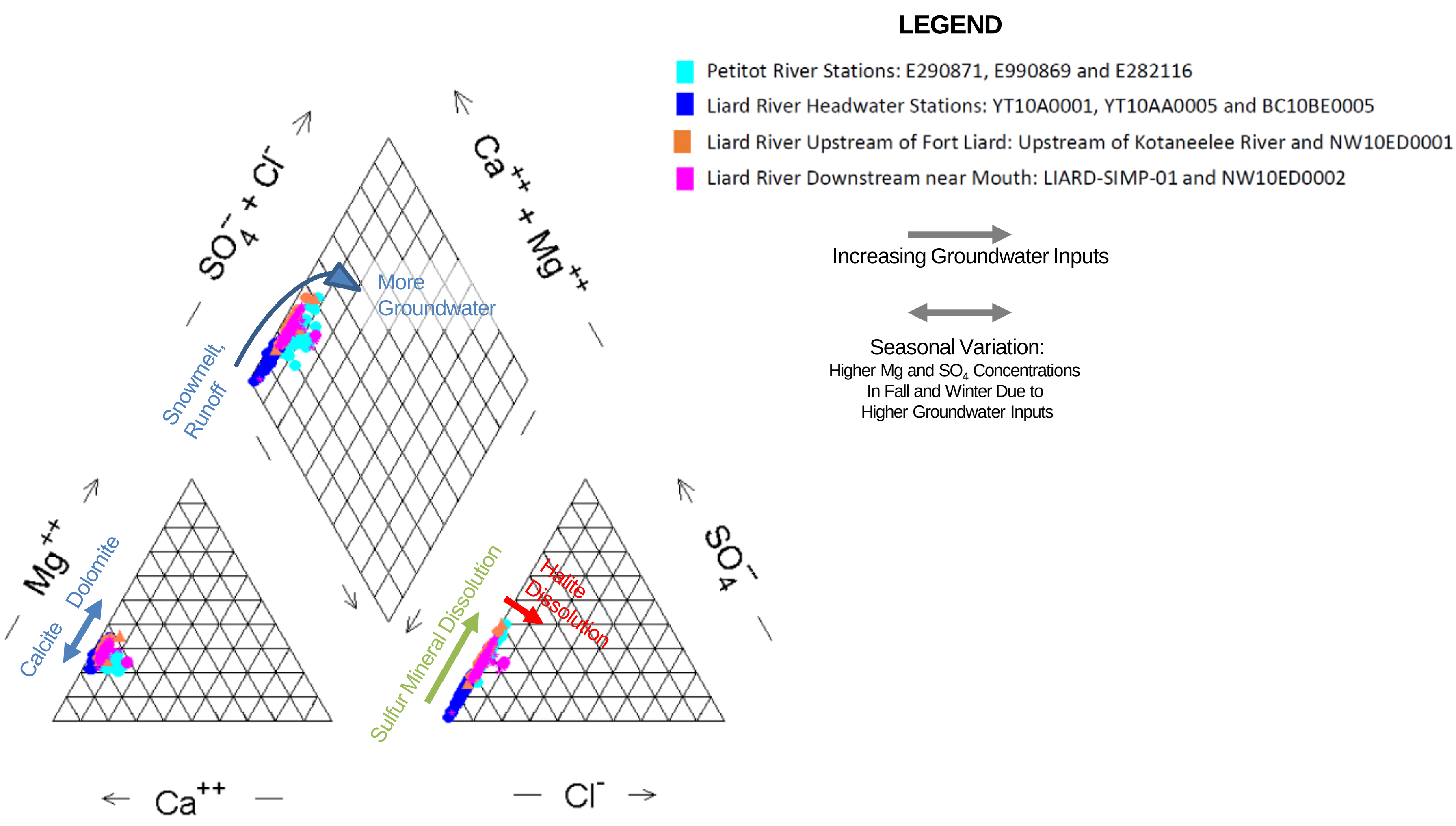
The water quality for three groundwater supply wells, sampled from 1995 to 2009, inclusive, was reviewed to provide additional context for the surface water quality discussion. Water analytical results for three wells (Fort Liard Well 1, Fort Liard Well 2, and Nahanni Butte Well) are provided in Appendix B.

Concentrations of TDS for these groundwater samples ranged from 266 to 490 mg/L, generally greater than Liard River concentrations sampled at Fort Liard (median TDS of 190 mg/L), arising from subsurface residence time and mineral dissolution. Major ion analyses were generally incomplete for the available groundwater results; available limited data suggested these groundwaters are calcium-bicarbonate type. Calcium-bicarbonate type waters are typical of groundwater flow paths with a short residence time, in contrast to watershed-scale flowpaths with residence times up to thousands of years. The dissolved load for this water type is typically associated with the dissolution of calcite by carbonic acid, as derived from atmospheric carbon dioxide. The concentrations of major calcium, magnesium, sodium, alkalinity, and chloride tended to be higher in these three wells than in the Liard River surface water. Concentrations of sulphate however, were within similar ranges for groundwater and surface water. Likely sources of these elements include dissolution of minerals such as calcite, dolomite, halite, gypsum, and pyrite.

### 5.4.4 Groundwater - Surface Water Quality

A Piper plot was used to characterize the surface water major ion chemistry of the Liard River and Petitot River, which showed these rivers to have distinct water types, with components of surface runoff and groundwater varying spatially along the flow path and temporally according to season, at each station. The Piper plot graphically represents major aqueous cations and anions (in milli-equivalent concentrations), on ternary plots with apexes of the cation plot being: calcium, magnesium and sodium plus potassium cations. Apexes of the anion plot are: sulphate, chloride and carbonate plus hydrogen carbonate anions. The two ternary plots are projected onto a central diamond graphic, that groups water types and identifies mineralization patterns, water mixing, etc. The headwater stations on the Liard River (blue symbols) on the Piper plot, Figure 56, have a calcium-bicarbonate water type dominated by snowmelt and runoff, plus minor loading by calcite dissolution products representing an end-member for waters from the Rocky Mountains. The Liard River gains magnesium, sodium, and sulphate downstream, from dissolution of dolomite and sulfur-bearing minerals indicative of higher proportions groundwater inputs. Some possible sources of sulphate include anhydrite and gypsum from Paleozoic evaporite formations and oxidation of sulphide minerals in Mesozoic and Quaternary deposits.

The headwater stations on the Petitot (light blue symbols) on the Piper plot, Figure 56, have a calcium-bicarbonate to calcium-sulphate-bicarbonate water type, with higher proportions of sodium and sulphate that are indicative of more groundwater inputs, relative to the Liard River and consistent with the setting on Western Canadian Sedimentary Basin. The Liard River downstream of the confluence with the Petitot River (pink symbols), Figure 56, has a major ion composition indicative of mixing of the two rivers with additional sodium and chloride associated with outcropping Devonian formations and regional discharges of brines from the dissolution of Devonian halite deposits. Most of the stations on these rivers exhibit seasonal variation in the major ion compositions, with lower concentrations and calcium-bicarbonate water types during freshet. Conversely, the rivers have higher magnesium and sulphate in fall and winter from the increased groundwater component in those seasons.






| | | | |
|---|---|---|---|
| CLIENT | GOVERNMENT OF NORTHWEST TERRITORIES | PROJECT | LIARD – PETITOT WATERSHED |
| CONSULTANT | Golder Associates | TITLE | **PIPER PLOT OF MAJOR IONS** |
| YYYY-MM-DD | 2017-0313 | | |
| PREPARED | JC | | |
| DESIGN | MN | | |
| REVIEW | MN | PROJECT No. | 1547195 |
| APPROVED | PM | Rev. / FIGURE | 0 / 56 |

## 5.5 Groundwater - Surface Water Interaction

Groundwater discharges to surface water have not been identified to date. Typically, several sources of information are combined to infer river reaches with significant groundwater contribution, including river baseflow analyses from hydrograph station data, and also the interpretation of hydrogeological mapping showing surficial aquifers and water tables or piezometric levels, within those aquifers. Traditional knowledge may also identify reaches of the Liard or Petitot rivers, or their main tributaries, with minimal or no ice-up in winter, the locations of spring-fed lakes, plus springs and seeps discharging groundwater to surface. Thermal imaging of rivers at key times of the year may also provide information for gaining river reaches, which receive significant groundwater contributions.

In terms of recharge, permafrost mapping indicates that the Study Area is categorized as being in an area of sporadic, discontinuous permafrost, with 10% to 50% of the land area underlain by permafrost (Ecological Stratification Working Group 1995). This mapping is quite dated however, in the context of changing permafrost conditions. It does suggest that permafrost within the Study Area in 2016 may be relict permafrost and the previously mapped category of ‘sporadic, discontinuous’ may have reduced to a lower category. The implications to groundwater of reduced permafrost extent, is the potential for water tables to receive increased recharge, notably in surficial aquifers, i.e., greater infiltration and recharge to water tables.

Groundwater and surface water data sources are included in Appendix B.

## 5.6 Existing Sediment Quality Conditions

### 5.6.1 Data Sources

A description of existing sediment quality conditions was based on a review and summary of digitally available suspended sediment (sediment) quality data collected from one station within the Liard River since 2001 (Table 42; Figure 2, Map A-18; Appendix F). Additionally, existing reports that described historical sediment quality conditions within the Liard River prior to 2001 (Table 43) were reviewed. Bottom sediment quality data were not available for the Liard River.

Since 2001, suspended sediment samples have been collected from the Liard River above the Kotaneelee and analysed for a variety of parameters including: conventional parameters (e.g., particle size and total organic carbon), metals (e.g., chromium and cadmium), organics (e.g., naphthalene and fluorene), pesticides (e.g., aldrin and dieldrin), and PCBs (polychlorinated biphenyls) (Table 44). Active oil and gas developments in the upper reaches of the Kotaneelee River could conceivably affect water quality in the Liard River; such an occurrence would confound inferences about the source of petroleum-derived contaminants, should any be found (Taylor et al 1998).

Suspended sediment quality samples were prepared by centrifuging water grab samples with a portable centrifuge on site during the open-water season; the suspended solids portion of the centrifugate sample was analyzed for sediment quality parameters (detailed methods described in Taylor et al. 1998). Winter collection of suspended sediment was attempted; however, due to lower suspended sediment concentrations during the winter, laboratory analyses could not be completed on the small amounts of suspended sediment collected during this season.

**Table 42: Suspended Sediment Quality Monitoring in the Liard River: Location, Duration, and Parameter Groups, 2001 to 2015**

| Station Description | Data Source | Location | | Laboratory | Monitoring Period(a) | Parameter Monitoring Groups(a) | | |
|---|---|---|---|---|---|---|---|---|
| | | Latitude (N) | Longitude (W) | | | Conventional Parameters | Metals | Organics, PCBs, and Pesticides |
| Liard River upstream of Kotaneelee River | AANDC/ GNWT | 60° 08' 56" | 123° 44' 06" | ALS | 2001 to 2015 | yes | yes | yes |
| | | | | AXYS | 2013 to 2015 | no | no | yes |

a) One to three samples per year were collected in 2001, 2002, 2007, and between 2013 and 2015. Not all parameter groups were analyzed during each sampling year.

AANDC = Aboriginal Affairs and Northern Development Canada; GNWT = Government of the Northwest Territories; PCB = polychlorinated biphenyl.

**Table 43: Technical Reports with Suspended Solids Quality Information**

| CITATION | SUMMARY |
|---|---|
| MacDonald (1993) | This report provides a summary of water quality monitoring within the Liard River basin, including a review of data collected by Indian and Northern Affairs Canada (INAC) and Environment Canada (EC) (data to the early 90's) and reference to other reports and studies. At the time of the report publication, there was only a single study on streambed sediment quality for the Liard River basin. |
| Taylor et al. (1998) | This report provides a summary of an environmental monitoring program for the Liard River basin. Samples were collected from the Liard River above Kotaneelee River for analysis of water (1991 to 1994) and suspended sediments (1992 to 1994). The study provides an overview of seasonality of water quality, and a comparison of water quality and sediment quality results to protection of aquatic life guidelines. These data were not available digitally and therefore only qualitative comparisons of the 1992 to 1994 data to recent data (i.e., 2001 onwards) were completed. |

**Table 44: Number of Sediment Quality Parameters Analyzed for the Liard River, 2001 to 2015**

| Sample Name | Laboratory | Sampling Date | Number of Parameters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Particle Size and Moisture Content | Naphthenic Acids | Parent PAHs | Alkylated PAHs | PCBs | Pesticides | PFCs | Chlorophenols | Total Metals | Carbon Content | Total |
| CLSA1319 | AXYS | 18-Jul-2013 | 1 | 59 | 26 | 49 | 232 | 44 | 13 | 0 | 0 | 0 | 424 |
| CLSA1321 | AXYS | 24-Aug-2013 | 1 | 60 | 26 | 49 | 190 | 44 | 0 | 0 | 0 | 0 | 370 |
| CLSA1423 | AXYS | 15-Jun-2014 | 1 | 60 | 26 | 49 | 195 | 44 | 0 | 0 | 0 | 0 | 375 |
| CLSA1425 | AXYS | 12-Jul-2014 | 1 | 0 | 26 | 49 | 0 | 0 | 0 | 0 | 0 | 0 | 76 |
| CLSA1427 | AXYS | 19-Aug-2014 | 1 | 0 | 26 | 49 | 0 | 0 | 0 | 0 | 0 | 0 | 76 |
| CLSA1529 | AXYS | 4-Jun-2015 | 1 | 60 | 26 | 49 | 0 | 38 | 0 | 0 | 0 | 0 | 174 |
| CLSA1531 | AXYS | 8-Jul-2015 | 1 | 60 | 26 | 49 | 0 | 69 | 0 | 0 | 0 | 0 | 205 |
| CLSA1533 | AXYS | 9-Aug-2015 | 1 | 60 | 26 | 49 | 0 | 69 | 0 | 0 | 0 | 0 | 205 |
| L45285-13 | ALS | 11-Sep-2001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 0 | 23 |
| L71860-1 | ALS | 4-Jul-2002 | 1 | 0 | 16 | 1 | 1 | 28 | 0 | 44 | 24 | 0 | 115 |
| L527001-1 | ALS | 4-Jul-2007 | 4 | 0 | 21 | 26 | 218 | 34 | 0 | 0 | 19 | 4 | 326 |
| L559132-1 | ALS | 12-Sep-2007 | 1 | 0 | 23 | 29 | 207 | 0 | 0 | 0 | 19 | 4 | 283 |
| L1335776-1 | ALS | 18-Jul-2013 | 1 | 1 | 0 | 0 | 10 | 49 | 0 | 0 | 32 | 4 | 97 |
| L1359824-18 | ALS | 24-Aug-2013 | 5 | 1 | 0 | 0 | 10 | 39 | 0 | 0 | 32 | 5 | 92 |
| L1472576-1 | ALS | 15-Jun-2014 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 5 | 41 |
| L1486938-2 | ALS | 12-Jul-2014 | 4 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 32 | 4 | 50 |
| L1506436-3 | ALS | 19-Aug-2014 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 6 |
| L1623172-1 | ALS | 4-Jun-2015 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 34 | 4 | 42 |
| L1656302-7 | ALS | 9-Aug-2015 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 34 | 4 | 41 |

PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyl; PFCs = perfluorinated compound; ALS = ALS laboratory Group; AXYS = Axys Analytical Services.

### 5.6.2 Summary of Data and Comparisons to Guidelines

Suspended sediment quality data collected from the Liard River upstream of Kotaneelee River since 2001 were summarized by calculating the median, minimum, and maximum concentrations for parameters with guidelines or for parameters with four or more data points. Due to the highly variable detection limits between laboratories, data from both laboratories were only combined for parameters that were detectable in more than 75% of the samples (other data were not combined for the analysis). When calculating the median concentrations, values less than the detection limit were replaced with values at the detection limit, but were ranked below values at the detection limit for the purposes of calculating median concentrations. The measured parameter concentrations of each sample were compared to sediment quality guidelines for the protection of freshwater aquatic life (BC MOE 2016b, CCME 1999) (Table 45). CCME and approved British Columbia Ministry of Environment (MOE) aquatic life guidelines were used because the Liard River flows through both the Northwest Territories and British Columbia. Sediment quality guidelines are typically applied to the concentrations in bottom sediments, where aquatic organisms are immersed in the sediments. However, because guidelines for suspended sediment do not exist, sediment quality guidelines were used to provide context.

**Table 45: Bottom Sediment Quality Guidelines for the Protection of Aquatic Life**

| Parameter | Units (Dry Weight) | Guidelines | | |
|---|---|---|---|---|
| | | CCME ISQG[(a)] | CCME PEL[(b)] | BC MOE SQG[(c)] |
| **Metals** | | | | |
| Arsenic | µg/g | 5.9 | 17 | - |
| Cadmium | µg/g | 0.6 | 3.5 | - |
| Chromium | µg/g | 37.3 | 90 | - |
| Copper | µg/g | 36 | 197 | - |
| Lead | µg/g | 35.7 | 91 | - |
| Mercury | µg/g | 0.17 | 0.49 | - |
| Zinc | µg/g | 123 | 315 | - |
| **Parent PAHs** | | | | |
| Naphthalene | µg/g | 0.035 | 0.39 | 0.01 - 0.02 |
| Acenaphthylene | µg/g | 0.0059 | 0.13 | - |
| Acenaphthene | µg/g | 0.0067 | 0.089 | 0.2 - 0.36 |
| Fluorene | µg/g | 0.021 | 0.14 | 0.3 - 0.5 |
| Phenanthrene | µg/g | 0.042 | 0.52 | 0.05 - 0.1 |
| Anthracene | µg/g | 0.047 | 0.25 | 0.8 - 1.4 |
| Pyrene | µg/g | 0.053 | 0.88 | - |
| Fluoranthene | µg/g | 0.11 | 2.4 | 3 - 5 |
| Benzo(a)anthracene | µg/g | 0.032 | 0.39 | 0.3 - 0.5 |
| Chrysene | µg/g | 0.057 | 0.86 | - |
| Benzo(a)pyrene | µg/g | 0.032 | 0.0942 | 0.08 - 0.14 |
| Dibenzo(a,h)anthracene | µg/g | 0.0062 | 0.14 | - |
| **Alkylated PAHs** | | | | |
| 2-Methylnaphthalene | µg/g | 0.02 | 0.2 | - |
| **PCBs** | | | | |
| Aroclor 1254 | µg/g | 0.06 | 0.34 | - |
| Total PCBs | µg/g | 0.034 | 0.28 | 0.03 - 0.05 |

**Table 45: Bottom Sediment Quality Guidelines for the Protection of Aquatic Life**

| Parameter | Units (Dry Weight) | Guidelines | | |
|---|---|---|---|---|
| | | CCME ISQG[(a)] | CCME PEL[(b)] | BC MOE SQG[(c)] |
| **Pesticides/Herbicides** | | | | |
| 2,4'-DDD | µg/g | 0.00354 | 0.00851 | - |
| 4,4'-DDD | µg/g | 0.00354 | 0.00851 | - |
| 2,4'-DDE | µg/g | 0.00142 | 0.00675 | - |
| 4,4'-DDE | µg/g | 0.00142 | 0.00675 | - |
| 4,4'-DDT | µg/g | 0.00119 | 0.00477 | - |
| 2,4'-DDT | µg/g | 0.00119 | 0.00477 | - |
| *cis*-Chlordane | µg/g | 0.0045 | 0.00887 | - |
| *trans*-Chlordane | µg/g | 0.0045 | 0.00887 | - |
| Oxychlordane | µg/g | 0.0045 | 0.00887 | - |
| Dieldrin | µg/g | 0.0029 | 0.0067 | - |
| Endrin | µg/g | 0.0027 | 0.062 | - |
| Heptachlor | µg/g | 0.0006 | 0.0027 | - |
| Lindane | µg/g | 0.00094 | 0.0014 | - |
| Toxaphene | µg/g | 0.0001 | - | - |

a) CCME ISQG (interim bottom sediment quality guideline) (CCME 1999).
b) CCME PEL (probable effect level) guideline (CCME 1999).
c) BC MOE SQGs (bottom sediment quality guidelines) (BC MOE 2016b) were based on the range of total organic carbon content (1.3 to 2.4%) observed for the Liard River upstream of the Kotaneelee River.
CCME = Canadian Council of Ministers of the Environment; BC MOE = British Columbia Ministry of Environment; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; µg/g = micrograms per gram (equivalent to mg/kg = milligrams per kilogram); - = no guideline.

The CCME bottom sediment quality guidelines are: interim sediment quality guidelines (ISQGs) and probable effect levels (PEL) (CCME 1999) (Table 45). The ISQG is the concentration of a substance below which an adverse effect on aquatic life is unlikely; the PEL is the concentration of a substance above which adverse effects are expected to occur frequently, but not always. In practice, the application of generic numerical guidelines has yielded a high percentage of false positives (Chapman and Mann 1999). The observation of a sediment concentration above the PEL value for a given parameter should not be interpreted as an indication that actual ecological harm has occurred or will occur, but rather that this is a possibility. Biological assessment, such as evaluation of the benthic invertebrate community, is necessary to determine whether adverse ecological effects may actually be occurring.

The BC MOE sediment quality guidelines were calculated based on the total organic carbon (TOC) content in the corresponding suspended sediment sample or the median TOC content in Liard River sediment samples, if the TOC content was not measured in the suspended sediment sample.

Data summaries were presented for all parameters with more than three samples but discussion of summary results were limited primarily to those parameters with bottom sediment quality guidelines. Trends of suspended sediment quality parameters over time in the Liard River were qualitatively identified by visually reviewing temporal plots for a subset of parameters. Values below detection limits were plotted at the detection limit as open data points.

## 5.6.3 Liard River Suspended Sediment Quality Results and Discussion

### *5.6.3.1 Conventional Parameters*

Particle size, or texture, is a measurement of the proportion of sand, silt, and clay in the sediment and is also indicative of the chemical constituents that may be adsorbed to the sediment (e.g., metals and organics tend to adsorbed on clays rather than sands [Taylor et al. 1998]). Total organic carbon and total inorganic carbon measure the amount of organic matter and inorganic material, respectively, found in the sediment. The BC MOE sediment guidelines account for the TOC, allowing a higher guideline concentration for higher TOC content.

On average, Liard River suspended sediments sampled between 2007 and 2015 were about 26% sand, 47% silt and 27% clay (Table 45, Figure 57). The high proportion of silts and clays, which was consistent with historical particle size data (Taylor et al. 1998), allows these suspended sediments to adsorb a greater proportion of metals compared to sediments mostly comprised of sands. Therefore, elevated metals concentrations in the suspended sediments and consequently in water samples with high concentrations of suspended sediments are expected.

The TOC content for the suspended sediments samples in the Liard River ranged from 1.3% to 2.4%, with a median of 1.6% (Table 45, Figure 58). No clear temporal trend in particle size or TOC content was observed in the suspended sediment quality (Figures 57 and 58); however, the ability to detect trends were limited due to the inconsistent and short period for sampling.

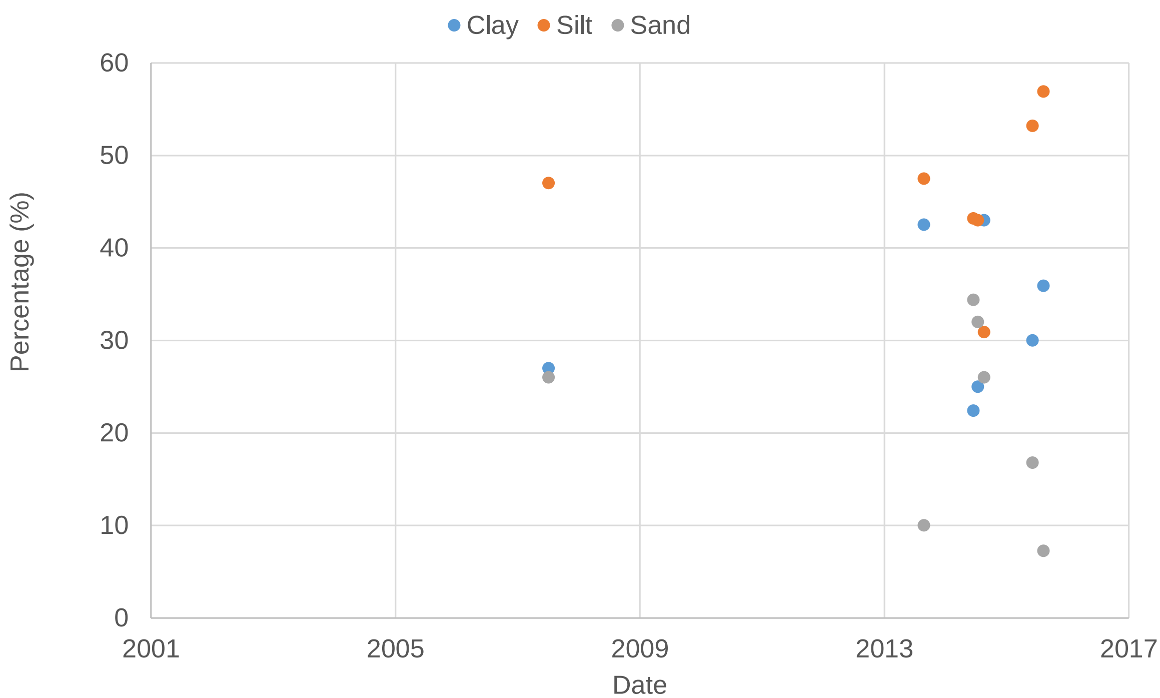



*Figure 57: Particle Size for Suspended Sediment in the Liard River Upstream of the Kotaneelee River, 2001 to 2015*

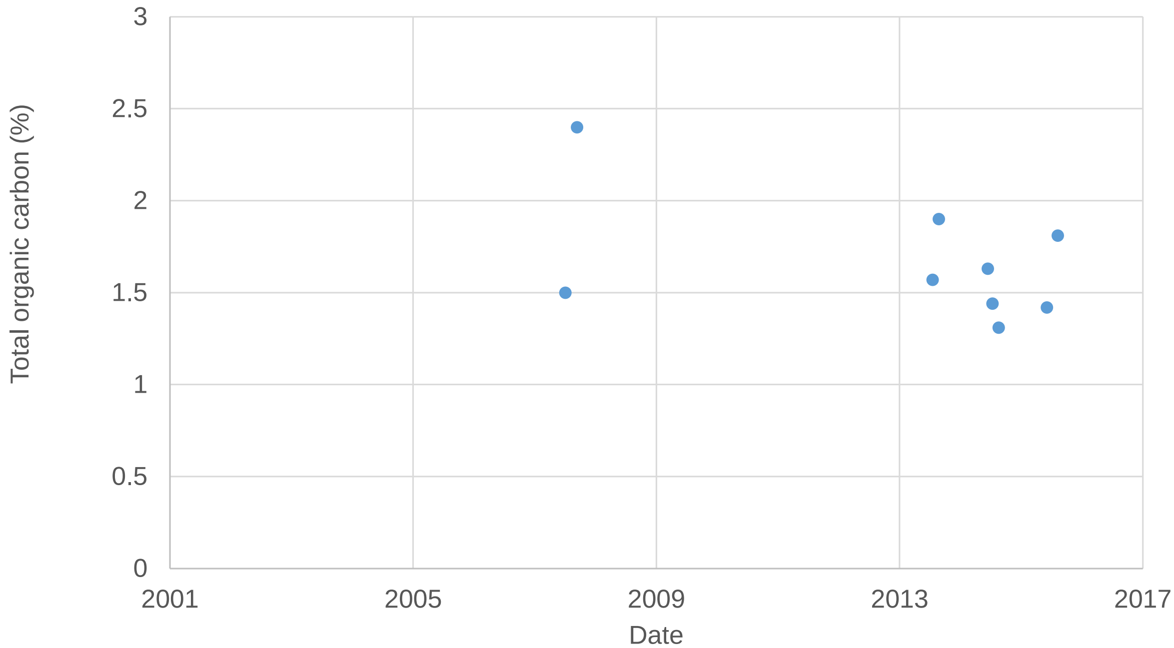
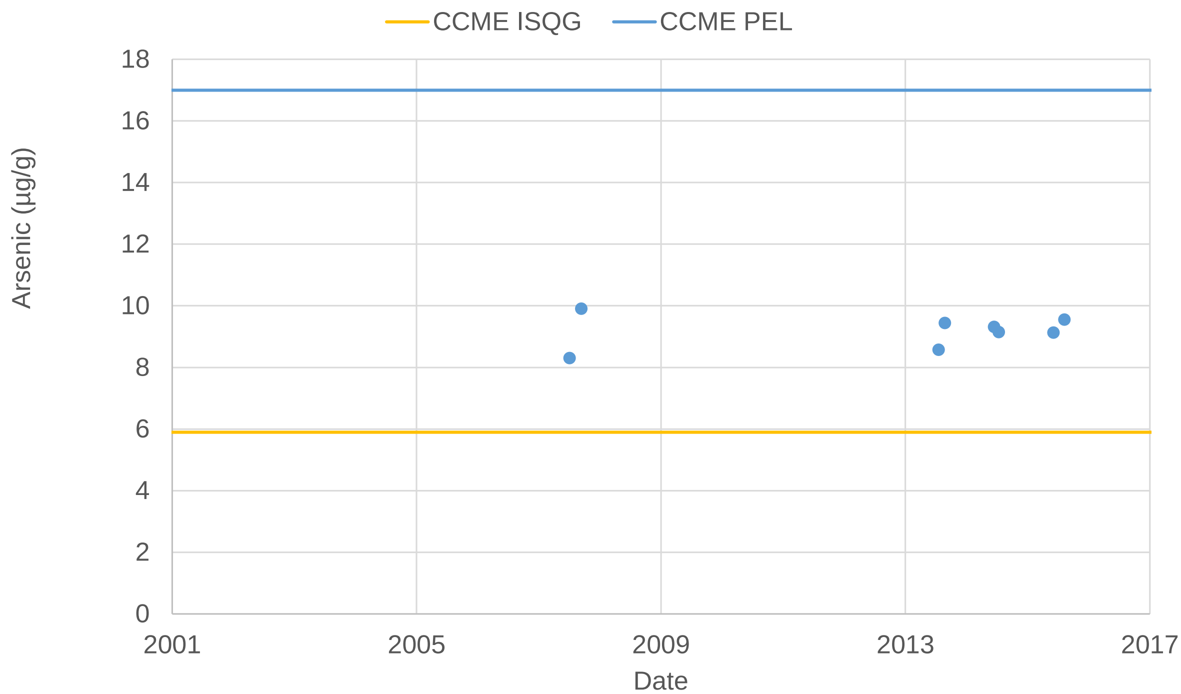



*Figure 58: Percent Total Organic Carbon in Suspended Sediment in the Liard River Upstream of the Kotaneelee River, 2001 to 2015*

#### 5.6.3.2 Metals

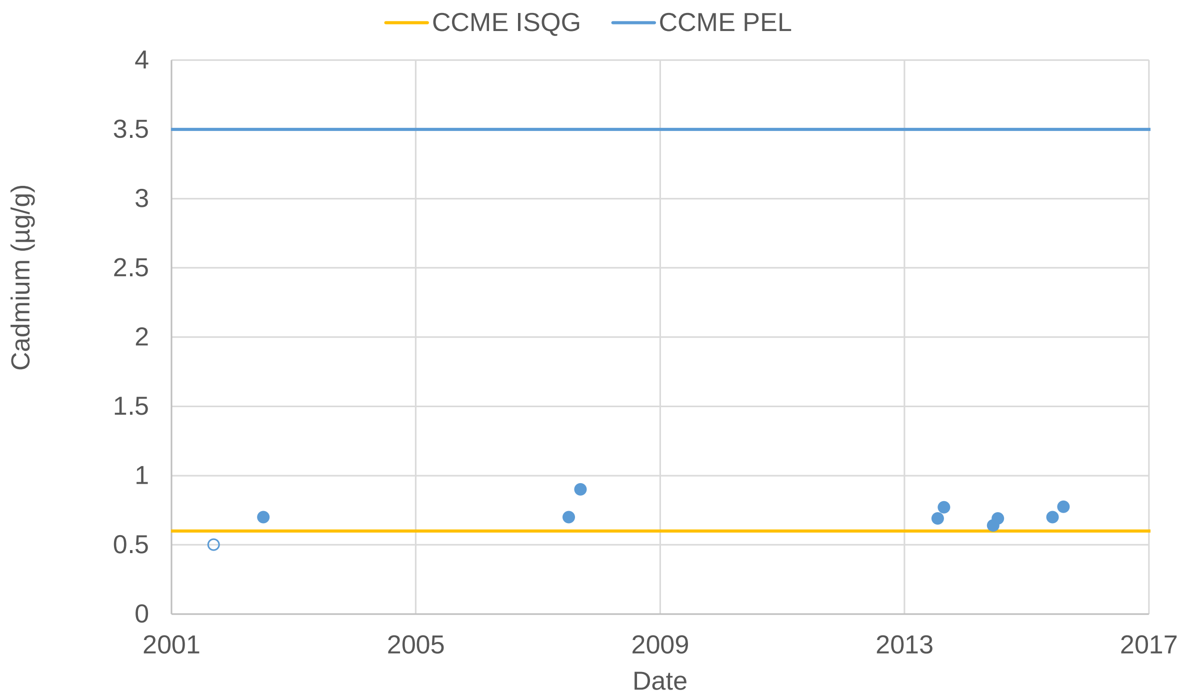
Metals naturally occur in sediments in small quantities. Metals that have a higher affinity to adsorbing to sediments, such as aluminum and iron, and are often found in higher concentrations in sediments compared to other metals. Aquatic organisms can show effects associated with high metal concentrations in bottom sediments; however, the level at which metals are toxic varies by metal. Metals associated with TSS that settle out of the water column may become biologically unavailable; however, toxicity to aquatic life living in bottom sediments (e.g., benthic invertebrates) can occur if conditions change such that the metals become bio-available. In this report, suspended sediment metal concentrations are discussed relative to sediment quality guidelines that are typically applicable to bottom sediments; the risk to aquatic life living in bottom sediments in the Liard River would need to consider both any sediment guideline exceedances and the similarity between the quality of the suspended and bottom sediments in the Liard River.

Metals concentrations in suspended sediment samples between 2007 and 2015 were below the CCME PEL guidelines but were above the CCME ISQGs for some metals. All suspended sediment arsenic and median cadmium concentrations were above the CCME ISQG (Table 45, Figures 59 and 60). Zinc concentrations were occasionally above the CCME ISQG (Figure 61); however, chromium, copper, lead, and mercury remained below all sediment quality guidelines. The guideline exceedances observed for metals in suspended sediments between 2001 and 2015 were consistent with the data collected from 1992 to 1994 (Taylor et al. 1998) indicating that the elevated concentrations are likely natural. Arsenic, cadmium and zinc concentrations in suspended sediments remained well below the CCME PEL guideline and were not identified as aquatic life COPCs based on water quality in the Liard River (Appendix D). Therefore, effects to aquatic biota from the observed suspended sediment concentration for these three metals are not expected. No clear temporal trends in metal concentrations were observed in the suspended sediment quality (Appendix F-1, Figures F1 (2) to (8); however, the ability to detect trends were limited due to the inconsistent and short period for sampling.




CCME = Canadian Council of Ministers of Environment; ISQG = interim sediment quality guideline; PEL = probable effect level; µg/g = micrograms per gram (equivalent to mg/kg [milligrams per kilogram]).

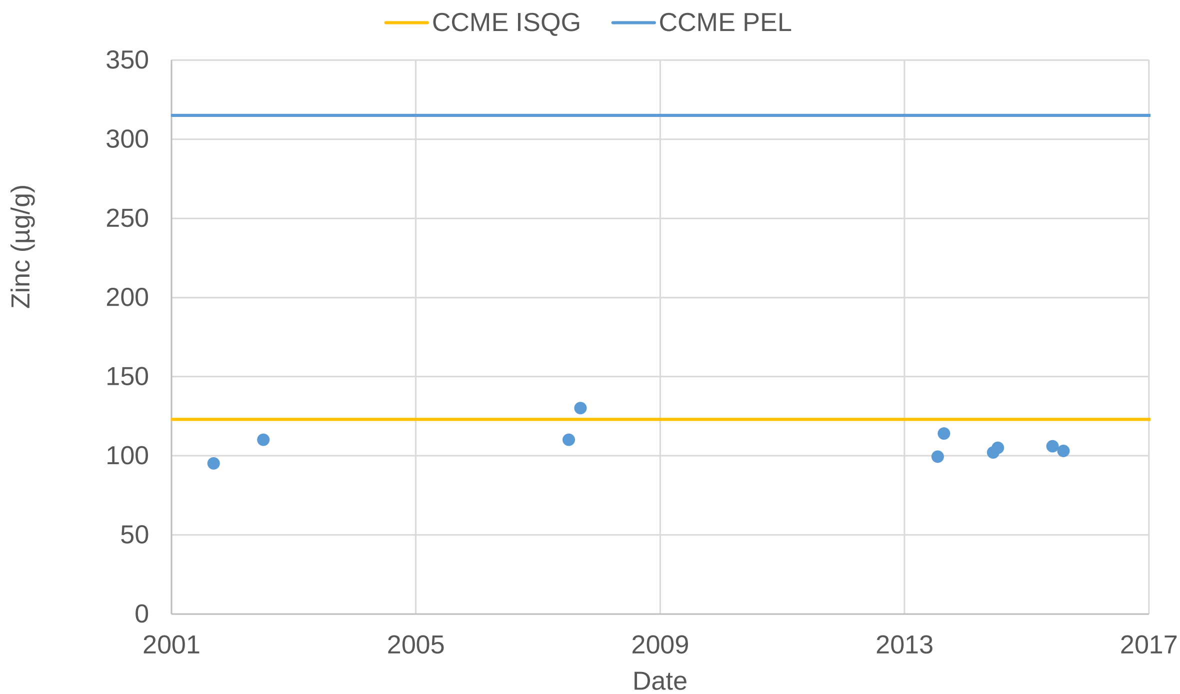
*Figure 59: Suspended Sediment Concentrations of Arsenic in the Liard River Upstream of the Kotaneelee River, 2007 to 2015*




Notes: Values reported as less than the detection limit were plotted as open data points at the detection limit.

CCME = Canadian Council of Ministers of Environment; ISQG = interim sediment quality guideline; PEL = probable effect level; µg/g = micrograms per gram (equivalent to mg/kg [milligrams per kilogram]).

*Figure 60: Suspended Sediment Concentrations of Cadmium in the Liard River Upstream of the Kotaneelee River, 2007 to 2015*




CCME = Canadian Council of Ministers of Environment; ISQG = interim sediment quality guideline; PEL = probable effect level; µg/g = micrograms per gram (equivalent to mg/kg [milligrams per kilogram]).

*Figure 61: Suspended Sediment Concentrations of Zinc in the Liard River Upstream of the Kotaneelee River, 2007 to 2015*

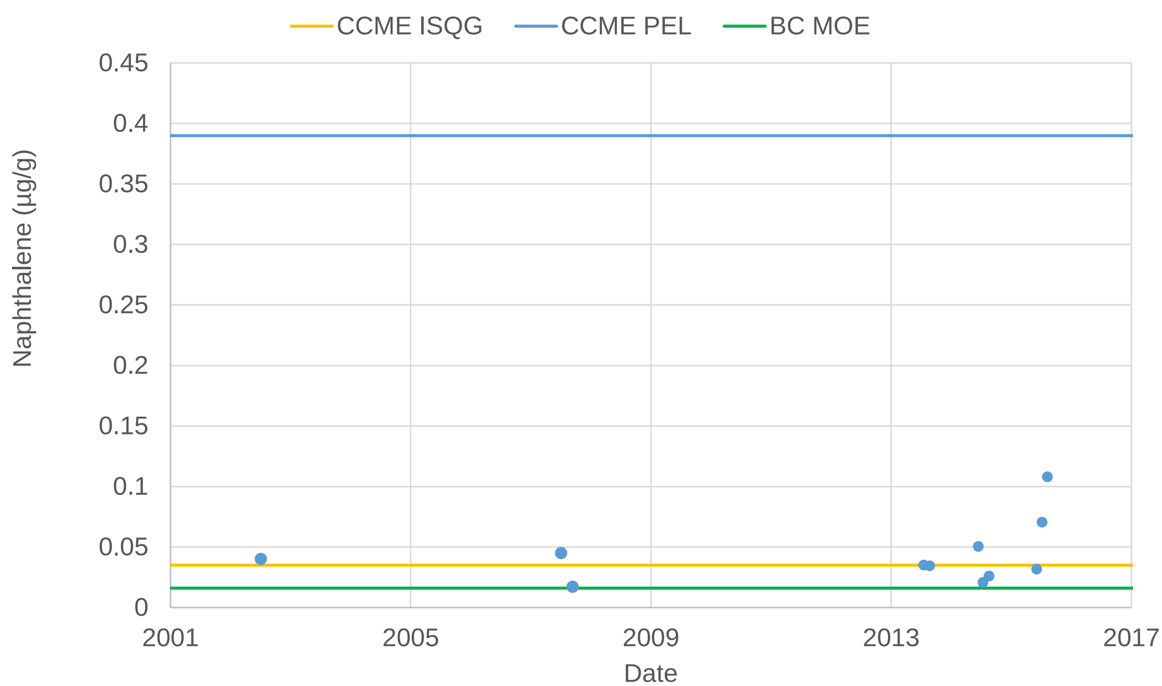
#### 5.6.3.3 Organic Compounds, PCBs and Pesticides

Organic compounds (organics) include chemicals consisting of chains or rings of carbon atoms, such as herbicides, solvents, hydrocarbons, phenols, polycyclic aromatic hydrocarbons (PAHs) and other petroleum products. Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds that contain two or more benzene rings in their structure (CCME 1999). These compounds may originate from natural sources (e.g., forest fires and watersheds that possess large deposits of bitumen, crude oil or shale oils) and inhabited areas (solvents, coolants), or may be released from industrial sources (e.g., vehicle exhaust, wastewater discharges); anthropogenic sources of PAHs are typically higher than natural sources (Blumer 1976). Sediment quality guidelines for PAHs have been developed for the protection of aquatic life.

Pesticides are beneficial in controlling weeds, insects, fungus, or other organisms but can be unintentionally released into natural waterbodies through surface runoff from agriculture or urban areas. Examples of pesticides include organochloride compounds, cholinesterase inhibitors, organophosphorus compounds and carbamates (Stephensen and Solomon 1993). PCBs are synthetic organic chlorine compounds that were primarily used for industrial purposes; although their use is now banned, these compounds continue to be persistent in some environments. Pesticides and PCBs are synthetic compounds and therefore the natural background concentrations of pesticides and PCBs in sediments are expected to be zero.

Elevated concentrations of PAHs, PCBs and pesticides may be harmful to aquatic organisms; however, toxicity, persistence, degradation and fate varies widely by chemical. In this report, concentrations of PAHs, PCBs and pesticides are discussed in terms of which substances are detectable in suspended solids in the Liard River and how concentrations compare to relevant aquatic life guidelines.

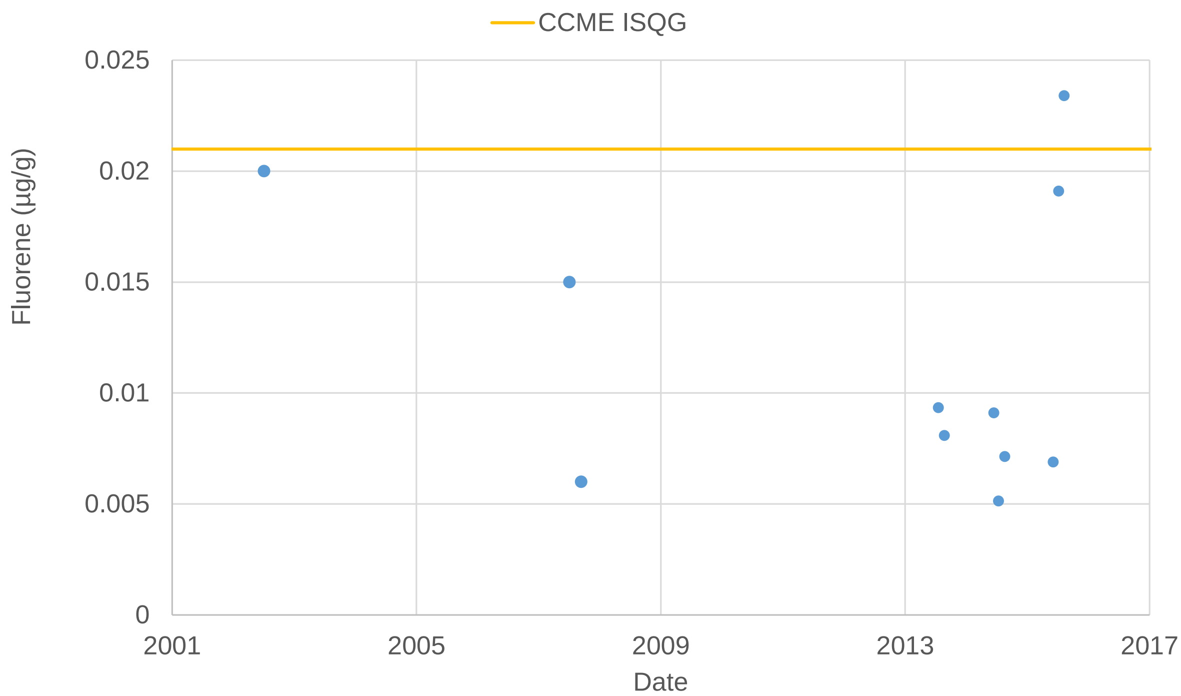
Concentrations of organic compounds in suspended sediment samples between 2001 and 2015 were below PEL guidelines, but some organics were above the CCME ISQG and/or BC MOE sediment quality guidelines. Concentrations of PAHs were detectable in most suspended sediment samples, which is consistent with the 1992 to 1994 historical PAH data (Taylor et al. 1998) and with the shale gas resources study undertaken within the Liard River basin (EMM 2013). All concentrations of naphthalene (Figure 62) and the median concentration of phenanthrene were above the CCME ISQG and BC MOE sediment quality guidelines (Table 45); maximum concentrations of fluorene and chrysene were above the CCME ISQG (Figures 63 and 64). These four PAHs are present both naturally and from human activities as pollutants in the environment. Forest fires, geologic activities, and watersheds that possess large deposits of bitumen, crude oil or shale oils are examples of natural sources of PAHs in the environment. The major sources of PAHs in the Liard-Petitot watershed are the leaching of shale gas deposits to the surface water environment and potential contamination from shale gas production. On occasions, forest fires may contribute PAHs in the drainage area. Because concentrations of naphthalene, phenanthrene, fluorene and chrysene in the suspended sediment remained well below the CCME PEL guideline and were not identified as COPCs based on water quality in the Liard River, biological effects from the observed PAH concentrations are not expected.




Note: BC MOE guidelines were calculated based on the minimum suspended sediment total organic carbon (1.3%).

CCME = Canadian Council of Ministers of Environment; BC MOE = British Columbia Ministry of the Environment; ISQG = interim sediment quality guideline; PEL = probable effect level; µg/g = micrograms per gram (equivalent to mg/kg [milligrams per kilogram]).

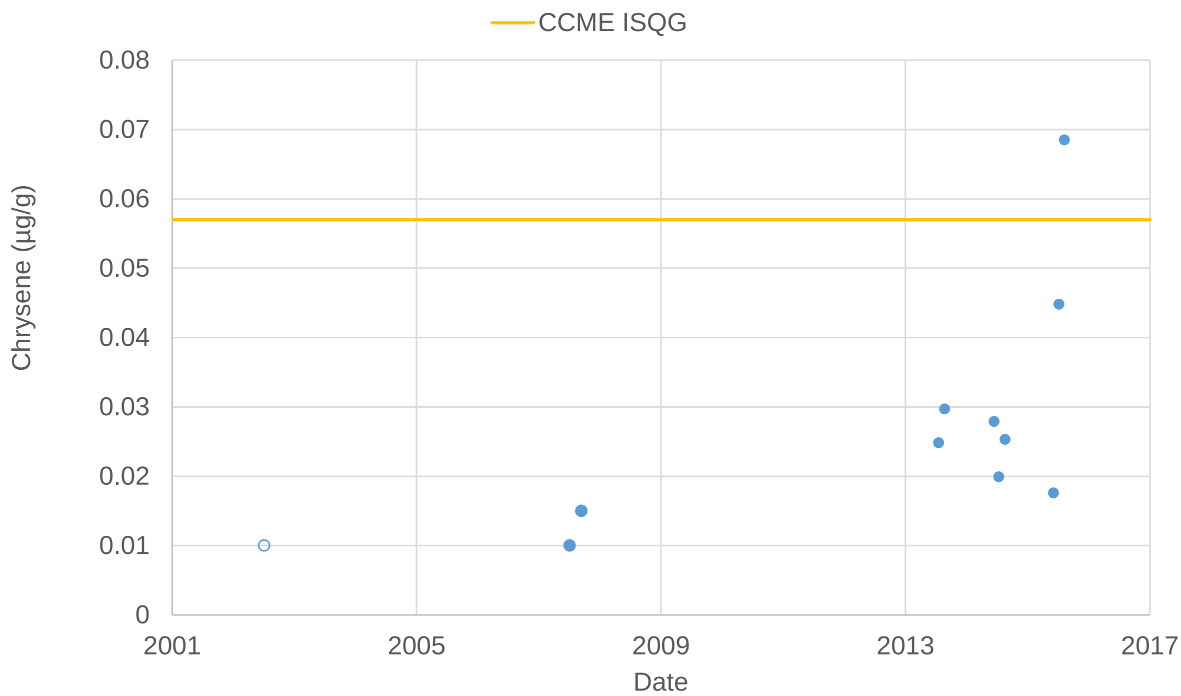
*Figure 62: Suspended Sediment Concentrations of Naphthalene in the Liard River Upstream of the Kotaneelee River, 2001 to 2015*




Note: For the purposes of visually reviewing the data, the CCME PEL (0.14 µg/g) and BC MOE (0.3 µg/g) guidelines are not shown.

CCME = Canadian Council of Ministers of Environment; BC MOE = British Columbia Ministry of the Environment; ISQG = interim sediment quality guideline; PEL = probable effect level; µg/g = micrograms per gram (equivalent to mg/kg [milligrams per kilogram]).

*Figure 63: Suspended Sediment Concentrations of Fluorene in the Liard River Upstream of the Kotaneelee River, 2001 to 2015*




Note: For the purposes of visually reviewing the data, the CCME PEL (0.86 µg/g) guideline is not shown.

CCME = Canadian Council of Ministers of Environment; ISQG = interim sediment quality guideline; PEL = probable effect level; µg/g = micrograms per gram (equivalent to mg/kg [milligrams per kilogram]).

*Figure 64: Suspended Sediment Concentrations of Chrysene in the Liard River Upstream of the Kotaneelee River, 2001 to 2015*

Concentrations of total PCBs were detectable but below the CCME ISQG and PEL guidelines and the BC MOE sediment quality guideline (Table 45). Concentrations of PCBs were not detectable in historical data, likely due to the higher detection level (0.01 µg/g) used in the laboratory analyses (Taylor et al. 1998) relative to the data collected between 2001 and 2015 (0.00001 µg/g).

Pesticides were not detected in suspended sediment quality samples (Table 46), which was consistent with findings of Taylor et al. (1998).

No clear temporal trends in PAH, PCB or pesticide concentrations were observed in the suspended sediment quality (Figures E.9 to E.33); however, the ability to detect trends were limited due to the inconsistent and short period for sampling.

**Table 46: Summary of Suspended Sediment Quality in the Liard River Upstream of the Kotaneelee River, 2001 to 2015**

| Parameter | Unit (Dry Weight) | Guidelines | | | Summary Statistics | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 2001 - 2015 | | | |
| | | CCME ISQG | CCME PEL | BC MOE SQG | Minimum | Median | Maximum | Count |
| **Particle Size And Moisture Content** | | | | | | | | |
| Clay | % | - | - | - | 22 | 27 | 43 | 5 |
| Sand | % | - | - | - | 10 | 26 | 34 | 5 |
| Silt | % | - | - | - | 43 | 47 | 53 | 5 |
| **Carbon Content** | | | | | | | | |
| Total organic carbon | % | - | - | - | 1.3 | 1.6 | 2.4 | 9 |
| $CaCO_3$ equivalent | % | - | - | - | 8.6 | 10 | 12 | 8 |
| Inorganic carbon | % | - | - | - | 1.0 | 1.3 | 1.3 | 9 |
| Inorganic carbon (as $CaCO_3$ equivalent) | % | - | - | - | 9.2 | - | 9.6 | 2 |
| Total carbon by combustion | % | - | - | - | 2.5 | 2.7 | 3.7 | 9 |
| **Total Metals** | | | | | | | | |
| Aluminum | µg/g | - | - | - | 10,500 | 11,400 | 15,500 | 7 |
| Arsenic | µg/g | 5.9 | 17 | - | 8.3(I) | 9.2(I) | 9.9(I) | 8 |
| Barium | µg/g | - | - | - | 222 | 328 | 396 | 10 |
| Boron (hot water extraction) | µg/g | - | - | - | 0.22 | 0.35 | 0.56 | 6 |
| Cadmium | µg/g | 0.6 | 3.5 | - | <0.5 | 0.7(I) | 0.9(I) | 10 |
| Calcium | µg/g | - | - | - | 28,200 | 33,400 | 38,200 | 8 |
| Chromium | µg/g | 37.3 | 90 | - | 17 | 24 | 30 | 10 |
| Cobalt | µg/g | - | - | - | 7.0 | 9.3 | 12 | 10 |
| Copper | µg/g | 36 | 197 | - | 19 | 22 | 25 | 10 |
| Iron | µg/g | - | - | - | 16,500 | 23,900 | 24,900 | 8 |
| Lead | µg/g | 35.7 | 91 | - | 8.0 | 12 | 14 | 10 |
| Lithium | µg/g | - | - | - | 17 | 17 | 19 | 6 |
| Magnesium | µg/g | - | - | - | 8,640 | 9,900 | 11,400 | 8 |
| Manganese | µg/g | - | - | - | 300 | 422 | 537 | 8 |
| Mercury | µg/g | 0.17 | 0.49 | - | 0.045 | 0.051 | 0.08 | 8 |

**Table 46: Summary of Suspended Sediment Quality in the Liard River Upstream of the Kotaneelee River, 2001 to 2015**

| Parameter | Unit (Dry Weight) | Guidelines | | | Summary Statistics | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 2001 - 2015 | | | |
| | | CCME ISQG | CCME PEL | BC MOE SQG | Minimum | Median | Maximum | Count |
| Molybdenum | µg/g | - | - | - | 1.0 | 2.1 | 3.3 | 10 |
| Nickel | µg/g | - | - | - | 22 | 32 | 37 | 10 |
| Phosphorus | µg/g | - | - | - | 710 | 763 | 837 | 8 |
| Potassium | µg/g | - | - | - | 1,280 | 1,645 | 3,180 | 8 |
| Selenium | µg/g | - | - | - | 0.75 | 0.84 | 1.2 | 8 |
| Sodium | µg/g | - | - | - | 100 | 120 | 193 | 8 |
| Strontium | µg/g | - | - | - | 64 | 87 | 111 | 8 |
| Titanium | µg/g | - | - | - | 17 | 62 | 157 | 8 |
| Vanadium | µg/g | - | - | - | 25 | 35 | 45 | 10 |
| Zinc | µg/g | 123 | 315 | - | 95 | 106 | 130[I] | 10 |
| **Parent PAHs** | | | | | | | | |
| Naphthalene | µg/g | 0.0346 | 0.391 | 0.01 - 0.02 | 0.017[B] | 0.035[I, B] | 0.108[I, B] | 11 |
| Biphenyl | µg/g | - | - | - | 0.007 | 0.01 | 0.033 | 10 |
| Fluorene | µg/g | 0.0212 | 0.144 | 0.3 - 0.5 | 0.0051 | 0.0091 | 0.0234[I] | 11 |
| Phenanthrene | µg/g | 0.0419 | 0.515 | 0.05 - 0.1 | 0.033 | 0.054[I, B] | 0.152[I, B] | 11 |
| Pyrene | µg/g | 0.053 | 0.875 | - | 0.011 | 0.02 | 0.04 | 11 |
| Fluoranthene | µg/g | 0.111 | 2.355 | 3 - 5 | 0.006 | 0.01 | 0.021 | 11 |
| Benzo(a)anthracene | µg/g | 0.0317 | 0.385 | 0.3 - 0.5 | 0.0027 | 0.0061 | 0.017 | 11 |
| Benzo(b)fluoranthene | µg/g | - | - | - | 0.008 | 0.012 | 0.034 | 11 |
| Benzo(j,k)fluoranthenes | µg/g | - | - | - | <0.00021 | 0.0033 | 0.022 | 8 |
| Benzo(g,h,i)perylene | µg/g | - | - | - | <0.01 | 0.03 | 0.0761 | 11 |
| Benzo(a)pyrene | µg/g | 0.0319 | 0.782 | 0.08 - 0.14 | <0.003 | 0.0061 | 0.0149 | 11 |
| Benzo(e)pyrene | µg/g | - | - | - | 0.019 | 0.029 | 0.076 | 8 |
| Chrysene | µg/g | 0.0571 | 0.862 | - | <0.01 | 0.0248 | 0.0685[I] | 11 |
| Perylene | µg/g | - | - | - | 0.059 | 0.11 | 0.25 | 8 |
| 1-Methyl-7-isopropyl-phenanthrene (Retene) | µg/g | - | - | - | 0.035 | 0.058 | 0.32 | 9 |

**Table 46: Summary of Suspended Sediment Quality in the Liard River Upstream of the Kotaneelee River, 2001 to 2015**

| Parameter | Unit (Dry Weight) | Guidelines | | | Summary Statistics | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 2001 - 2015 | | | |
| | | CCME ISQG | CCME PEL | BC MOE SQG | Minimum | Median | Maximum | Count |
| **PCBs** | | | | | | | | |
| Total PCBs | µg/g | 0.034 | 0.28 | 0.03 - 0.05 | 0.000025 | 0.000068 | 0.0013 | 5 |
| **Pesticides/Herbicides** | | | | | | | | |
| Hexachlorobenzene | µg/g | - | - | - | 0.000033 | 0.00005 | <0.0001 | 7 |

Note: **Bolded** values are higher than sediment quality guidelines:
(I) = value higher than the CCME ISQG.
(P) = value higher than the CCME PEL.
(B) = value higher than the BC MOE SQG.
Sediment quality data shown in this table were rounded to reflect laboratory precision *after* comparisons to guidelines. Therefore, values slightly above guidelines may be displayed as being equal to the guidelines and identified as exceedances. Measured concentrations equal to the guideline values were not identified as exceedances.
BC MOE SQG = British Columbia Ministry of Environment; CCME = Canadian Council of Ministers of the Environment; ISQG = interim sediment quality guideline; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; PEL= probable effect level; SQG = sediment quality guideline; µg/g = mg/kg; - = no guideline or data.

## 5.7 Aquatic Ecosystem Structure

Publicly available reports were reviewed to assess the biological data available to describe the current aquatic ecosystem (aquatic plants, zooplankton, benthic invertebrate community, and fish) within the watershed.

### 5.7.1 Aquatic Plants, Zooplankton, and Benthic Invertebrate Community

A small set of benthic invertebrate data are available from the Liard River from the early 1980s. These data were compiled to establish the presence and absence of species in an Assessment of Ambient Conditions of the Liard River Basin (MacDonald 1993).

Benthic macroinvertebrate data have recently been collected in Northeastern British Columbia to establish baseline benthic macroinvertebrate conditions for the development of a reference condition model for future water quality assessment. Approximately 25 sites per year were sampled by Environment Canada following CABIN (Canadian Aquatic Biomonitoring Network) protocols. It is expected that a reference condition model will be forthcoming for future monitoring purposes.

Monitoring data for aquatic plants and plankton (including zooplankton, phytoplankton, and picoplankton) in the Liard or Petitot rivers were not identified.

### 5.7.2 Fish

Key fish species were identified based on high presence and residency time in the Liard River, their importance as food for humans (commercial, recreational, and aboriginal use), their high potential to accumulate contaminants, and their high degree of sediment exposure (Table 47). Other species that have been previously documented in the Liard River basin are summarized in Table 48.

**Table 47: Key Fish Species in the Study Area**

| Species | Risk Status | | | | | | Primary adult feeding strategy |
|---|---|---|---|---|---|---|---|
| | NWT Species at Risk | Yukon Species at Risk | Alberta Species at Risk | BC Species at Risk[(a)] | COSEWIC | Federal *Species at Risk Act* | |
| Arctic Grayling | sensitive | none | sensitive | blue | none | none | omnivore |
| Burbot | secure | none | secure | none | none | none | benthic piscivore, insectivore |
| Inconnu | may be at risk | none | none | blue | none | none | piscivore |
| Lake Trout | secure | none | sensitive | none | none | none | apex predator, piscivore |
| Mountain Whitefish | secure | none | secure | none | none | none | benthic insectivore |
| Lake Whitefish | secure | none | secure | none | none | none | pelagic omnivore |
| Northern Pike | secure | none | secure | none | none | none | apex predator, piscivore |
| Walleye | sensitive | none | secure | none | none | none | benthic predator |

**Table 47: Key Fish Species in the Study Area**

| Species | Risk Status | | | | | | Primary adult feeding strategy |
|---|---|---|---|---|---|---|---|
| | NWT Species at Risk | Yukon Species at Risk | Alberta Species at Risk | BC Species at Risk[(a)] | COSEWIC | Federal *Species at Risk Act* | |
| Longnose Sucker | secure | none | secure | none | none | none | benthic omnivore |
| White Sucker | secure | none | secure | none | none | none | benthic omnivore |

Notes: List of species compiled from Taylor et al. (1998); MRBB (2004); McPhail (2007); Sawatzky et al. (2007); Nelson and Paetz (2012); and Davies and Walker (2013)

[(a)] BC Species at Risk classifications are: red – endangered, threatened, or extirpated; blue – not immediately threatened, but of concern; yellow- all other species

**Table 48: Other Confirmed Fish Species present in the Study Area**

| Species | Risk Status | | | | | | Primary adult feeding strategy |
|---|---|---|---|---|---|---|---|
| | NWT Species at Risk | Yukon Species at Risk | Alberta Species at Risk | BC Species at Risk[(a)] | COSEWIC | Federal *Species at Risk Act* | |
| Bull Trout | may be at risk | special concern | sensitive | blue | special concern | under consideration | apex predator |
| Chinook Salmon | Vagrant /accidental | none | none | none | none | none | piscivore |
| Chum Salmon | undetermined | none | none | none | none | none | piscivore |
| Dolly Varden | sensitive | special concern | exotic/alien | yellow | special concern | under consideration | apex predator, piscivore |
| Goldeye | secure | none | secure | blue | none | none | planktivore, insectivore |
| Arctic Cisco | sensitive | none | none | red | none | none | insectivore, molluscivore, piscivore |
| Emerald Shiner | secure | none | secure | none | none | none | planktivore |
| Finescale Dace | secure | none | undetermined | none | none | none | insectivore, molluscivore, planktivore |
| Flathead Chub | secure | none | secure | none | none | none | insectivore, piscivore |
| Lake Chub | secure | none | secure | none | none | none | insectivore, planktivore |
| Lake Cisco | secure | none | secure | red | none | none | pelagic omnivore |
| Longnose Dace | secure | none | secure | none | none | none | insectivore/molluscivore |

| Species | Risk Status | | | | | | Primary adult feeding strategy |
|---|---|---|---|---|---|---|---|
| | NWT Species at Risk | Yukon Species at Risk | Alberta Species at Risk | BC Species at Risk[(a)] | COSEWIC | Federal *Species at Risk Act* | |
| Northern Redbelly Dace | secure | none | sensitive | blue | none | none | insectivore, molluscivore, planktivore |
| Pond Smelt | undetermined | none | none | none | none | none | pelagic omnivore |
| Round Whitefish | secure | none | undetermined | none | none | none | benthic omnivore |
| Slimy Sculpin | secure | none | secure | none | none | none | benthic insectivore, molluscivore |
| Spottail Shiner | secure | none | secure | red | none | none | insectivore, molluscivore, planktivore |
| Trout-Perch | secure | none | secure | none | none | none | omnivore |

Notes: List of species compiled from Taylor et al. (1998); MRBB (2004); McPhail (2007); Sawatzky et al. (2007); Nelson and Paetz (2012); and Davies and Walker (2013) [(a)] BC Species at Risk classifications are: red – endangered, threatened, or extirpated; blue – not immediately threatened, but of concern; yellow- all other species

Bistcho Lake, in northwestern Alberta was the only commercial fishery operating in the Liard River basin and has been closed since 2014. However, Walleye, Northern Pike, Lake Whitefish, Mountain Whitefish, Lake Trout, Arctic Grayling, and Inconnu represent popular fishing for the general public and sustenance species for First Nation communities in the Liard River basin (MRBB 2004).

In addition to the aforementioned species, Burbot, White Sucker, and Longnose Sucker are valuable First Nations subsistence species and are used extensively by residents of the Liard River basin (MRBB 2004). Both sucker species are used as food for people and dogs. The large liver of Burbot is eaten preferentially by First Nations communities, so the health of Burbot and the quality of their liver are important. All of the species listed in Table 47 are abundant and common in the Liard River, complete most or all of their life cycles within the basin, and represent a variety of trophic levels. The fish species listed in Table 47 were targeted using mesh sizes of capture nets chosen to catch fish of sizes similar to those caught by local fishers. The sampling program thus concentrated on fish of the size most likely to be caught, and eaten, by people (Taylor et al. 1998).

Fish are particularly susceptible to accumulation of lipophilic substances because they have a relatively high content of fatty tissues, and they often feed on other organisms which may themselves contain contaminants. As a result, fish tend to bioaccumulate these pollutants to a greater degree than other organisms. Fish serve as a good signal of contamination in an aquatic environment, and may be the first species to show signs of ill health if contaminant loads are high.

### 5.7.3 Wildlife

Wildlife in the Study Areas include large mammals (caribou, moose, bison), carnivores (wolf, wolverine, black bear), mammals with a large aquatic component to their habitat (beaver, muskrat, river otter, mink), and a range of migratory an non-migratory birds (including upland birds, water birds and raptors, Table 49). The Study Areas also includes species of concern, such as the grizzly bear, wood bison, rusty blackbird, horned grebe, peregrine falcon and short-eared owl.

**Table 49: Summary of Wildlife and Wildlife Species of Concern in the Study Areas**

| Species | NWT Species at Risk | Yukon Species at Risk | Alberta Species at Risk | BC Species at Risk [(a)] | COSEWIC | Federal *Species at Risk Act* |
|---|---|---|---|---|---|---|
| American black bear | secure | none | secure | none | not at risk | none |
| Beaver | secure | none | none | none | none | none |
| Grizzly bear | sensitive | none | threatened | blue | special concern | none |
| Canada lynx | none | none | sensitive | none | not at risk | none |
| American mink | secure | none | none | none | none | none |
| Moose | secure | none | none | none | none | none |
| Muskrat | none | none | none | none | none | none |
| North American deer mouse | secure | none | secure | none | none | none |
| American water shrew | secure | none | secure | red | none | none |
| Wolf | secure | not at risk | secure | none | not at risk | none |
| Wolverine | not at risk | none | may be at risk | none | special concern | none |
| North American river otter | secure | none | none | none | none | none |
| Woodland caribou | northern mountain - secure boreal - sensitive | none | threatened | none | non-active | schedule 1 |
| Wood bison | at risk | none | at risk | none | special concern | schedule 1 |
| American bittern | sensitive | none | sensitive | blue | none | none |
| Bank swallow | secure | threatened | secure | yellow | threatened | none |
| Barn swallow | sensitive | threatened | sensitive | blue | threatened | none |
| Bay-breasted warbler | none | none | sensitive | red | none | none |
| Cape may warbler | secure | none | sensitive | red | none | none |
| Le Conte's sparrow | secure | none | secure | blue | none | none |
| Olive-sided flycatcher | at risk | threatened | may be at risk | blue | threatened | schedule 1 |

**Table 49: Summary of Wildlife and Wildlife Species of Concern in the Study Areas**

| Species | NWT Species at Risk | Yukon Species at Risk | Alberta Species at Risk | BC Species at Risk [(a)] | COSEWIC | Federal *Species at Risk Act* |
|---|---|---|---|---|---|---|
| Rusty blackbird | sensitive | special concern | sensitive | blue | special concern | schedule 1 |
| Horned grebe | sensitive | special concern | sensitive | yellow | special concern | none |
| American golden-plover | none | none | none | blue | none | none |
| Red-necked phalarope | sensitive | special concern | secure | blue | special concern | none |
| Spotted sandpiper | secure | none | secure | none | none | none |
| Harlequin duck | may be at risk | none | species of special concern | none | special concern | schedule 1 |
| Mallard | secure | none | secure | none | none | none |
| Surf scoter | sensitive | none | secure | blue | none | none |
| White-winged scoter | none | none | species of special concern | none | none | none |
| Sandhill crane | secure | none | sensitive | yellow | not at risk | none |
| Trumpeter swan | sensitive | none | species of special concern | none | not at risk | none |
| Barred owl | undetermined | none | species of special concern | none | none | none |
| Common nighthawk | at risk | threatened | sensitive | yellow | threatened | schedule 1 |
| Gyrfalcon | secure | none | secure | blue | not at risk | none |
| Peregrine falcon | sensitive | special concern | threatened | red | special concern | schedule 1 |
| Swainson's hawk | none | none | sensitive | red | none | none |
| Osprey | secure | none | sensitive | none | none | none |
| Bald eagle | secure | not at risk | sensitive | none | not at risk | none |
| Short-eared owl | sensitive | special concern | may be at risk | blue | special concern | schedule 1 |

[(a)] BC Species at Risk classifications are: red – endangered, threatened, or extirpated; blue – not immediately threatened, but of concern; yellow- all other species

# 6.0 KNOWLEDGE GAPS

This section describes the knowledge gaps that would need to be addressed should the Liard and Petitot Rivers Transboundary Class be increased to Level 3.

## 6.1 Climate

Available historic climate data in the Liard and Petitot Rivers is considered sufficient. However, the following gaps were identified with respect to predicting the effects of climate change on the Liard-Petitot system:

- A better understanding of the extent and volume of permafrost in the Liard-Petitot system is needed to evaluate potential risks to human health, safety and the environment due to climate change induced permafrost degradation.
- Federal, provincial and territorial authorities should encourage the development of vulnerability assessments and then rank and seek to mitigate potential risks through the development of adaptation plans.
- Steps should be taken to determine potential risks to public and private engineered structures that were most likely designed to accommodate historic climate conditions, not predictions of future climate. For example by encouraging the use of Engineers Canada *Public Infrastructure Engineering Vulnerability Committee Protocol*.

## 6.2 Traditional Land Use and Traditional Knowledge

Confidential Traditional Land Use (TLU) and TK information was not included in the review as permission was required from select Aboriginal groups for its public use. Publicly accessible information regarding TLU and TK of the Study Areas was not available for some of the Aboriginal groups identified as having Aboriginal interests in the region. In addition, TLU and TK are dynamic, and are often influenced by ecological conditions and anthropogenic disturbances, as well as various cultural and socio-economic factors. Therefore, the identification of comprehensive and current information regarding Aboriginal groups TLU and TK from the Study Areas is identified as a gap in this review. A gap also was identified in regard to the limited amount of TK data available about aquatic ecological health and groundwater.

As a result, it is recommended that a program be implemented to collect and record current TLU and TK related to the Study Areas with those Aboriginal groups that have interests in the region.

## 6.3 Water Quality and Sediment Quality

Water quality information in the Liard River is considered adequate for general characterization of water quality. Based on the activities in the watershed that could affect water quality (Section 4), the list of water quality parameters currently monitored in the Liard River is expected to be adequate however, improved consistency in the specific parameters, frequencies, and detection limits is recommended. The parameter list should be reviewed periodically to evaluate whether updates to analytical techniques or changes in watershed activities warrant changes to the parameter list. Monitoring at the historical long-term station at the Lower Crossing is recommended to recommence so that temporal comparisons can be made at this location. Additional recommendations to the water quality monitoring programs in the Liard River are:

- Field measurements of temperature, pH and dissolved oxygen should be collected during each sampling event;

- A standard list of parameters, analyzed at consistent detection limits, should be used for all sampling events at all stations so that data are more comparable to each other;
- Consistent seasonal monitoring at all stations so that annual averages are not skewed by differences in monitoring timing; and
- Upstream monitoring of organics and pesticides to allow for an upstream and downstream comparison of these parameters.

Water quality monitoring on the Petitot River should continue so that sufficient data are available for temporal trend analyses. Consideration should be made to increase the frequency of monitoring to collect at least one sample in each season annually (if possible) and expand the water quality parameter suite so that field pH and dissolved oxygen, total phosphorus and metals, and possibly organics and pesticides, are monitored similar to the Liard River.

The current monitoring of suspended sediment quality, including the list of parameters, in the Liard River upstream of the Kotaneelee River is sufficient for defining the quality of the suspended sediment at this location; continued monitoring at the Liard River upstream of the Kotaneelee River will allow for temporal analyses of trends in suspended sediment quality. To assess spatial trends in suspended sediment quality, monitoring at additional stations for suspended sediment quality could be completed. Additional sediment quality monitoring locations could be located where water quality is sampled if sufficient sediment can be collected at these stations. It is recommended that bottom sediment quality in the Liard River should also be monitored so that the potential for biological effects from suspended sediment quality can be more directly evaluated; sampling locations would have to be determined through a sediment-specific study.

Suspended and bottom sediment quality data monitoring are not recommended for the Petitot River until more data related to TSS concentrations have been collected for the Petitot River and the need for sediment quality monitoring in the Petitot River can be assessed.

Additional water and sediment quality monitoring will need to be evaluated for practical considerations, such as health and safety (e.g., if samples can be collected safely) and feasibility (e.g., sufficient suspended solids in water column available for sampling). The technical and financial resources needed to support any additional sampling and field measurements will also require consideration.

## 6.4 Water Quantity

Water quantity data collection on the Liard and Petitot rivers is considered sufficient.

## 6.5 Groundwater

Under its *Protection and Management of Groundwater* program, the Government of British Columbia has been mapping and classifying aquifers for over 15 years, involving a comprehensive ranking system of groundwater quantity and quality. Similar programs in the remainder of the Groundwater Study Area have not been undertaken, other than general data collection in terms of groundwater well locations, depths, etc. In this regard, aquifer use appears to be the main initiator of aquifer assessment and mapping programs.

The presence of discontinuous permafrost and its currently mapped status within the Groundwater Study Area is a significant data gap, given the trend for southerly areas of permafrost to exhibit permafrost decline to residual presence. Permafrost losses could increase the proportion of runoff water that becomes groundwater recharge, exhibited as shallower groundwater levels and increasing areas and flows of groundwater discharge to surface watercourses, water bodies and new springs, etc.

From aquifer mapping and identification of significant reaches of major surface watercourses within the Groundwater Study Area, the areas where groundwater discharges may exhibit the greatest increases from permafrost loss can be identified. The areas of surface water–groundwater mixing will have a higher potential for water quality change as well as a higher risk potential for detrimental surface water impact, in the case of surface contamination to shallow aquifers.

Limited groundwater quality information was identified for the Groundwater Study Area, as described in Section 5.4. Of the locations with available groundwater quality identified in this study, the most recent data were found to be from 2008. Water well licenses typically require the license holder to annually sample and analyze groundwater quality for parameters with respect to portability, i.e., the highest end-use for groundwater, although this does not appear to be occurring, or is unreported and not entered into groundwater quality databases.

## 6.6 Aquatic Ecosystem

Insufficient biological data are available for aquatic plants, plankton, and benthic invertebrates for the Liard and Petitot rivers. Studies of fish health have been conducted, including Taylor et al. (1998) as described in Section 5.7.2. It is recommended that benthic invertebrate monitoring is prioritized and be completed at least annually on both the Liard and Petitot rivers. Consideration should be given to monitoring benthic invertebrates, where possible, adjacent to long-term water quality monitoring stations to provide historical context for water quality conditions at the stations. However, the most appropriate sampling methods, frequency, and locations should be evaluated prior to establishing a long-term monitoring program for benthic invertebrates.

# 7.0 MONITORING REQUIREMENTS

## 7.1 Monitoring Approaches, Procedures, and Methodology

Monitoring locations and data collected for water and sediment quality, water quantity, and biological indicators and aquatic ecosystem are given in Sections 5.2.1, 5.3, and 5.7 respectively.

A summary of monitoring programs, including triggers and tracking metrics where applicable, is shown in Table 50.

**Table 50: Current Monitoring Programs in the Liard and Petitot Basins**

| Data Type | Water Quality and Sediment Quality | | | Biological Indicators and Aquatic Ecosystem | Hydrology (Water Quantity) | Groundwater |
|---|---|---|---|---|---|---|
| **Program** | EC and NWT Long-term Monitoring for the Liard River | GNWT Kotaneelee (Liard River) Project | EC and BC Long-term Monitoring Program (Petitot River Basin) | n/a | Water Survey of Canada hydrometric monitoring | Community drinking water programs in Fort Liard and Nahanni Butte |
| **Methods** | Water quality sampling and field measurements | Water and suspended sediment quality monitoring | Water quality sampling and field measurements | n/a | Automated water level monitoring and manual discrete discharge measurements | Grab samples sent to laboratories for analysis, every 1 – 3 years |
| **Number of Sites** | 3 | 1 | 3 | n/a | 7 on Liard River, 1 on Petitot River | 2 wells in Fort Liard; 1 well in Nahanni Butte |
| **Duration of Program** | Variable depending on station, from 1960 to 2015 | 1992 to 1995, 2001 to 2015 | 2013 to 2015 | n/a | 1942 - present | Nahanni Butte: 1995 – present; Fort Liard: 2004 - present |
| **Tracking Metrics** | Conventional parameters, nutrients, metals, organics and pesticides | Conventional parameters, nutrients, metals, organics and pesticides, but parameters monitored have varied over time | Conventional parameters and nutrients | n/a | Water Level, Discharge | Chemistry |
| **Triggers** | n/a | n/a | n/a | n/a | n/a | n/a |
| **Reporting Requirements** | Data provided by Environment Canada and have been reported in historical publically available documents | Data provided by GNWT and have been reported in historical publically available documents | Data provided by Environment Canada | n/a | Data published to www.wateroffice.ec.gc.ca | n/a |
| **Recommendations** | Consistent frequency at each location and recommence monitoring at the Lower Crossing station | Continue current water quality monitoring program and consider expanding sediment quality monitoring to other locations on the Liard River so that spatial and temporal comparisons can be completed. | Expand water quality parameters to include a similar parameter suite to the Liard River locations | n/a | Continue current monitoring program | Continue current program; evaluate groundwater quality data needs and increase monitoring as required |

# 8.0 CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

**GOLDER ASSOCIATES LTD.**

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https://capws.golder.com/sites/1547195liardpetitotlearningplans/liard_petitot_working_version_multiuser/1547195_liard petitot final report_march 2017.docx

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# IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT

**Standard of Care:** Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practicing under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

**Basis and Use of the Report:** This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder cannot be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client cannot rely upon the electronic media versions of Golder's report or other work products.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder cannot be responsible for use of portions of the report without reference to the entire report.

Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

**Soil, Rock and Groundwater Conditions:** Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. **The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report.** The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

**Sample Disposal:** Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

**Follow-Up and Construction Services:** All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

**Changed Conditions and Drainage:** Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly. Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.

# APPENDIX A

## Liard and Petitot River Basins State of Knowledge Report Mapbook

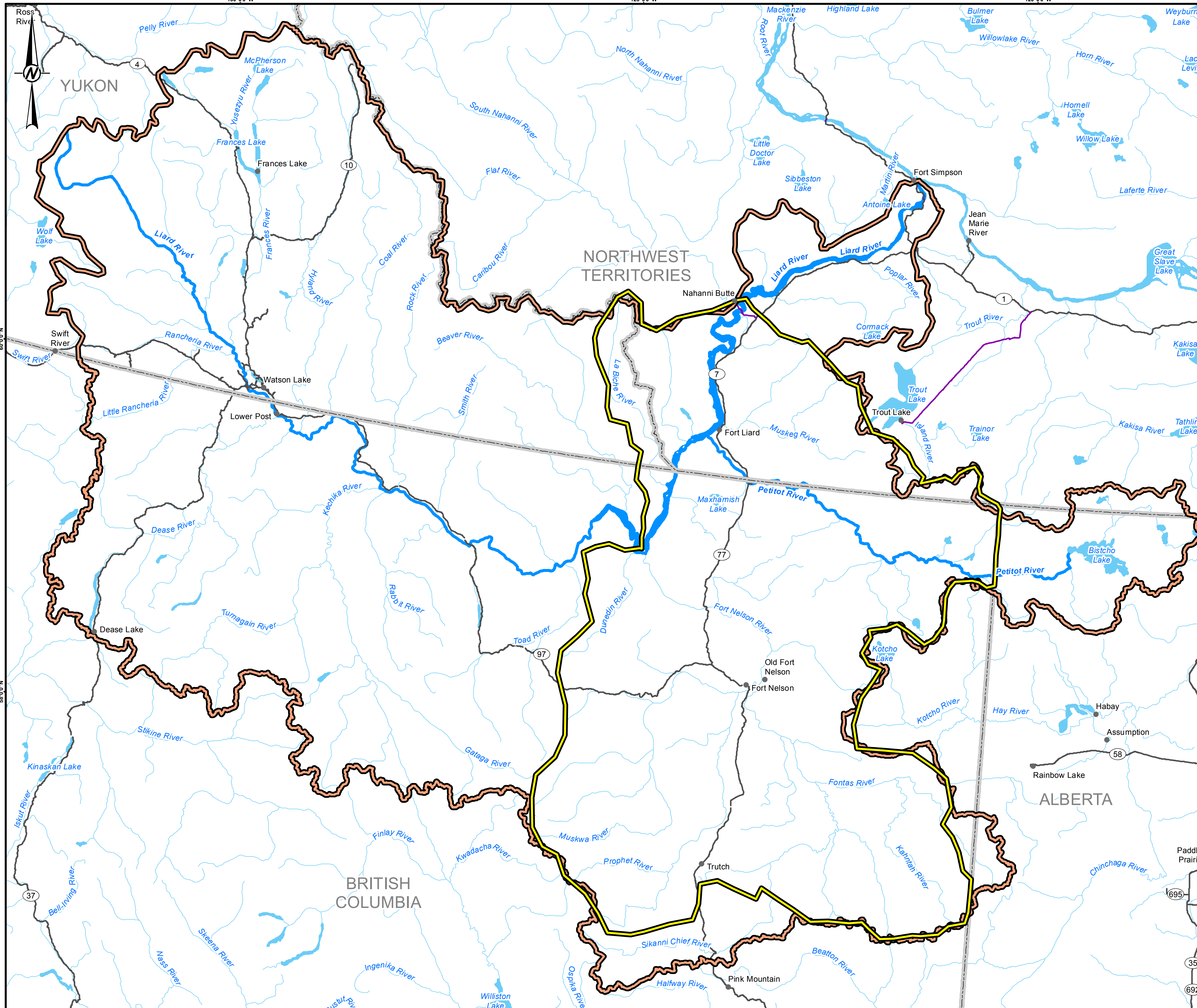
March 2017

# LIARD AND PETITOT RIVER BASINS STATE OF KNOWLEDGE REPORT MAPBOOK

## British Columbia - Northwest Territories Bilateral Water Management Agreement


Map A-1 – Location of Groundwater and Surface Water Study Areas
Map A-2 – Ecozones
Map A-3 – Ecoregions
Map A-4 – Shaded Relief
Map A-5 – Sub-Basin Boundaries, EC Climate Stations, and EC Hydrological Stations
Map A-6 – Bedrock Geology
Map A-7 – Surficial Geology
Map A-8 – Land Cover Classification
Map A-9 – Fire History
Map A-10 – Water Licences
Map A-11 – Protected Areas
Map A-12 – Potential Point Sources in Study Areas
Map A-13 – Land Disturbances in Fort Nelson Area
Map A-14 – Activities Related to the Exploration and Extraction of Oil and Gas
Map A-15 – Activities Related to the Exploration and Extraction of Minerals
Map A-16 – Forestry Areas and Activities
Map A-17 – Federal Contaminated Sites in the Groundwater Study Area
Map A-18 – Surface Water and Groundwater Monitoring Stations


MAPBOOK




**LEGEND**

- POPULATED PLACE
- ALL-SEASON ROAD
- WINTER ROAD
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

0 50 100

1:2,500,000 KILOMETRES

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT

GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**LOCATION OF GROUNDWATER AND SURFACE WATER STUDY AREAS**

CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

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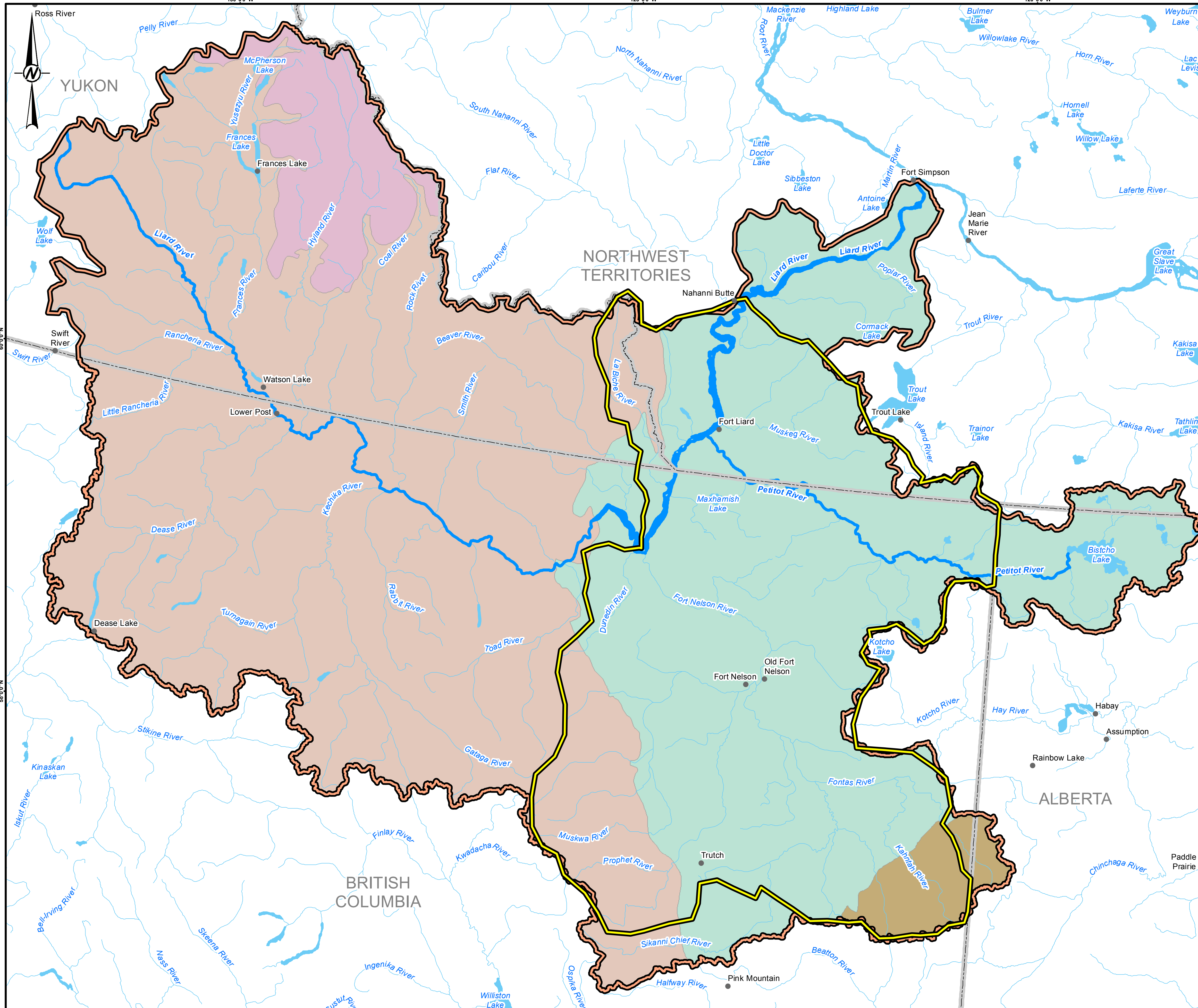
PATH: I:\2015\1547195\Figures\MAPBOOK\FIG A-1 - 1547195 Study Areas.mxd




**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

**ECOZONES**

- BOREAL CORDILLERA
- BOREAL PLAIN
- TAIGA CORDILLERA
- TAIGA PLAIN

0 50 100

1:2,500,000 KILOMETRES

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. ECOZONES OBTAINED FROM AGRICULTURE AND AGRI-FOOD CANADA (AAFC).

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT

GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**ECOZONES**

CONSULTANT

Golder Associates

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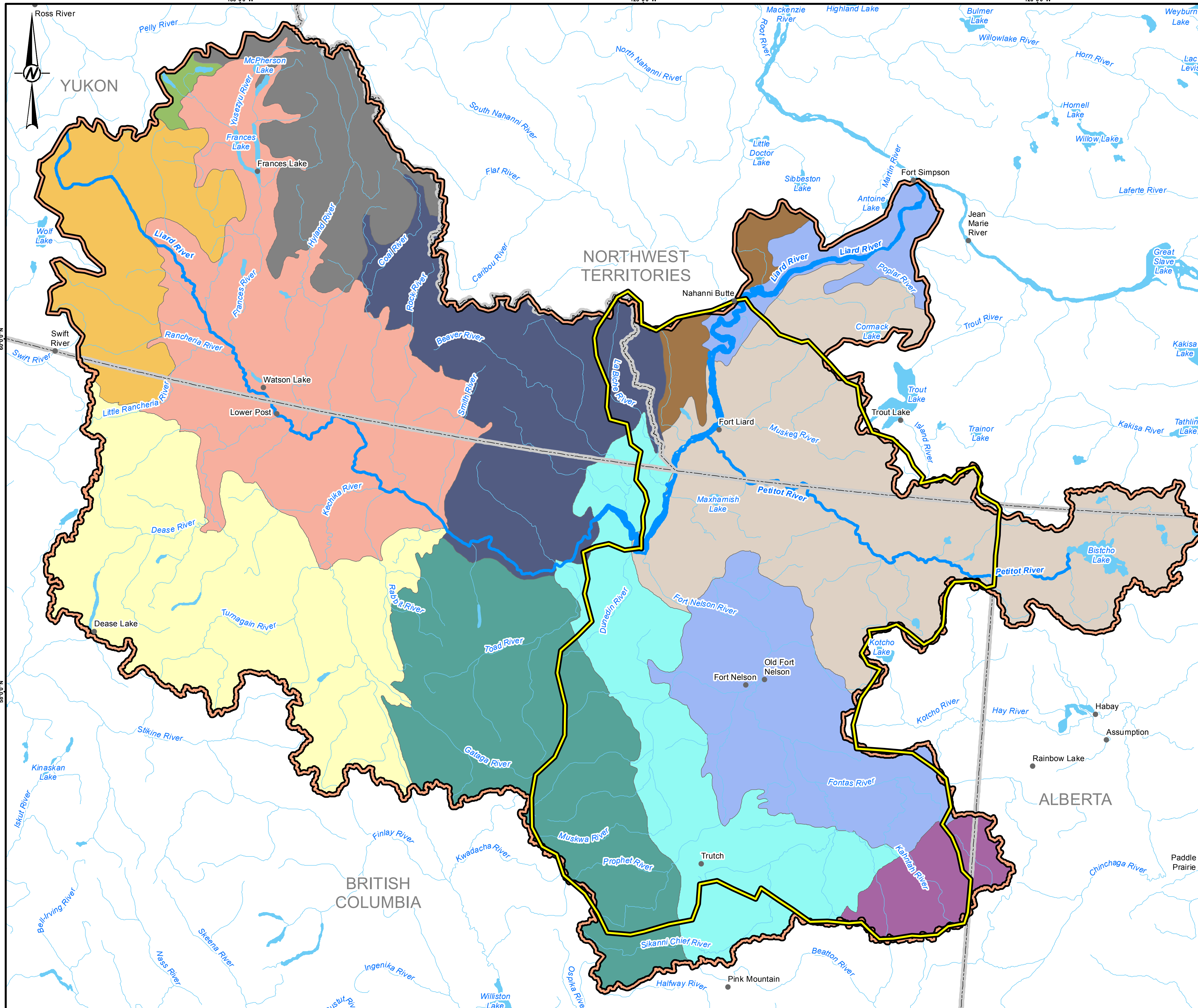


LEGEND

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

ECOREGIONS

- BOREAL MOUNTAINS AND PLATEAUS
- CLEAR HILLS UPLAND
- HAY RIVER LOWLAND
- HYLAND HIGHLAND
- LIARD BASIN
- MUSKWA PLATEAU
- NORTHERN ALBERTA UPLANDS
- NORTHERN CANADIAN ROCKY MOUNTAINS
- PELLY MOUNTAINS
- SELWYNN MOUNTAINS
- SIBBESTON LAKE PLAIN
- YUKON PLATEAU-NORTH

0 50 100

1:2,500,000 KILOMETRES

REFERENCE(S)

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. ECOREGIONS OBTAINED FROM AGRICULTURE AND AGRI-FOOD CANADA (AAFC).

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT

GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**ECOREGIONS**

CONSULTANT

Golder Associates

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| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
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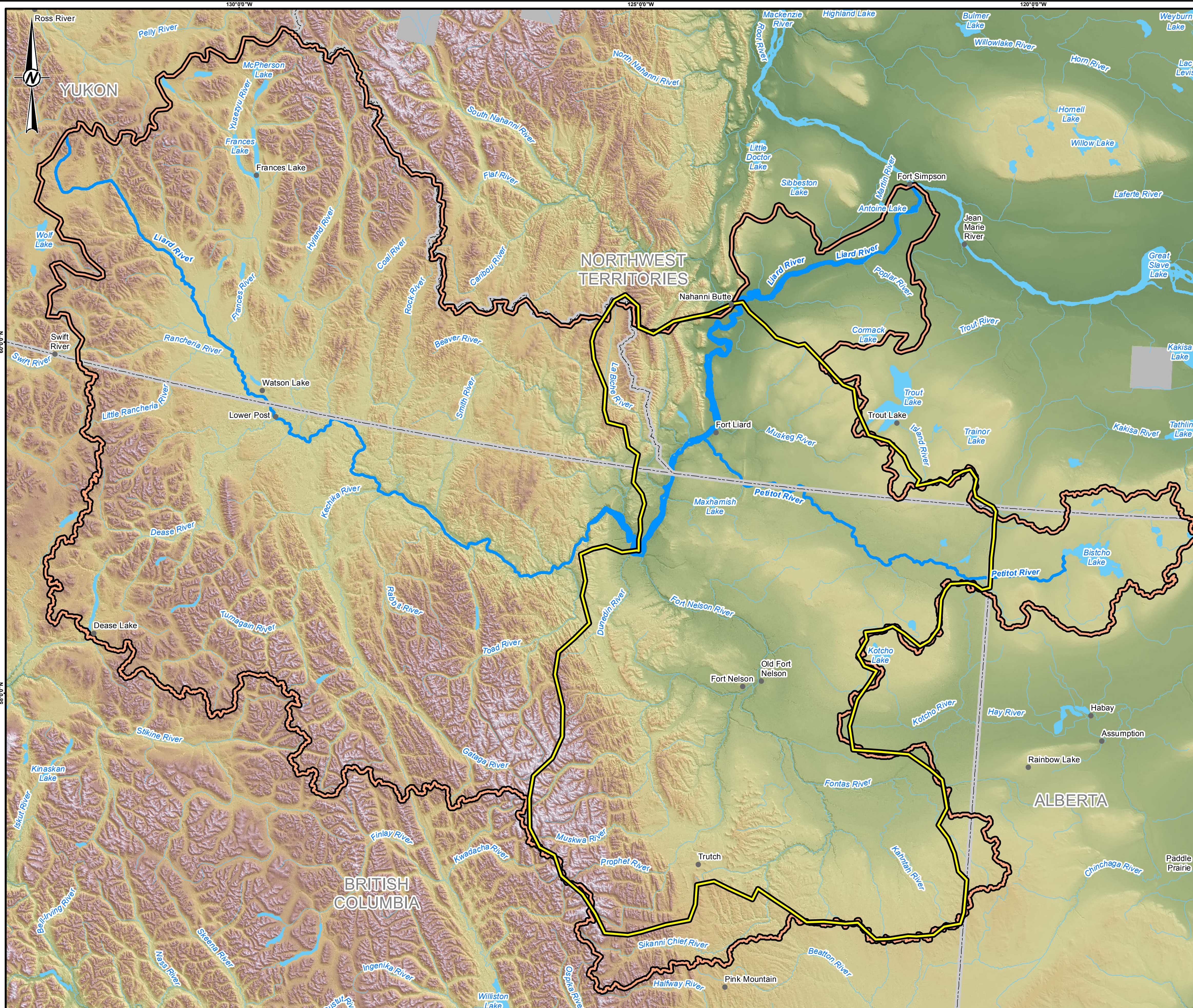


LEGEND

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

ELEVATION (m)

- NO DATA
- HIGH : 2855
- LOW : 97

0 50 100

1:2,500,000 KILOMETRES

REFERENCE(S)

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
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GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**SHADED RELIEF**

CONSULTANT

Golder Associates

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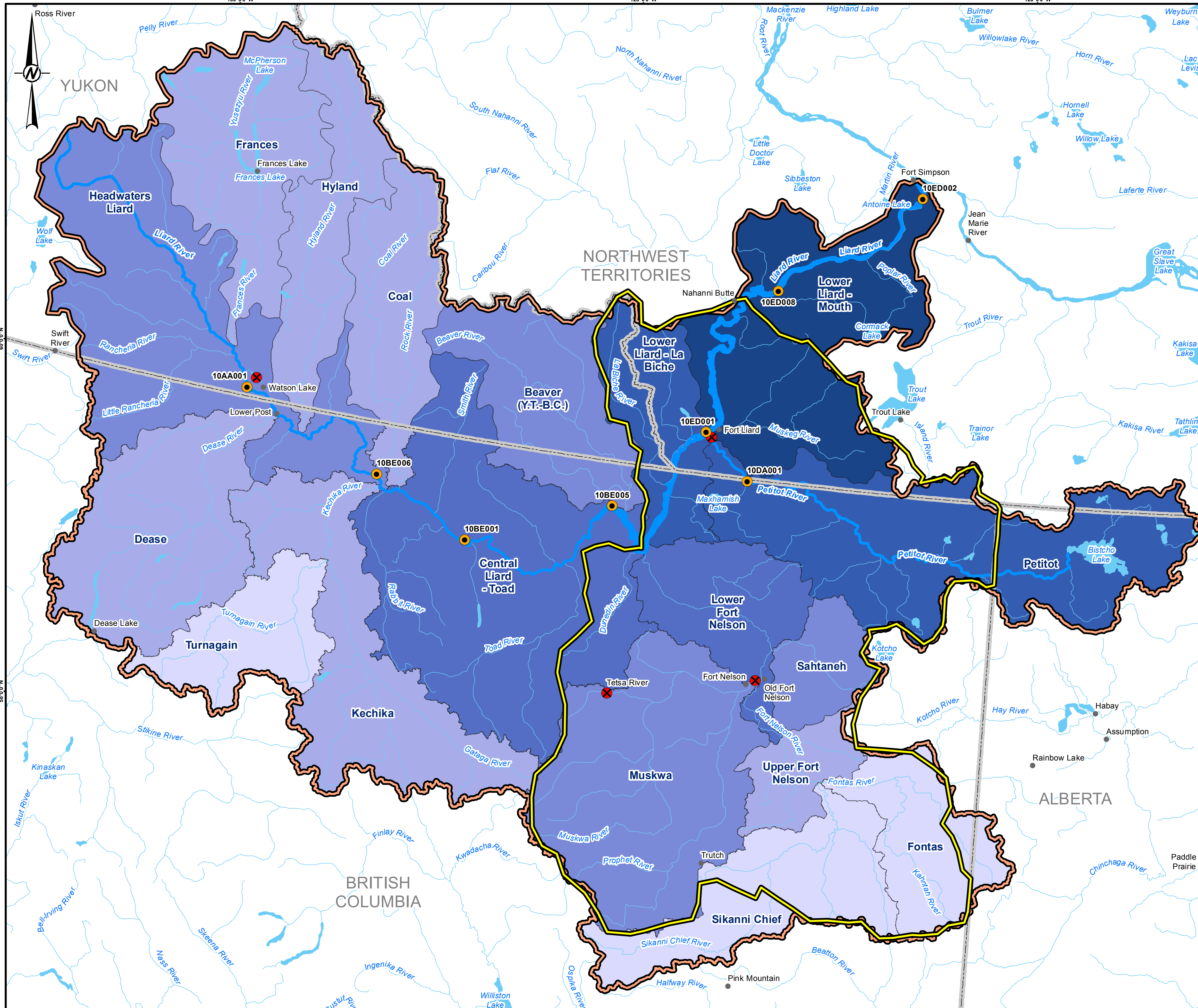


**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA
- CLIMATE STATION
- HYDROLOGICAL STATION

**SUB-BASINS**

UPSTREAM

DOWNSTREAM

0 50 100

1:2,500,000 KILOMETRES

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. WATER SURVEY OF CANADA SUB-BASIN BOUNDARIES OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.

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GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**SUB-BASIN BOUNDARIES, EC CLIMATE STATIONS, AND EC HYDROLOGICAL STATIONS**

CONSULTANT

Golder Associates

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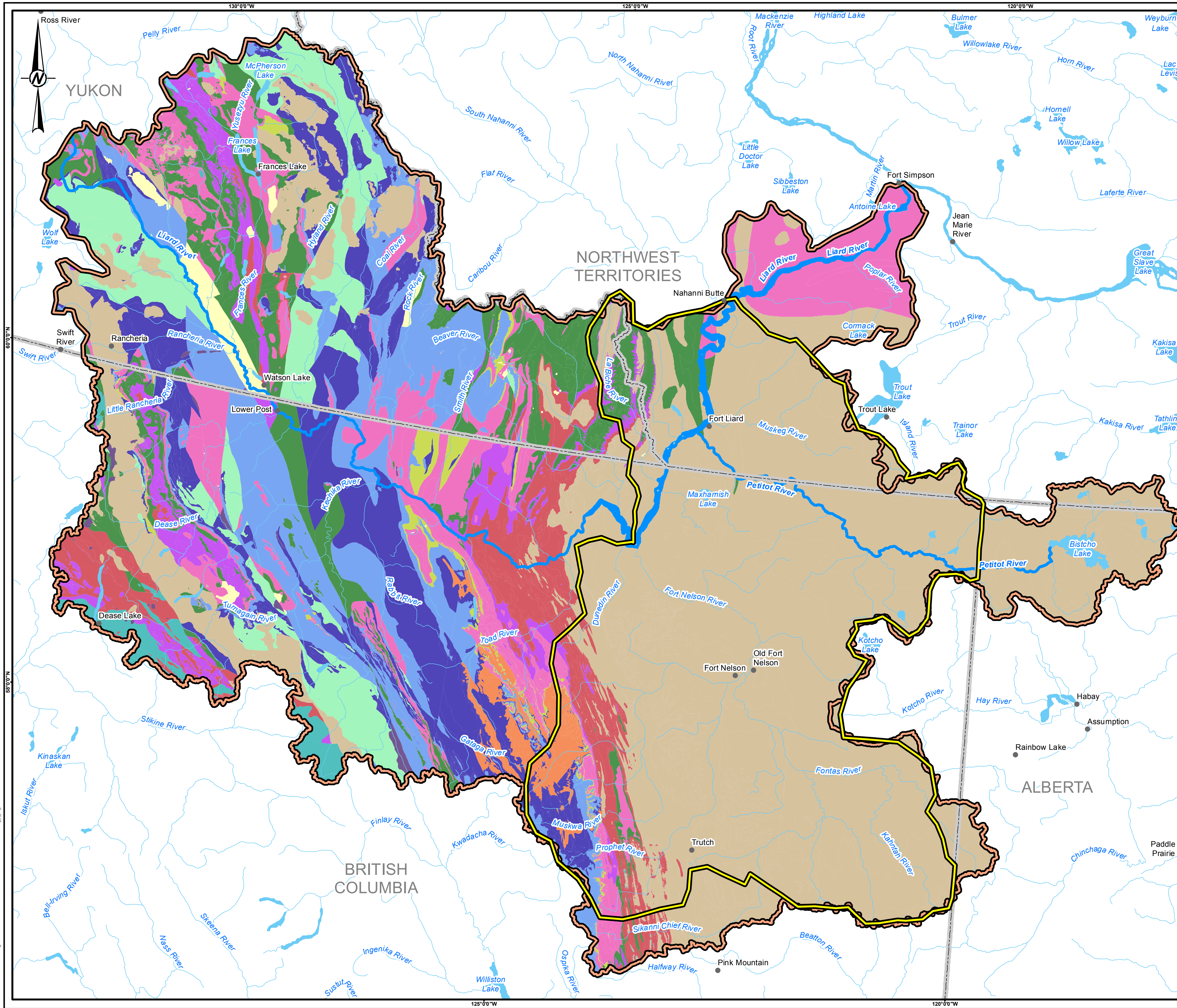


**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

**BEDROCK GEOLOGY AGE**

- QUATERNARY
- PALEOGENE
- CRETACEOUS
- JURASSIC
- TRIASSIC
- PERMIAN
- CARBONIFEROUS
- DEVONIAN
- SILURIAN
- ORDOVICIAN
- CAMBRIAN
- NEOPROTEROZOIC
- MESOPROTEROZOIC

0 50 100
1:2,500,000 KILOMETRES

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. BEDROCK GEOLOGY DATA: CONTAINS INFORMATION LICENCED UNDER THE OPEN GOVERNMENT LICENCE – BRITISH COLUMBIA; YUKON GEOLOGICAL SURVEY - JANUARY 2016 RELEASE; GOVERNMENT OF NORTHWEST TERRITORIES; ALBERTA GEOLOGICAL SURVEY.

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

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PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**BEDROCK GEOLOGY**

CONSULTANT

Golder Associates

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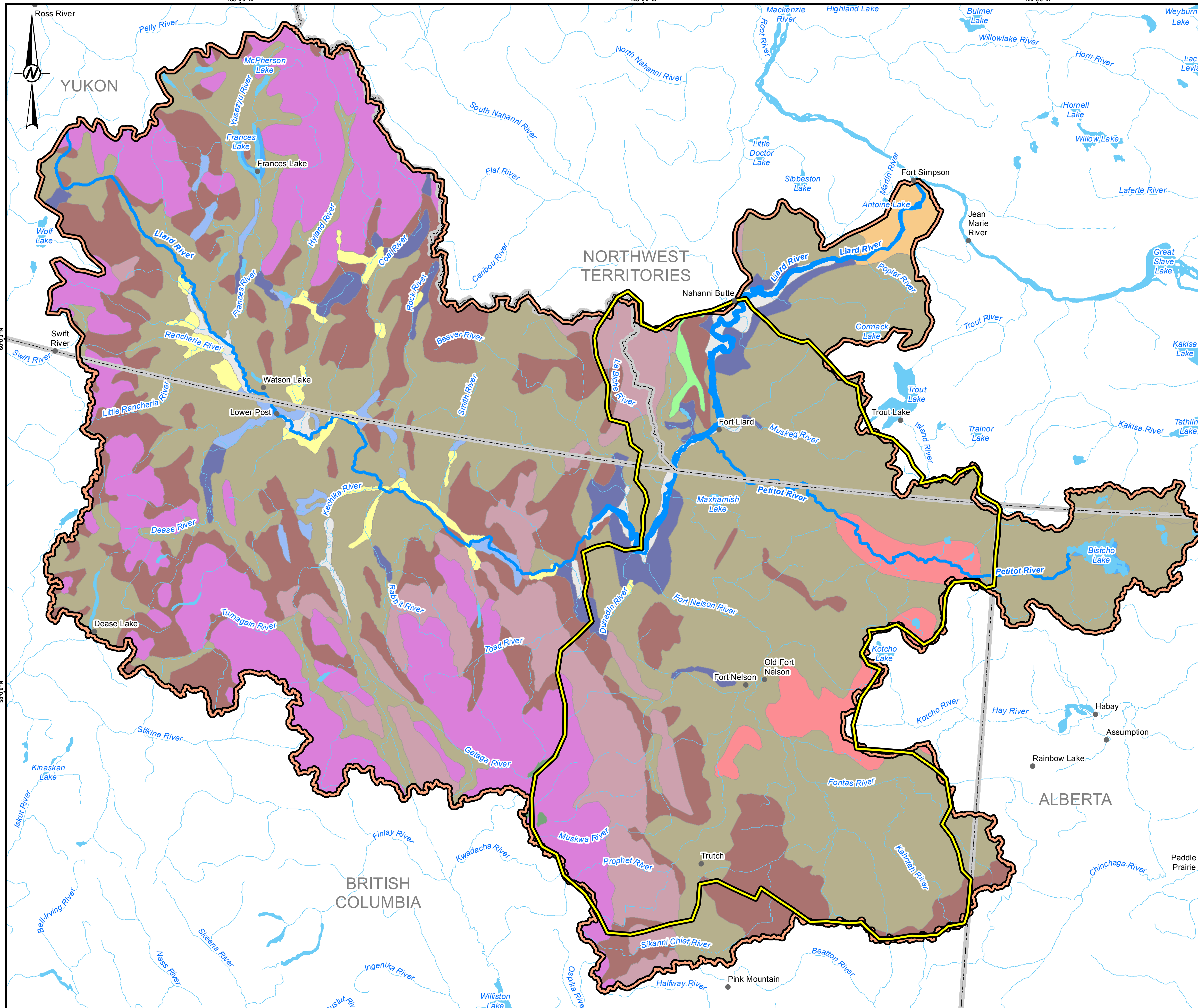


**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

**SURFICIAL GEOLOGY**

- ALLUVIAL DEPOSITS
- ALPINE COMPLEXES
- COARSE GRAINED (GLACIO)LACUSTRINE
- COLLUVIAL FINES
- COLLUVIAL RUBBLE
- FINE GRAINED (GLACIO)LACUSTRINE
- GLACIERS
- GLACIOFLUVIAL COMPLEX
- GLACIOFLUVIAL PLAIN
- ORGANIC DEPOSITS
- TILL BLANKET
- TILL VENEER
- WATER

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
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CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**SURFICIAL GEOLOGY**

CONSULTANT
Golder Associates

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|---|---|
| YYYY-MM-DD | 2017-03-13 |
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| REVIEWED | RB |
| APPROVED | DP |

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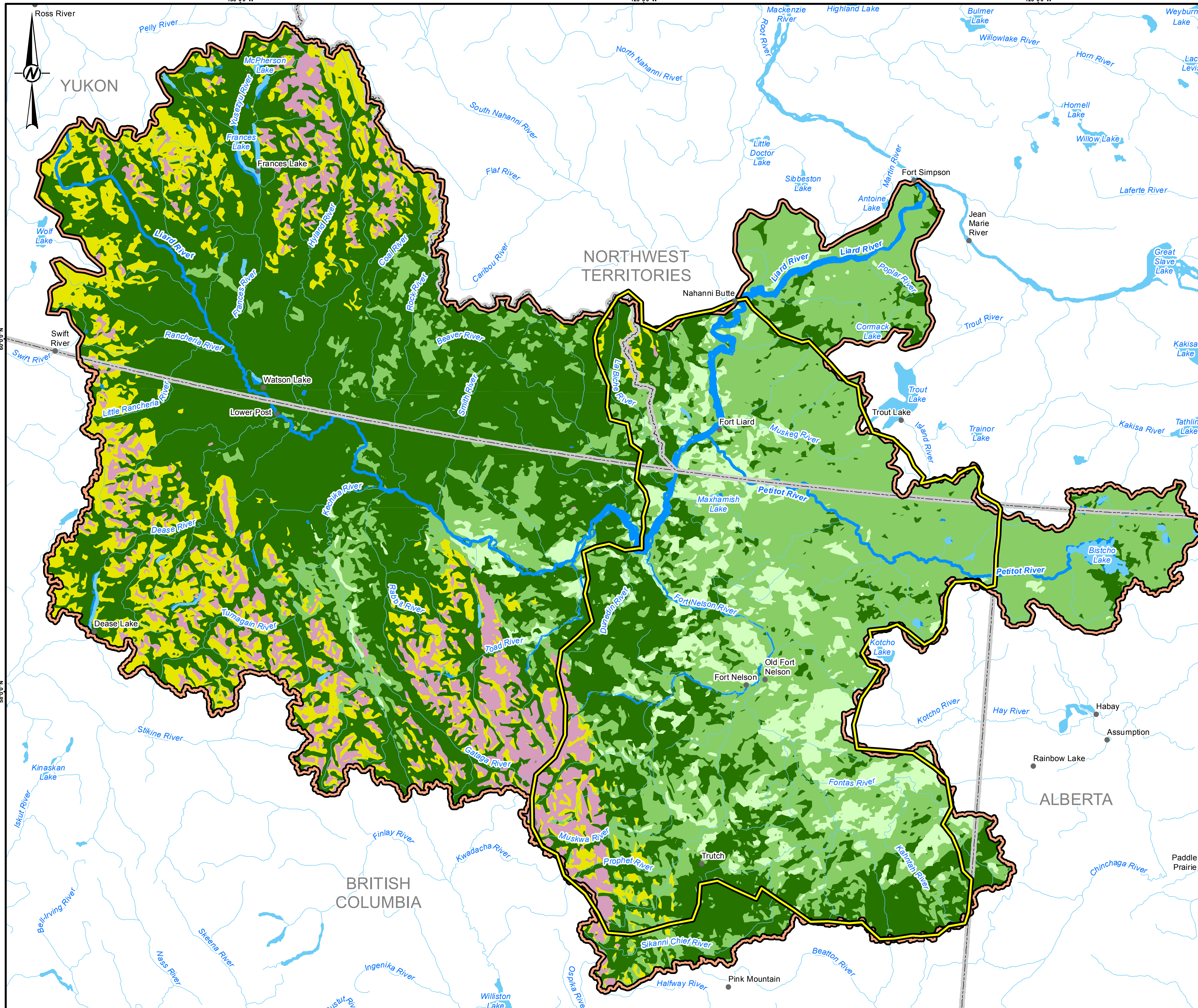
PATH: I:\2015\1547195\Figures\MAPBOOK\FIG A-7 - 1547195 Surficial Geology.mxd




**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

**LAND COVER CLASSIFICATION**

- CONIFEROUS FOREST
- DECIDUOUS TREES
- MIXED FOREST
- TUNDRA
- BARREN LAND
- ICE/SNOW
- WATER

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. AVHRR LAND COVER CLASSIFICATION OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**LAND COVER CLASSIFICATION**

CONSULTANT
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
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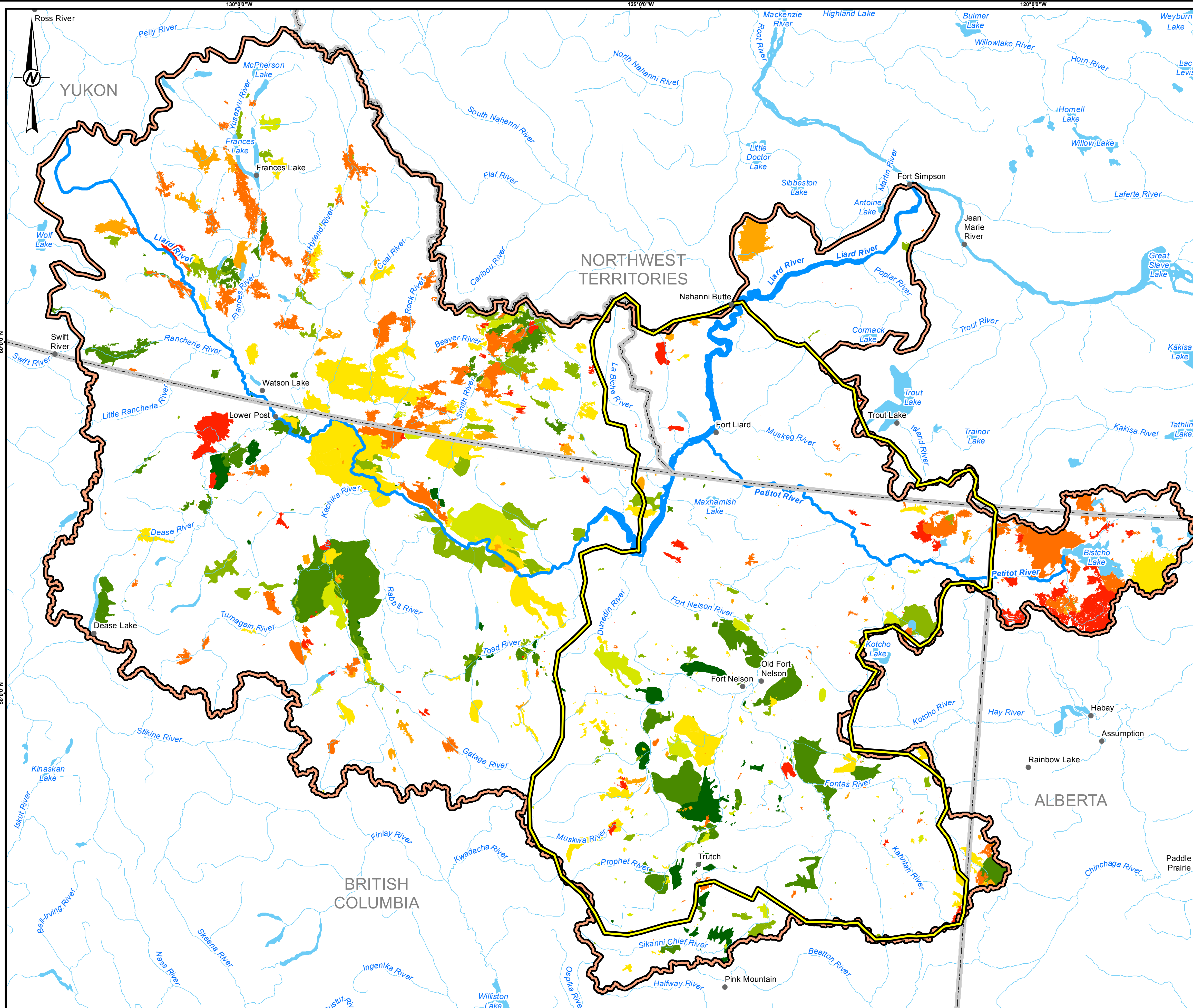
| 1547195 | 3000 | 0 | A-8 |




**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

**HISTORY OF FIRE**

- 1940-1949
- 1950-1959
- 1960-1969
- 1970-1979
- 1980-1989
- 1990-1999
- 2000-2009
- 2010-2012

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. NATIONAL FIRE DATABASE OBTAINED FROM DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
# FIRE HISTORY

CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
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| 1547195 | 3000 | 0 | A-9 |

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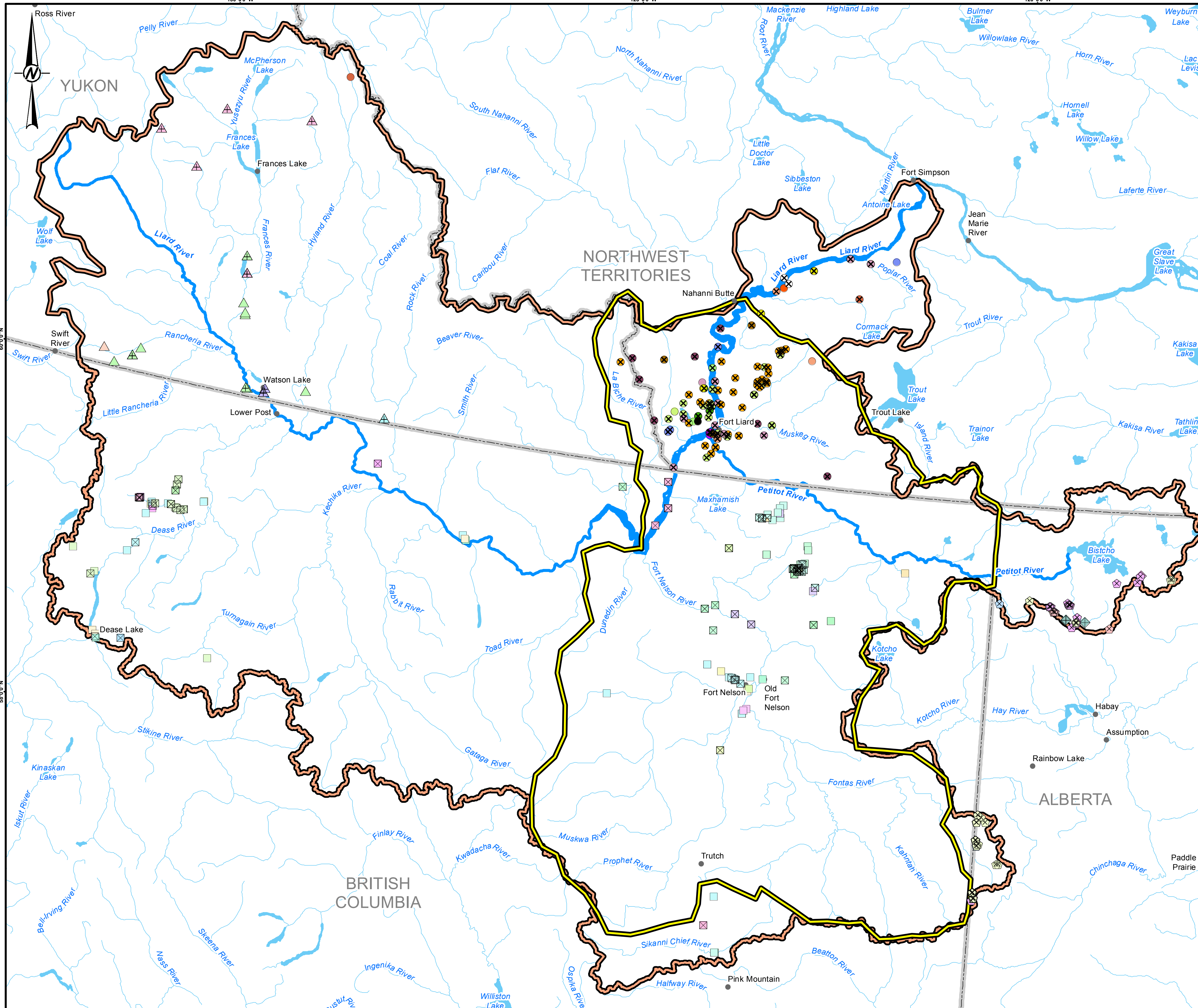
PATH: I:\2015\1547195\Figures\MAPBOOK\FIG A-9 - 1547195 Fire History.mxd




**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

**NWT PERMITS AND LICENCES**

- CAMP (J)
- FUEL STORAGE (H)
- INDUSTRIAL (L1)
- MINING EXPLORATION (C)
- MISCELLANEOUS (L8)
- MISCELLANEOUS (X)
- MUNICIPAL (L3)
- OIL AND GAS (A)
- PIPELINE (P)
- POWER (L4)
- QUARRYING (Q)
- ROAD PRIVATE (F)
- ROAD PUBLIC (E)
- SEISMIC (B)
- STAGING AREA (T)
- WOOD OPS (W)
- CLOSED OR EXPIRED
- APPLICATION

**YUKON WATER LICENCES**

- HYDRO (POWER)
- MISCELLANEOUS
- MUNICIPAL
- PLACER MINING (+5 TO 10 YR)
- QUARTZ MINING
- CLOSED

**AB GROUNDWATER LICENCES**

- OILFIELD INJECTION
- SPECIFIED BY THE DIRECTOR
- EXPIRED

**AB SURFACE WATER LICENCES**

- CONSTRUCTION
- CONSTRUCTION RELATED TO OIL&GAS ACTIVITY
- HYDROSTATIC TESTING
- OILFIELD INJECTION
- EXPIRED/CANCELLED

**BC WATER LICENCES**

- BOTTLE SALES
- CAMPS
- COOLING
- DOMESTIC
- DUST CONTROL
- ENTERPRISE
- IRRIGATION
- LAND IMPROVE
- MINING EQUIPMENT
- MINING-PLACER
- MINING-PROCESSING ORE
- OIL FIELD INJECTION
- POWER-GENERAL
- POWER-RESIDENTIAL
- PROCESSING
- ROAD MAINTENANCE
- STOCKWATERING
- STORAGE-NON POWER
- STORAGE-POWER
- TRUCK WASHING
- WATER DELIVERY
- WATERWORKS (OTHER)
- WATERWORKS LOCAL AUTH
- WORK CAMPS
- EXPIRED/CANCELLED/ABANDONED/PENDING

0 50 100
1:2,500,000 KILOMETRES

REFERENCE(S)
1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. WATER LICENCE DATA: GOVERNMENT OF YUKON, SAHTU LAND AND WATER BOARD, GOVERNMENT OF ALBERTA; LICENCED UNDER THE OPEN GOVERNMENT LICENCE – BRITISH COLUMBIA.
PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**WATER LICENCES**

CONSULTANT

| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
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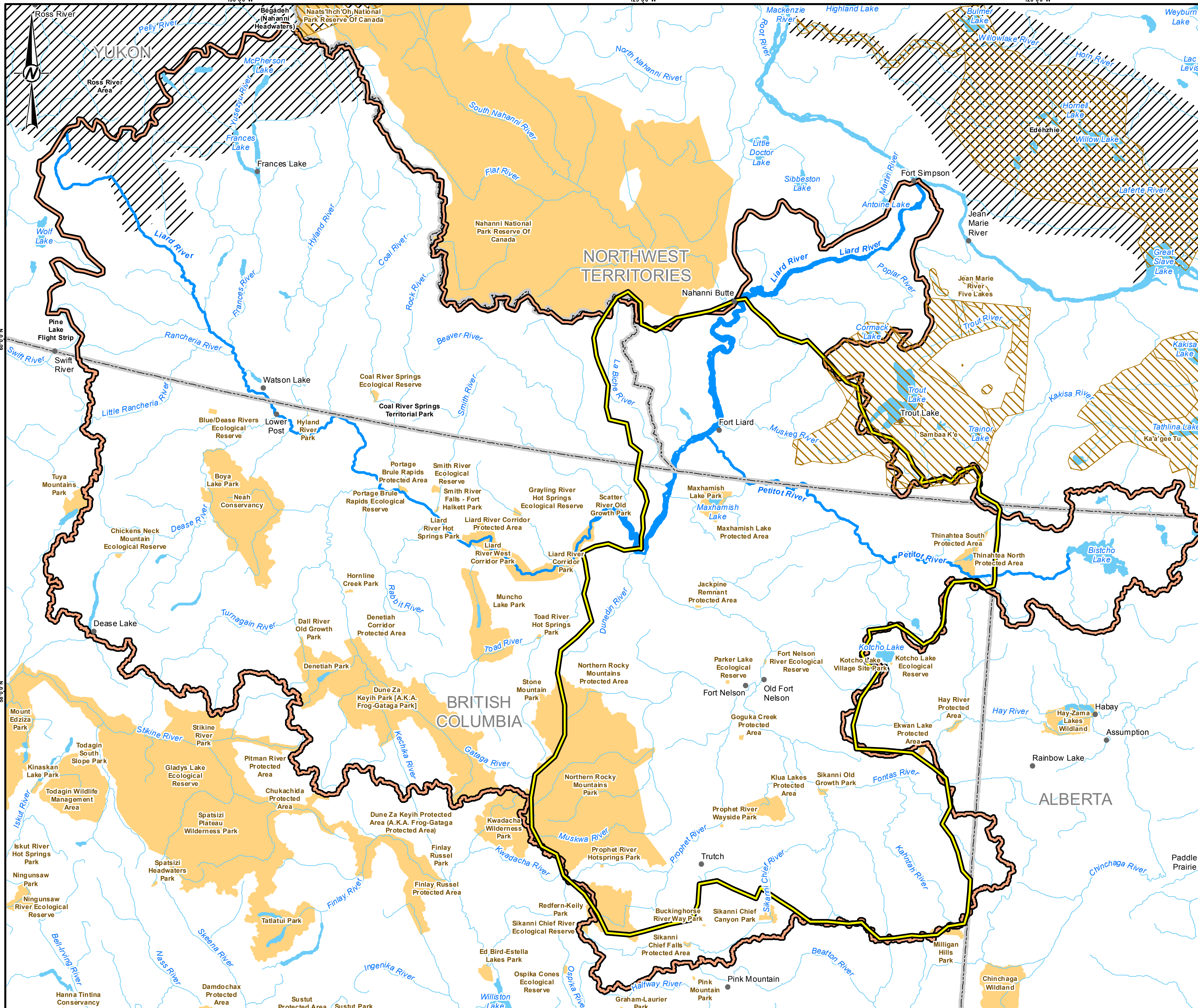
| 1547195 | 3000 | 0 | A-10 |




**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA
- AREAS WITH PERMANENT PROTECTION
- AREAS WITH INTERIM PROTECTION
- PROPOSED PROTECTED AREA

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. PROTECTED AREAS (NATIONAL DATASET) OBTAINED FROM CANADIAN COUNCIL ON ECOLOGICAL AREAS.
5. INTERIM PROTECTION AREAS OBTAINED FROM GOVERNMENT OF YUKON AND NORTHWEST TERRITORIES PROTECTED AREAS STRATEGY (NWT-PAS), DEPARTMENT OF RESOURCES, WILDLIFE AND ECONOMIC DEVELOPMENT (RWED), GOVERNMENT OF THE NORTHWEST TERRITORIES (GNWT), 2002
6. PROPOSED PROTECTED AREAS OBTAINED FROM GOVERNMENT OF NORTHWEST TERRITORIES

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**PROTECTED AREAS**

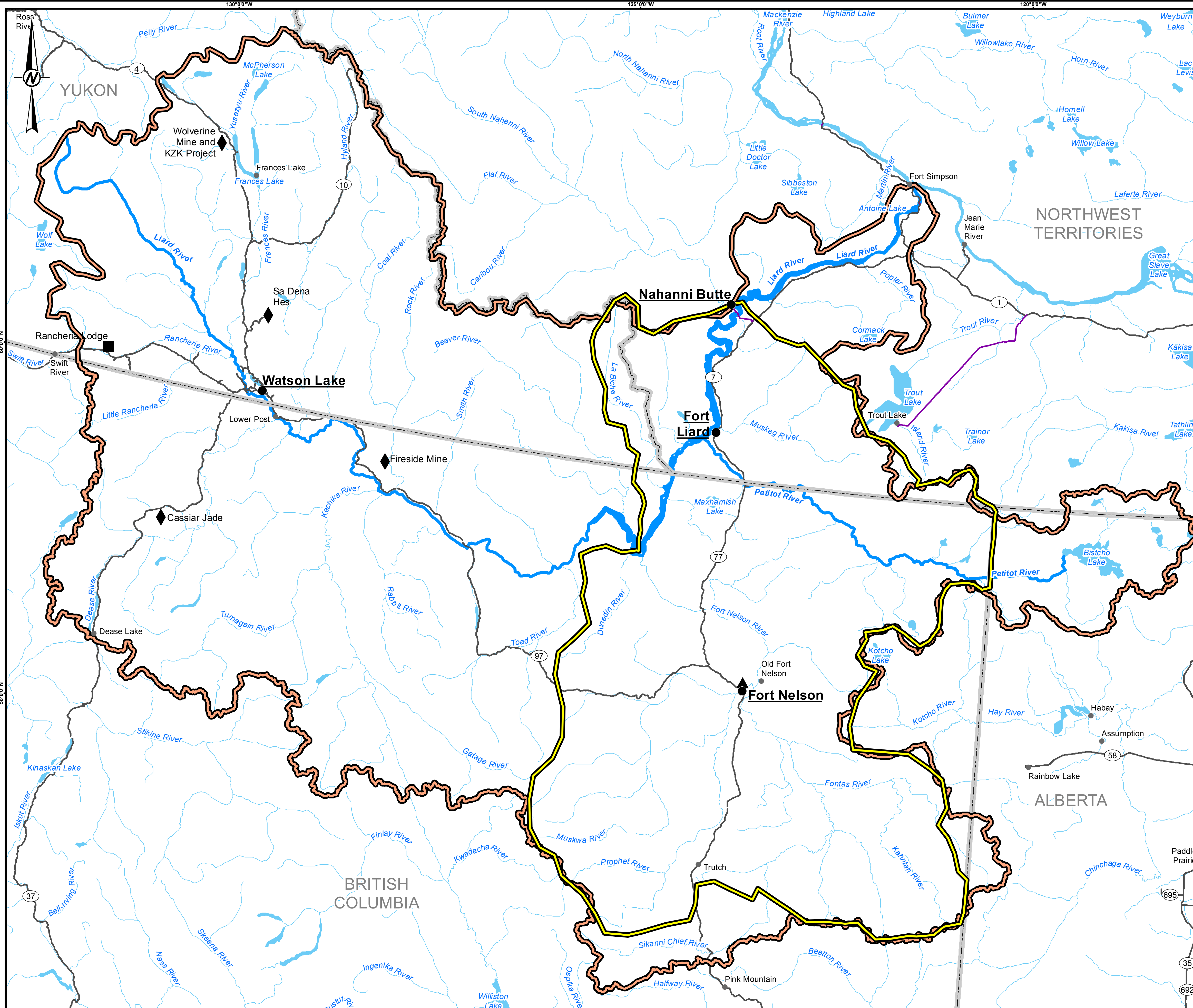
CONSULTANT
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2017-03-29 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
|---|---|---|---|
| 1547195 | 3000 | 0 | A-11 |

PATH: I:\2015\1547195\Figures\MAPBOOK\FIG A-11 - 1547195 Protected Areas.mxd

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B




**LEGEND**

- POPULATED PLACE
- ALL-SEASON ROAD
- WINTER ROAD
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

**POINT SOURCE**

- COMMUNITY
- HYDROELECTRIC
- MINING
- OIL AND GAS

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT

GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**POTENTIAL POINT SOURCES IN STUDY AREAS**

CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | MH |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
|---|---|---|---|
| 1547195 | 3000 | 0 | A-12 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

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LEGEND

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

DISTURBANCES

- CAMP - CLOSED - END OF OPERATION
- FUEL STORAGE - CLOSED - END OF OPERATION
- MISCELLANEOUS - EXPIRED - NOT CLOSED
- MISCELLANEOUS - CLOSED - END OF OPERATION
- OIL AND GAS - ACTIVE - PERMIT / LICENSE ISSUED OR EXTENDED / RENEWED
- OIL AND GAS - EXPIRED - NOT CLOSED
- OIL AND GAS - CLOSED - END OF OPERATION
- QUARRYING - EXPIRED - NOT CLOSED
- QUARRYING - CLOSED - END OF OPERATION
- ROAD PRIVATE - CLOSED - END OF OPERATION
- ROAD PUBLIC - ACTIVE - PERMIT / LICENSE ISSUED
- ROAD PUBLIC - CLOSED - END OF OPERATION
- SEISMIC - CLOSED - END OF OPERATION
- WOODS / FORESTRY OPERATIONS - CLOSED - END OF OPERATION
- MISCELLANEOUS - EXPIRED - NOT CLOSED
- MISCELLANEOUS - CLOSED - END OF OPERATION
- OIL AND GAS - ACTIVE - PERMIT / LICENSE ISSUED
- OIL AND GAS - EXPIRED - NOT CLOSED
- OIL AND GAS - CLOSED - END OF OPERATION
- QUARRYING - CLOSED - END OF OPERATION
- ROAD PRIVATE - CLOSED - END OF OPERATION

UNVALIDATED DISTURBANCES

- OIL AND GAS
- QUARRYING
- RUNWAY
- UNKNOWN
- WOODS / FORESTRY OPERATIONS
- ROAD
- SEISMIC

0 20 40

1:1,000,000 KILOMETRES

REFERENCE(S)
1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**LAND DISTURBANCES IN THE FORT LIARD AREA**

CONSULTANT

Golder Associates

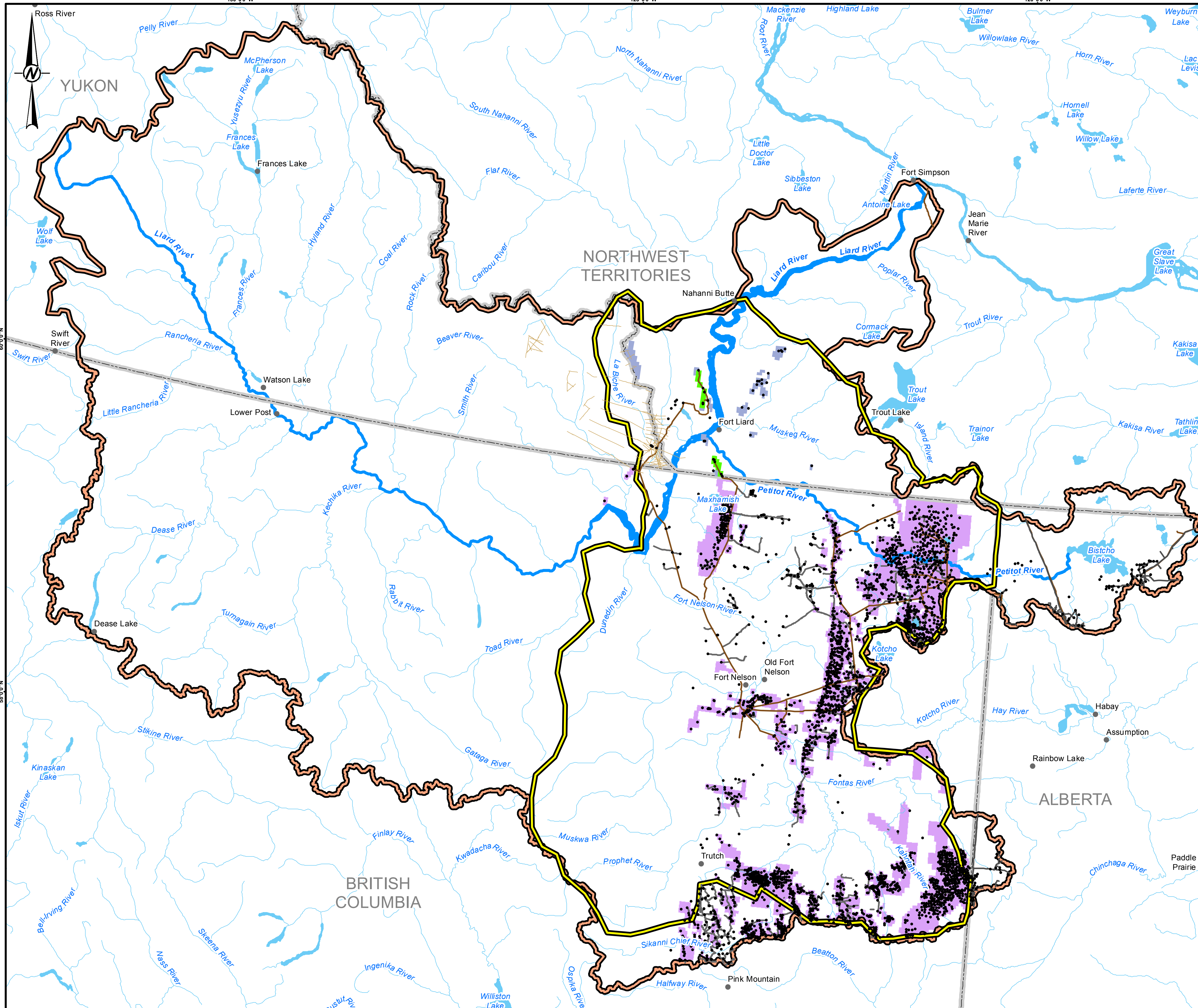
| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
|---|---|---|---|
| 1547195 | 3000 | 0 | A-13 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25mm

PATH: I:\2015\1547195\Figures\MAPBOOK\FIG A-13 - 1547195 Disturbance NWT.mxd




**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA
- ACTIVE WELL (ALBERTA, BRITISH COLUMBIA, NORTHWEST TERRITORIES, AND YUKON)
- YUKON OIL AND GAS SEISMIC LINE
- ALBERTA PIPELINE ROUTE
- NORTHWEST TERRITORIES AND SURROUNDING AREA PIPELINE
- BRITISH COLUMBIA PIPELINE RIGHT-OF-WAY
- BRITISH COLUMBIA OIL AND GAS FIELD

**NWT OIL AND GAS RIGHTS**

- PRODUCTION LICENSE
- SIGNIFICANT DISCOVERY LICENSE

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. ALBERTA OIL AND GAS DATA OBTAINED FROM IHS ENERGY INC.
5. BC OIL AND GAS DATA CONTAINS INFORMATION LICENCED UNDER THE OPEN GOVERNMENT LICENCE – BRITISH COLUMBIA.
6. YUKON OIL AND GAS DATA: OBTAINED FROM GOVERNMENT OF YUKON.
7. NWT OIL AND GAS DATA OBTAINED FROM GOVERNMENT OF NORTHWEST TERRITORIES.

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**ACTIVITIES RELATED TO THE EXPLORATION AND EXTRACTION OF OIL AND GAS**

CONSULTANT
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
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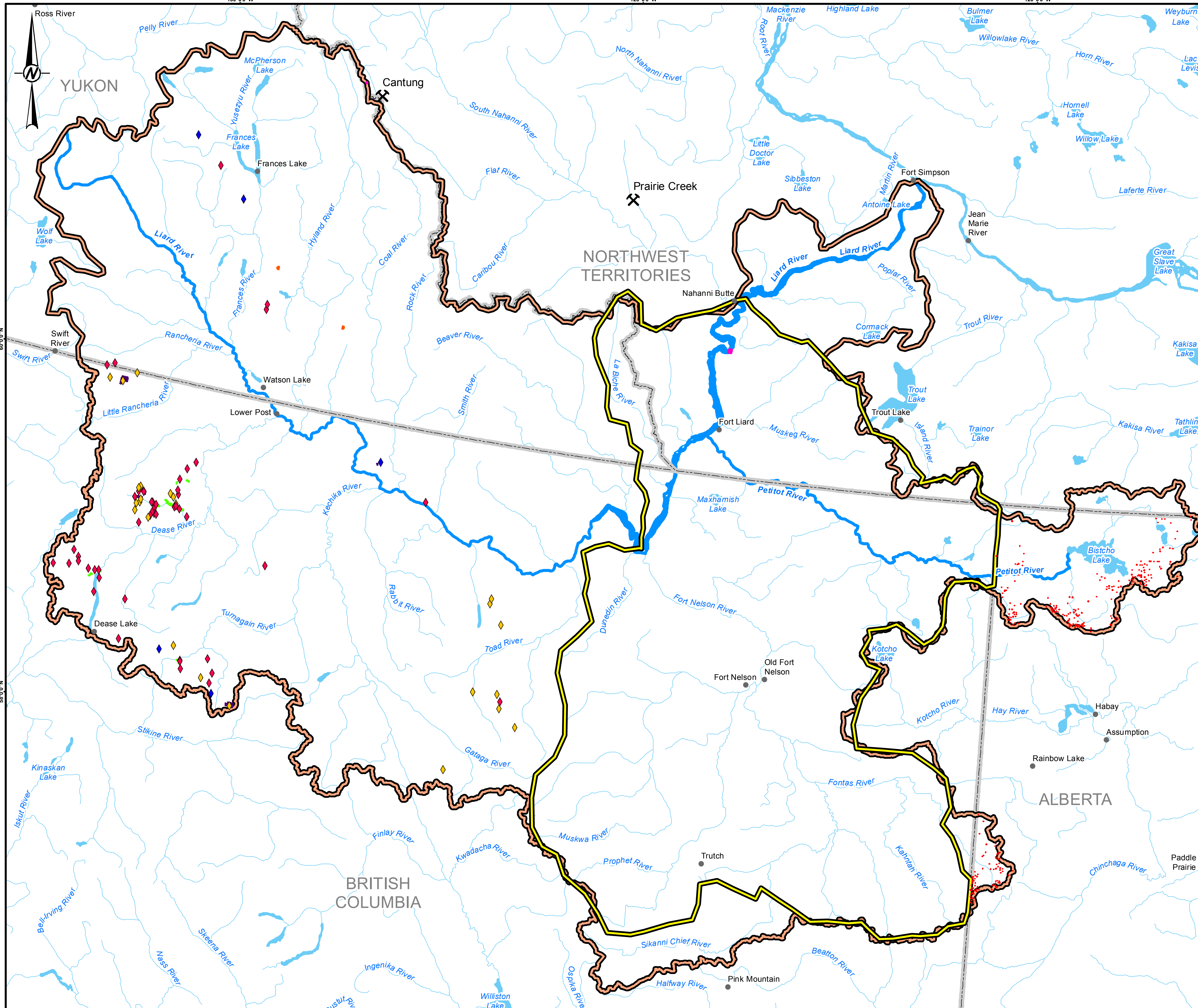
| 1547195 | 3000 | 0 | A-14 |



PATH: I:\2015\1547195\Figures\MAPBOOK\FIG A-14 - 1547195 Oil and Gas.mxd




**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

**MINERAL OCCURRENCES (BRITISH COLUMBIA AND YUKON)**

- DEVELOPED PROSPECT
- PAST PRODUCER
- PRODUCER
- NWT PROPOSED MINE LOCATION
- ALBERTA MINERAL SURFACE LEASE - ACTIVE/DISPOSED
- BRITISH COLUMBIA MINERAL LEASE - ACTIVE
- BRITISH COLUMBIA PLACER LEASE - ACTIVE
- NORTHWEST TERRITORIES MINING LEASE - ACTIVE
- YUKON QUARTZ LEASE - ACTIVE

0 50 100

1:2,500,000 KILOMETRES

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. MINERAL DATA: CONTAINS INFORMATION LICENCED UNDER THE OPEN GOVERNMENT LICENCE – BRITISH COLUMBIA; DATA OBTAINED FROM GOVERNMENT OF NORTHWEST TERRITORIES; DATA OBTAINED FROM GOVERNMENT OF YUKON; AND © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED

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CLIENT

GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

**ACTIVITIES RELATED TO THE EXPLORATION AND EXTRACTION OF MINERALS**

CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
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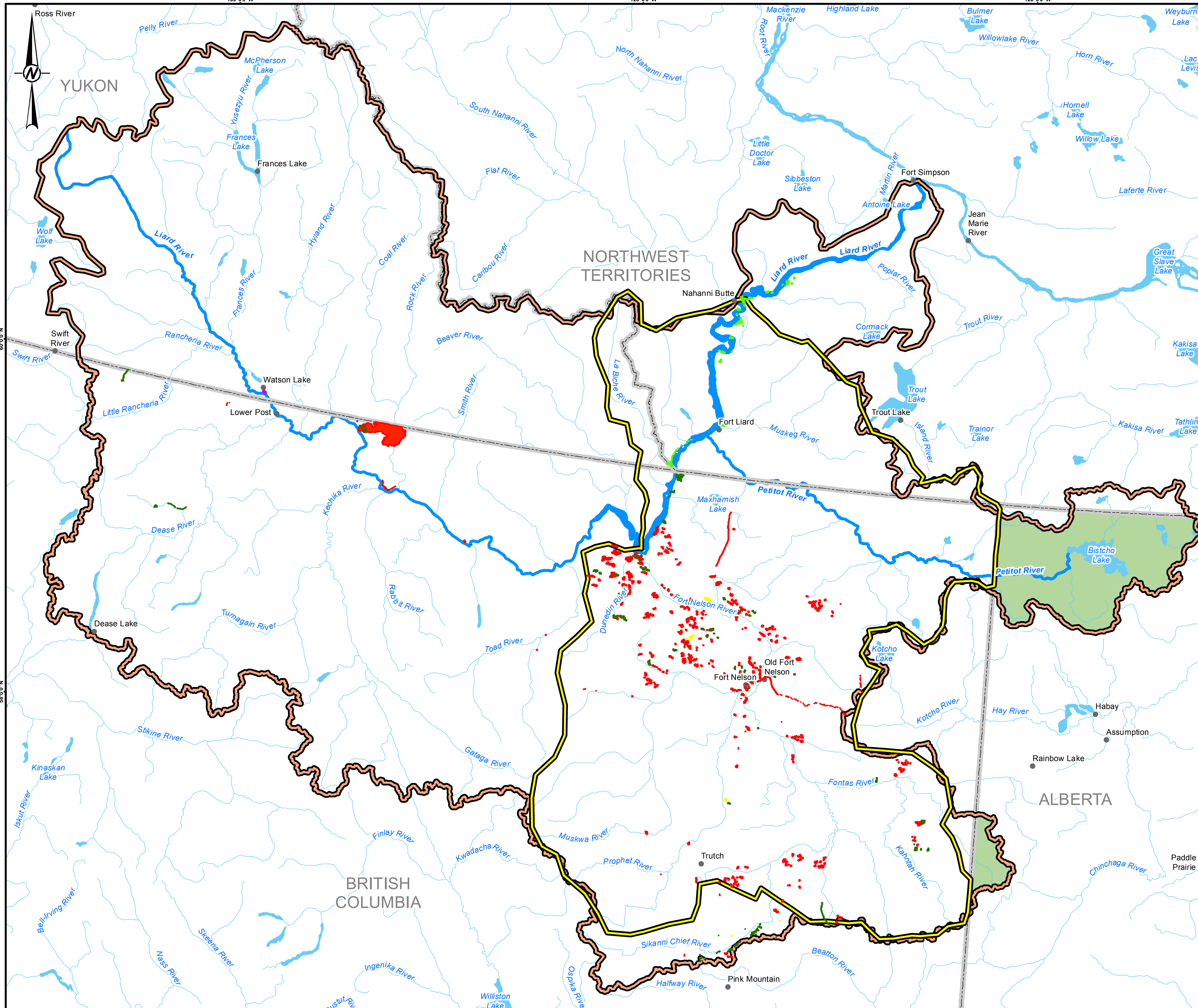
| 1547195 | 3000 | 0 | A-15 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25mm

PATH: I:\2015\1547195\Figures\MAPBOOK\FIG A-15 - 1547195 Mineral.mxd




**LEGEND**

- POPULATED PLACE
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA
- ALBERTA FOREST PROTECTION AREA
- NORTHWEST TERRITORIES HISTORICAL CUTBLOCK
- YUKON LOGGED AREA

**BRITISH COLUMBIA FOREST TENURE CUTBLOCKS**

- ACTIVE
- PENDING
- RETIRED

0 50 100

1:2,500,000 KILOMETRES

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. FORESTRY DATA: CONTAINS INFORMATION LICENCED UNDER THE OPEN GOVERNMENT LICENCE – BRITISH COLUMBIA; DATA OBTAINED FROM GOVERNMENT OF YUKON; DATA OBTAINED FROM GOVERNMENT OF NORTHWEST TERRITORIES; DATA © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.

PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT

GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT

LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE

# FORESTRY AREAS AND ACTIVITIES

CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | DP |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
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| 1547195 | 3000 | 0 | A-16 |

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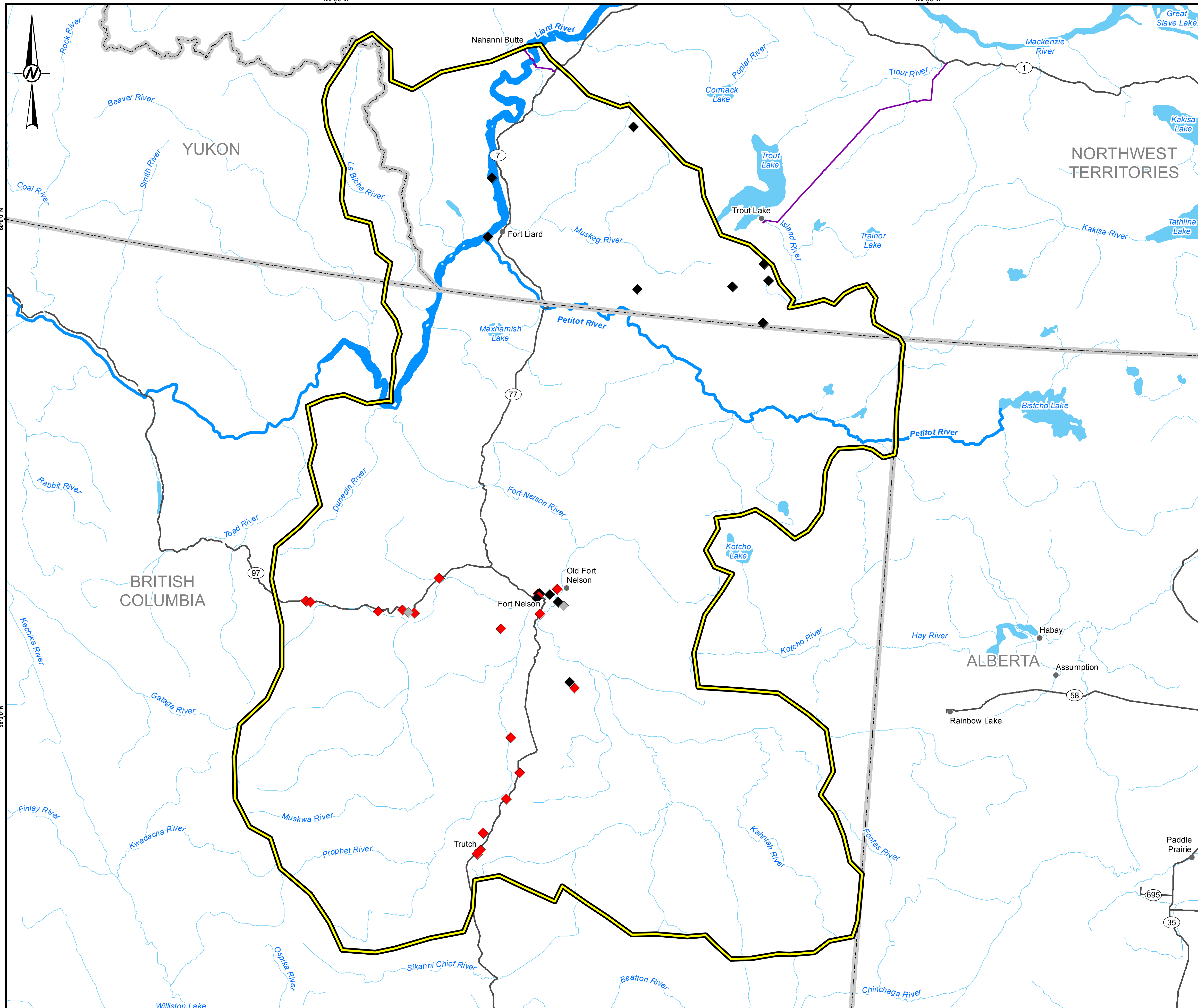
25mm

PATH: I:\2015\1547195\Figures\MAPBOOK\FIG A-16 - 1547195 Forestry.mxd




**LEGEND**

- POPULATED PLACE
- ALL-SEASON ROAD
- WINTER ROAD
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA

**FEDERAL CONTAMINATED SITES**

- ACTIVE
- CLOSED
- SUSPECTED

0 40 80
1:1,750,000 KILOMETRES

**REFERENCE(S)**

1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. CONTIMINATED SITES OBTAINED FROM GOVERNMENT OF CANADA
PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**FEDERAL CONTAMINATED SITES IN THE GROUNDWATER STUDY AREA**

CONSULTANT
Golder Associates

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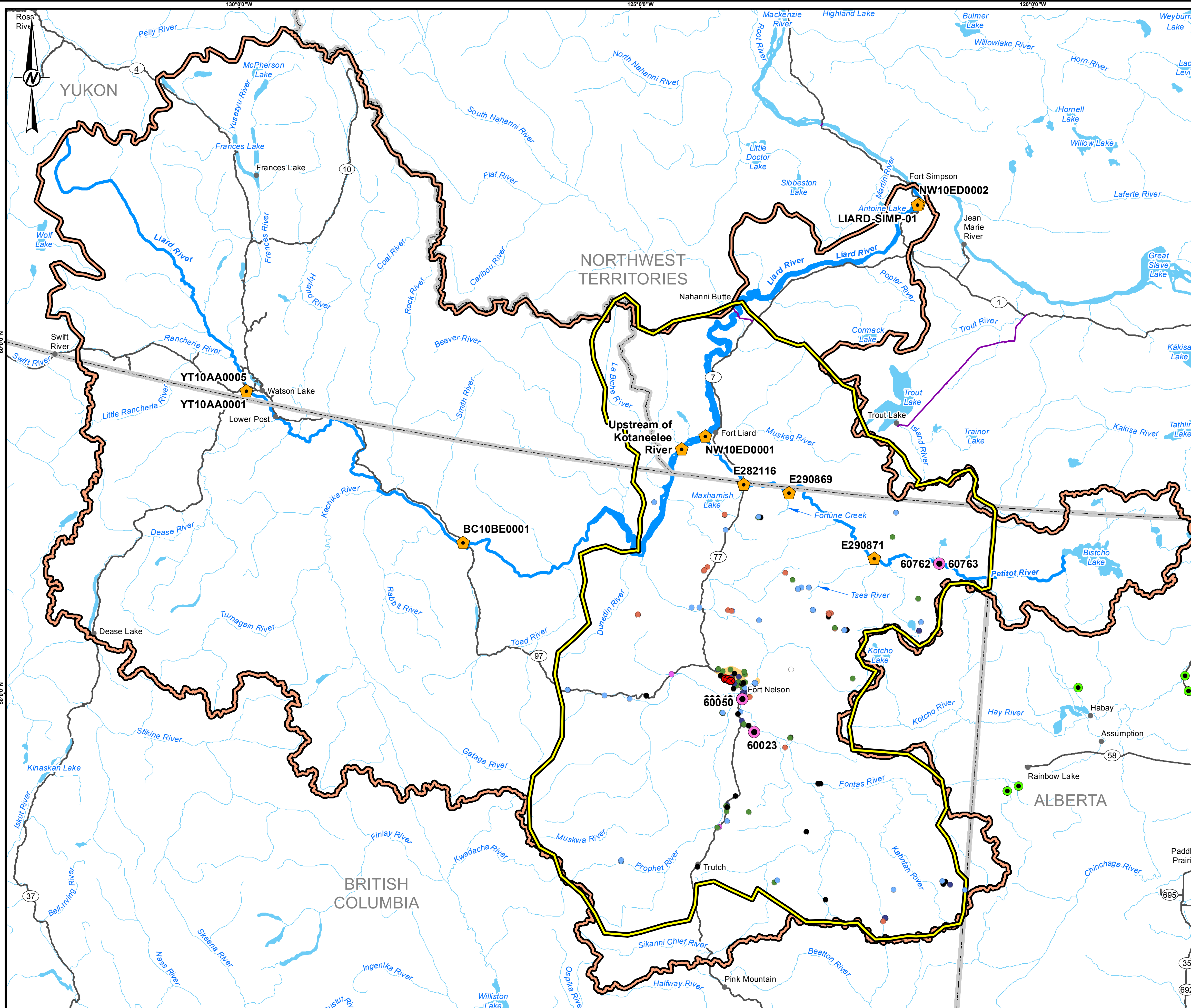
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | TG |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
|---|---|---|---|
| 1547195 | 3000 | 0 | A-17 |




LEGEND

- POPULATED PLACE
- ALL-SEASON ROAD
- WINTER ROAD
- PROVINCIAL BOUNDARY
- GROUNDWATER STUDY AREA
- SURFACE WATER STUDY AREA

GROUNDWATER DATA

- ALBERTA CHEMISTRY WELL
- BRITISH COLUMBIA CHEMISTRY STATION

BRITISH COLUMBIA GROUNDWATER WELLS

- OTHER
- ABANDONED
- COMMERCIAL AND INDUSTRIAL
- OBSERVATION WELL
- PRIVATE DOMESTIC
- TEST
- UNKNOWN WELL USE
- WATER SUPPLY SYSTEM
- LICENSED SPRING
- AQUIFER

SURFACE WATER DATA

- SURFACE WATER MONITORING STATION

0 50 100
1:2,500,000 KILOMETRES

NOTE(S)
1. GROUNDWATER DATA SHOWN ON THIS MAP HAS BEEN CLIPPED TO THE GROUNDWATER STUDY AREA.
2. SURFACE WATER DATA SHOWN ON THIS MAP HAS BEEN CLIPPED TO THE SURFACE WATER STUDY AREA.

REFERENCE(S)
1. STUDY AREAS CREATED FROM SUB-BASINS PROVIDED BY WATER SURVEY OF CANADA AND BC MINISTRY OF ENVIRONMENT.
2. WATER: ATLAS OF CANADA 2M SCALE
3. ROADS: NATIONAL ROAD NETWORK, GEOBASE
4. BC DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE - BRITISH COLUMBIA
5. AB DATA OBTAINED FROM GOVERNMENT OF ALBERTA.
PROJECTION: CANADA LAMBERT CONFORMAL CONIC

CLIENT
GOVERNMENT OF NORTHWEST TERRITORIES

PROJECT
LIARD AND PETITOT SURFACE AND GROUNDWATER STATE OF KNOWLEDGE REPORT

TITLE
**SURFACE WATER AND GROUNDWATER MONITORING STATIONS**

CONSULTANT
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2017-03-13 |
| DESIGNED | TG |
| PREPARED | LMS |
| REVIEWED | RB |
| APPROVED | DP |

| PROJECT NO. | PHASE | REV. | FIGURE |
|---|---|---|---|
| 1547195 | 3000 | 0 | A-18 |

# APPENDIX B

## Water Quality Data Summary

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Upper Crossing | | | | | | | Upper Crossing-Westbank | | | | | | | Lower Crossing | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960-2015 | | | | | | | 1983-1994 | | | | | | | 1984-1994 | | | | | | |
| | | Min | 25$^{th}$ Percentile[B] | Median | 75$^{th}$ Percentile[B] | Max | Percent Below Detection Limit | Count | Min | 25$^{th}$ Percentile[B] | Median | 75$^{th}$ Percentile[B] | Max | Percent Below Detection Limit | Count | Min | 25$^{th}$ Percentile[B] | Median | 75$^{th}$ Percentile[B] | Max | Percent Below Detection Limit | Count |
| **Conventional Parameters** | | | | | | | | | | | | | | | | | | | | | | |
| Dissolved inorganic carbon | mg/L | 15 | 20 | 22 | 28 | 34 | 0% | 261 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Dissolved organic carbon | mg/L | 0.4 | 0.9 | 1.5 | 2.3 | 7.6 | 17% | 258 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Hardness, as $CaCO_3$ | mg/L | 69 | 94 | 106 | 129 | 160 | 0% | 369 | 0.35 | 87 | 97 | 124 | 219 | 0% | 82 | 76 | 92 | 107 | 122 | 177 | 0% | 72 |
| Total dissolved solids | mg/L | 90 | 113 | 125 | 150 | 195 | 0% | 66 | 19 | 107 | 130 | 150 | 283 | 0% | 27 | 42 | 120 | 130 | 159 | 243 | 0% | 58 |
| pH | - | 7.7 | 8.0 | 8.1 | 8.2 | 8.6[D] | 0% | 344 | 7.7 | 8.1 | 8.2 | 8.3 | 8.6[D] | 0% | 55 | 7.8 | 8.1 | 8.2 | 8.3 | 8.4 | 0% | 57 |
| Specific conductivity | µS/cm | 141 | 184 | 206 | 246 | 273 | 0% | 365 | 97 | 167 | 189 | 238 | 402 | 0% | 82 | 153 | 181 | 208 | 229 | 316 | 0% | 72 |
| Total Alkalinity, as $CaCO_3$ | mg/L | 62 | 83 | 96 | 119 | o | 0% | 367 | 63 | 80 | 88 | 113 | 223 | 0% | 82 | 65 | 79 | 91 | 105 | 152 | 0% | 72 |
| Total inorganic carbon | mg/L | 15 | 19 | 22 | 29 | 32 | 0% | 75 | 18 | - | - | - | 20 | 0% | 2 | 16 | 17 | 18 | 19 | 22 | 0% | 6.0 |
| Total organic carbon | mg/L | <0.5 | 0.5 | 1.2 | 2.2 | 10 | 12% | 75 | <0.5 | 1.0 | 2.1 | 3.4 | 4.7 | 25% | 4 | 0.7 | 0.88 | 1.2 | 1.7 | 2.3 | 0% | 6.0 |
| Total suspended solids | mg/L | <1.0 | <10 | <10 | 10 | 190 | 50% | 109 | <5.0 | <10 | 11 | 30 | 168 | 42% | 36 | <5.0 | 21 | 51 | 100 | 364 | 16% | 61 |
| Turbidity | NTU | 0.09 | 0.5 | 0.95 | 3.0 | 110 | 0% | 359 | 0.12 | 0.48 | 1.0 | 2.7 | 20 | 0% | 84 | 0.1 | 2.9 | 15 | 26 | 120 | 0% | 72 |
| Calcium | mg/L | - | - | - | - | - | - | - | 19 | 26 | 29 | 35 | 58 | 0% | 62 | 24 | 28 | 32 | 36 | 47 | 0% | 38 |
| Magnesium | mg/L | - | - | - | - | - | - | - | 4.1 | 5.5 | 6.1 | 7.7 | 18 | 0% | 62 | 4.9 | 6.5 | 8.1 | 9.4 | 15 | 0% | 38 |
| Potassium | mg/L | - | - | - | - | - | - | - | 0.4 | 0.5 | 0.6 | 0.7 | 1.2 | 0% | 62 | 0.4 | 0.5 | 0.5 | 0.7 | 1.0 | 0% | 38 |
| Sodium | mg/L | 1.7 | - | - | - | 1.8 | 0% | 2 | 0.9 | 1.2 | 1.3 | 1.6 | 3.0 | 0% | 62 | 0.8 | 1.1 | 1.2 | 1.4 | 1.9 | 0% | 38 |
| Sulphate | mg/L | 7.1 | 13 | 14 | 16 | 19 | 0% | 364 | 2.3 | 7.1 | 9.5 | 11 | 19 | 0% | 83 | 7.9 | 13 | 16 | 18 | 24 | 0% | 72 |
| Chloride | mg/L | <0.05 | 0.2 | 0.29 | 0.33 | 0.9 | 13% | 365 | 0.2 | 0.28 | 0.3 | 0.4 | 0.9 | 0% | 84 | 0.2 | 0.3 | 0.4 | 0.4 | 1.0 | 0% | 72 |
| Fluoride | mg/L | <0.01 | 0.07 | 0.08 | 0.09 | 0.2[C] | 1% | 365 | <0.05 | 0.054 | 0.073 | 0.09 | 0.16[C] | 19% | 84 | <0.05 | 0.055 | 0.07 | 0.082 | 0.14[C] | 14% | 72 |
| Silica | mg/L | 2.7 | 3.1 | 3.4 | 3.9 | 5.0 | 0% | 147 | 2.5 | 3.2 | 3.4 | 4.2 | 6.3 | 0% | 15 | 2.7 | 3.0 | 3.2 | 3.5 | 5.3 | 0% | 32 |
| **Nutrients** | | | | | | | | | | | | | | | | | | | | | | |
| Dissolved ortho-phosphate | mg/L | 0.004 | <0.05 | <0.05 | <0.1 | <0.1 | 96% | 156 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Dissolved phosphorus | mg-P/L | 0.0008 | <0.002 | <0.002 | 0.0025 | 0.004 | 50% | 4 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Nitrate | mg-N/L | <0.002 | 0.02 | 0.036 | 0.09 | 0.36 | 2% | 294 | - | 0.033 | 0.033 | 0.033 | - | 0% | 1 | 0.025 | 0.026 | 0.026 | 0.037 | 0.047 | 0% | 3.0 |
| Nitrate + nitrite | mg-N/L | <0.002 | 0.03 | 0.044 | 0.095 | 0.17 | 2% | 53 | 0.006 | 0.022 | 0.036 | 0.063 | 0.31 | 0% | 79 | 0.015 | 0.028 | 0.04 | 0.07 | 0.29 | 0% | 67 |
| Nitrite | mg-N/L | <0.005 | <0.005 | <0.005 | <0.005 | 0.009 | 79% | 196 | - | - | - | - | - | - | - | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 100% | 3.0 |
| Particulate organic Nitrogen | mg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Particulate phosphorus (calculated) | mg-P/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Total ammonia | mg-N/L | <0.001 | - | - | - | <0.005 | 100% | 2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Total Kjeldahl nitrogen | mg-N/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Total nitrogen | mg-N/L | 0.07 | 0.1 | 0.13 | 0.15 | 0.5 | 0% | 83 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Total phosphorus | mg-P/L | 0.0016 | 0.004 | 0.007 | 0.015 | 0.17 | 7% | 362 | 0.004 | 0.007 | 0.014 | 0.031 | 0.26 | 0% | 79 | 0.003 | 0.013 | 0.039 | 0.092 | 0.79 | 0% | 67 |
| **Total Metals** | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum | µg/L | <2.0 | 15 | 39 | 144 | 2,150[C, D] | 1% | 334 | 32 | 42 | 106[C, D] | 409 | 2,090[C, D] | 0% | 19 | 103[C, D] | 264 | 736[C, D] | 1323 | 6,200[C, D] | 0% | 34 |
| Antimony | µg/L | 0.023 | 0.06 | 0.065 | 0.074 | 0.19 | 0% | 156 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Arsenic | µg/L | 0.1 | 0.4 | 0.44 | 0.55 | 2.3 | 0% | 209 | 0.1 | 0.4 | 0.5 | 0.7 | 6.9[C, Mn] | 0% | 77 | 0.2 | 0.45 | 0.7 | 1.1 | 4.4 | 0% | 67 |
| Barium | µg/L | 40 | 52 | 61 | 75 | 105 | 0% | 352 | 44 | 51 | 69 | 82 | 293 | 0% | 17 | 54 | 58 | 65 | 77 | 238 | 0% | 34 |
| Beryllium | µg/L | <0.001 | <0.05 | <0.05 | 0.05 | 0.14[Mn] | 44% | 354 | <0.05 | <0.05 | <0.05 | <0.05 | 0.13 | 84% | 19 | <0.05 | <0.05 | 0.05 | 0.07 | 0.25[Mn] | 44% | 34 |
| Bismuth | µg/L | <0.001 | <0.001 | 0.001 | 0.004 | 0.047 | 30% | 158 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Boron | µg/L | <0.5 | 1.2 | 1.4 | 1.7 | 3.6 | 9% | 159 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Cadmium | µg/L | <0.001 | <0.1 | <0.1 | 0.1 | 0.9[C] | 35% | 349 | <0.1 | <1 | 0.2[C] | <1 | <1.0[DL>C] | 86% | 7.0 | <0.1 | 0.1 | 0.2[C] | 0.7 | 2.0[C] | 21% | 28 |
| Cesium | µg/L | <0.005 | 0.008 | 0.014 | 0.029 | 0.27 | 1% | 77 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Upper Crossing | | | | | | | Upper Crossing-Westbank | | | | | | | Lower Crossing | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960-2015 | | | | | | | 1983-1994 | | | | | | | 1984-1994 | | | | | | |
| | | Min | $25^{th}$ Percentile[B] | Median | $75^{th}$ Percentile[B] | Max | Percent Below Detection Limit | Count | Min | $25^{th}$ Percentile[B] | Median | $75^{th}$ Percentile[B] | Max | Percent Below Detection Limit | Count | Min | $25^{th}$ Percentile[B] | Median | $75^{th}$ Percentile[B] | Max | Percent Below Detection Limit | Count |
| Chromium | µg/L | 0.067 | <0.2 | <0.2 | 0.37 | 3.8[C, Mn] | 22% | 338 | 0.2 | 0.35 | 0.8 | 1.3 | 1.4[C, Mn] | 0% | 4.0 | 0.3 | 1.0 | 1.5[C, Mn] | 2.9 | 11[C, Mn] | 0% | 22 |
| Cobalt | µg/L | 0.019 | 0.063 | 0.1 | 0.2 | 2.0 | 7% | 355 | <0.1 | 0.15 | 0.4 | 0.55 | 1.9 | 11% | 19 | 0.2 | 0.33 | 0.65 | 1.1 | 5.2[Mn] | 0% | 34 |
| Copper | µg/L | <0.2 | 0.4 | 0.52 | 0.83 | 4.6[C, Mn] | 2% | 322 | 0.3 | 0.98 | 2.0 | 3.5 | 7.9[C, Mn] | 0% | 8.0 | 0.6 | 1.3 | 2.7[C] | 3.4 | 11[C, Mn, Mx] | 4% | 28 |
| Iron | µg/L | 38 | 69 | 100 | 282 | 3,990[C, Mx] | 0% | 334 | 36 | 109 | 230 | 584 | 5,510[C, Mx] | 0% | 78 | 100 | 310 | 1,190[C, Mx] | 2390 | 13,000[C, Mx] | 0% | 67 |
| Lead | µg/L | 0.013 | <0.2 | <0.2 | 0.25 | 3.3[C] | 31% | 351 | <0.2 | <1 | 0.6 | 1.0 | 1.0 | 50% | 8.0 | <0.2 | 0.7 | 1.5 | 2.0 | 9.5[C, Mn] | 14% | 28 |
| Lithium | µg/L | 1.3 | 1.7 | 1.9 | 2.1 | 4.8 | 0% | 355 | 1.7 | 2.0 | 2.4 | 2.7 | 4.5 | 0% | 19 | 2.7 | 3.1 | 3.6 | 4.2 | 16 | 0% | 34 |
| Magnesium | mg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Manganese | µg/L | 4.4 | 7.0 | 8.7 | 14 | 133 | 0% | 335 | <2.0 | 9.0 | 15 | 26 | 147 | 1% | 78 | <2.0 | 11 | 31 | 53 | 252 | 4% | 67 |
| Mercury | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Molybdenum | µg/L | 0.2 | 0.6 | 0.7 | 0.8 | 1.4 | 0% | 350 | 0.2 | 0.55 | 0.6 | 0.7 | 0.8 | 0% | 19 | 0.2 | 0.6 | 0.7 | 0.8 | 1.2 | 0% | 34 |
| Nickel | µg/L | <0.2 | 0.51 | 0.7 | 1.1 | 6.5 | 1% | 334 | <0.2 | 0.4 | 0.9 | 1.3 | 5.1 | 11% | 19 | 0.4 | 1.3 | 2.3 | 3.7 | 16 | 0% | 34 |
| Rubidium | µg/L | 0.64 | 0.7 | 0.75 | 0.91 | 3.5 | 0% | 159 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Selenium | µg/L | <0.1 | 0.2 | 0.23 | 0.26 | 0.9 | 3% | 210 | <0.1 | 0.2 | 0.2 | 0.3 | 0.7 | 12% | 76 | <0.1 | 0.28 | 0.3 | 0.4 | 0.7 | 3% | 64 |
| Silver | µg/L | <0.001 | <0.1 | 0.009 | 0.1 | 0.1 | 45% | 264 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Sodium | mg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Strontium | µg/L | 92 | 120 | 132 | 153 | 216 | 0% | 355 | 96 | 108 | 141 | 163 | 183 | 0% | 19 | 114 | 129 | 139 | 153 | 178 | 0% | 34 |
| Thallium | µg/L | <0.001 | 0.002 | 0.003 | 0.005 | 0.036 | 3% | 158 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Tin | µg/L | <0.005 | <0.005 | <0.005 | <0.005 | 0.021 | 81% | 74 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Uranium | µg/L | 0.75 | 0.88 | 0.95 | 1.1 | 1.2 | 0% | 159 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Vanadium | µg/L | 0.08 | 0.1 | 0.19 | 0.39 | 3.8 | 6% | 331 | <0.1 | 0.2 | 0.3 | 0.9 | 4.3 | 11% | 19 | 0.3 | 0.58 | 1.7 | 3.2 | 13 | 0% | 34 |
| Zinc | µg/L | <0.2 | 0.7 | 1.0 | 1.9 | 15[Mn] | 1% | 318 | 0.5 | 1.4 | 3.5 | 9.5 | 25 | 0% | 8 | 1.8 | 5.2 | 8.5 | 11 | 59[C, Mn, Mx] | 0% | 28 |
| **Dissolved Metals** | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Antimony | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Arsenic | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Barium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Beryllium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Bismuth | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Boron | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Cadmium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Cesium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Chromium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Cobalt | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Copper | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Iron | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Lead | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Lithium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Manganese | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Molybdenum | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Nickel | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Niobium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Platinum | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Upper Crossing | | | | | | | Upper Crossing-Westbank | | | | | | | Lower Crossing | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960-2015 | | | | | | | 1983-1994 | | | | | | | 1984-1994 | | | | | | |
| | | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count |
| Silver | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Strontium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Thallium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Tin | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Uranium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Vanadium | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Zinc | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **Organics** | | | | | | | | | | | | | | | | | | | | | | |
| Acenaphthylene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Anthracene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Benzo(a)anthracene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Benzo(a)pyrene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Chrysene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Dibenzothiophene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Fluoranthene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Fluorene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Indene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Naphthalene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Perylene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Phenanthrene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Pyrene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **Pestcides** | | | | | | | | | | | | | | | | | | | | | | |
| Aldrin | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Alpha-Benzenehexachloride | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Alpha-Chlordane | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Alpha-Endosulfan | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Beta-Endosulfan | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Beta-HCH | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Cis-Nonachlor | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Dieldrin | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Endrin | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Gamma-Chlordane | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Heptachlor | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Heptachlor Epoxide | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Hexachlorobutadiene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Methoxychlor (P,P'-Methoxychlor). | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Mirex | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| O,P'-DDD | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| O,P'-DDE | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| O,P'-DDT | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Oxychlordane | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P,P'-DDD (TDP) | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Upper Crossing | | | | | | | Upper Crossing-Westbank | | | | | | | Lower Crossing | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1960-2015 | | | | | | | 1983-1994 | | | | | | | 1984-1994 | | | | | | |
| | | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count |
| P,P'-DDE | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| P,P'-DDT | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| PCB-TOTAL | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Pentachloroanisole | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Pentachlorobenzene | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Trans-Nonachlor | µg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Values in shaded cells are above guidelines:
(A) = concentration higher than the relevant acute aquatic life guideline or beyond the recommended pH or DO concentration range.
(B) = 25th and 75th percentile values are not screened with any guidelines because they are interpolated values.
(C) = concentration higher than the relevant chronic aquatic life guideline or beyond the recommended pH, DO or total alkalinity concentration range.
(D) = concentration higher than the relevant drinking water guideline or beyond the recommended pH or DO concentration range.
(Mn) = concentration higher than the relevant 30-day mean aquatic life guideline or beyond the recommended pH or DO concentration range.
(Mx) = concentration higher than the relevant maximum aquatic life guideline or beyond the recommended pH or DO concentration range.
(DL>C) = analytical detection limit was higher than the relevant chronic aquatic life guideline.
(DL>D) = analytical detection limit was higher than the relevant drinking water guideline.
(DL>Mn) = analytical detection limit was higher than the relevant 30-day mean aquatic life guideline.
Water quality data and guidelines shown in this table were rounded to reflect laboratory or field instrument precision *after* comparisons to guidelines. Therefore, values slightly above guidelines may be displayed as being equal to the guidelines and identified as exceedances. Measured concentrations equal to the guideline values were not identified as exceedances.
- = no data.

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Upstream Kotaneelee River | | | | | | | Fort Liard | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2001-2015 | | | | | | | 1960-2015 | | | | | | |
| | | Min | 25th Percentile[B] | Median | 75th Percentile[B] | Max | Percent Below Detection Limit | Count | Min | 25th Percentile[B] | Median | 75th Percentile[B] | Max | Percent Below Detection Limit | Count |
| **Conventional Parameters** | | | | | | | | | | | | | | | |
| Dissolved inorganic carbon | mg/L | - | - | - | - | - | - | - | 20 | 22 | 27 | 38 | 40 | 0% | 7 |
| Dissolved organic carbon | mg/L | 2.0 | 3.4 | 4.2 | 5.2 | 10 | 0% | 29 | 1.0 | 2.6 | 4.0 | 7.8 | 26 | 0% | 70 |
| Hardness, as $CaCO_3$ | mg/L | 109 | 122 | 147 | 156 | 168 | 0% | 31 | 22 | 118 | 151 | 198 | 235 | 0% | 247 |
| Total dissolved solids | mg/L | 135 | 158 | 170 | 184 | 239 | 0% | 31 | 19 | 160 | 190 | 222 | 305 | 0% | 162 |
| pH | - | 8.0 | 8.1 | 8.2 | 8.3 | 8.6[D] | 0% | 31 | 7.5 | 7.9 | 8.1 | 8.2 | 9[D] | 0% | 249 |
| Specific conductivity | µS/cm | 211 | 226 | 279 | 294 | 310 | 0% | 37 | 21 | 226 | 278 | 358 | 446 | 0% | 281 |
| Total Alkalinity, as $CaCO_3$ | mg/L | 82 | 88 | 113 | 120 | 145 | 0% | 31 | 19[Mn] | 94 | 116 | 158 | 191 | 0% | 253 |
| Total inorganic carbon | mg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Total organic carbon | mg/L | 2.1 | 3.0 | 3.9 | 6.7 | 16 | 0% | 31 | <0.5 | 2.0 | 4.4 | 9.6 | 29 | 6% | 83 |
| Total suspended solids | mg/L | <3.0 | 8.0 | 25 | 130 | 1560 | 14% | 37 | <1.0 | 10 | 59 | 195 | 2490 | 16% | 204 |
| Turbidity | NTU | 1.0 | 18 | 31 | 91 | 991 | 0% | 37 | <0.1 | 2.2 | 12 | 60 | 3900 | 0% | 252 |
| Calcium | mg/L | 30 | 33 | 41 | 43 | 45 | 0% | 12 | 6.7 | 35 | 41 | 55 | 78 | 0% | 192 |
| Magnesium | mg/L | 8.6 | 9.2 | 11 | 11.3 | 14 | 0% | 12 | 1.4 | 8.1 | 11 | 15 | 18 | 0% | 158 |
| Potassium | mg/L | 0.5 | 0.6 | 0.6 | 0.6 | 1.6 | 0% | 12 | 0.13 | 0.64 | 0.78 | 0.91 | 2.4 | 0% | 192 |
| Sodium | mg/L | 1.5 | 1.6 | 1.9 | 2 | 2.3 | 0% | 12 | 0.41 | 2.1 | 2.9 | 3.4 | 12 | 0% | 194 |
| Sulphate | mg/L | 27 | 30 | 36 | 37 | 53 | 0% | 31 | 4.6 | 26 | 35 | 41 | 300 | 0% | 272 |
| Chloride | mg/L | <0.2 | <0.7 | <0.7 | 0.7 | 0.7 | 58% | 31 | 0.15 | 0.5 | 0.8 | 1.1 | 9.6 | 1% | 272 |
| Fluoride | mg/L | <0.1 | <0.1 | <0.1 | 0.1 | 0.1 | 69% | 13 | 0.02 | 0.07 | 0.09 | 0.1 | 0.23[C] | 7% | 230 |
| Silica | mg/L | 0.13 | 4.8 | 4.9 | 5.0 | 5.1 | 0% | 8 | 0.69 | 3.4 | 4.5 | 6.0 | 21 | 0% | 159 |
| **Nutrients** | | | | | | | | | | | | | | | |
| Dissolved ortho-phosphate | mg/L | - | - | - | - | - | - | - | <0.002 | 0.004 | 0.007 | 0.01 | 0.05 | 22% | 9 |
| Dissolved phosphorus | mg-P/L | - | - | - | - | - | - | - | <0.002 | <0.01 | <0.01 | 0.02 | 0.11 | 45% | 77 |
| Nitrate | mg-N/L | <0.01 | 0.024 | 0.037 | 0.08 | 0.18 | 14% | 29 | <0.002 | 0.052 | 0.13 | 0.32 | 3.6[C, Mn] | 3% | 77 |
| Nitrate + nitrite | mg-N/L | <0.01 | 0.03 | 0.08 | 0.1 | 0.2 | 24% | 17 | <0.005 | 0.04 | 0.057 | 0.13 | <2.0 | 3% | 155 |
| Nitrite | mg-N/L | <0.008 | <0.01 | <0.01 | <0.01 | 0.02 | 90% | 29 | <0.005 | <0.01 | <0.01 | 0.01 | 0.03[Mn] | 67% | 61 |
| Particulate organic Nitrogen | mg/L | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Particulate phosphorus (calculated) | mg-P/L | - | - | - | - | - | - | - | <0.004 | <0.004 | 0.035 | 0.17 | 1.4 | 25% | 36 |
| Total ammonia | mg-N/L | <0.005 | <0.005 | 0.005 | 0.017 | 0.058 | 50% | 30 | <0.001 | <0.01 | <0.01 | 0.023 | 0.7 | 48% | 79 |
| Total Kjeldahl nitrogen | mg-N/L | - | - | - | - | - | - | - | <0.5 | - | - | - | <0.5 | 100% | 2 |
| Total nitrogen | mg-N/L | 0.17 | - | - | - | 0.22 | 0% | 2 | 0.056 | 0.17 | 0.23 | 0.45 | 4.0 | 0% | 69 |
| Total phosphorus | mg-P/L | - | - | - | - | - | - | - | 0.0003 | 0.01 | 0.044 | 0.19 | 2.7 | 8% | 198 |
| **Total Metals** | | | | | | | | | | | | | | | |
| Aluminum | µg/L | 79 | 825 | 1,245[C, D] | 4378 | 34,600[C, D] | 0% | 36 | 11 | 58 | 517[C, D] | 1925 | 21,400[C, D] | 0% | 152 |
| Antimony | µg/L | 0.1 | 0.2 | 0.3 | 0.5 | 0.9 | 22% | 36 | 0.001 | 0.086 | 0.1 | 0.15 | 0.33 | 0% | 65 |
| Arsenic | µg/L | 0.3 | 1.0 | 1.2 | 1.8 | 11[C, D, Mn] | 21% | 33 | <0.1 | 0.26 | 0.6 | 1.8 | 20[C, D, Mn] | 2% | 174 |
| Barium | µg/L | 65 | 77 | 89 | 194 | 659 | 0% | 36 | 18 | 81 | 90 | 125 | 1,050[D, Mn] | 0% | 158 |
| Beryllium | µg/L | <0.1 | <2 | 0.45[Mn] | 2.0 | <2.0[DL>Mn] | 75% | 36 | <0.001 | 0.05 | 0.051 | 0.15 | 1.3[Mn] | 24% | 158 |
| Bismuth | µg/L | <0.2 | <0.4 | <0.4 | 0.43 | 2.3 | 65% | 20 | <0.001 | 0.001 | 0.0035 | 0.022 | 0.087 | 12% | 34 |
| Boron | µg/L | 6.4 | 8.8 | 10 | 13 | 39 | 0% | 20 | 2.0 | 7.1 | 8.3 | 9.7 | 22 | 0% | 65 |
| Cadmium | µg/L | 0.06 | <0.3 | 0.2 | 0.3 | 0.9[C] | 64% | 36 | 0.016 | 0.092 | 0.1 | 0.51 | 17[A, C, D] | 21% | 160 |
| Cesium | µg/L | <0.1 | <0.4 | <0.4 | 0.73 | 3.6 | 25% | 36 | <0.005 | 0.015 | 0.051 | 0.35 | 1.5 | 5% | 65 |
| Chromium | µg/L | 0.3 | <3 | <3.0[DL>C, DL>Mn] | 9.0 | 43[C, Mn] | 17% | 36 | <0.02 | 0.23 | 1.1[C, Mn] | 3.4 | 8,530[C, D, Mn] | 7% | 151 |

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Upstream Kotaneelee River | | | | | | | Fort Liard | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2001-2015 | | | | | | | 1960-2015 | | | | | | |
| | | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count |
| Cobalt | µg/L | <0.1 | <1 | <1.0 | 4.3 | 14(Mn) | 19% | 36 | 0.025 | 0.1 | 0.65 | 2.0 | 22(Mn) | 1% | 158 |
| Copper | µg/L | 0.8 | 1.9 | 2.2 | 18 | 32(C, Mn, Mx) | 17% | 36 | 0.3 | 0.72 | 2.0 | 5.5 | 54(C, Mn, Mx) | 1% | 160 |
| Iron | µg/L | 119 | 1235 | 1,680(C, Mx) | 4455 | 32,300(C, Mx) | 0% | 39 | 1.0 | 150 | 870(C) | 4230 | 57,600(C, Mx) | 0% | 207 |
| Lead | µg/L | <0.1 | <1 | 1.1 | 7.3 | 19(C, D, Mn) | 25% | 36 | <0.005 | 0.2 | 0.91 | 2.9 | 33(C, D, Mn) | 19% | 160 |
| Lithium | µg/L | 3.6 | 5.0 | 6.0 | 9.0 | 31 | 0% | 36 | 1.0 | 6.1 | 7.1 | 9.4 | 32 | 0% | 158 |
| Magnesium | mg/L | - | - | - | - | - | - | - | 1.4 | 10 | 13 | 15 | 16 | 0% | 16 |
| Manganese | µg/L | 10 | 25 | 38 | 140 | 509 | 0% | 36 | 1.7 | 13 | 31 | 90 | 1040 | 0% | 207 |
| Mercury | µg/L | <0.01 | <0.05 | 0.01 | 0.05 | 0.1(C, Mn) | 64% | 39 | - | - | - | - | - | - | - |
| Molybdenum | µg/L | <1.0 | 1.1 | 1.3 | 1.5 | 4.1 | 19% | 36 | <0.1 | 0.89 | 1.1 | 1.3 | 3.0 | 1% | 158 |
| Nickel | µg/L | 1.4 | 2.4 | 3.1 | 11 | 42 | 0% | 36 | 0.4 | 1.1 | 2.8 | 6.7 | 62 | 0% | 158 |
| Rubidium | µg/L | 0.7 | 2.6 | 3.5 | 8.6 | 53 | 0% | 36 | 0.12 | 0.74 | 0.94 | 3.9 | 26 | 0% | 65 |
| Selenium | µg/L | <0.5 | <10 | 2.3(C, Mn) | 10 | <10(DL>C, DL>Mn) | 64% | 36 | <0.1 | 0.5 | 0.6 | 0.74 | 12(C, Mn) | 1% | 168 |
| Silver | µg/L | <0.1 | <0.3 | 0.2 | 0.33 | 1.5(C) | 53% | 36 | <0.001 | 0.002 | 0.038 | 0.1 | 0.55(C) | 17% | 83 |
| Sodium | mg/L | - | - | - | - | - | - | - | 0.35 | 1.7 | 2.0 | 2.6 | 3.1 | 0% | 16 |
| Strontium | µg/L | 110 | 158 | 168 | 186 | 205 | 0% | 36 | 25 | 149 | 172 | 213 | 400 | 0% | 158 |
| Thallium | µg/L | <0.1 | <0.4 | 0.15 | <0.4 | 0.4 | 83% | 36 | <0.001 | 0.006 | 0.009 | 0.051 | 0.42 | 2% | 65 |
| Tin | µg/L | <0.1 | 0.3 | 0.5 | 0.75 | 4.4 | 5% | 20 | <0.005 | <0.005 | <0.005 | 0.01 | 0.09 | 55% | 65 |
| Uranium | µg/L | 0.7 | 1.0 | 1.2 | 1.4 | 2.5 | 0% | 36 | 0.7 | 1.1 | 1.4 | 1.5 | 4.4 | 0% | 59 |
| Vanadium | µg/L | 0.5 | 3.0 | 4.1 | 16 | 93 | 0% | 36 | 0.078 | 0.25 | 1.4 | 5.9 | 44 | 0% | 158 |
| Zinc | µg/L | 6.5 | <10 | <10 | 46 | 149(C, Mn, Mx) | 25% | 36 | <0.05 | 3.0 | 9.1 | 22 | 209(C, Mn, Mx) | 1% | 160 |
| **Dissolved Metals** | | | | | | | | | | | | | | | |
| Aluminum | µg/L | 15 | 27 | 41 | 63 | 260(Mn, Mx) | 0% | 24 | 4.6 | 11 | 36 | 48 | 803(Mn, Mx) | 0% | 44 |
| Antimony | µg/L | <0.1 | 0.2 | 0.25 | 0.33 | 1.0 | 13% | 24 | 0.093 | 0.13 | 0.15 | 0.19 | 0.43 | 0% | 42 |
| Arsenic | µg/L | 0.2 | 0.3 | 0.3 | 0.43 | <1.0 | 13% | 24 | 0.1 | 0.2 | 0.3 | 0.38 | <5.0 | 3% | 66 |
| Barium | µg/L | 36 | 44 | 52 | 63 | 70 | 0% | 24 | 31 | 54 | 61 | 84 | 104 | 0% | 42 |
| Beryllium | µg/L | <0.02 | <0.1 | <0.1 | <0.1 | <0.1 | 92% | 24 | <0.001 | 0.0023 | 0.006 | 0.008 | 0.064 | 2% | 42 |
| Bismuth | µg/L | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 100% | 11 | <0.001 | <0.001 | 0.001 | 0.002 | 0.015 | 36% | 42 |
| Boron | µg/L | 3.9 | 4.4 | 5.4 | 7.2 | 13 | 0% | 17 | 2.2 | 6.9 | 8.1 | 9.1 | 30 | 0% | 44 |
| Cadmium | µg/L | <0.02 | <0.05 | <0.05 | <0.05 | 0.07 | 79% | 24 | 0.012 | 0.018 | 0.023 | 0.034 | <1.0(DL>Mn) | 14% | 49 |
| Cesium | µg/L | 0.037 | <0.1 | <0.1 | <0.1 | <0.1 | 88% | 24 | 0.004 | 0.005 | 0.007 | 0.009 | 0.26 | 14% | 42 |
| Chromium | µg/L | <0.1 | <0.1 | 0.2 | 0.2 | 0.3 | 25% | 24 | 0.068 | 0.13 | 0.15 | 0.19 | 1.7 | 0% | 42 |
| Cobalt | µg/L | <0.1 | <0.1 | <0.1 | 0.13 | 0.44 | 71% | 24 | 0.025 | 0.053 | 0.072 | 0.12 | 0.94 | 0% | 42 |
| Copper | µg/L | <0.2 | 0.69 | 0.9 | 2.3 | 6.5 | 8% | 24 | 0.35 | 0.88 | 1.5 | 3.4 | <64 | 9% | 57 |
| Iron | µg/L | 12 | 44 | 56 | 102 | 166 | 13% | 24 | <1.0 | 37 | 76 | 133 | 1,980(Mx) | 5% | 62 |
| Lead | µg/L | <0.1 | <0.1 | <0.1 | 0.31 | 6.1 | 54% | 24 | 0.011 | 0.054 | 0.11 | 1.0 | <50 | 21% | 57 |
| Lithium | µg/L | 2.4 | 3.3 | 4.0 | 4.7 | 6.3 | 0% | 24 | 1.9 | 3.8 | 4.8 | 5.4 | 7.4 | 0% | 42 |
| Manganese | µg/L | 0.8 | 3.9 | 4.5 | 6.5 | 18 | 0% | 24 | <1.0 | 4.5 | 8.0 | 10 | 116 | 24% | 62 |
| Molybdenum | µg/L | 0.8 | 0.91 | 1.2 | 1.3 | 1.5 | 0% | 24 | 0.49 | 1.0 | 1.1 | 1.3 | 1.6 | 0% | 42 |
| Nickel | µg/L | 0.7 | 1.2 | 1.3 | 2.1 | 2.5 | 0% | 24 | 0.74 | 1.1 | 1.2 | 1.8 | 3.5 | 0% | 42 |
| Niobium | µg/L | - | - | - | - | - | - | - | <0.001 | 0.001 | 0.002 | 0.0048 | 0.027 | 19% | 42 |
| Platinum | µg/L | - | - | - | - | - | - | - | <0.001 | <0.001 | <0.001 | <0.001 | 0.004 | 86% | 42 |
| Silver | µg/L | <0.006 | <0.1 | <0.1 | <0.1 | <0.1 | 92% | 24 | <0.001 | 0.001 | 0.0015 | 0.002 | 0.038 | 21% | 42 |
| Strontium | µg/L | 94 | 124 | 150 | 161 | 177 | 0% | 24 | 77 | 135 | 166 | 215 | 408 | 0% | 42 |

**Table B1:** **Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Upstream Kotaneelee River | | | | | | | Fort Liard | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2001-2015 | | | | | | | 1960-2015 | | | | | | |
| | | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count |
| Thallium | µg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 24 | 0.001 | 0.005 | 0.0055 | 0.0068 | 0.028 | 0% | 42 |
| Tin | µg/L | <0.1 | <0.1 | <0.1 | 0.1 | 0.9 | 71% | 17 | <0.005 | <0.005 | <0.005 | 0.011 | 0.021 | 55% | 42 |
| Uranium | µg/L | 0.5 | 0.8 | 0.9 | 1.0 | 1.3 | 0% | 24 | 0.46 | 0.89 | 1.1 | 1.4 | 1.9 | 0% | 42 |
| Vanadium | µg/L | 0.2 | 0.2 | 0.3 | 0.4 | 0.64 | 0% | 24 | 0.091 | 0.16 | 0.24 | 0.32 | 2.5 | 0% | 42 |
| Zinc | µg/L | <0.4 | <0.4 | 1.5 | 2.4 | 5.0 | 33% | 24 | 0.6 | 1.0 | 1.2 | 5.6 | 23 | 16% | 57 |
| **Organics** | | | | | | | | | | | | | | | |
| Acenaphthylene | µg/L | <0.000028 | <0.00014 | <0.00014 | <0.0002 | 0.0007 | 80% | 10 | <0.0065 | <0.0065 | <0.0065 | <0.016 | <0.016 | 100% | 22 |
| Anthracene | µg/L | <0.000023 | <0.00012 | <0.00012 | 0.00015 | 0.00031 | 70% | 10 | <0.0061 | <0.0061 | <0.0061 | <0.02 | 0.034(C) | 95% | 22 |
| Benzo(a)anthracene | µg/L | <0.000023 | <0.000047 | <0.000047 | 0.000064 | 0.0015 | 70% | 10 | <0.01 | <0.01 | <0.01 | <0.02 | <0.02(DL>C) | 100% | 22 |
| Benzo(a)pyrene | µg/L | <0.00005 | <0.00014 | <0.00014 | <0.00029 | 0.0015 | 80% | 10 | <0.006 | <0.0094 | <0.0094 | <0.069 | <0.069(DL>C, DL>D, DL>Mn) | 100% | 21 |
| Chrysene | µg/L | 0.00011 | 0.00032 | 0.00041 | 0.00048 | 0.008 | 0% | 10 | <0.003 | <0.02 | 0.0086 | 0.02 | 0.03 | 68% | 22 |
| Dibenzothiophene | µg/L | <0.000014 | <0.00012 | <0.00012 | 0.00022 | 0.0019 | 60% | 10 | <0.0052 | <0.0082 | <0.0082 | <0.0082 | 0.029 | 87% | 15 |
| Fluoranthene | µg/L | 0.00018 | 0.00036 | 0.00043 | 0.00056 | 0.0025 | 0% | 10 | <0.0041 | <0.0087 | 0.0078 | 0.0087 | 0.028 | 64% | 22 |
| Fluorene | µg/L | <0.000082 | <0.00018 | 0.00022 | 0.00034 | 0.002 | 40% | 10 | <0.0064 | <0.025 | 0.012 | 0.025 | 0.044 | 73% | 22 |
| Indene | µg/L | - | - | - | - | - | - | - | <0.0051 | <0.0051 | <0.0051 | <0.015 | <0.015 | 100% | 22 |
| Naphthalene | µg/L | 0.0035 | 0.0056 | 0.0057 | 0.01 | 0.02 | 0% | 10 | <0.0058 | <0.02 | 0.02 | 0.049 | 0.16 | 27% | 22 |
| Perylene | µg/L | <0.000051 | 0.00024 | 0.00094 | 0.0015 | 0.031 | 22% | 9 | <0.009 | <0.1 | 0.02 | <0.1 | 0.12 | 76% | 21 |
| Phenanthrene | µg/L | 0.00062 | 0.0012 | 0.0016 | 0.0016 | 0.013 | 0% | 10 | <0.0062 | <0.034 | <0.034 | 0.04 | 0.24 | 36% | 22 |
| Pyrene | µg/L | 0.00026 | 0.00048 | 0.00057 | 0.00072 | 0.0048 | 0% | 10 | <0.0039 | <0.0078 | <0.0078 | 0.011 | 0.059(C, Mn) | 59% | 22 |
| **Pestcides** | | | | | | | | | | | | | | | |
| Aldrin | µg/L | <0.002 | <0.05 | <0.05 | <0.1 | <0.1 | 100% | 7 | <0.00017 | <0.00027 | <0.00027 | <0.00077 | <0.00077 | 100% | 22 |
| Alpha-Benzenehexachloride | µg/L | <0.002 | <0.05 | <0.05 | <0.1 | <0.1 | 100% | 7 | <0.0002 | <0.00035 | <0.00035 | <0.0011 | <0.0011 | 100% | 22 |
| Alpha-Chlordane | µg/L | <0.1 | - | - | - | <0.1 | 100% | 2 | <0.00031 | <0.0006 | <0.0006 | <0.0006 | <0.0006 | 100% | 22 |
| Alpha-Endosulfan | µg/L | <0.002 | <0.01 | <0.01 | <0.1 | <0.1 | 100% | 7 | <0.00022 | <0.00062 | <0.00062 | <0.00064 | <0.00064 | 100% | 22 |
| Beta-Endosulfan | µg/L | <0.002 | <0.01 | <0.01 | <0.1 | <0.1 | 100% | 7 | <0.00036 | <0.00059 | <0.00059 | <0.00088 | <0.00088 | 100% | 22 |
| Beta-HCH | µg/L | <0.00004 | <0.000042 | <0.000042 | <0.00015 | <0.00015 | 100% | 6 | <0.00085 | <0.0016 | <0.0016 | <0.0016 | <0.0016 | 100% | 17 |
| Cis-Nonachlor | µg/L | <0.05 | - | - | - | <0.05 | 100% | 2 | <0.0006 | <0.0011 | <0.0011 | <0.0011 | <0.0011 | 100% | 17 |
| Dieldrin | µg/L | <0.002 | <0.05 | <0.05 | <0.1 | <0.1 | 100% | 7 | <0.00035 | <0.0011 | <0.0011 | <0.0013 | <0.0013 | 100% | 22 |
| Endrin | µg/L | <0.002 | <0.02 | <0.02 | <0.1 | <0.1 | 100% | 7 | <0.00055 | <0.0013 | <0.0013 | <0.0013 | <0.0013 | 100% | 22 |
| Gamma-Chlordane | µg/L | <0.1 | - | - | - | <0.1 | 100% | 2 | <0.00019 | <0.00031 | <0.00031 | <0.00041 | <0.00041 | 100% | 22 |
| Heptachlor | µg/L | <0.002 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 7 | <0.00035 | <0.00056 | <0.00056 | <0.00082 | <0.00082 | 100% | 22 |
| Heptachlor Epoxide | µg/L | <0.003 | <0.052 | <0.052 | <0.1 | <0.1 | 100% | 4 | <0.00017 | <0.00033 | <0.00033 | <0.0006 | <0.0006 | 100% | 22 |
| Hexachlorobutadiene | µg/L | 0.000024 | 0.000025 | 0.000025 | 0.000073 | 0.00012 | 0% | 3 | <0.00025 | <0.00041 | <0.00041 | <0.00053 | <0.00053 | 100% | 17 |
| Methoxychlor (P,P'-Methoxychlor). | µg/L | <0.0002 | <0.00021 | <0.00021 | <0.00068 | <0.00068 | 100% | 5 | <0.0032 | <0.0051 | <0.0051 | <0.0079 | <0.0079 | 100% | 22 |
| Mirex | µg/L | <0.002 | <0.05 | <0.05 | <0.1 | <0.1 | 100% | 7 | <0.00051 | <0.00082 | <0.00082 | <0.0014 | <0.0014 | 100% | 22 |
| O,P'-DDD | µg/L | - | - | - | - | - | - | - | <0.00048 | <0.00078 | <0.00078 | <0.00094 | <0.00094 | 100% | 17 |
| O,P'-DDE | µg/L | - | - | - | - | - | - | - | <0.00074 | <0.0012 | <0.0012 | <0.0013 | <0.0013 | 100% | 17 |
| O,P'-DDT | µg/L | - | - | - | - | - | - | - | <0.00035 | <0.00056 | <0.00056 | <0.0018 | <0.0018 | 100% | 22 |
| Oxychlordane | µg/L | <0.002 | <0.05 | <0.05 | <0.1 | <0.1 | 100% | 7 | <0.00045 | <0.001 | <0.001 | <0.001 | <0.001 | 100% | 17 |
| P,P'-DDD (TDP) | µg/L | <0.002 | <0.01 | <0.01 | <0.1 | <0.1 | 100% | 3 | <0.00055 | <0.00088 | <0.00088 | <0.0022 | <0.0022 | 100% | 22 |
| P,P'-DDE | µg/L | <0.002 | <0.01 | <0.01 | <0.1 | <0.1 | 100% | 3 | <0.0004 | <0.00065 | <0.00065 | <0.0013 | <0.0013 | 100% | 22 |
| P,P'-DDT | µg/L | <0.002 | <0.01 | <0.01 | <0.1 | <0.1 | 100% | 3 | <0.00072 | <0.0012 | <0.0012 | <0.0016 | <0.0016 | 100% | 22 |
| PCB-TOTAL | µg/L | <0.05 | <0.05 | <0.05 | <2.5 | <2.5 | 100% | 4 | <0.00034 | - | - | - | <0.00034 | 100% | 2 |

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Upstream Kotaneelee River | | | | | | | Fort Liard | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2001-2015 | | | | | | | 1960-2015 | | | | | | |
| | | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count |
| Pentachloroanisole | µg/L | - | - | - | - | - | - | - | <0.00017 | <0.00028 | <0.00028 | <0.00048 | <0.00048 | 94% | 17 |
| Pentachlorobenzene | µg/L | - | - | - | - | - | - | - | <0.00021 | <0.00034 | <0.00034 | <0.0008 | <0.0008 | 100% | 18 |
| Trans-Nonachlor | µg/L | <0.05 | <0.075 | <0.075 | <0.1 | <0.1 | 100% | 4 | <0.00046 | <0.00074 | <0.00074 | <0.00074 | <0.00074 | 100% | 17 |

Values in shaded cells are above guidelines:
(A) = concentration higher than the relevant acute aquatic life guideline or beyond the recommended pH or DO concentration range.
(B) = 25th and 75th percentile values are not screened with any guidelines because they are interpolated values.
(C) = concentration higher than the relevant chronic aquatic life guideline or beyond the recommended pH, DO or total alkalinity concentration range.
(D) = concentration higher than the relevant drinking water guideline or beyond the recommended pH or DO concentration range.
(Mn) = concentration higher than the relevant 30-day mean aquatic life guideline or beyond the recommended pH or DO concentration range.
(Mx) = concentration higher than the relevant maximum aquatic life guideline or beyond the recommended pH or DO concentration range.
(DL>C) = analytical detection limit was higher than the relevant chronic aquatic life guideline.
(DL>D) = analytical detection limit was higher than the relevant drinking water guideline.
(DL>Mn) = analytical detection limit was higher than the relevant 30-day mean aquatic life guideline.
Water quality data and guidelines shown in this table were rounded to reflect laboratory or field instrument precision *after* comparisons to guidelines. Therefore, values slightly above guidelines may be displayed as being equal to the guidelines and identified as exceedances. Measured concentrations equal to the guideline values were not identified as exceedances.
- = no data.

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Fort Simpson-Upstream of the Ferry | | | | | | | Fort Simpson | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2013-2015 | | | | | | | 1960-2015 | | | | | | |
| | | Min | 25th Percentile[(B)] | Median | 75th Percentile[(B)] | Max | Percent Below Detection Limit | Count | Min | 25th Percentile[(B)] | Median | 75th Percentile[(B)] | Max | Percent Below Detection Limit | Count |
| **Conventional Parameters** | | | | | | | | | | | | | | | |
| Dissolved inorganic carbon | mg/L | - | - | - | - | - | - | - | 9.6 | 19 | 20 | 36 | 42 | 0% | 19 |
| Dissolved organic carbon | mg/L | 3.5 | 4.1 | 6.2 | 6.6 | 7.0 | 0% | 8 | 0.1 | 2.6 | 3.7 | 6.8 | 32 | 0% | 237 |
| Hardness, as $CaCO_3$ | mg/L | - | - | - | - | - | - | - | 57 | 114 | 149 | 205 | 249 | 0% | 254 |
| Total dissolved solids | mg/L | 136 | 139 | 168 | 177 | 196 | 0% | 8 | 33 | 166 | 194 | 240 | 400 | 0% | 121 |
| pH | - | 8.0 | 8.0 | 8.1 | 8.1 | 8.3 | 0% | 8 | 5.5[(C,D)] | 7.8 | 8.0 | 8.2 | 9.1[(C,D)] | 0% | 295 |
| Specific conductivity | µS/cm | 226 | 230 | 251 | 281 | 320 | 0% | 8 | 120 | 220 | 284 | 380 | 510 | 0% | 295 |
| Total Alkalinity, as $CaCO_3$ | mg/L | 77 | 81 | 92 | 103 | 118 | 0% | 8 | 63 | 89 | 116 | 165 | 210 | 0% | 286 |
| Total inorganic carbon | mg/L | - | - | - | - | - | - | - | 0.64 | 15 | 18 | 25 | 46 | 0% | 37 |
| Total organic carbon | mg/L | 3.0 | 4.2 | 5.9 | 6.4 | 6.7 | 0% | 8 | <0.5 | 3.1 | 5.0 | 12 | 46 | 1% | 203 |
| Total suspended solids | mg/L | 12 | 41 | 90 | 210 | 290 | 0% | 8 | <1.0 | 3.0 | 40 | 231 | 3627 | 20% | 249 |
| Turbidity | NTU | 8.8 | 29 | 57 | 127 | 214 | 0% | 8 | 0.6 | 3.1 | 28 | 132 | 2872 | 0% | 282 |
| Calcium | mg/L | 31 | 34 | 38 | 41 | 47 | 0% | 8 | 12 | 33 | 41 | 56 | 68 | 0% | 292 |
| Magnesium | mg/L | 7.4 | 8.4 | 10 | 11 | 13 | 0% | 8 | 5.6 | 8.0 | 11 | 16 | 19 | 0% | 252 |
| Potassium | mg/L | 0.6 | 0.6 | 0.6 | 0.78 | 1.0 | 0% | 8 | 0.2 | 0.64 | 0.78 | 0.89 | 3.8 | 0% | 288 |
| Sodium | mg/L | 1.6 | 2.0 | 2.1 | 3.9 | 8.4 | 0% | 8 | 0.68 | 1.9 | 2.6 | 4.2 | 13 | 0% | 288 |
| Sulphate | mg/L | 26 | 32 | 38 | 45 | 54 | 0% | 8 | 2.6 | 26 | 37 | 43 | 71 | 0% | 292 |
| Chloride | mg/L | <0.7 | <0.7 | <0.7 | 2.4 | 7.6 | 75% | 8 | 0.1 | 0.7 | 1.3 | 2.6 | 15 | 0% | 292 |
| Fluoride | mg/L | <0.1 | <0.1 | <0.1 | <0.1 | 0.1 | 88% | 8 | 0.02 | 0.08 | 0.09 | 0.11 | 0.3[(C)] | 3% | 283 |
| Silica | mg/L | - | - | - | - | - | - | - | 2.3 | 4.6 | 5.3 | 6.6 | 7.8 | 0% | 169 |
| **Nutrients** | | | | | | | | | | | | | | | |
| Dissolved ortho-phosphate | mg/L | - | - | - | - | - | - | - | <0.002 | <0.002 | <0.002 | 0.004 | 0.031 | 70% | 27 |
| Dissolved phosphorus | mg-P/L | <0.002 | <0.002 | <0.002 | 0.0023 | 0.004 | 63% | 8 | <0.002 | <0.01 | 0.006 | 0.01 | 0.5 | 37% | 234 |
| Nitrate | mg-N/L | 0.07 | 0.088 | 0.1 | 0.11 | 0.15 | 0% | 8 | 0 | 0.058 | 0.13 | 0.19 | 0.5 | 0% | 46 |
| Nitrate + nitrite | mg-N/L | - | - | - | - | - | - | - | <0.001 | 0.04 | 0.067 | 0.13 | <2.0 | 2% | 173 |
| Nitrite | mg-N/L | <0.01 | <0.01 | <0.01 | <0.01 | 0.01 | 88% | 8 | <0.01 | <0.01 | <0.01 | <0.01 | 1.3[(C, D, Mn, Mx)] | 80% | 41 |
| Particulate organic Nitrogen | mg/L | - | - | - | - | - | - | - | 0.13 | 0.14 | 0.15 | 0.15 | 0.15 | 0% | 4.0 |
| Particulate phosphorus (calculated) | mg-P/L | - | - | - | - | - | - | - | 0 | <0.98 | 0.038 | 0.18 | 2.4 | 39% | 174 |
| Total ammonia | mg-N/L | <0.005 | <0.005 | <0.005 | 0.0055 | 0.01 | 63% | 8 | 0.002 | <0.05 | 0.0085 | 0.013 | 0.3 | 41% | 94 |
| Total Kjeldahl nitrogen | mg-N/L | - | - | - | - | - | - | - | <0.1 | <0.5 | <0.5 | 0.7 | 2.3 | 50% | 30 |
| Total nitrogen | mg-N/L | 0.14 | 0.21 | 0.23 | 0.26 | 0.44 | 0% | 8 | 0.08 | 0.18 | 0.25 | 0.46 | 44 | 0% | 212 |
| Total phosphorus | mg-P/L | 0.013 | 0.028 | 0.067 | 0.17 | 0.21 | 0% | 8 | <0.002 | 0.01 | 0.049 | 0.2 | 2.5 | 7% | 268 |
| **Total Metals** | | | | | | | | | | | | | | | |
| Aluminum | µg/L | 258[(C, D)] | 437 | 1,690[(C, D)] | 2365 | 3,760[(C, D)] | 0% | 8 | 7.0 | 39 | 570[(C, D)] | 2858 | 65,100[(C, D)] | 0% | 130 |
| Antimony | µg/L | 0.1 | 0.2 | 0.3 | 1.1 | 11[(D, Mn)] | 0% | 8 | 0.079 | 0.1 | 0.13 | 0.2 | 0.37 | 0% | 70 |
| Arsenic | µg/L | 0.8 | 0.98 | 1.9 | 2.6 | 3.8 | 0% | 8 | 0.16 | 0.26 | 0.89 | 2.0 | 8.0[(C, Mn)] | 0% | 65 |
| Barium | µg/L | 46 | 79 | 112 | 133 | 196 | 0% | 8 | 46 | 80 | 93 | 134 | 773 | 16% | 213 |
| Beryllium | µg/L | <0.1 | <0.1 | <0.1 | 0.2 | 0.2[(Mn)] | 63% | 8 | <0.001 | <0.05 | <0.05 | 0.16 | 1.6[(Mn)] | 24% | 131 |
| Bismuth | µg/L | - | - | - | - | - | - | - | <0.001 | 0.0015 | 0.011 | 0.042 | 0.11 | 15% | 39 |
| Boron | µg/L | - | - | - | - | - | - | - | 5.6 | 8.1 | 9.0 | 11 | 16 | 0% | 70 |
| Cadmium | µg/L | <0.1 | 0.18 | 0.25[(C)] | 0.4 | 0.4[(C)] | 25% | 8 | 0.012 | <1 | 0.1 | 0.58 | 11[(A, C, D)] | 31% | 217 |
| Cesium | µg/L | <0.1 | <0.1 | 0.35 | 0.6 | 1.0 | 25% | 8 | 0.005 | 0.013 | 0.13 | 0.48 | 1.3 | 0% | 70 |
| Chromium | µg/L | 0.7 | 1.7 | 3.9[(C, Mn)] | 23 | 152[(C, D, Mn)] | 0% | 8 | 0.05 | 0.2 | 0.8 | 3.9 | 32[(C, Mn)] | 11% | 131 |

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Fort Simpson-Upstream of the Ferry | | | | | | | Fort Simpson | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2013-2015 | | | | | | | 1960-2015 | | | | | | |
| | | Min | 25th Percentile[B] | Median | 75th Percentile[B] | Max | Percent Below Detection Limit | Count | Min | 25th Percentile[B] | Median | 75th Percentile[B] | Max | Percent Below Detection Limit | Count |
| Cobalt | µg/L | <0.1 | 0.35 | 1.1 | 2.3 | 3.0 | 13% | 8 | 0.017 | 0.33 | 0.8 | 2.1 | 22[Mn] | 21% | 217 |
| Copper | µg/L | 0.9 | 1.9 | 5.5[C, Mn] | 6.7 | 8.6[C, Mn] | 0% | 7 | <0.2 | 0.74 | 2.0 | 5.8 | 132[C, Mn, Mx] | 5% | 217 |
| Iron | µg/L | 380[C] | 678 | 2,535[C, Mx] | 4983 | 7,530[C, Mx] | 0% | 8 | 1.0 | 133 | 1,120[C, Mx] | 5040 | 93,500[C, Mx] | 0% | 131 |
| Lead | µg/L | 0.2 | 0.83 | 2.9 | 44 | 306[C, D, Mn, Mx] | 0% | 8 | 0.012 | <1 | <1 | 3.3 | 33[C, D, Mn] | 24% | 217 |
| Lithium | µg/L | 4.3 | 6.1 | 7.0 | 7.8 | 11 | 0% | 8 | 4.5 | 6.4 | 7.9 | 10 | 69 | 0% | 131 |
| Magnesium | mg/L | - | - | - | - | - | - | - | 7.0 | 12 | 14 | 16 | 26 | 0% | 61 |
| Manganese | µg/L | 9.1 | 18 | 55 | 114 | 121 | 0% | 8 | 0.9 | 8.5 | 35 | 112 | 1,300[Mn] | 0% | 131 |
| Mercury | µg/L | 0.0013 | 0.0022 | 0.006 | 0.013 | 0.031[C, Mn] | 0% | 8 | - | - | - | - | 0.057[C, Mn] | 0% | 1.0 |
| Molybdenum | µg/L | 0.8 | 1.4 | 1.6 | 3.5 | 15 | 0% | 8 | 0.1 | 1.0 | 1.4 | 1.6 | 5.6 | 0% | 131 |
| Nickel | µg/L | 1.5 | 2.1 | 5.5 | 9.2 | 14 | 0% | 8 | 0.7 | 1.7 | 2.9 | 7.9 | 65 | 1% | 216 |
| Rubidium | µg/L | 1.3 | 1.6 | 4.3 | 5.5 | 10 | 0% | 8 | 0.66 | 0.82 | 1.6 | 4.6 | 22 | 0% | 70 |
| Selenium | µg/L | <0.5 | <0.5 | <0.5 | 0.5 | 1.0 | 63% | 8 | <0.05 | 0.53 | 0.62 | 0.78 | 1.1[C] | 2% | 65 |
| Silver | µg/L | <0.1 | <0.1 | 0.25 | 0.55 | 1.1[C] | 38% | 8 | <0.001 | 0.0045 | 0.047 | 0.1 | 0.9[C] | 22% | 91 |
| Sodium | mg/L | - | - | - | - | - | - | - | 0.64 | 1.4 | 2.2 | 3.8 | 6.2 | 2% | 61 |
| Strontium | µg/L | 136 | 162 | 178 | 185 | 196 | 0% | 8 | 119 | 167 | 187 | 236 | 284 | 0% | 131 |
| Thallium | µg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 8 | 0.004 | 0.0085 | 0.022 | 0.064 | 0.34 | 0% | 70 |
| Tin | µg/L | - | - | - | - | - | - | - | <0.005 | <0.005 | <0.005 | 0.0095 | 0.074 | 56% | 70 |
| Uranium | µg/L | 0.4 | 1.2 | 1.4 | 1.5 | 1.9 | 0% | 8 | 0.4 | 1.3 | 1.5 | 1.7 | 3.1 | 0% | 65 |
| Vanadium | µg/L | 1.3 | 1.9 | 4.9 | 8.1 | 13 | 0% | 8 | 0 | 0.5 | 1.2 | 4.8 | 68 | 12% | 217 |
| Zinc | µg/L | <5.0 | 11 | 26 | 48 | 51[C, Mn] | 13% | 8 | 0.8 | 2.9 | 8.6 | 24 | 388[C, Mn, Mx] | 0% | 217 |
| **Dissolved Metals** | | | | | | | | | | | | | | | |
| Aluminum | µg/L | 2.6 | 25 | 36 | 44 | 57[Mn] | 0% | 8 | 6.8 | 19 | 40 | 69 | 196[Mn, Mx] | 2% | 53 |
| Antimony | µg/L | <0.1 | <0.1 | 0.1 | 0.1 | 0.1 | 38% | 8 | 0.11 | 0.14 | 0.16 | 0.19 | 0.37 | 0% | 49 |
| Arsenic | µg/L | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0% | 8 | <0.1 | 0.21 | 0.37 | 0.5 | 13 | 17% | 250 |
| Barium | µg/L | 39 | 43 | 43 | 51 | 61 | 0% | 8 | 40 | 46 | 57 | 85 | 103 | 0% | 49 |
| Beryllium | µg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 8 | 0.001 | 0.003 | 0.007 | 0.008 | 0.018 | 0% | 49 |
| Bismuth | µg/L | - | - | - | - | - | - | - | <0.001 | <0.001 | 0.001 | 0.002 | 0.005 | 45% | 49 |
| Boron | µg/L | - | - | - | - | - | - | - | 4.7 | 9.0 | 40 | 60 | 580 | 3% | 133 |
| Cadmium | µg/L | <0.05 | <0.05 | <0.05 | <0.05 | 0.24 | 88% | 8 | 0.014 | 0.021 | 0.026 | 0.032 | 0.067 | 0% | 49 |
| Cesium | µg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 8 | 0.003 | 0.005 | 0.007 | 0.011 | 0.055 | 12% | 49 |
| Chromium | µg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 8 | 0.07 | 0.1 | 0.12 | 0.15 | 0.32 | 0% | 49 |
| Cobalt | µg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 8 | 0.021 | 0.044 | 0.064 | 0.093 | 0.2 | 0% | 49 |
| Copper | µg/L | <0.2 | <0.2 | 0.6 | 1.1 | 1.7 | 25% | 8 | 0.37 | 0.65 | 1.3 | 1.9 | 6.0 | 0% | 53 |
| Iron | µg/L | <5.0 | <5 | 8.5 | 14 | 16 | 38% | 8 | <10 | 37 | 60 | 102 | 350 | 3% | 61 |
| Lead | µg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 8 | 0.012 | 0.036 | 0.068 | 0.1 | 6.0 | 6% | 53 |
| Lithium | µg/L | 3.3 | 3.8 | 4.5 | 4.7 | 5.2 | 0% | 8 | 2.8 | 3.9 | 4.8 | 6.0 | 8.6 | 2% | 50 |
| Manganese | µg/L | <0.1 | 0.2 | 0.25 | 0.65 | 2.0 | 13% | 8 | 0.49 | 3.3 | 5.1 | 9.6 | 17 | 18% | 60 |
| Molybdenum | µg/L | 0.5 | 1.1 | 1.2 | 1.3 | 1.5 | 0% | 8 | 0.71 | 1.1 | 1.5 | 1.6 | 1.8 | 0% | 49 |
| Nickel | µg/L | 0.8 | 0.9 | 1.1 | 1.2 | 1.4 | 0% | 8 | 0.97 | 1.5 | 1.8 | 2.0 | 3.4 | 2% | 50 |
| Niobium | µg/L | - | - | - | - | - | - | - | <0.001 | 0.001 | 0.002 | 0.004 | 0.018 | 20% | 49 |
| Platinum | µg/L | - | - | - | - | - | - | - | <0.001 | <0.001 | <0.001 | <0.001 | 0.002 | 86% | 49 |
| Silver | µg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 8 | <0.001 | 0.001 | 0.001 | 0.003 | 0.007 | 20% | 49 |

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

| Parameter | Units | Fort Simpson-Upstream of the Ferry | | | | | | | Fort Simpson | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2013-2015 | | | | | | | 1960-2015 | | | | | | |
| | | Min | 25th Percentile[B] | Median | 75th Percentile[B] | Max | Percent Below Detection Limit | Count | Min | 25th Percentile[B] | Median | 75th Percentile[B] | Max | Percent Below Detection Limit | Count |
| Strontium | µg/L | 121 | 130 | 137 | 164 | 190 | 0% | 8 | 96 | 131 | 173 | 234 | 285 | 0% | 50 |
| Thallium | µg/L | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 100% | 8 | 0.003 | 0.005 | 0.007 | 0.008 | 0.051 | 0% | 49 |
| Tin | µg/L | - | - | - | - | - | - | - | <0.005 | <0.005 | 0.005 | 0.01 | 0.13 | 47% | 49 |
| Uranium | µg/L | 0.4 | 0.78 | 1.0 | 1.1 | 1.4 | 0% | 8 | 0.39 | 0.93 | 1.3 | 1.7 | 1.9 | 0% | 50 |
| Vanadium | µg/L | 0.1 | 0.18 | 0.2 | 0.2 | 0.3 | 0% | 8 | 0.086 | 0.14 | 0.27 | 0.36 | 0.7 | 0% | 49 |
| Zinc | µg/L | <0.4 | <0.4 | <0.4 | 0.53 | 0.9 | 63% | 8 | 0.5 | 0.86 | 1.3 | 2.7 | 140 | 0% | 53 |
| **Organics** | | | | | | | | | | | | | | | |
| Acenaphthylene | µg/L | - | - | - | - | - | - | - | <0.0065 | <0.01 | <0.01 | <0.016 | <0.016 | 98% | 48 |
| Anthracene | µg/L | - | - | - | - | - | - | - | <0.005 | <0.0061 | <0.0061 | <0.02 | <0.02[DL>C] | 100% | 38 |
| Benzo(a)anthracene | µg/L | - | - | - | - | - | - | - | <0.005 | <0.01 | <0.01 | <0.02 | <0.02[DL>C] | 100% | 38 |
| Benzo(a)pyrene | µg/L | - | - | - | - | - | - | - | <0.006 | <0.0094 | <0.0094 | <0.069 | <0.069[DL>C, DL>D, DL>Mn] | 100% | 43 |
| Chrysene | µg/L | - | - | - | - | - | - | - | <0.003 | <0.02 | <0.02 | 0.02 | 0.054 | 71% | 38 |
| Dibenzothiophene | µg/L | - | - | - | - | - | - | - | <0.0052 | <0.0082 | <0.0082 | <0.0082 | 0.073 | 91% | 22 |
| Fluoranthene | µg/L | - | - | - | - | - | - | - | <0.0041 | <0.0087 | <0.0087 | <0.015 | 0.068[C] | 83% | 48 |
| Fluorene | µg/L | - | - | - | - | - | - | - | <0.0064 | <0.015 | <0.015 | <0.025 | 0.068 | 85% | 48 |
| Indene | µg/L | - | - | - | - | - | - | - | <0.0051 | <0.01 | <0.01 | <0.03 | 0.084 | 96% | 48 |
| Naphthalene | µg/L | - | - | - | - | - | - | - | <0.0058 | <0.02 | <0.02 | 0.033 | 0.13 | 32% | 38 |
| Perylene | µg/L | - | - | - | - | - | - | - | <0.009 | <0.1 | 0.018 | <0.1 | 0.23 | 83% | 35 |
| Phenanthrene | µg/L | - | - | - | - | - | - | - | <0.0062 | <0.034 | 0.034 | 0.034 | 0.28 | 57% | 47 |
| Pyrene | µg/L | - | - | - | - | - | - | - | <0.0039 | <0.0078 | <0.0078 | 0.015 | 0.15[C, Mn] | 71% | 48 |
| **Pestcides** | | | | | | | | | | | | | | | |
| Aldrin | µg/L | - | - | - | - | - | - | - | <0.000091 | <0.00027 | <0.00027 | <0.0021 | <0.0021 | 100% | 40 |
| Alpha-Benzenehexachloride | µg/L | - | - | - | - | - | - | - | 0.00014 | <0.00035 | <0.00035 | <0.0023 | <0.0023 | 98% | 40 |
| Alpha-Chlordane | µg/L | - | - | - | - | - | - | - | <0.00012 | <0.0006 | <0.0006 | <0.0029 | <0.0029 | 100% | 40 |
| Alpha-Endosulfan | µg/L | - | - | - | - | - | - | - | <0.00015 | <0.00062 | <0.00062 | <0.0031 | <0.0031 | 100% | 40 |
| Beta-Endosulfan | µg/L | - | - | - | - | - | - | - | <0.00029 | <0.00059 | <0.00059 | <0.0059 | <0.0059 | 100% | 40 |
| Beta-HCH | µg/L | - | - | - | - | - | - | - | <0.001 | <0.0016 | <0.0016 | <0.0016 | <0.0016 | 100% | 27 |
| Cis-Nonachlor | µg/L | - | - | - | - | - | - | - | <0.00068 | <0.0011 | <0.0011 | <0.0011 | <0.0011 | 100% | 27 |
| Dieldrin | µg/L | - | - | - | - | - | - | - | <0.00015 | <0.0011 | <0.0011 | <0.0068 | <0.0068 | 100% | 40 |
| Endrin | µg/L | - | - | - | - | - | - | - | <0.00025 | <0.0013 | <0.0013 | <0.0073 | <0.0073 | 100% | 40 |
| Gamma-Chlordane | µg/L | - | - | - | - | - | - | - | <0.00012 | <0.00031 | <0.00031 | <0.0028 | <0.0028 | 100% | 40 |
| Heptachlor | µg/L | - | - | - | - | - | - | - | <0.00011 | <0.00056 | <0.00056 | <0.0043 | <0.0043 | 100% | 40 |
| Heptachlor Epoxide | µg/L | - | - | - | - | - | - | - | <0.000096 | <0.00033 | <0.00033 | <0.0032 | <0.0032 | 100% | 40 |
| Hexachlorobutadiene | µg/L | - | - | - | - | - | - | - | <0.00025 | <0.00041 | <0.00041 | <0.00041 | <0.00041 | 100% | 27 |
| Methoxychlor (P,P'-Methoxychlor). | µg/L | - | - | - | - | - | - | - | <0.0015 | <0.0051 | <0.0051 | <0.048 | <0.048 | 100% | 40 |
| Mirex | µg/L | - | - | - | - | - | - | - | <0.00013 | <0.00082 | <0.00082 | <0.0044 | <0.0044 | 100% | 40 |
| O,P'-DDD | µg/L | - | - | - | - | - | - | - | <0.00048 | <0.00078 | <0.00078 | <0.00078 | <0.00078 | 100% | 27 |
| O,P'-DDE | µg/L | - | - | - | - | - | - | - | <0.00074 | <0.0012 | <0.0012 | <0.0012 | <0.0012 | 100% | 27 |
| O,P'-DDT | µg/L | - | - | - | - | - | - | - | <0.00035 | <0.00056 | <0.00056 | <0.0094 | <0.0094 | 100% | 40 |
| Oxychlordane | µg/L | - | - | - | - | - | - | - | <0.00064 | <0.001 | <0.001 | <0.001 | <0.001 | 100% | 27 |
| P,P'-DDD (TDP) | µg/L | - | - | - | - | - | - | - | <0.000076 | <0.00088 | <0.00088 | <0.017 | <0.017 | 100% | 40 |
| P,P'-DDE | µg/L | - | - | - | - | - | - | - | <0.00023 | <0.00065 | <0.00065 | <0.0064 | <0.0064 | 100% | 40 |
| P,P'-DDT | µg/L | - | - | - | - | - | - | - | <0.00021 | <0.0012 | <0.0012 | <0.0093 | <0.0093 | 100% | 40 |

**Table B1: Summary of Statistics of Water Quality in the Liard River at Seven Monitoring Stations**

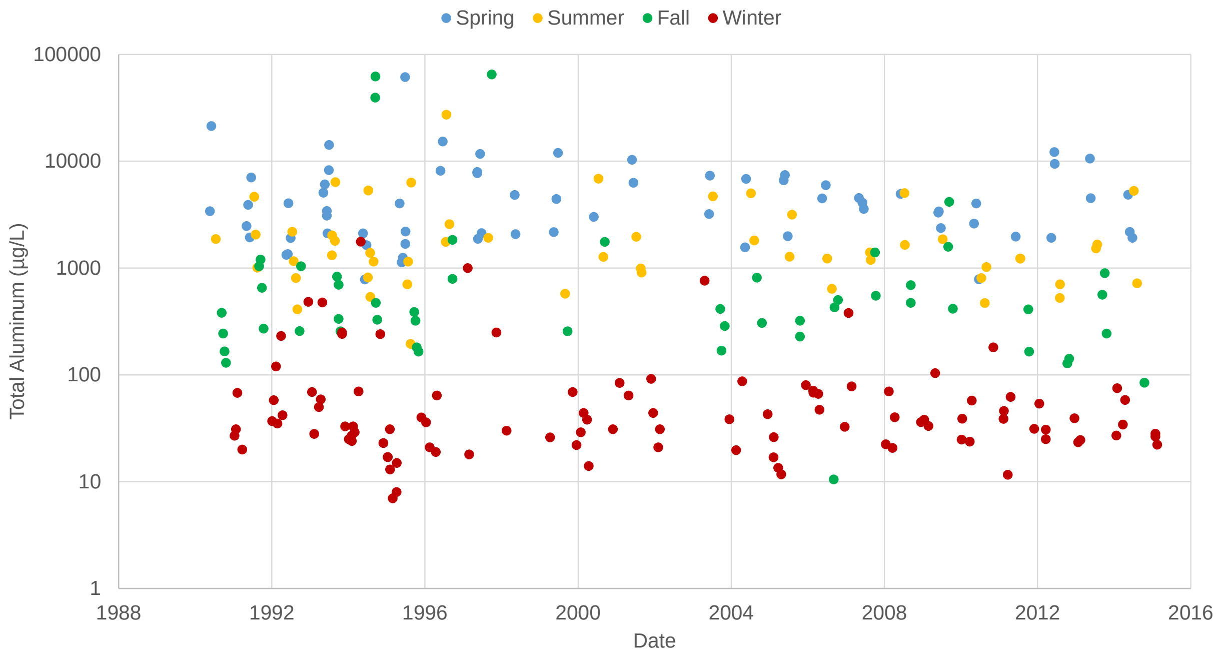
| Parameter | Units | Fort Simpson-Upstream of the Ferry | | | | | | | Fort Simpson | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2013-2015 | | | | | | | 1960-2015 | | | | | | |
| | | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count | Min | 25th Percentile(B) | Median | 75th Percentile(B) | Max | Percent Below Detection Limit | Count |
| PCB-TOTAL | µg/L | - | - | - | - | - | - | - | <0.00021 | <0.00034 | <0.00034 | <0.011 | <0.011 | 83% | 6 |
| Pentachloroanisole | µg/L | - | - | - | - | - | - | - | <0.00017 | <0.00028 | <0.00028 | <0.00028 | 0.00081 | 89% | 27 |
| Pentachlorobenzene | µg/L | - | - | - | - | - | - | - | 0.0002 | <0.00034 | <0.00034 | <0.0027 | <0.0027 | 97% | 31 |
| Trans-Nonachlor | µg/L | - | - | - | - | - | - | - | <0.00046 | <0.00074 | <0.00074 | <0.00074 | <0.00074 | 100% | 27 |

Values in shaded cells are above guidelines:
(A) = concentration higher than the relevant acute aquatic life guideline or beyond the recommended pH or DO concentration range.
(B) = 25th and 75th percentile values are not screened with any guidelines because they are interpolated values.
(C) = concentration higher than the relevant chronic aquatic life guideline or beyond the recommended pH, DO or total alkalinity concentration range.
(D) = concentration higher than the relevant drinking water guideline or beyond the recommended pH or DO concentration range.
(Mn) = concentration higher than the relevant 30-day mean aquatic life guideline or beyond the recommended pH or DO concentration range.
(Mx) = concentration higher than the relevant maximum aquatic life guideline or beyond the recommended pH or DO concentration range.
(DL>C) = analytical detection limit was higher than the relevant chronic aquatic life guideline.
(DL>D) = analytical detection limit was higher than the relevant drinking water guideline.
(DL>Mn) = analytical detection limit was higher than the relevant 30-day mean aquatic life guideline.
Water quality data and guidelines shown in this table were rounded to reflect laboratory or field instrument precision *after* comparisons to guidelines. Therefore, values slightly above guidelines may be displayed as being equal to the guidelines and identified as exceedances. Measured concentrations equal to the guideline values were not identified as exceedances.
\- = no data.

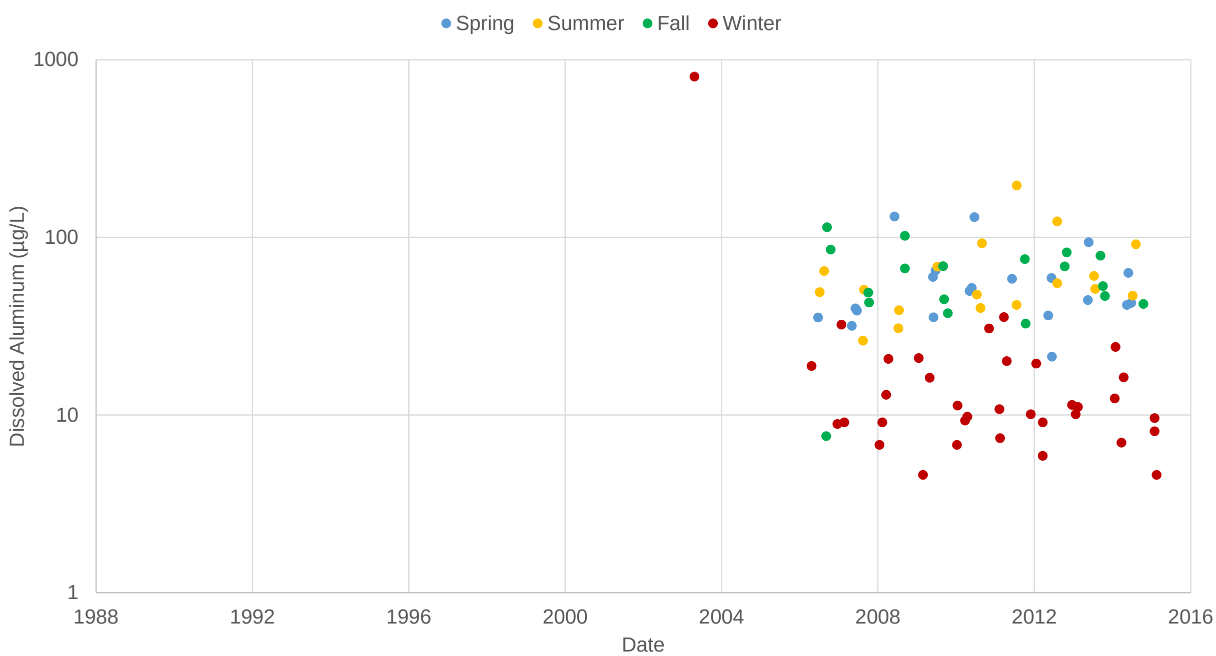
Note: For all figures, values below the detection limit are shown at the detection limit with an open data point.

*Figure B1: Seasonal Concentrations or Values in the Liard River downstream stations (Fort Liard and Fort Simpson), 1988 to 2015*

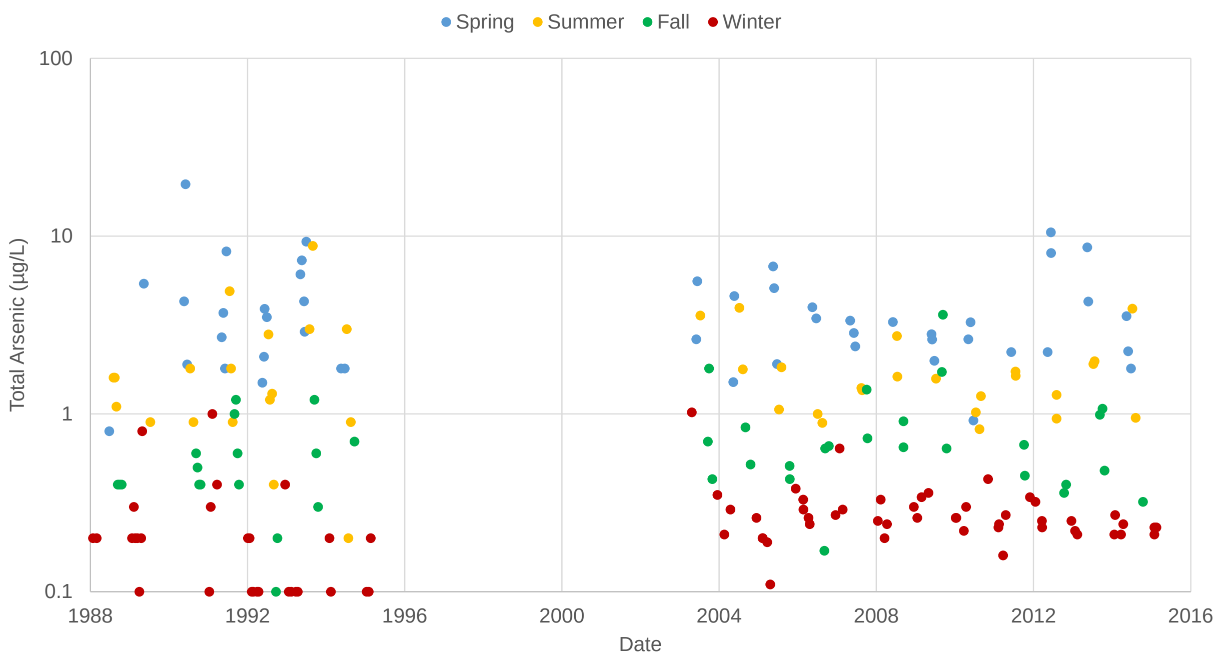
**(1) Total Aluminum**



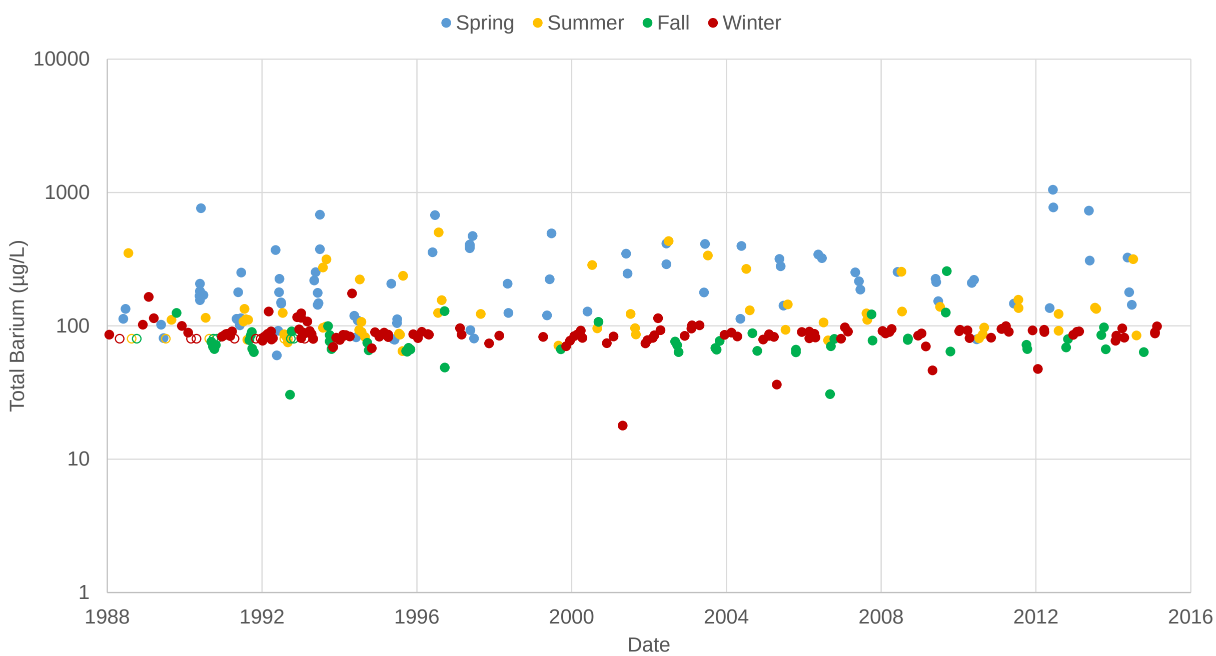

**(2) Dissolved Aluminum**



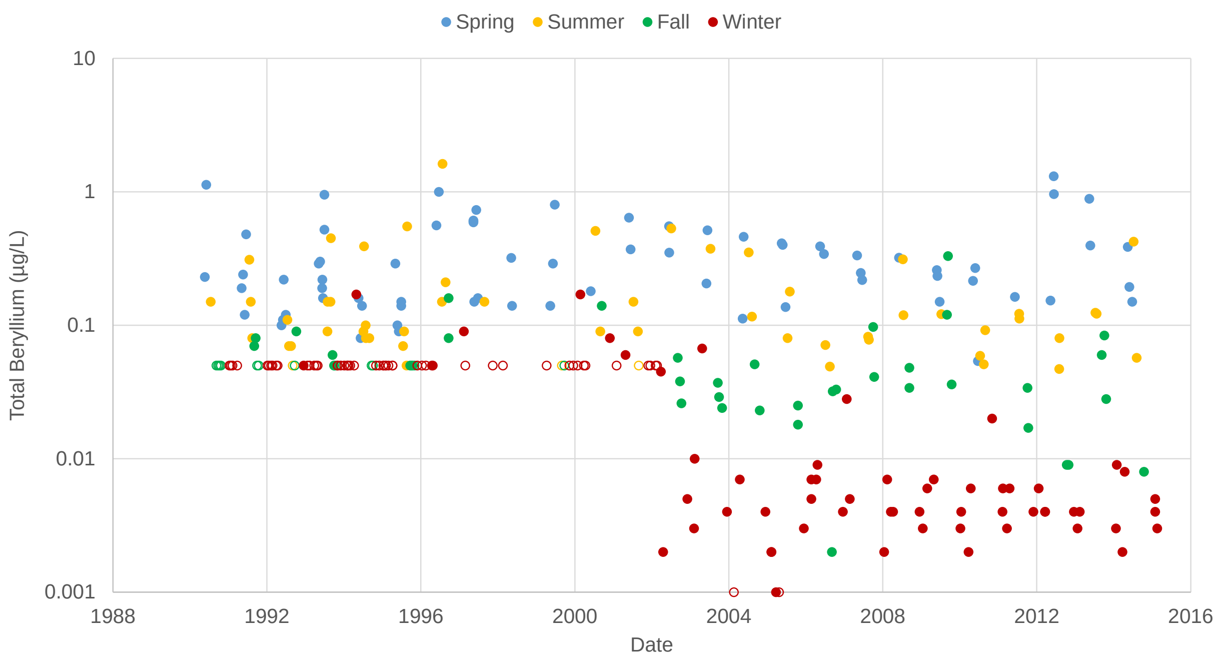
**(3) Total Arsenic**



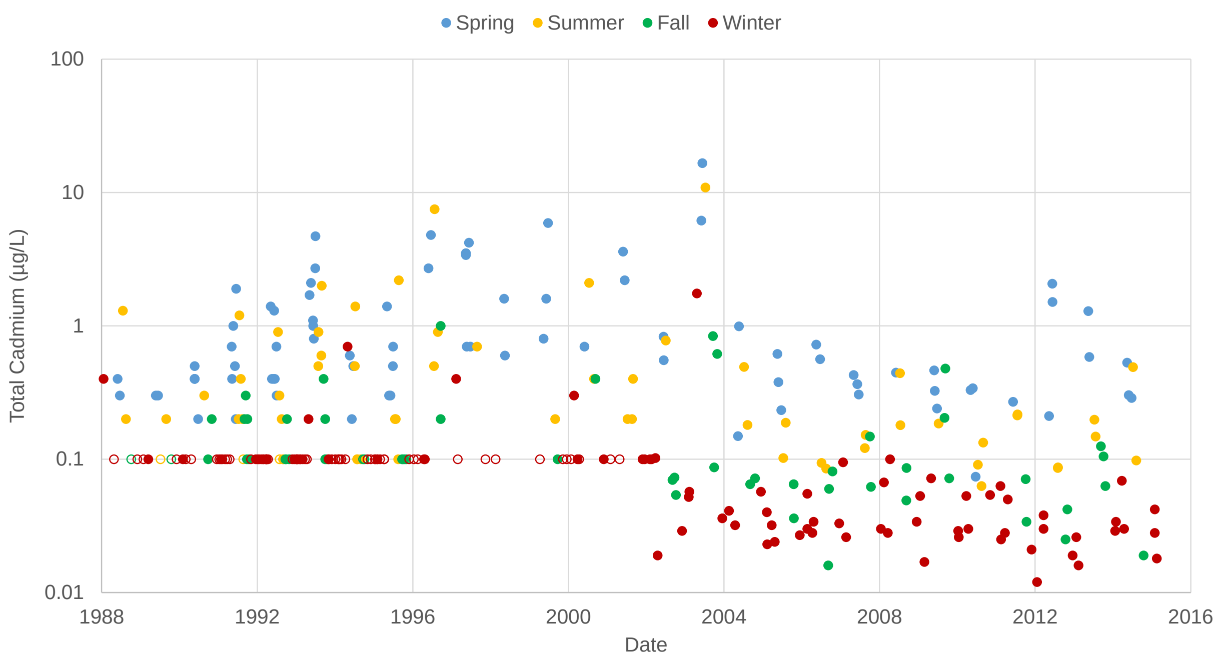

**(4) Total Barium**



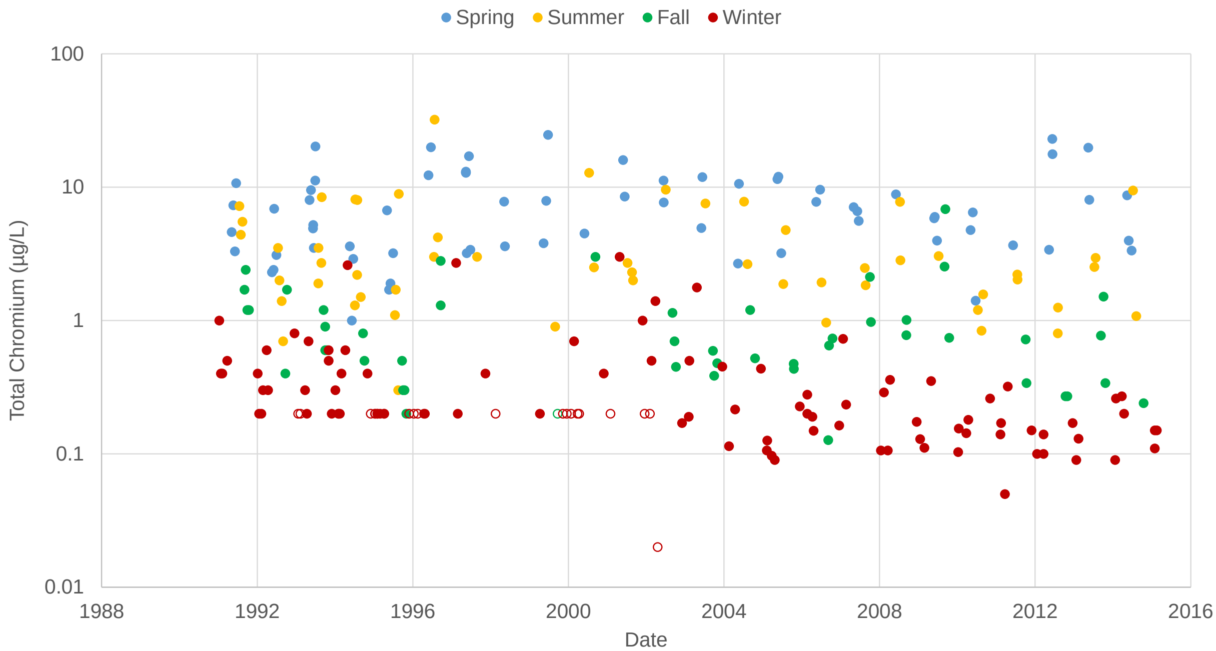
**(5) Total Beryllium**



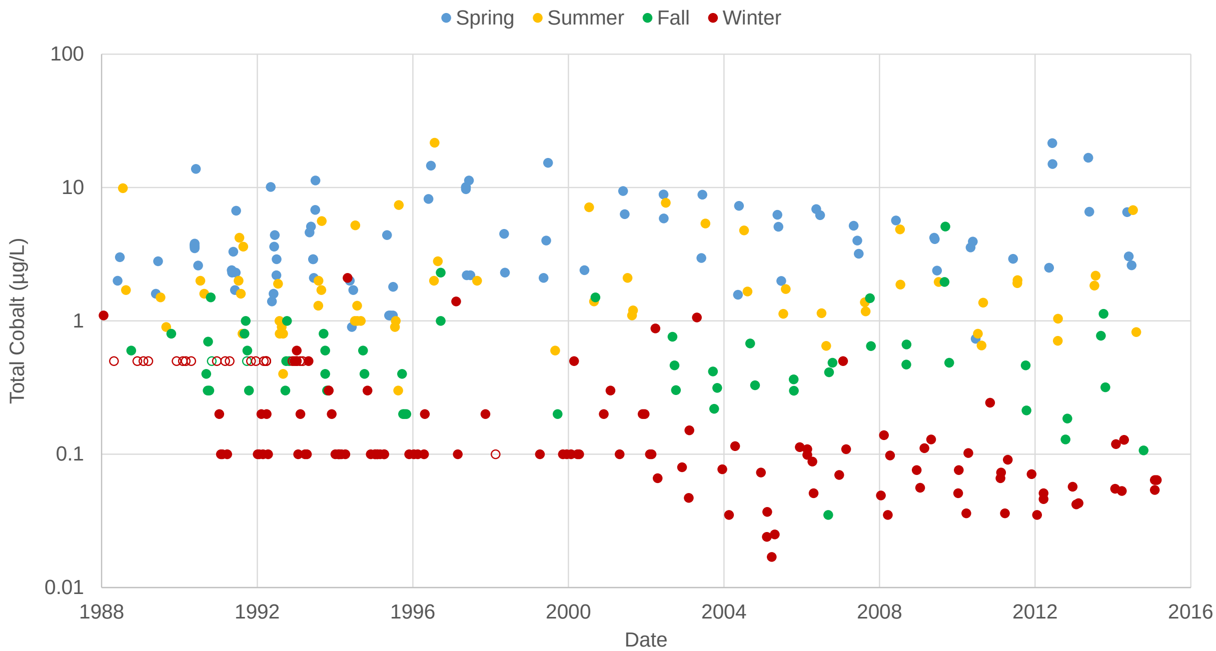

**(6) Total Cadmium**



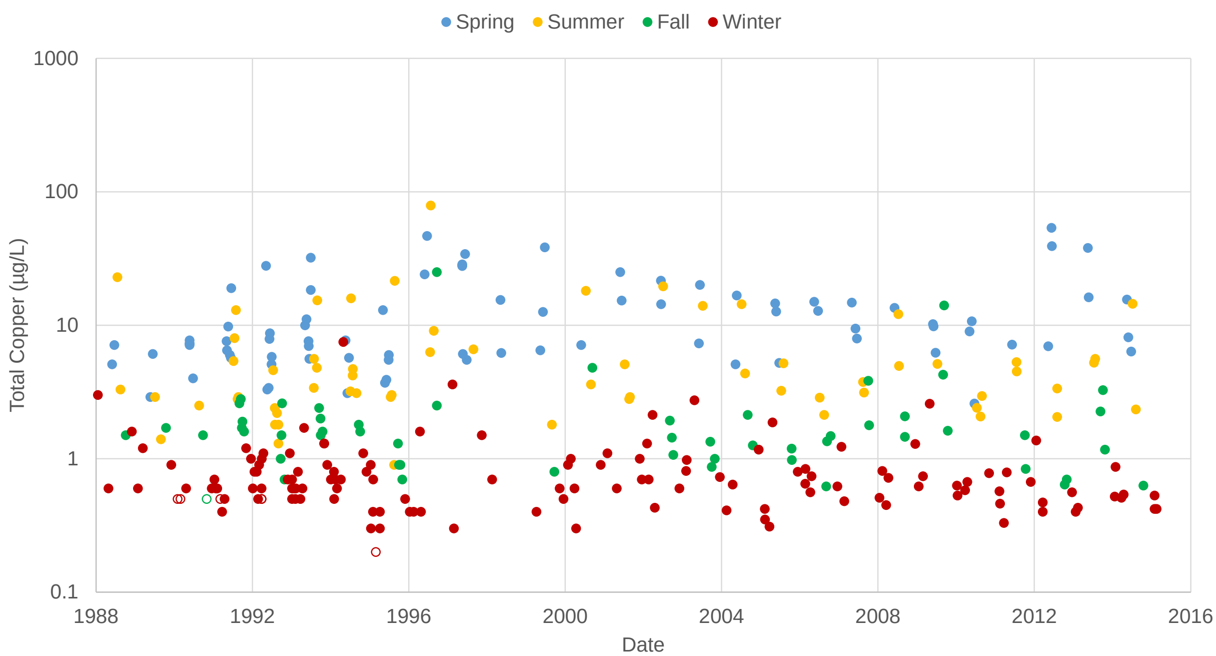
**(7) Total Chromium**



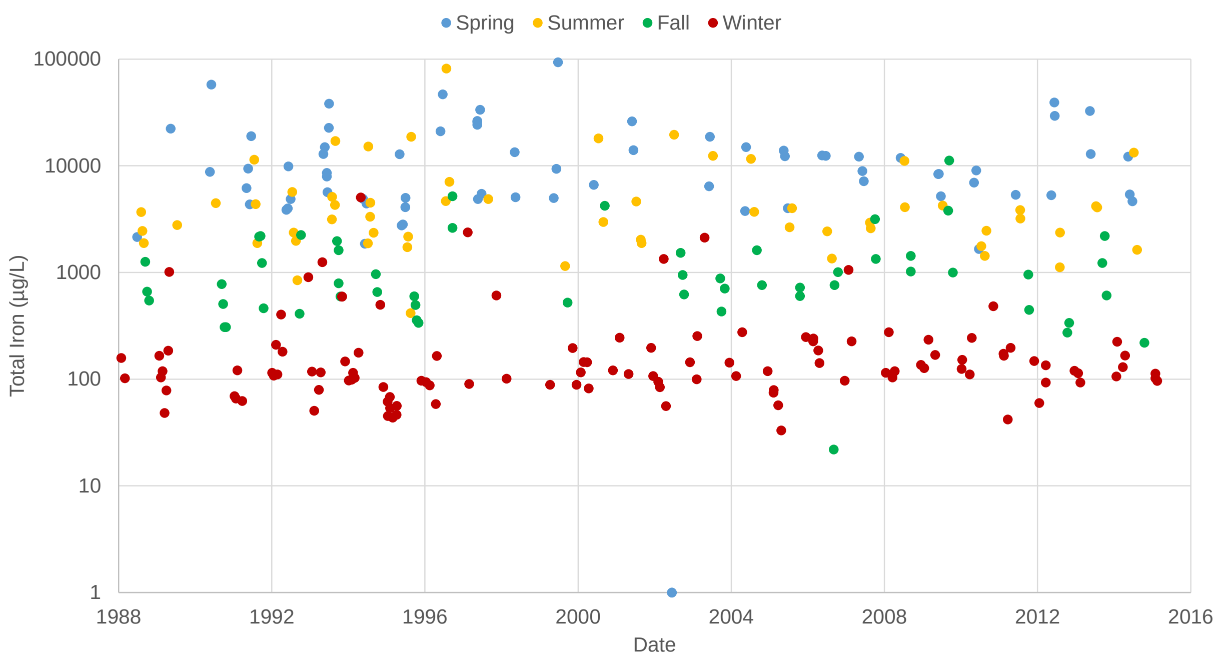

**(8) Total Cobalt**



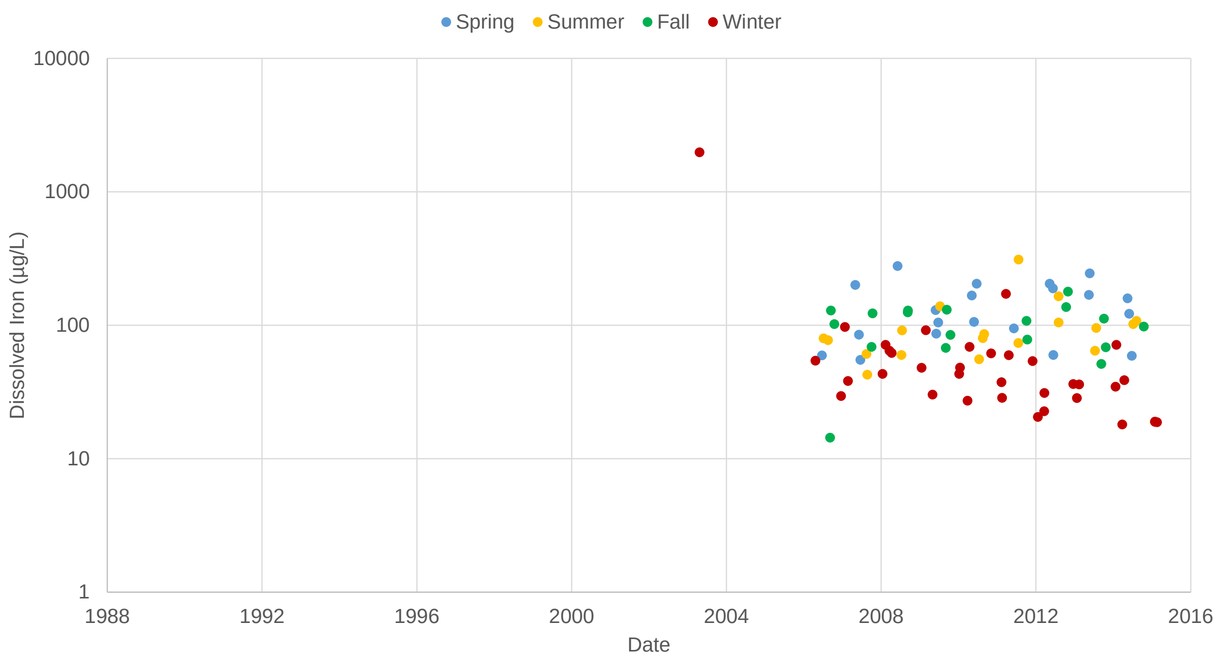
**(9) Total Copper**



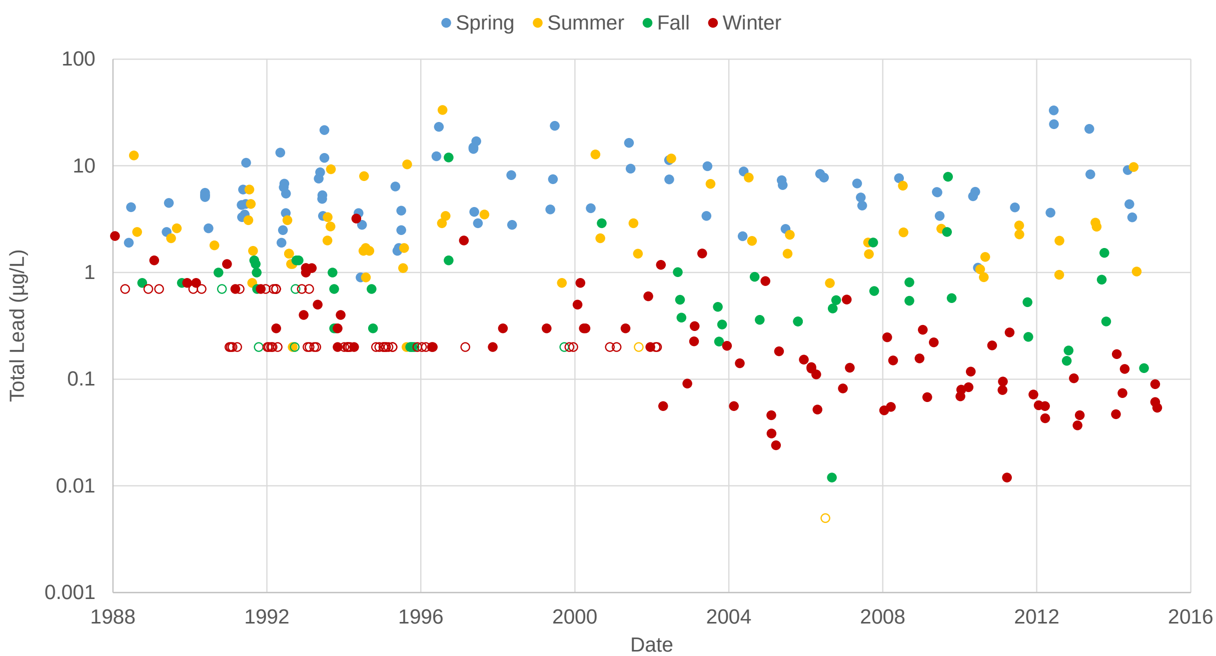

**(10) Total Iron**



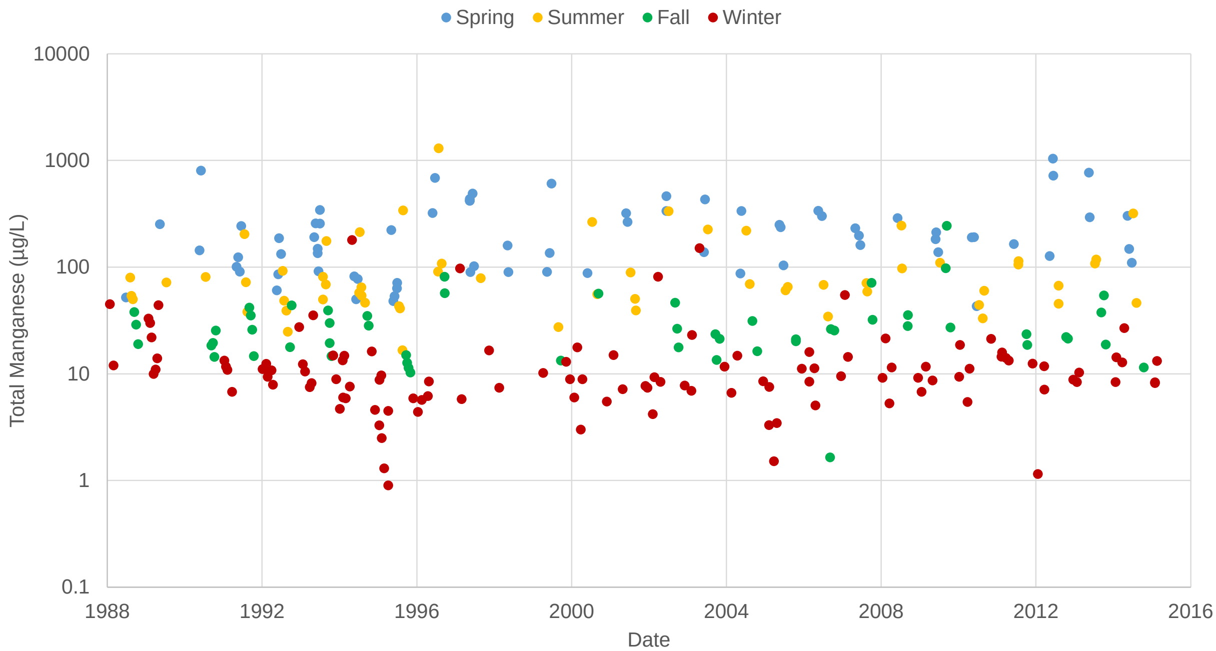
**(11) Dissolved Iron**



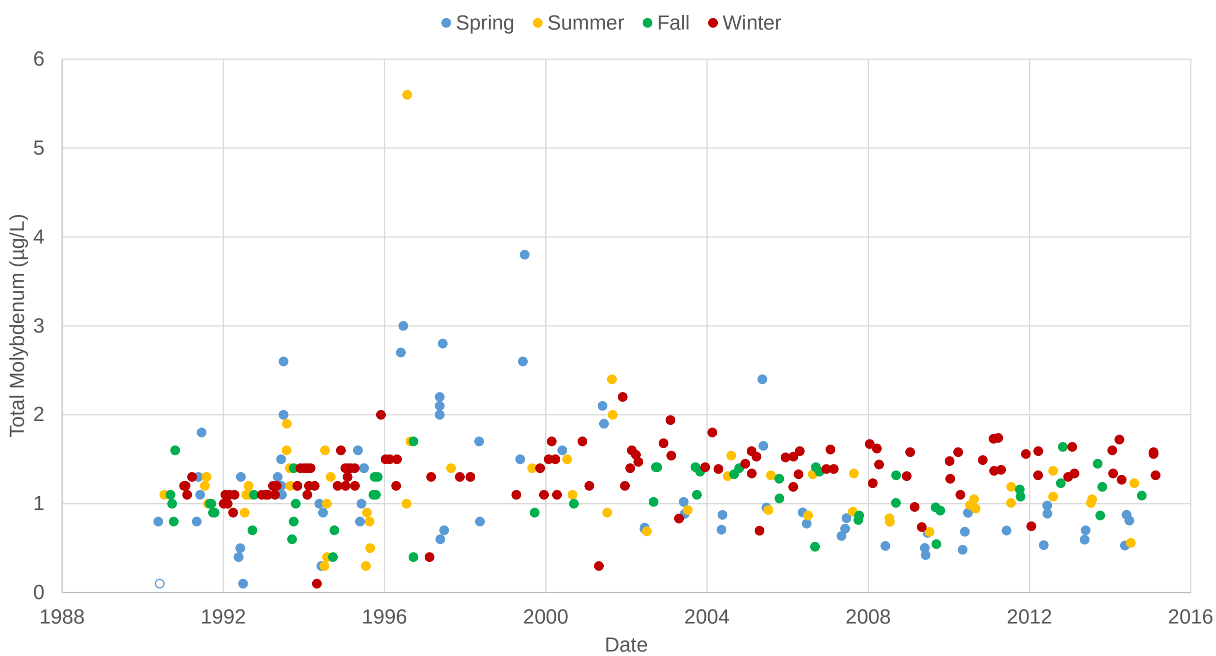

**(12) Total Lead**



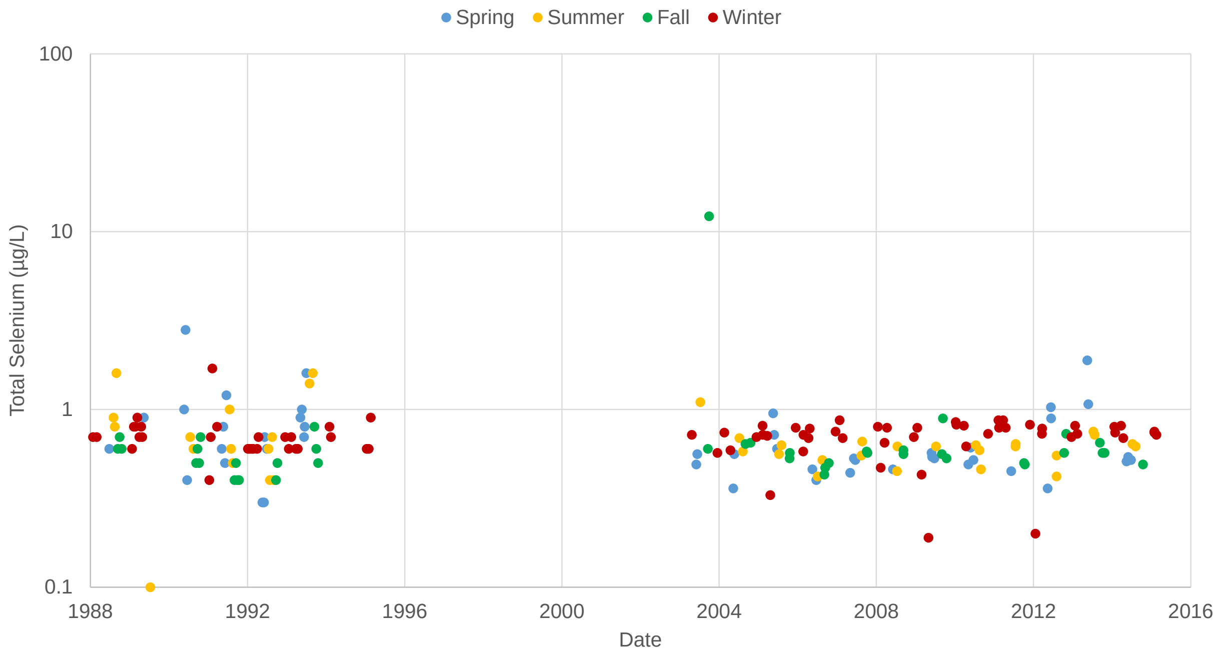
**(13) Total Manganese**



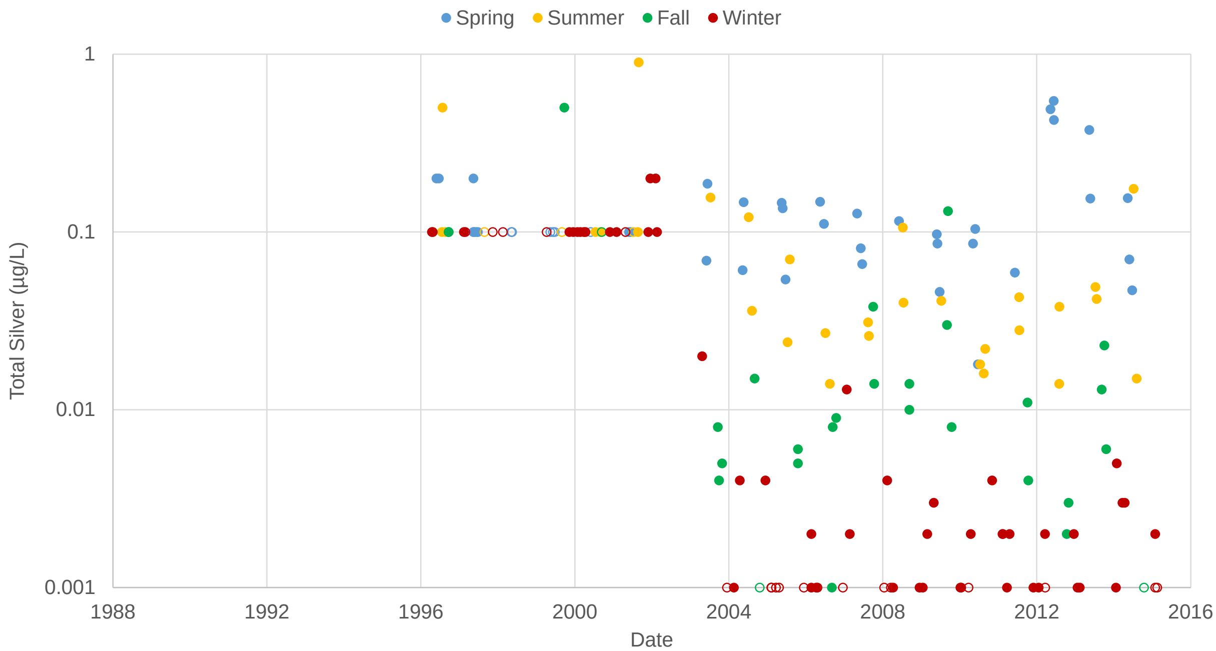

**(14) Total Molybdenum**



**(15) Total Selenium**




**(16) Total Silver**



**(17) Total Zinc**

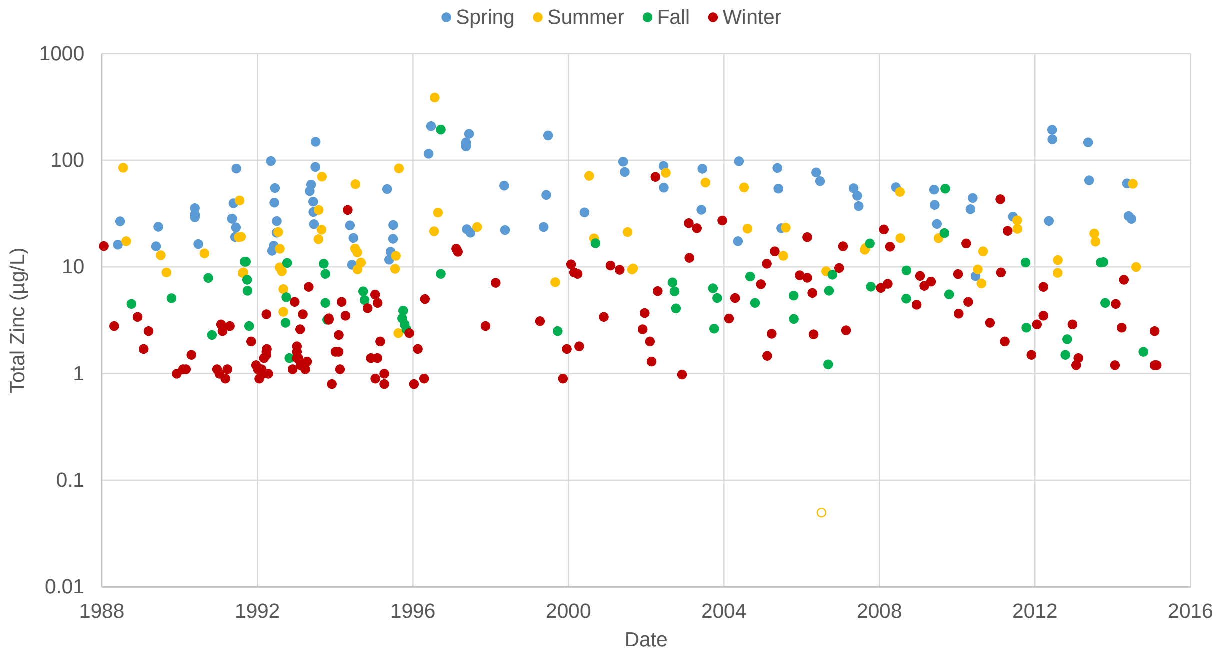
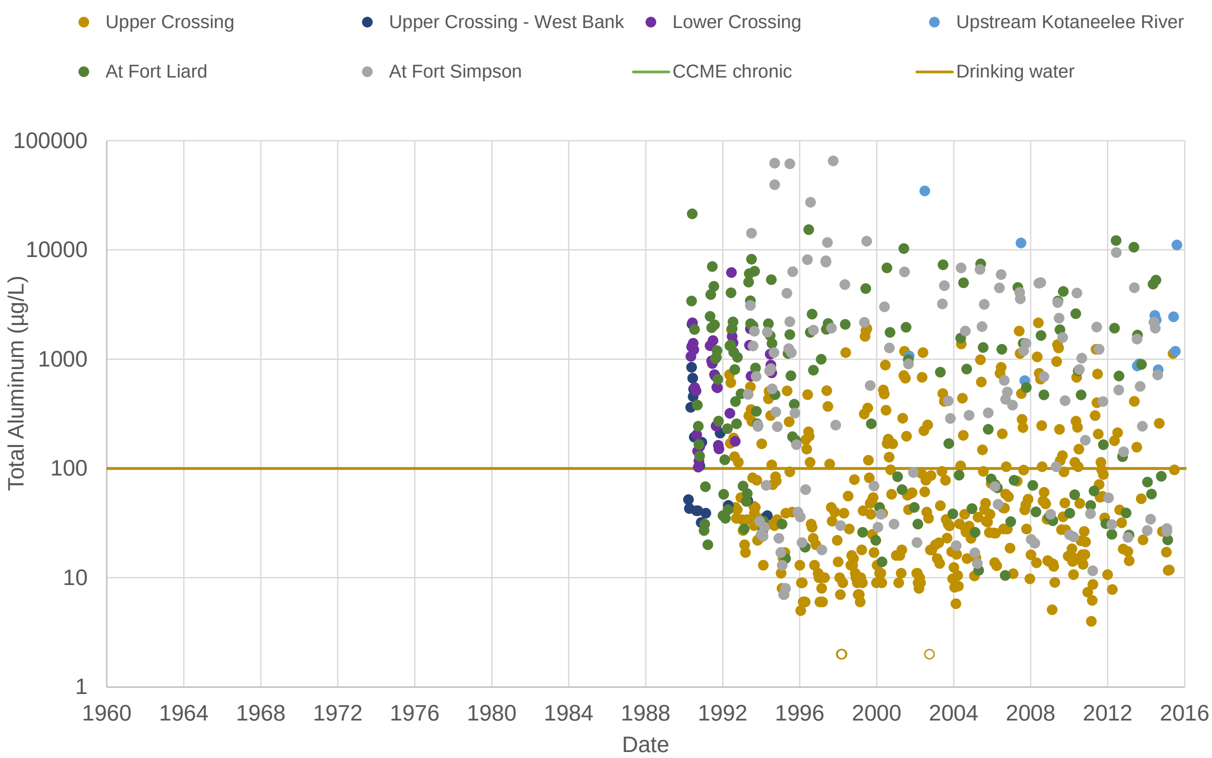
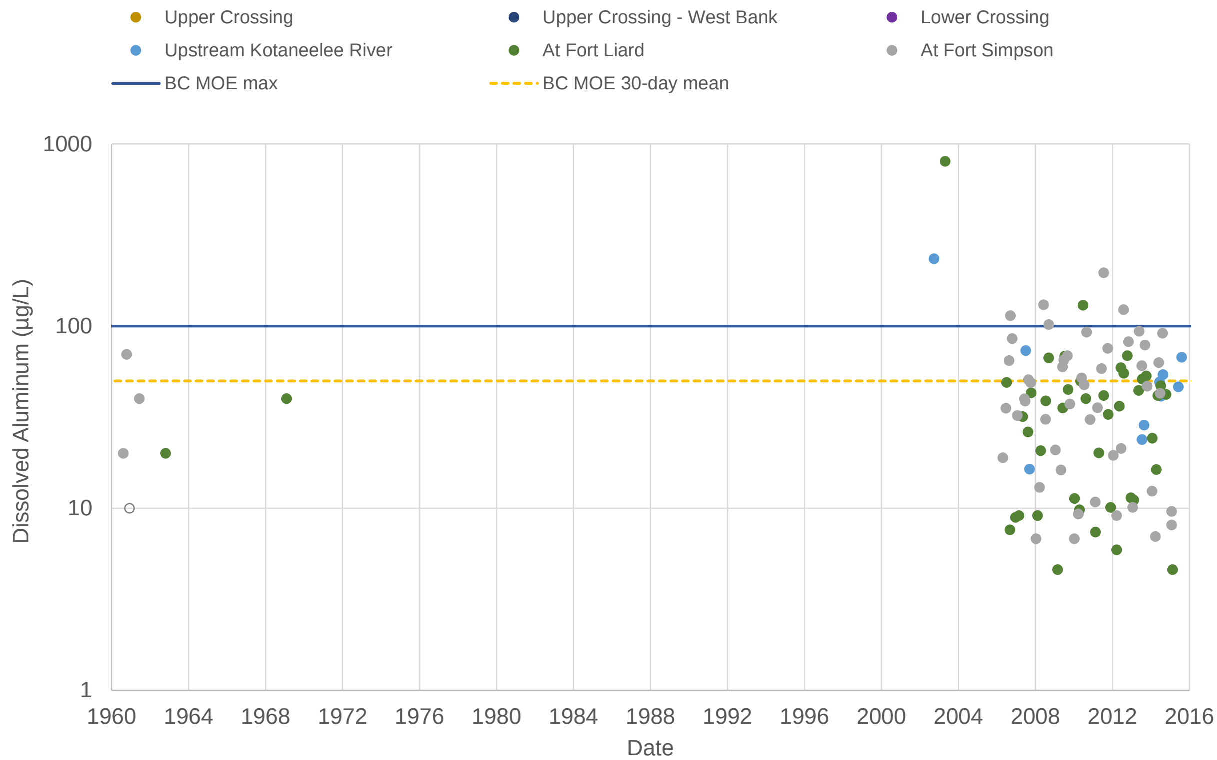


*Figure B2: Water Quality Values or Concentrations in the Liard River Monitoring Stations, 1960 to 2015*

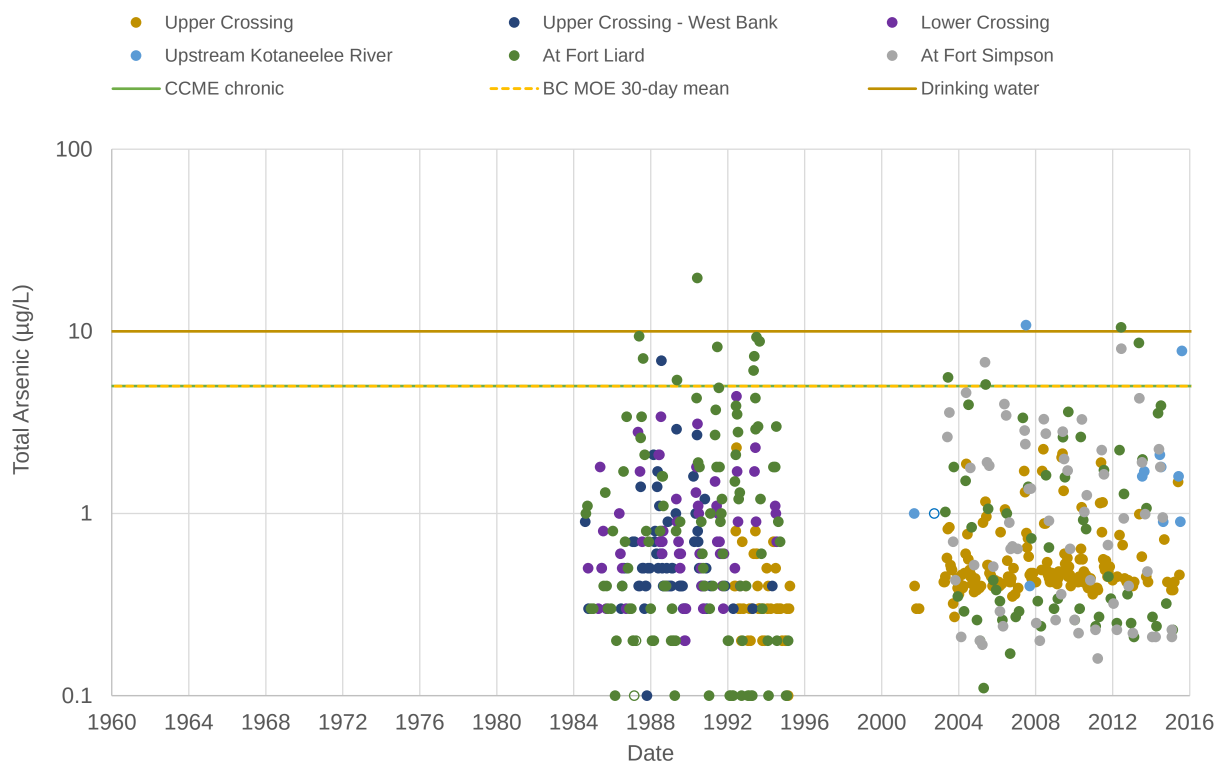
**(1) Total Aluminum**



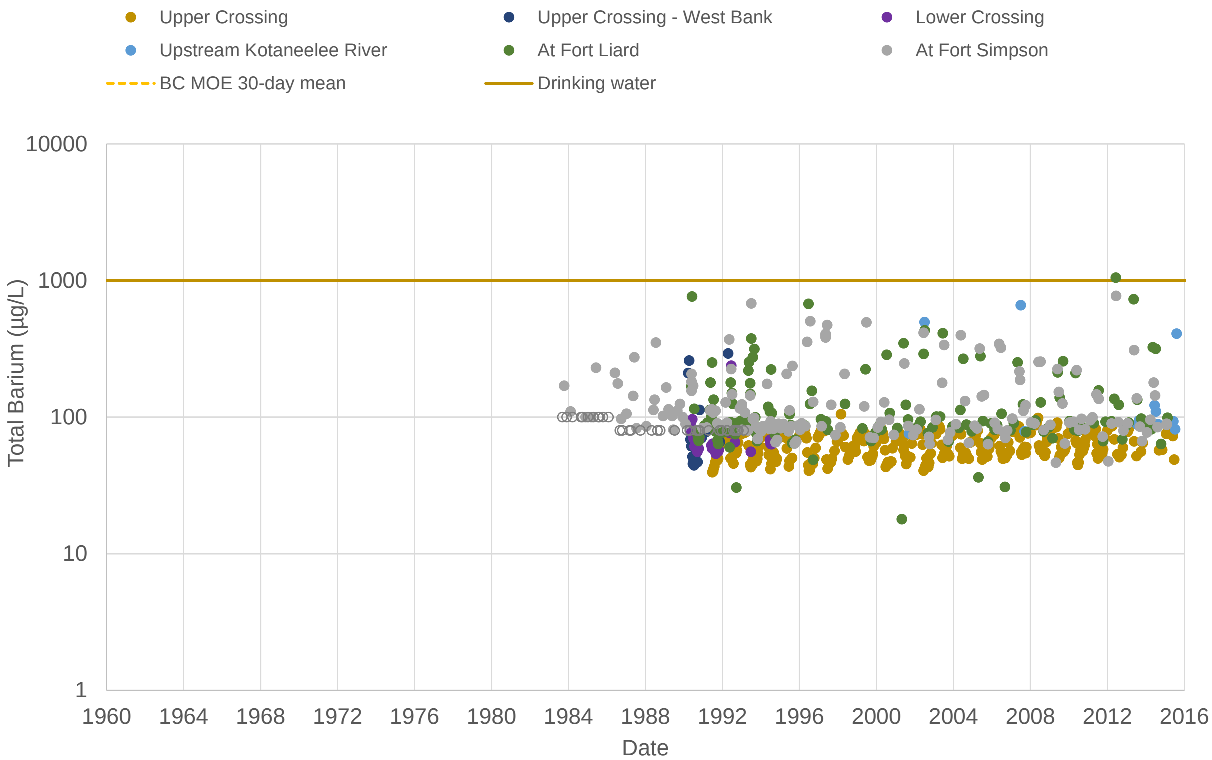
**(2) Dissolved Aluminum**



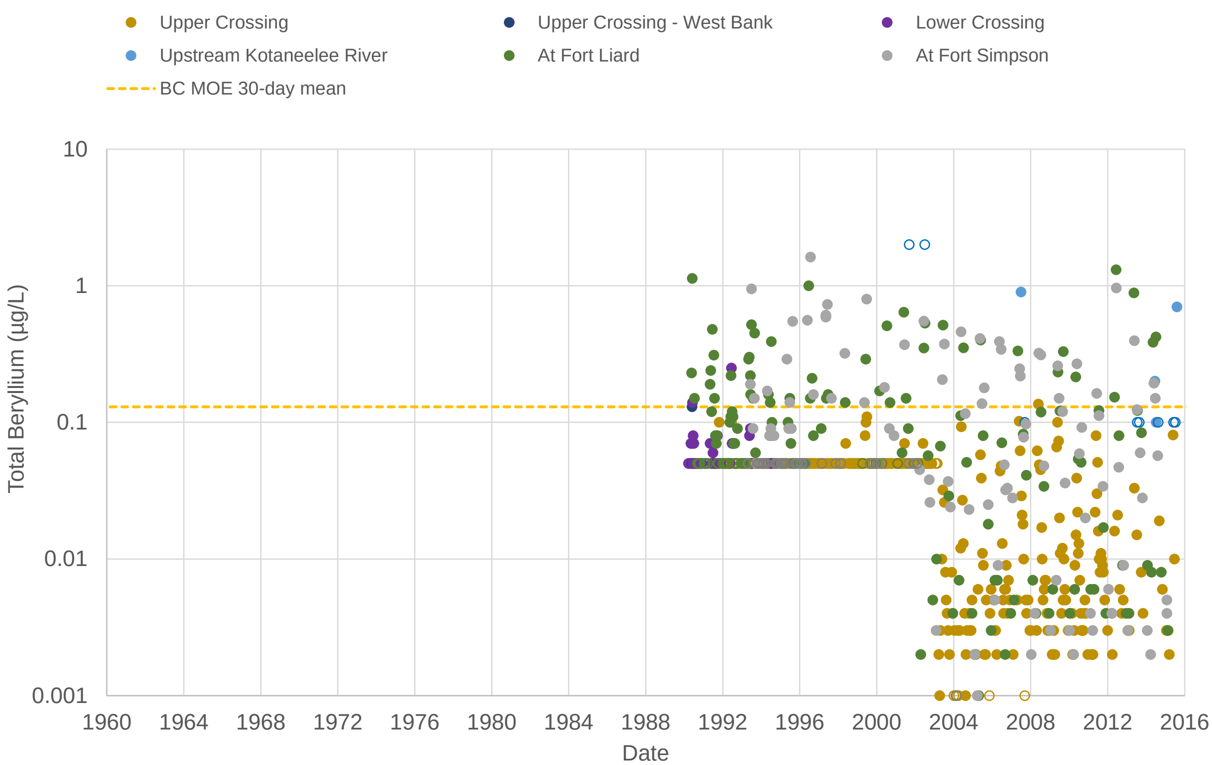

**(3) Total Arsenic**



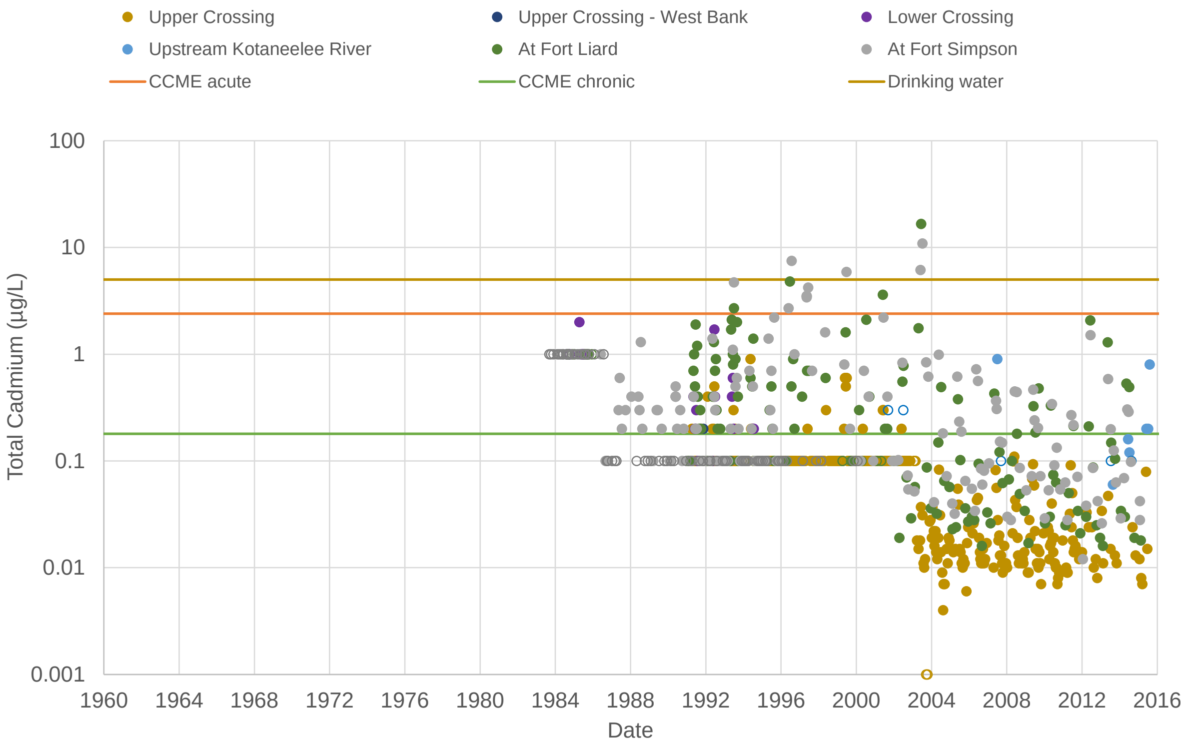
**(4) Total Barium**



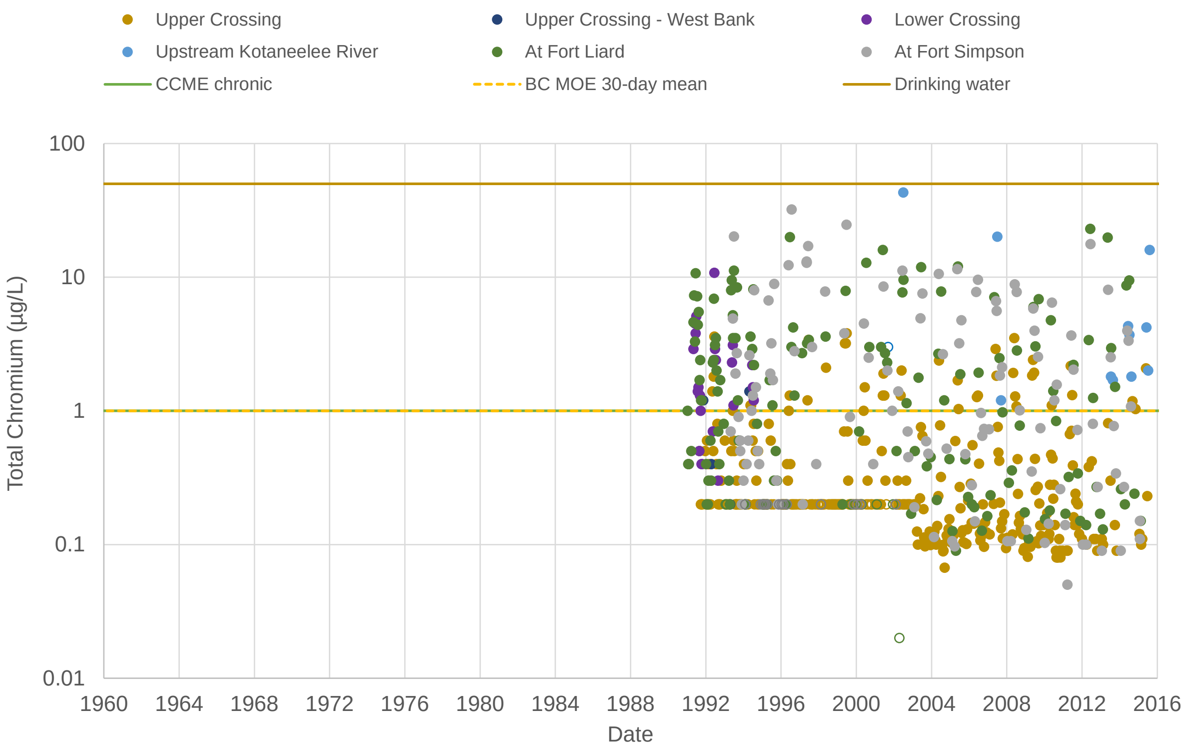

**(5) Total Beryllium**



**(6) Total Cadmium**

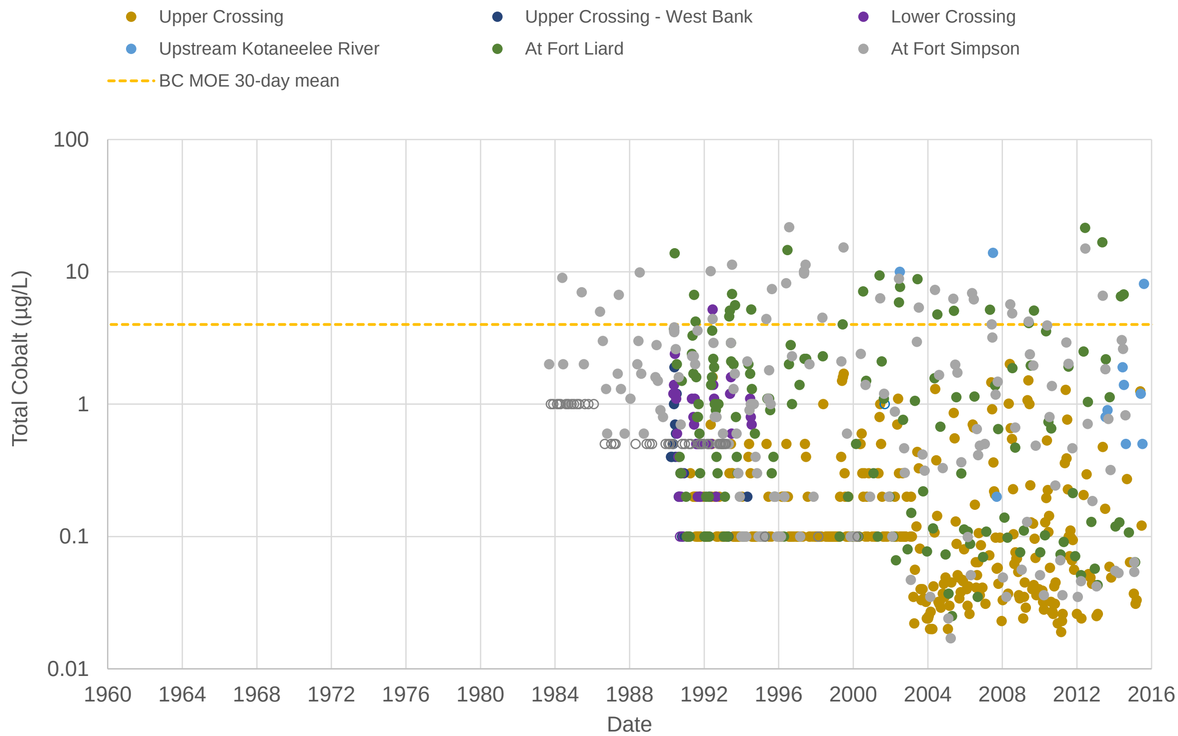



**(7) Total Chromium**



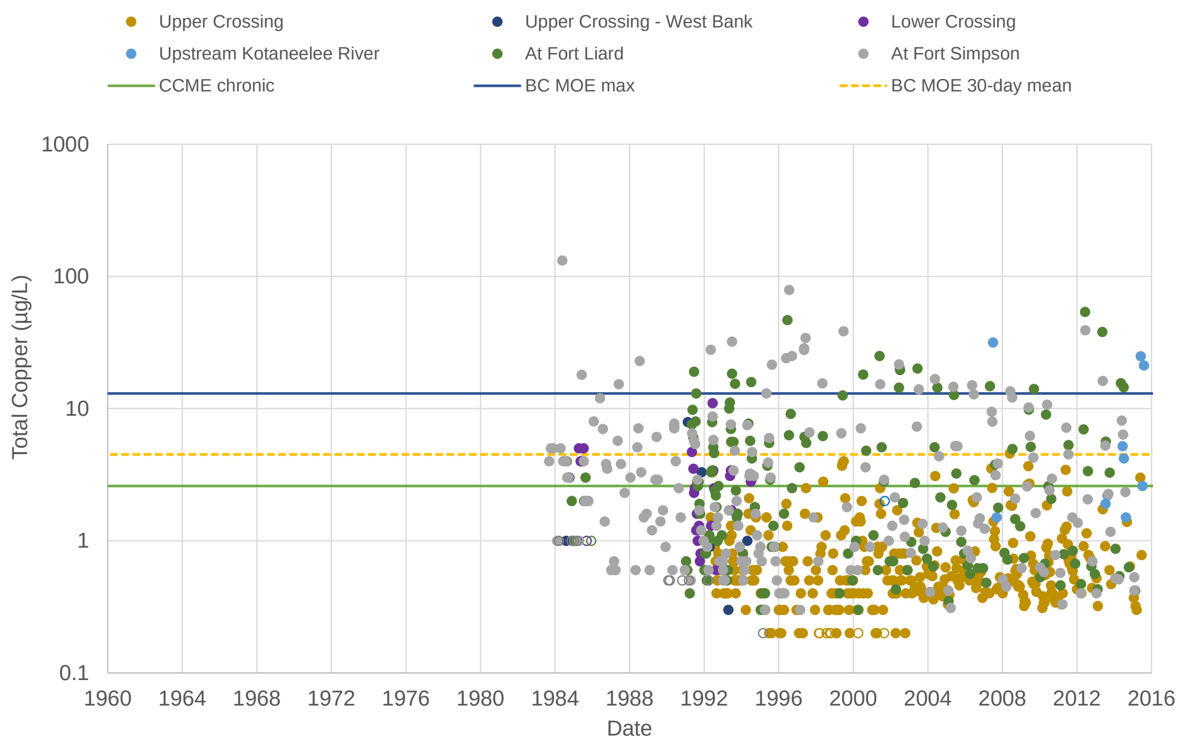

Note: For the purposes of visually reviewing the data, one data point was removed: 8530 µg/Lat Fort Liard on June 27, 1995.

**(8) Total Cobalt**



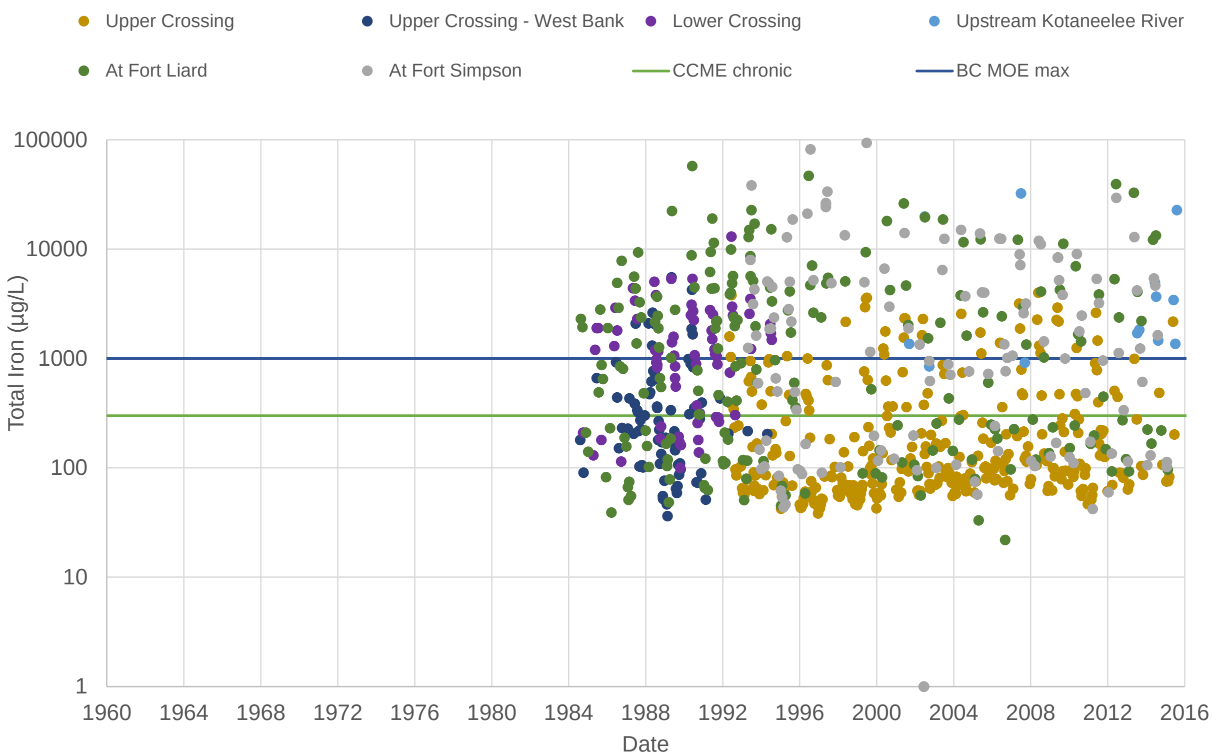

Note: For the purposes of visually reviewing the data, BC MOE's maximum (110 mg/L) guideline is not shown.

**(9) Total Copper**

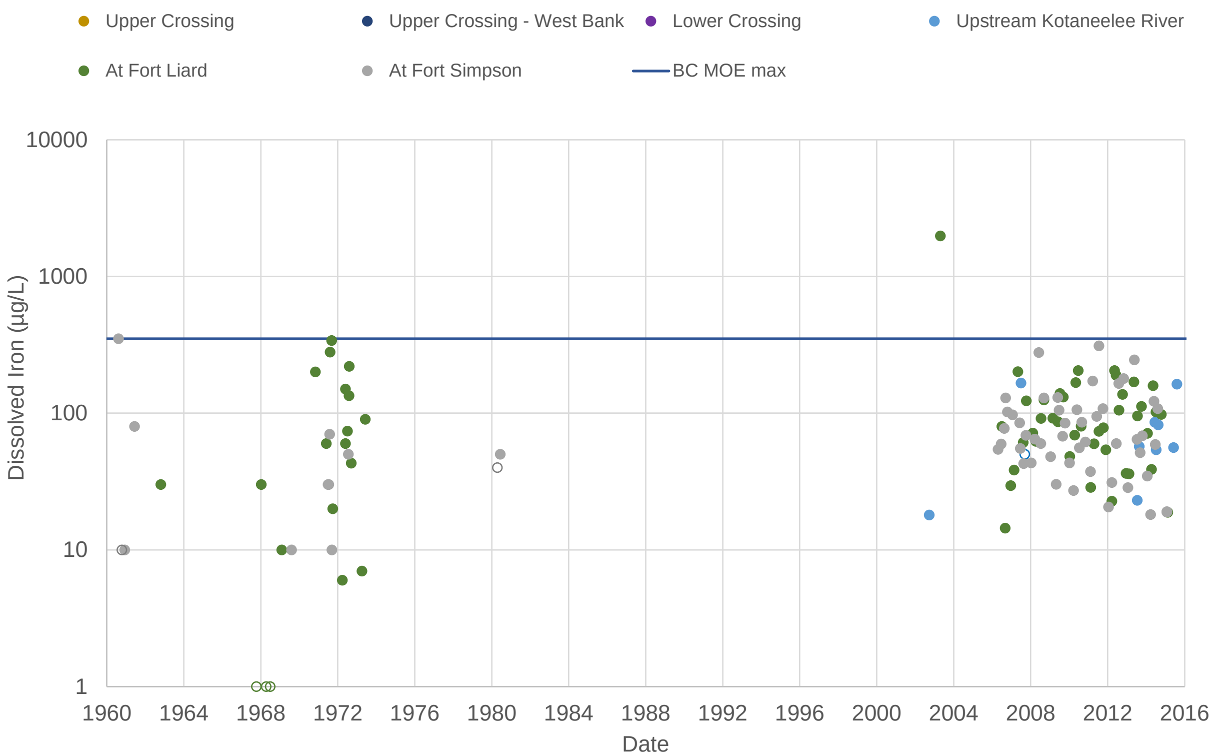



Note: For the purposes of visually reviewing the data, one data point was removed: 132 µg/L at Fort Simpson on May 23, 1984.

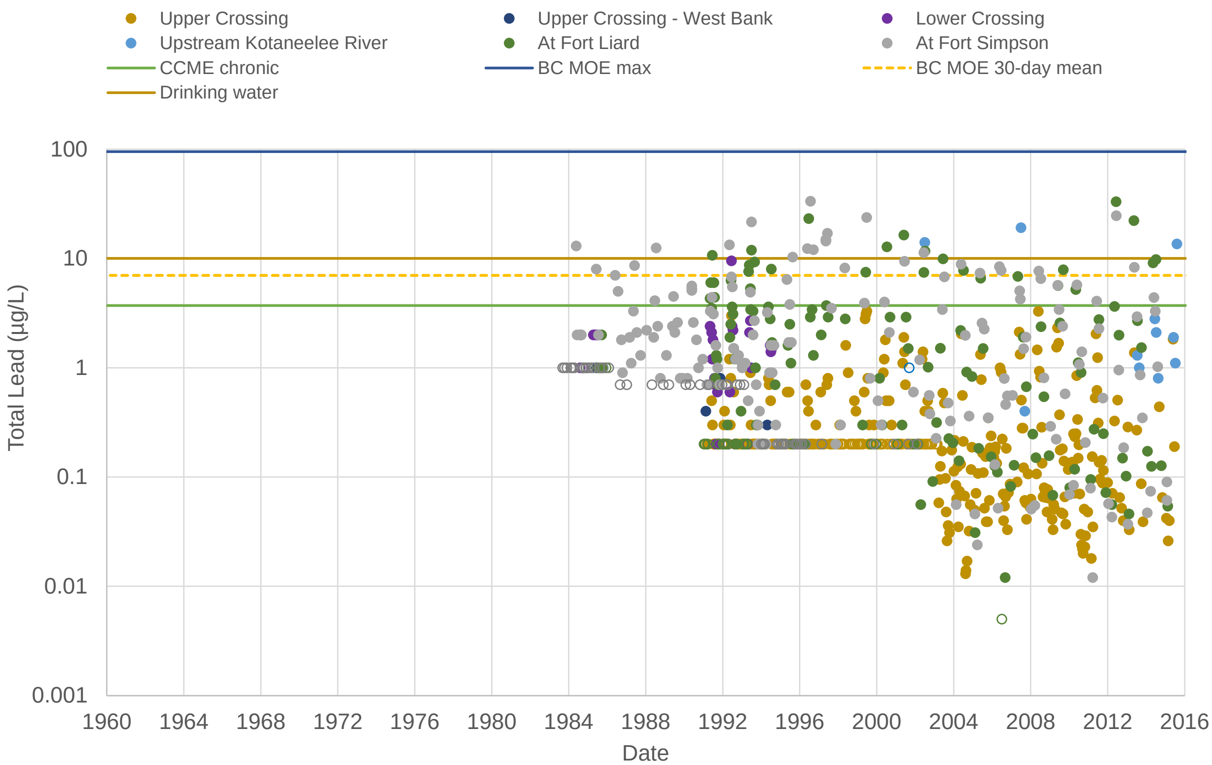
**(10) Total Iron**



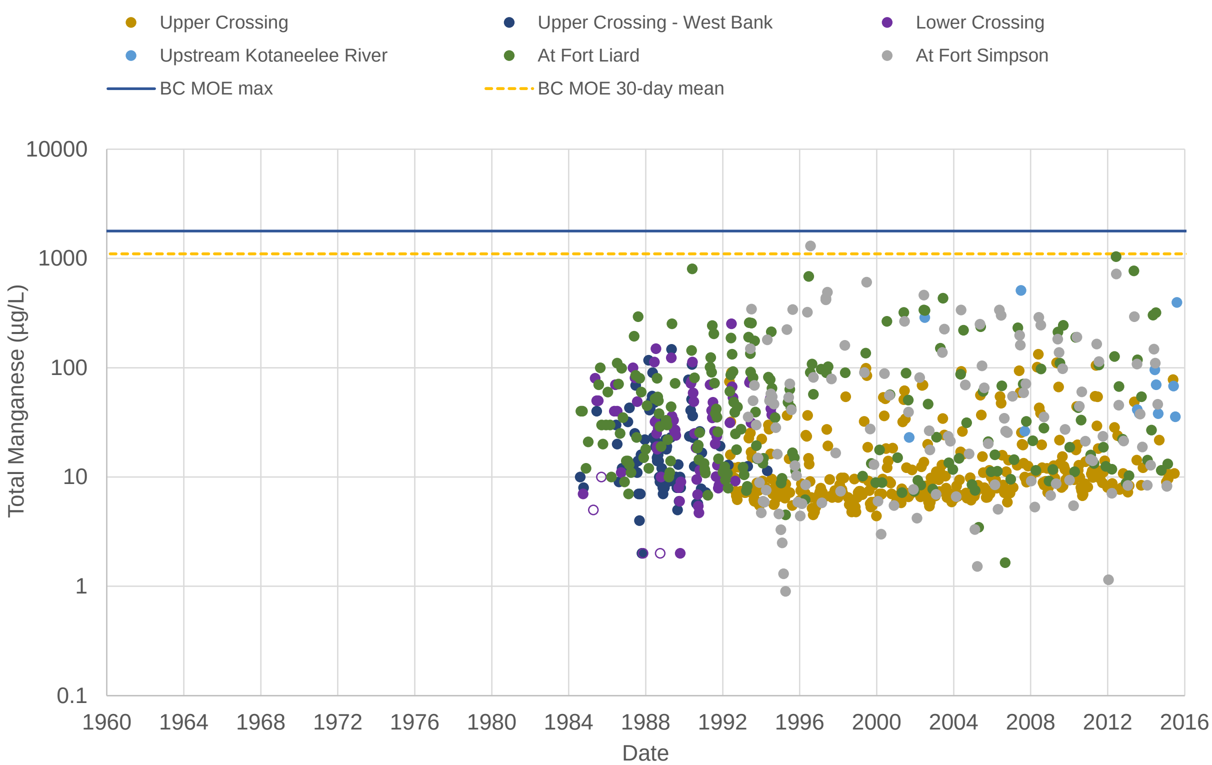

**(11) Dissolved Iron**



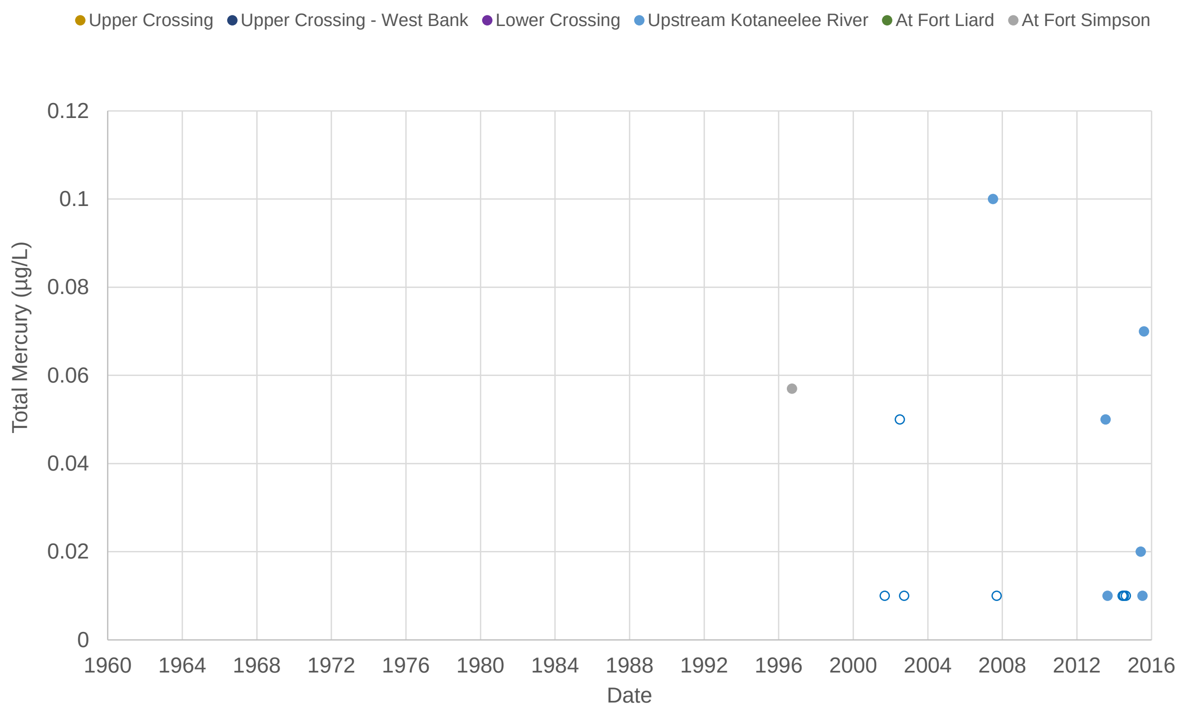
**(12) Total Lead**



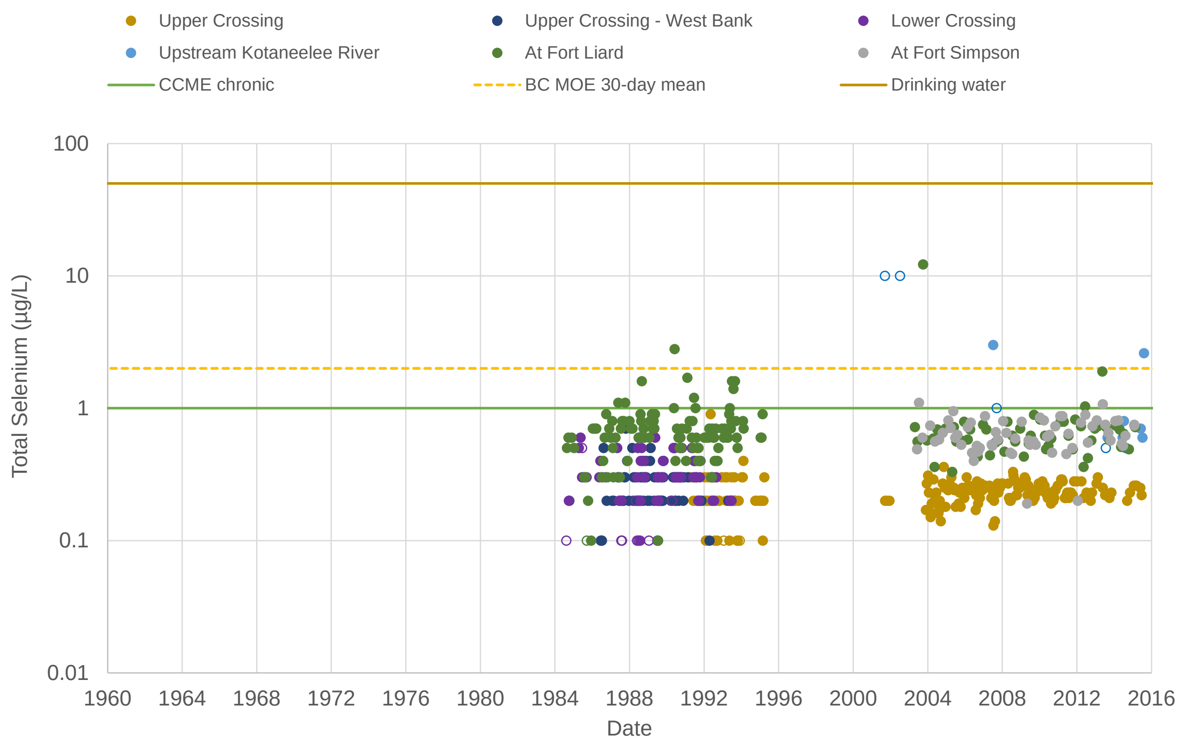

**(13) Total Manganese**



**(14) Total Mercury**

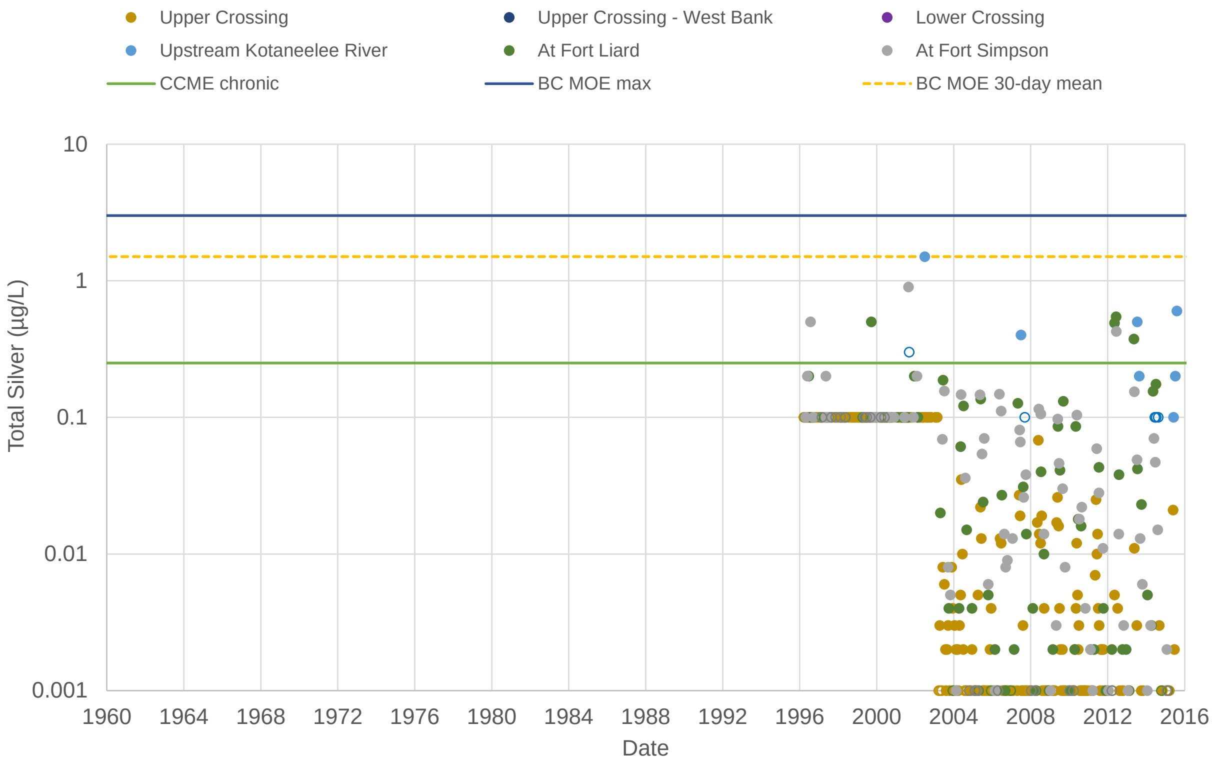



**(15) Total Selenium**

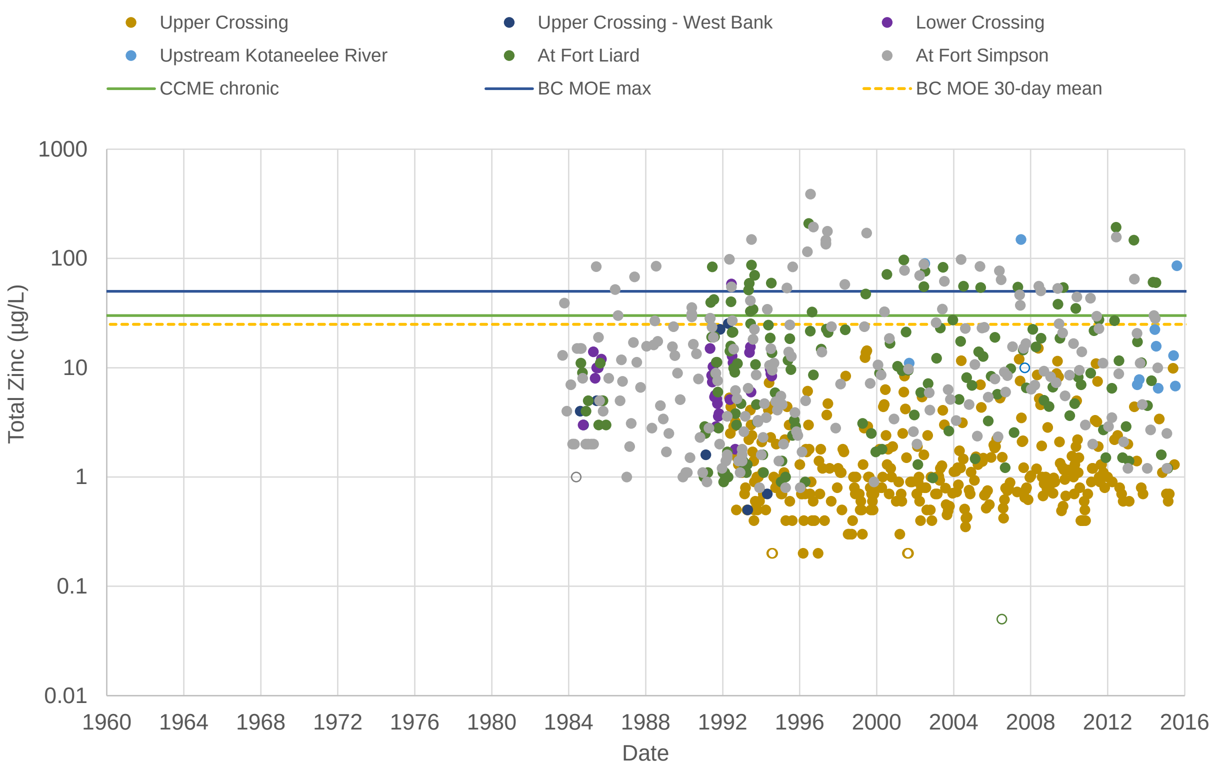



Note: For the purposes of visually reviewing the data, the drinking water guideline (50 µg/L) is not shown and one data point was removed: <0.05 mg/L at Fort Simpson on October 10, 2003.

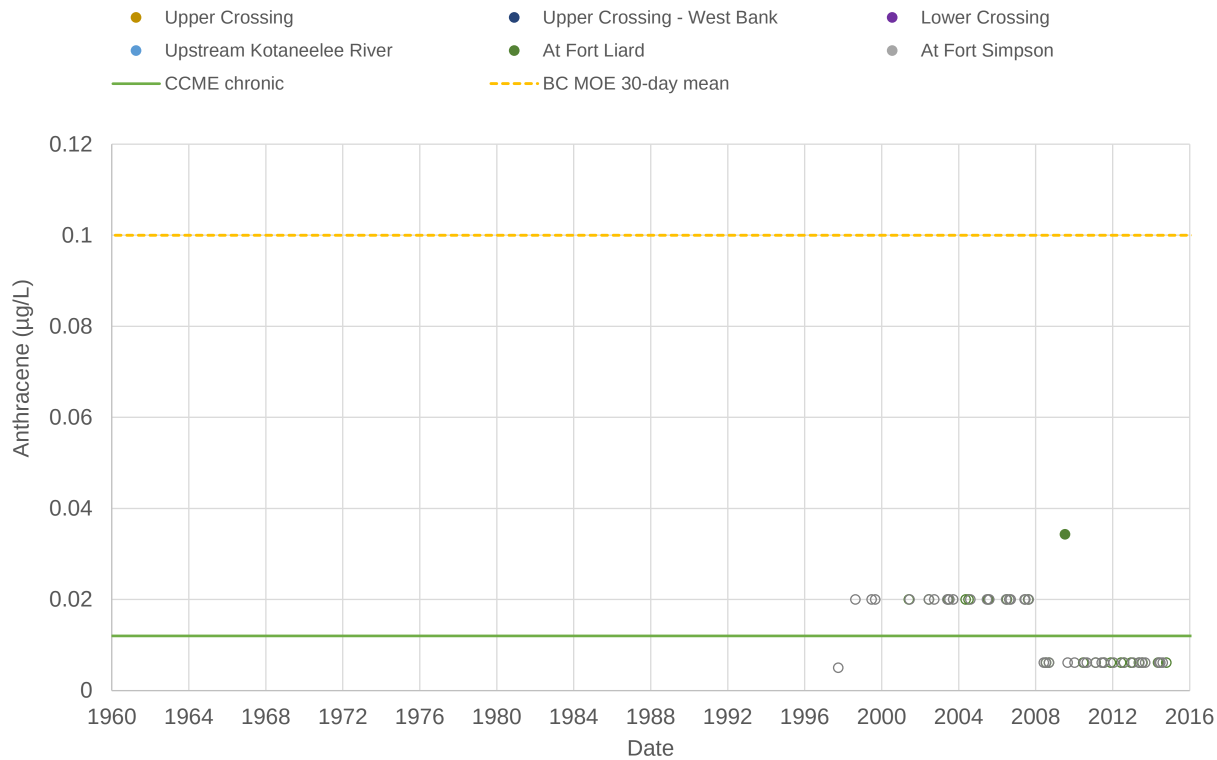
**(16) Total Silver**



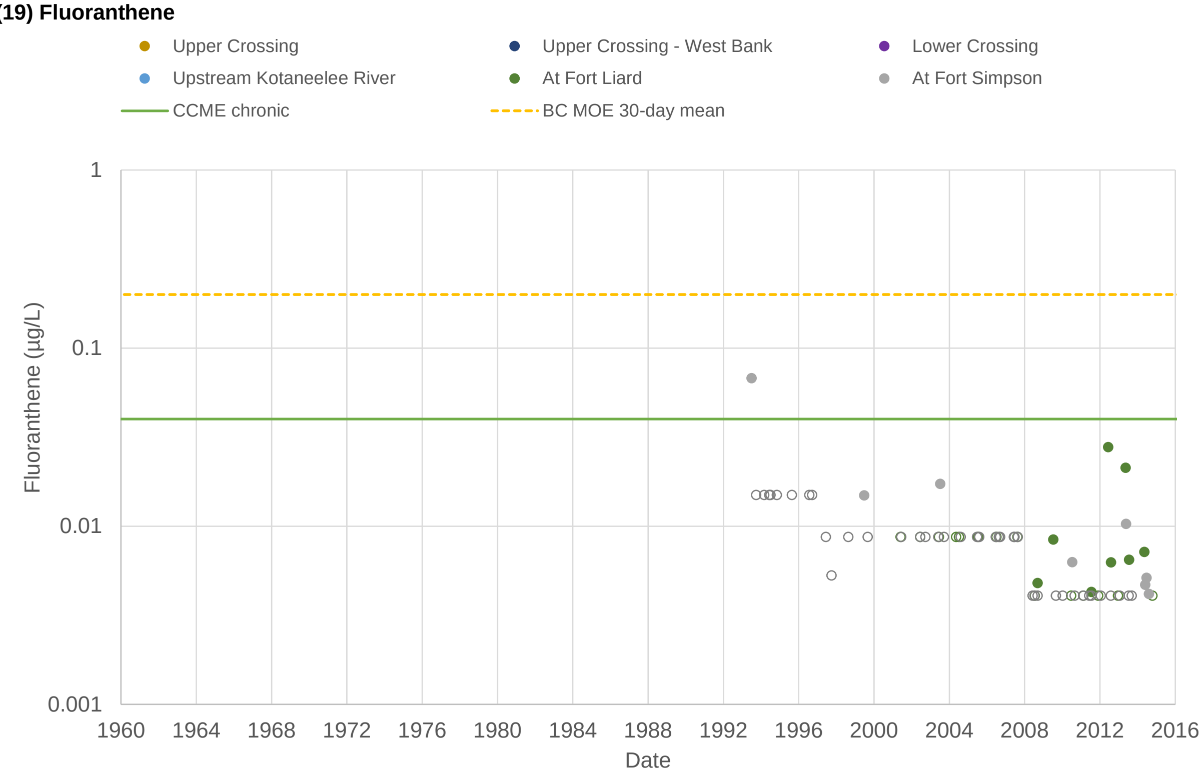

**(17) Total Zinc**



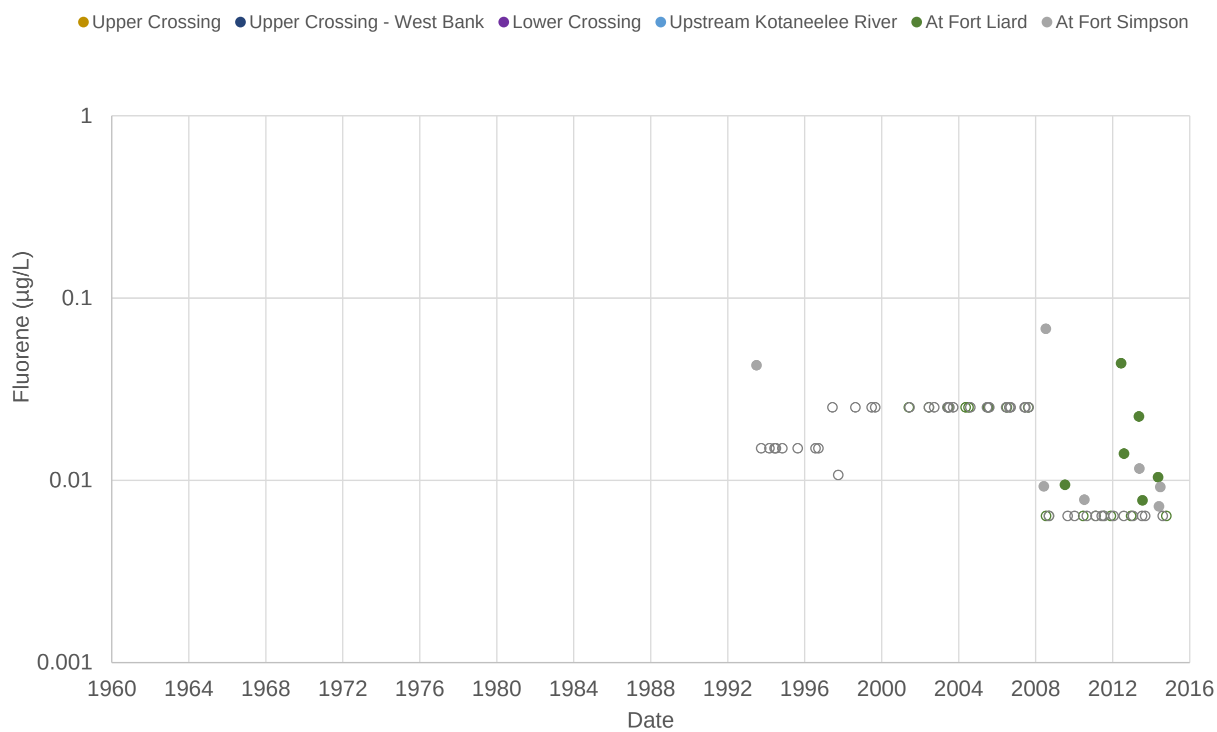
**(18) Anthracene**



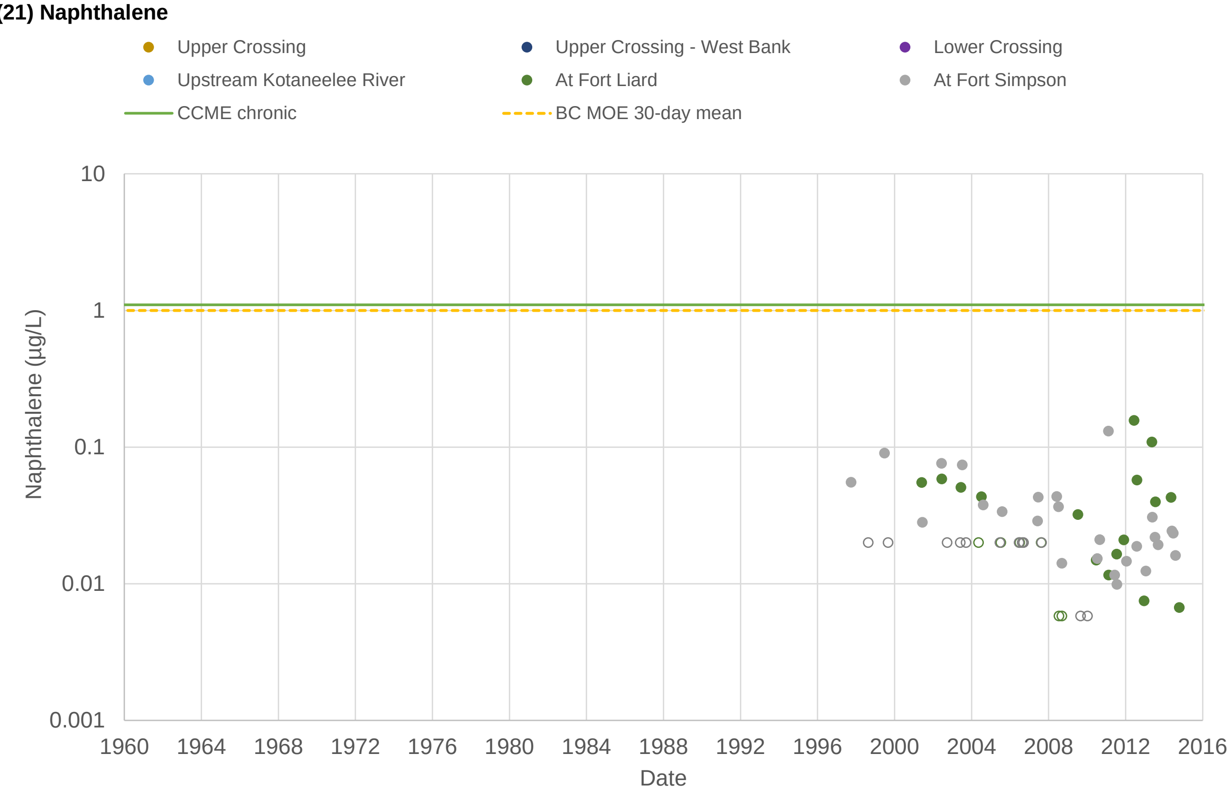

**(19) Fluoranthene**



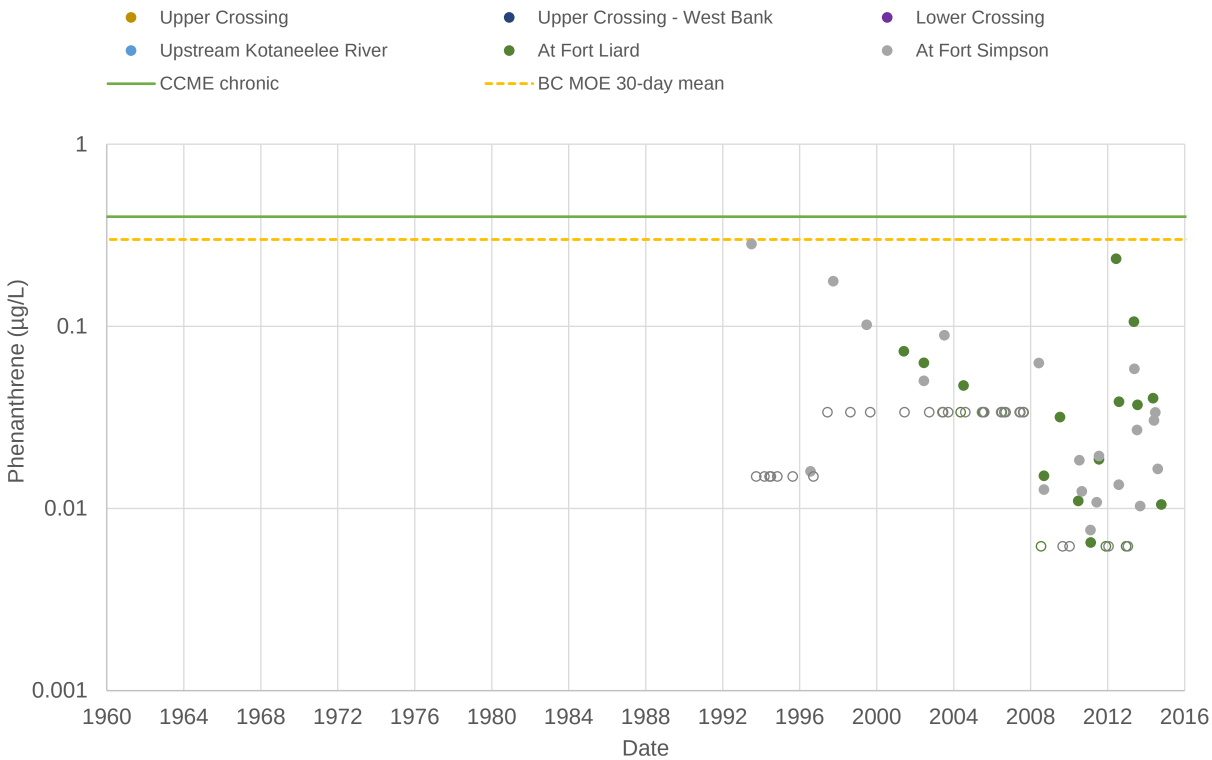
**(20) Fluorene**




**(21) Naphthalene**



(22) Phenanthrene




(23) Pyrene

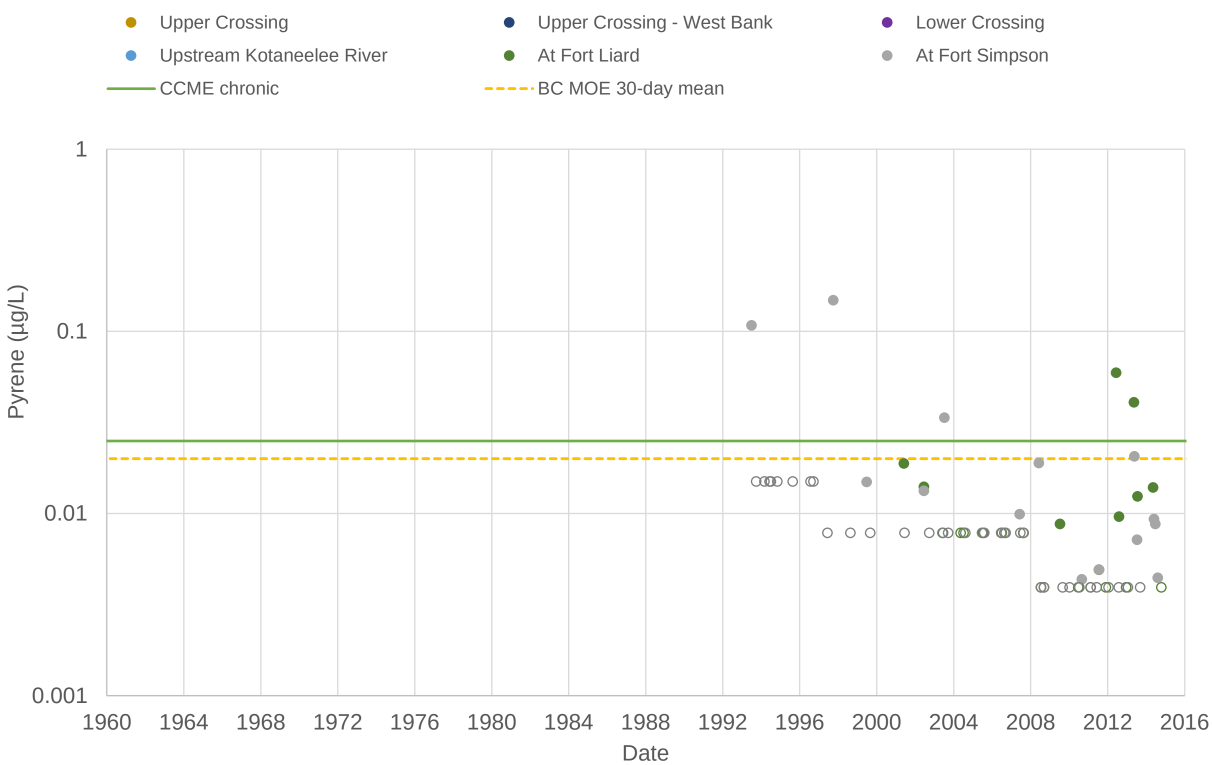
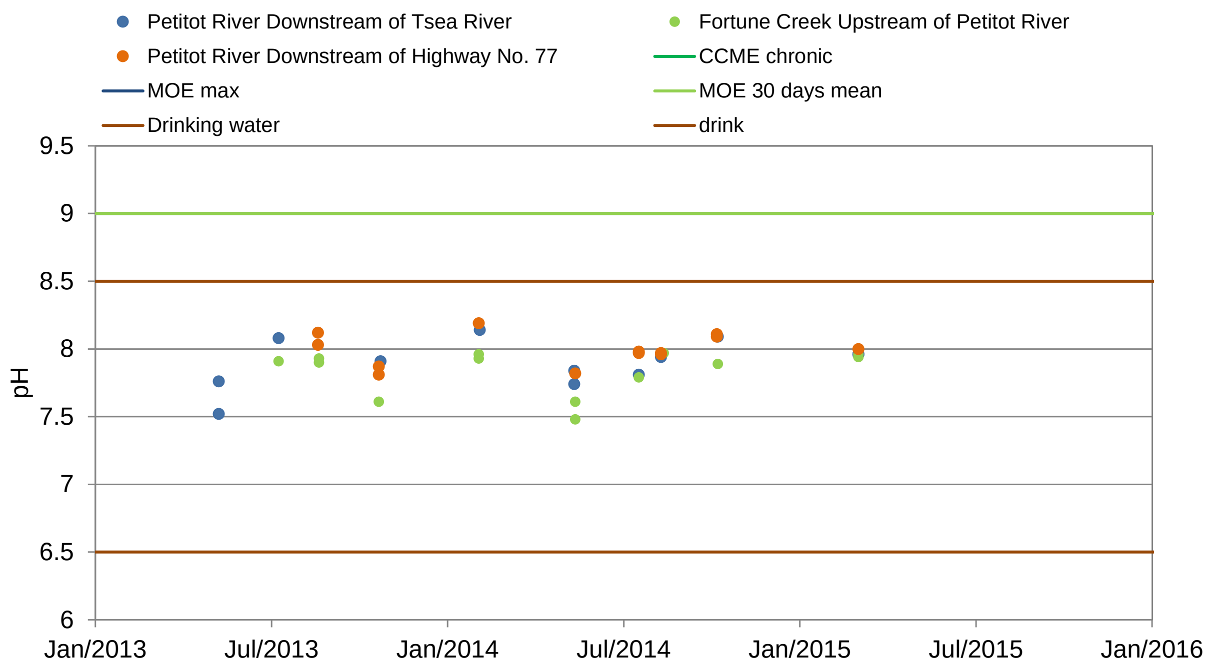


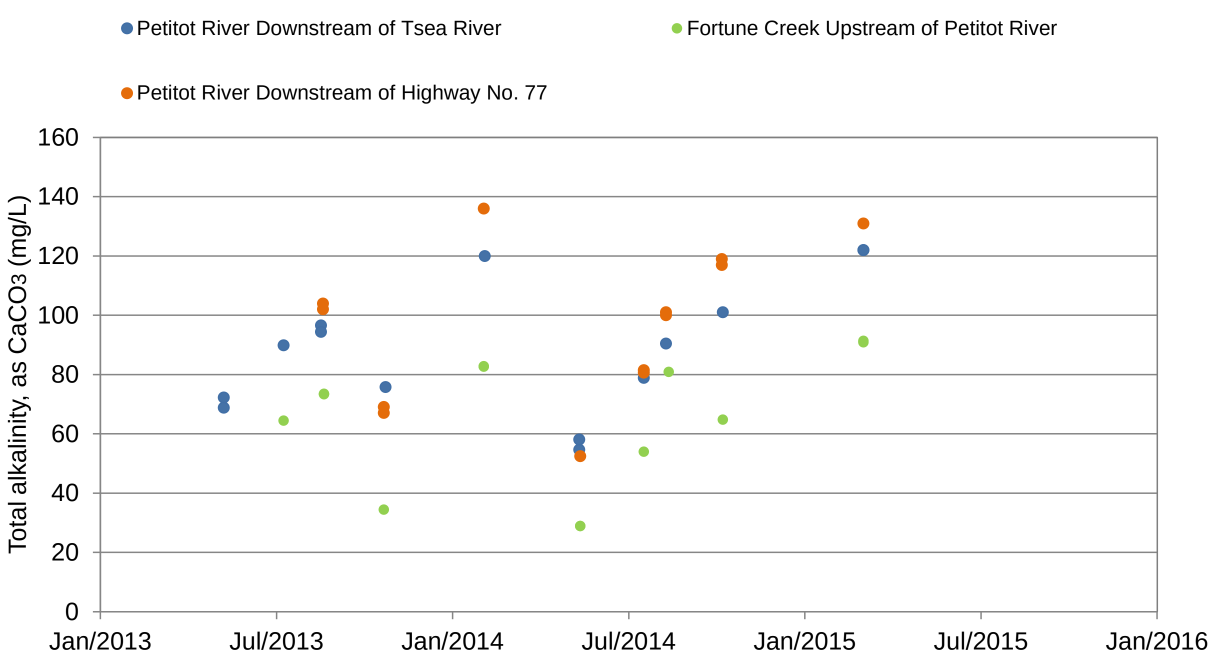
*Figure B3: Water Quality Values or Concentrations in the Petitot River and Fortune Creek, 2013 to 2015*

**(1) Laboratory pH**

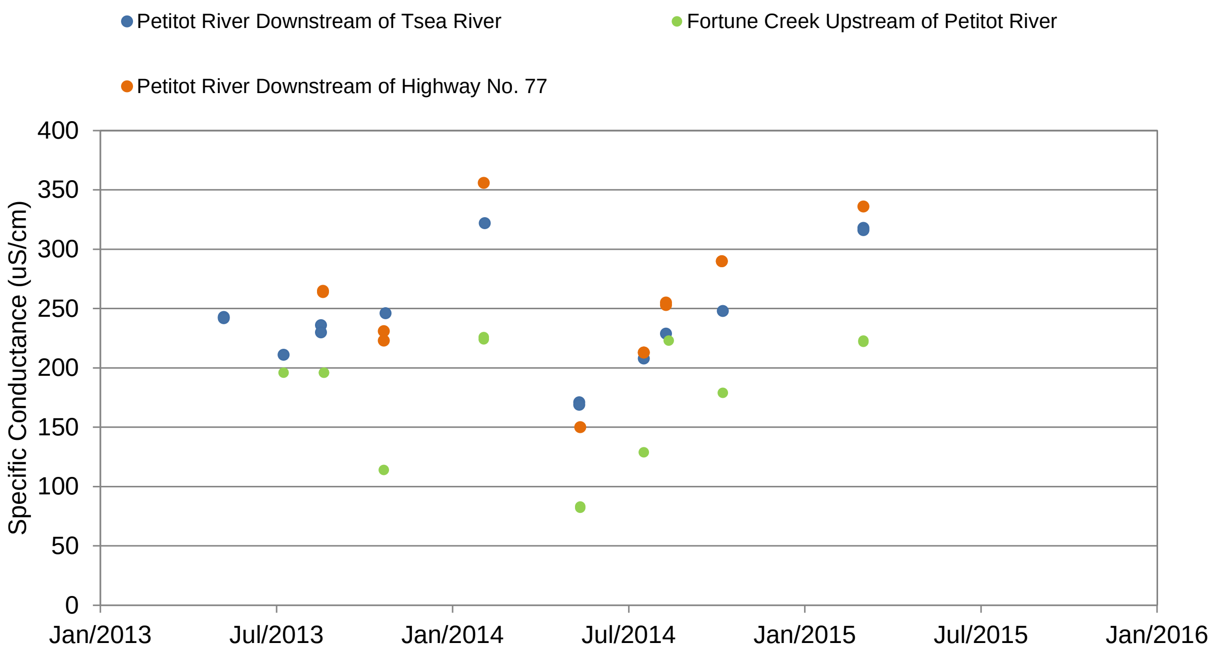



Note: Lower bands of all the pH guidelines are overlapping.

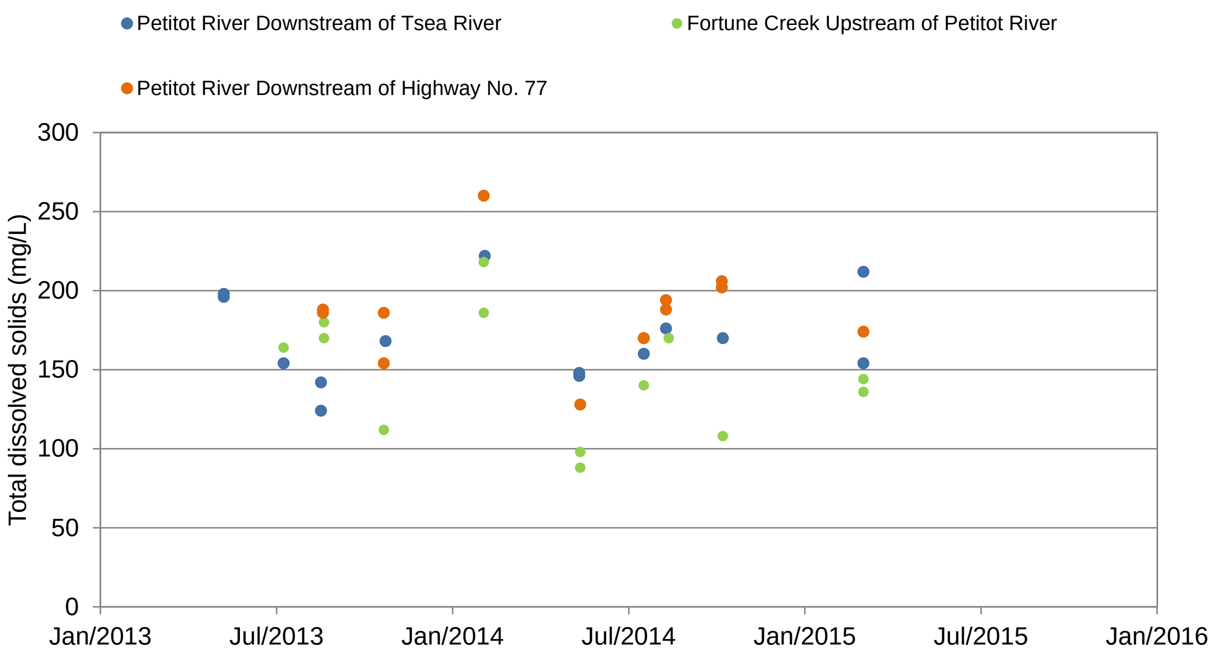
**(2) Total Alkalinity, as $CaCO_3$**



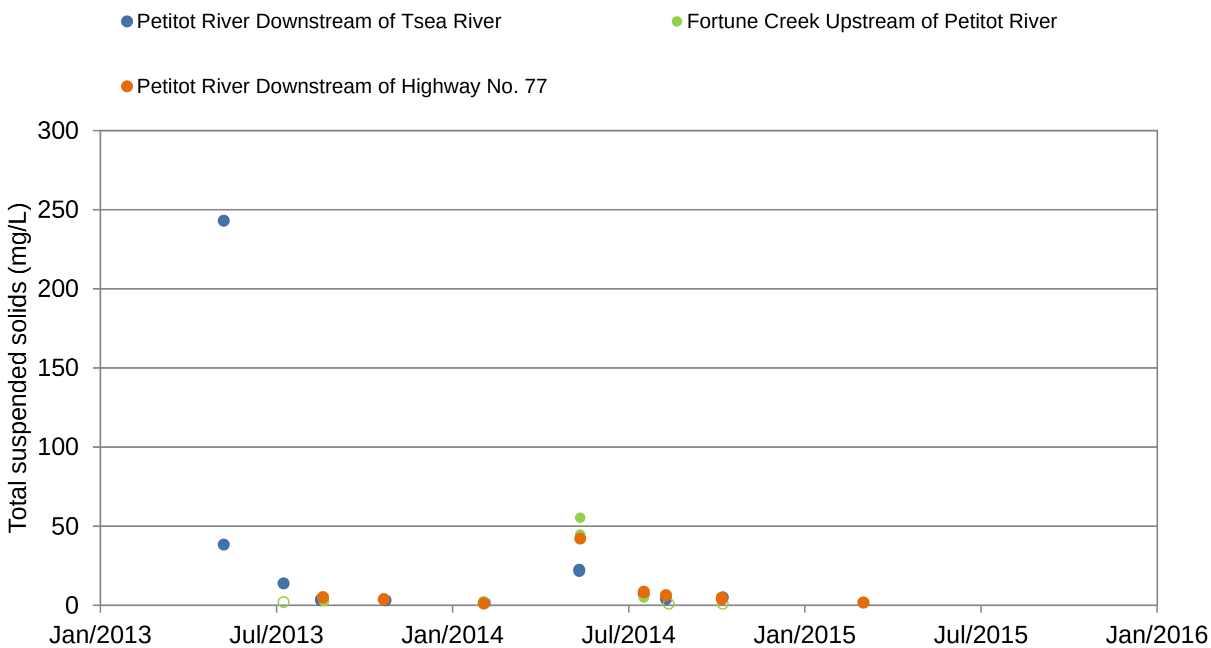
**(3) Laboratory Specific Conductivity**




**(4) Total Dissolved Solids**

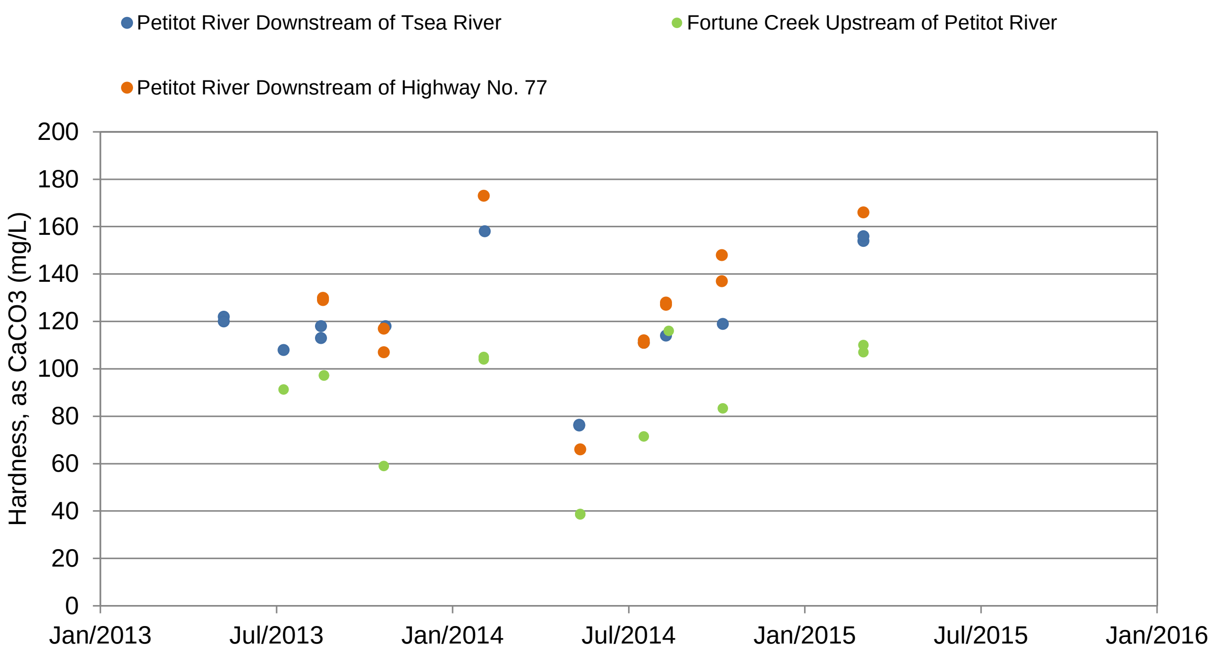


**(5) Total Suspended Solids**

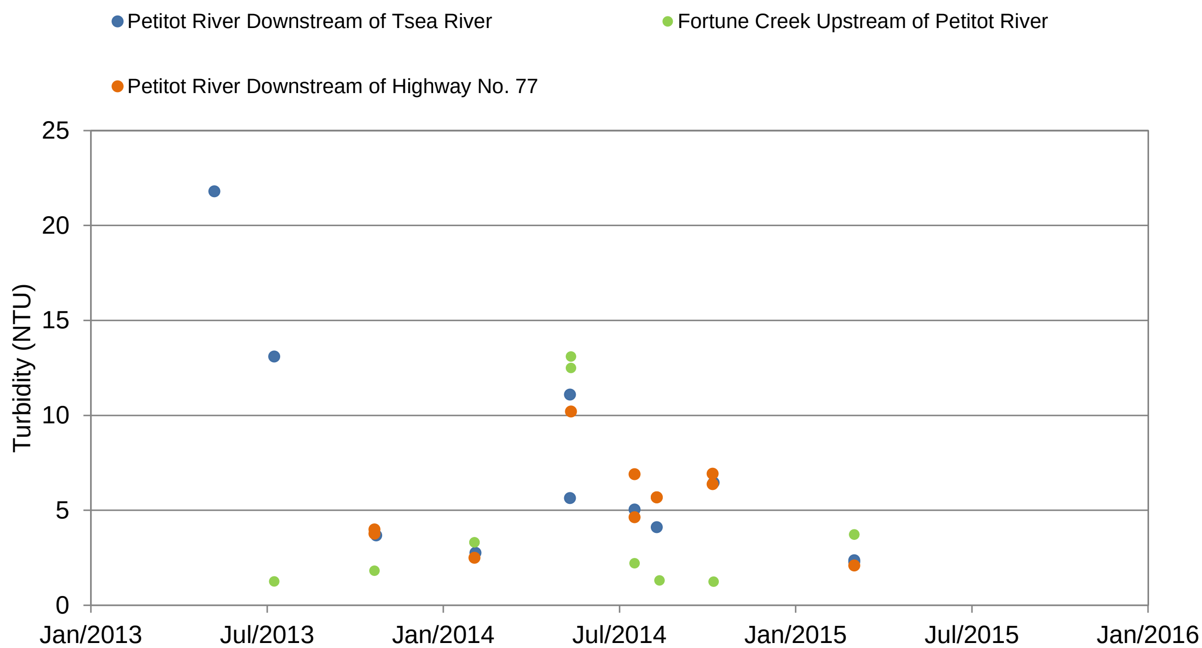



Note: Open data points indicate values below the detection limit.

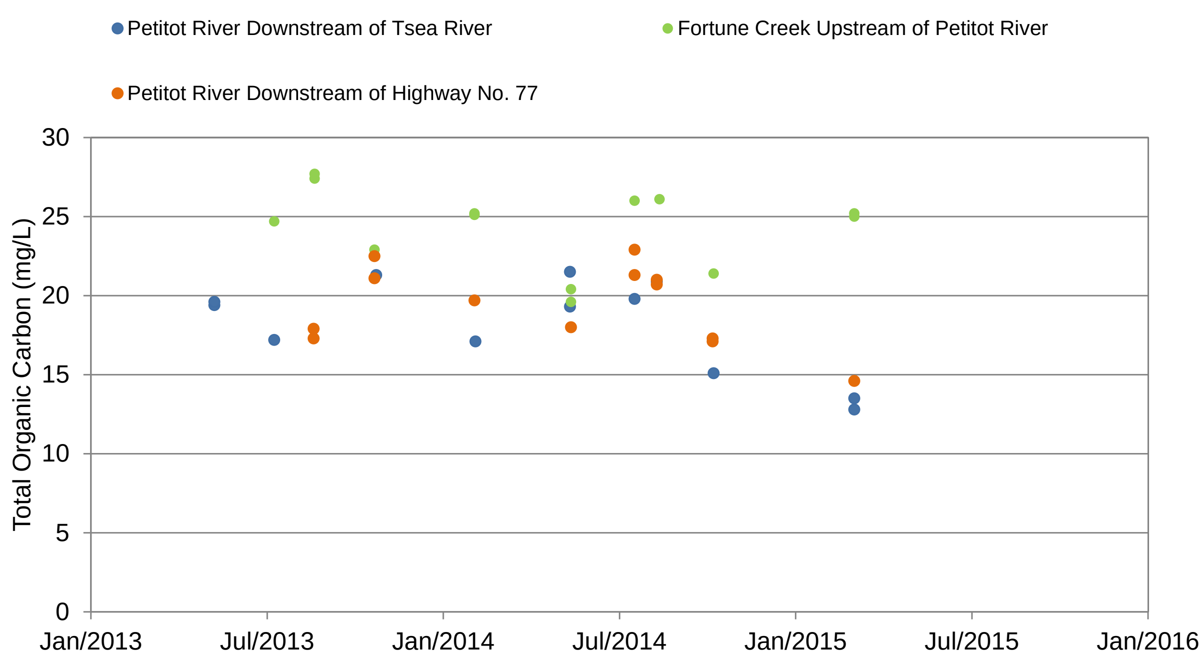
**(6) Hardness, as $CaCO_3$**



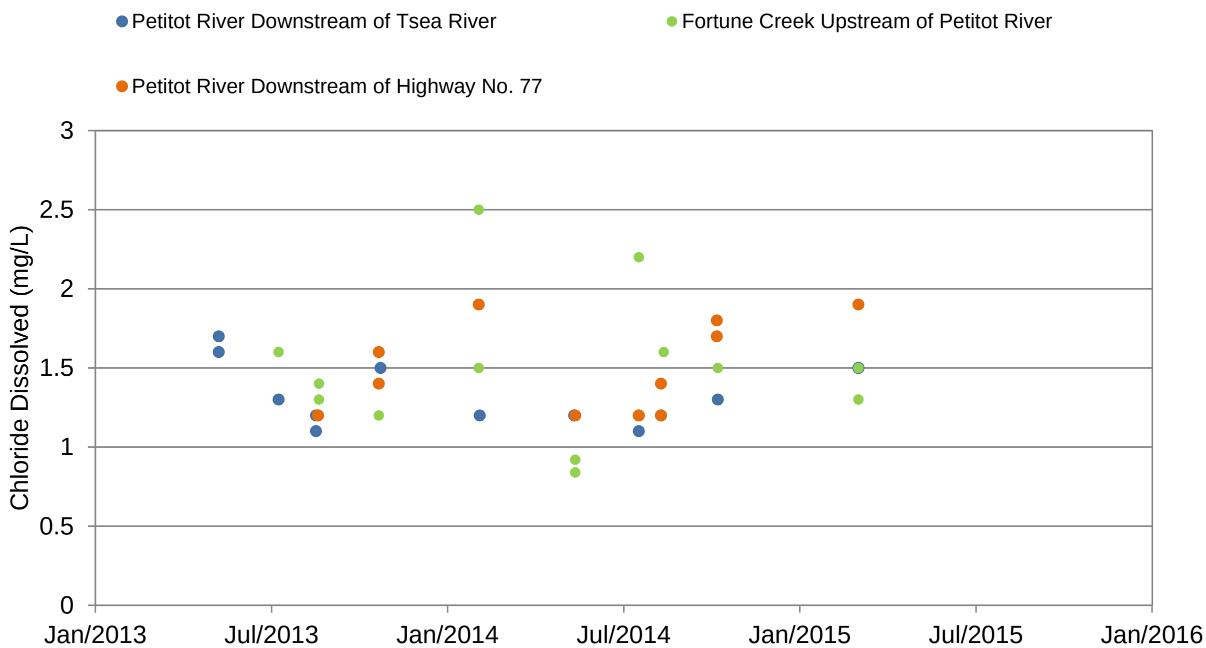
**(7) Turbidity**




**(8) Total Organic Carbon**

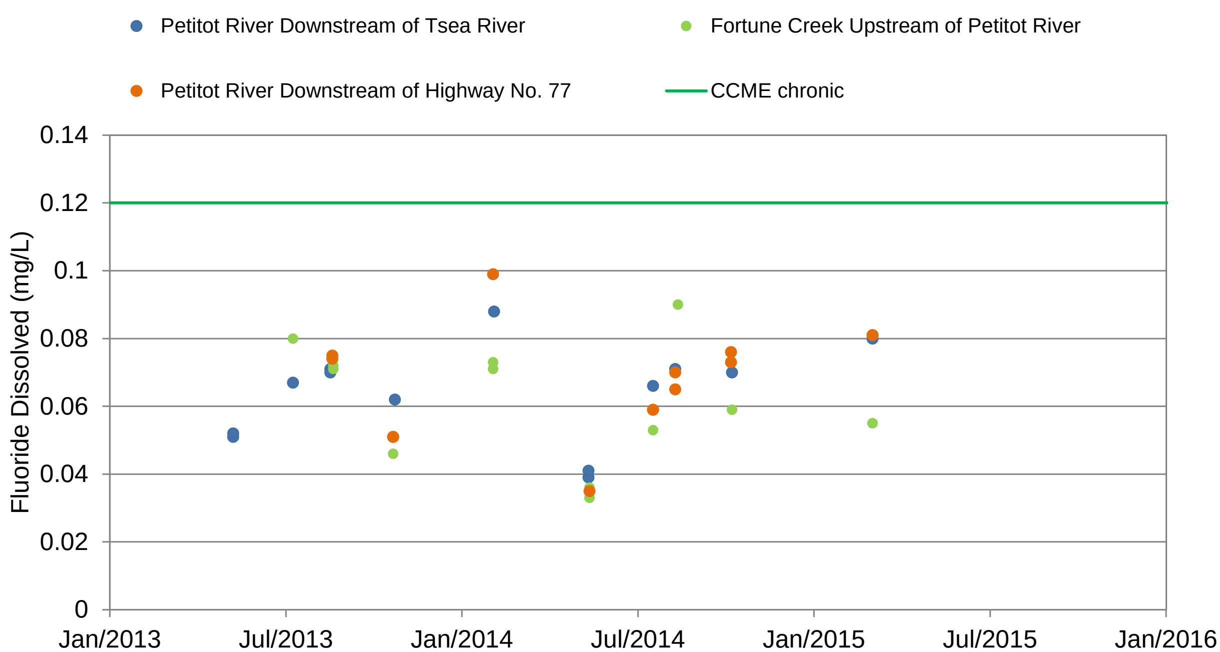


**(9) Chloride**

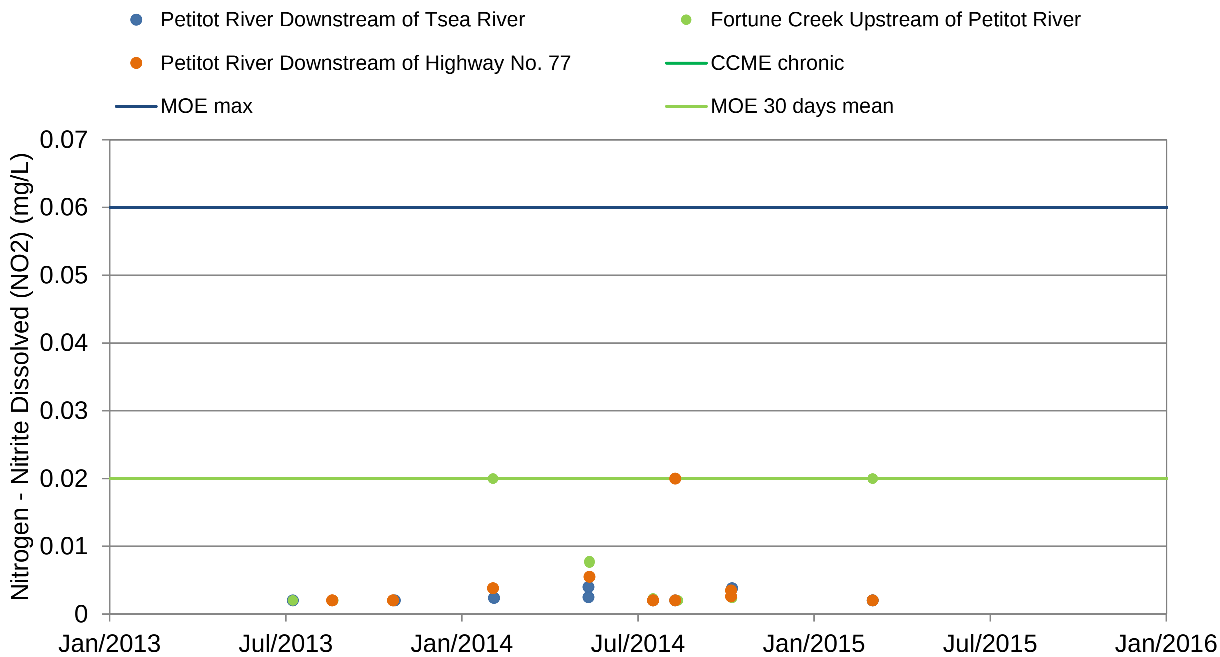



Note: For the purposes of visually reviewing the data: CCME acute (640 mg/L), CCME chronic (120 mg/L), BC MOE maximum (600 mg/L) and BC MOE 30-day mean (150 mg/L) guidelines are not shown.

**(10) Fluoride**

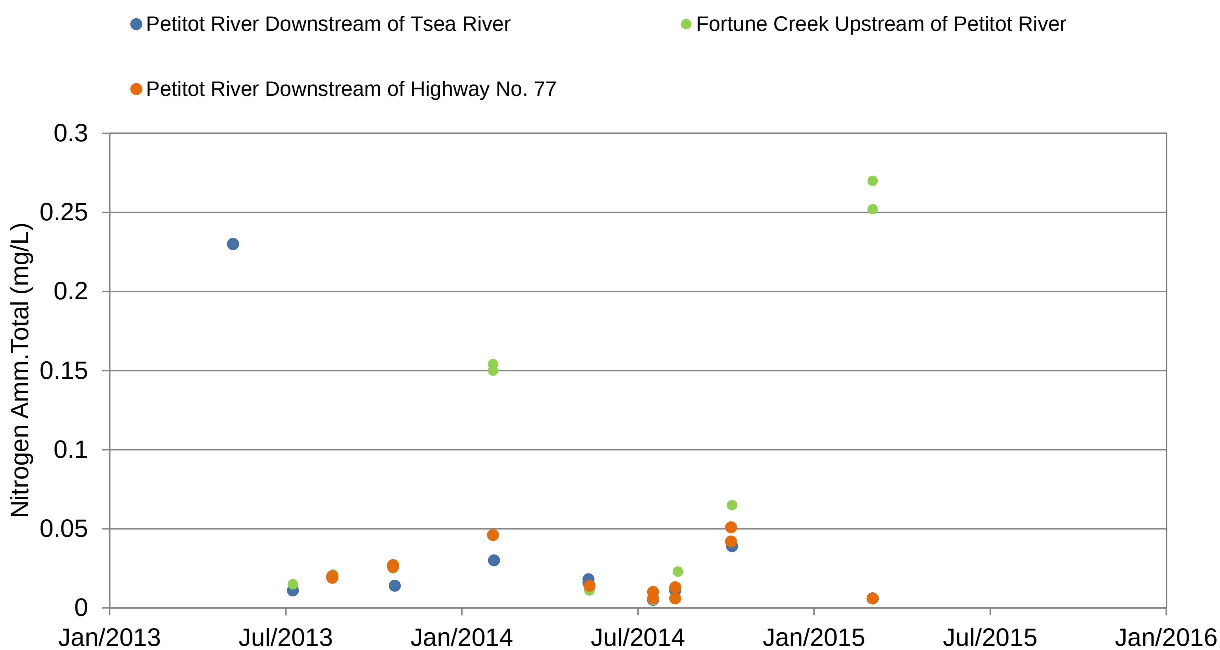


**(11) Nitrite**

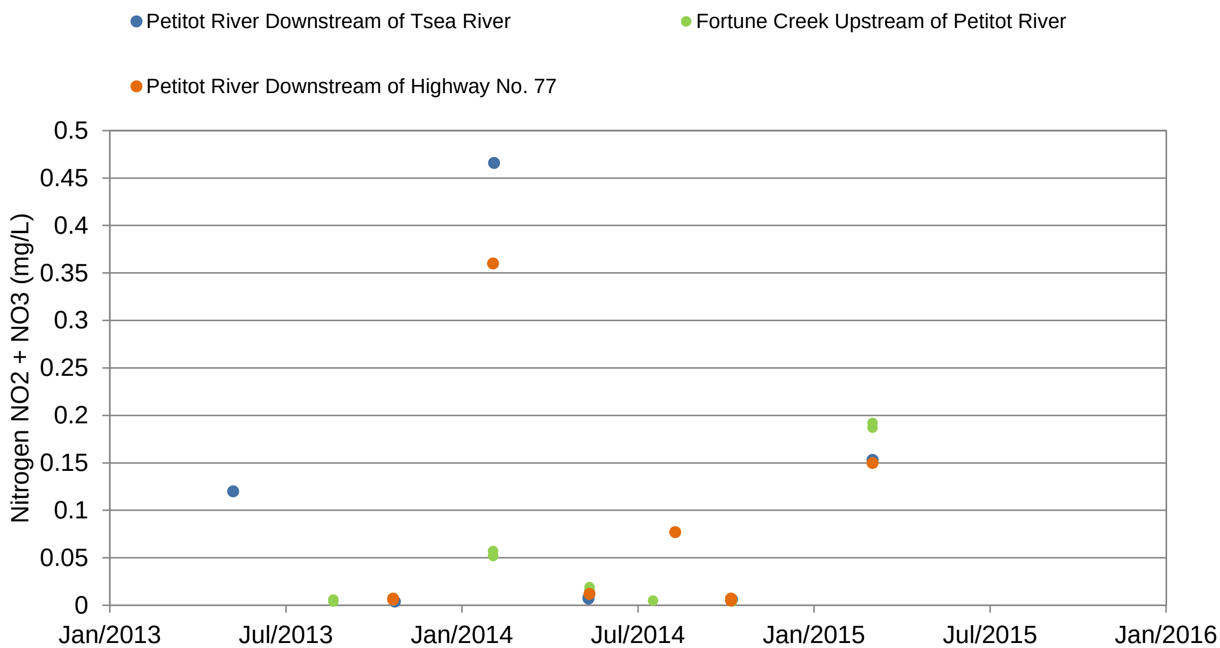



Notes: For the purposes of visually reviewing the data, the drinking water guideline (1 mg/L) is not shown. The CCME chronic guideline is the same as the BC MOE's maximum guideline.

**(12) Total Ammonia**



**(13) Nitrate + Nitrite**




**(14) Dissolved Phosphorus**

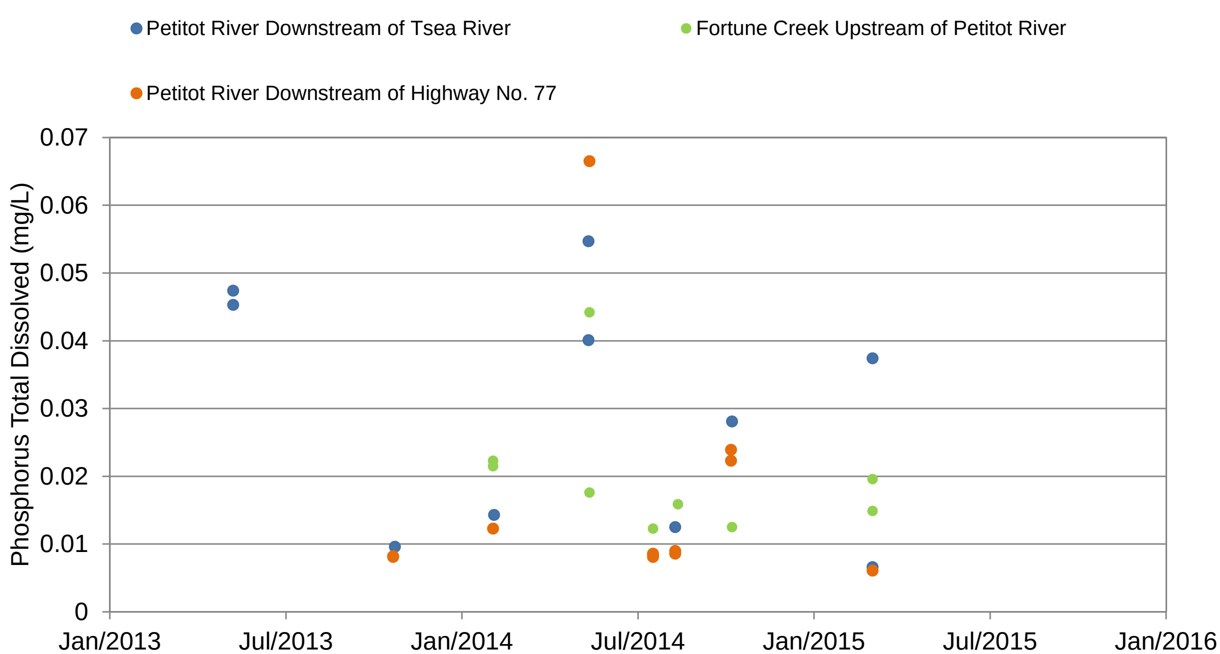


**Table B-2: Fort Liard Well 1**

| Sample ID | | | | | Fort Liard | 28250-1 | 30348-001 | Well 1 |
|---|---|---|---|---|---|---|---|---|
| Date | | | | | 19/02/2004 | 27/09/2007 | 30/11/2008 | 10/02/2010 |
| Laboratory | | | | | ALS Laboratory (Edmonton) | Alpha Laboratory Services LTD. (Edmonton) | Alpha Laboratory Services LTD. (Edmonton) | Alpha Laboratory Services LTD. (Edmonton) |
| | | GCDWQ | | | Value | Value | Value | Value |
| | Units | MAC | IMAC | AO | | | | |
| **Physicals** | | | | | | | | |
| * pHec | | | | 6.5 - 8.5 | 7.74 | 7.91 | 8.05 | 7.78 |
| * True Colour | TCU | | | <=15 | 25 | 15 | 32 | 20 |
| * Turbidity | NTU | 0.3/1.0/0.1 | | | 4.5 | 2.8 | 4.4 | 4.1 |
| **Nutrients** | | | | | | | | |
| * Nitrate-N | mg/L | 45 | | | <0.05 | <0.05 | <0.05 | <0.05 |
| * Total Dissolved Solids | mg/L | | | | 352 | | 490 | 360 |
| **Organics** | | | | | | | | |
| * Cyanide | mg/L | 0.2 | | | <0.001 | <0.01 | <0.01 | <0.01 |
| * THM-Bromodichloromethane | mg/L | | | | | | 11 | <.001 |
| * Total Trihalomethanes (THM's) | mg/L | 0.1 | | | <.001 | | | |
| **Major Ions** | | | | | | | | |
| * Chloride | mg/L | | | <=250 | 9.9 | 9.8 | 13 | 11 |
| * Fluoride | mg/L | 1.5 | | | 0.12 | 0.13 | <0.10 | 0.13 |
| * Sodium | mg/L | | | <=200 | 19 | 16 | 8 | 20 |
| * Sulphate | mg/L | | | <=500 | 26 | 23 | 26 | 25 |

**Table B-2: Fort Liard Well 1**

| Sample ID | | | | | Fort Liard | 28250-1 | 30348-001 | Well 1 |
|---|---|---|---|---|---|---|---|---|
| **Date** | | | | | **19/02/2004** | **27/09/2007** | **30/11/2008** | **10/02/2010** |
| **Laboratory** | | | | | **ALS Laboratory (Edmonton)** | **Alpha Laboratory Services LTD. (Edmonton)** | **Alpha Laboratory Services LTD. (Edmonton)** | **Alpha Laboratory Services LTD. (Edmonton)** |
| | | **GCDWQ** | | | Value | Value | Value | Value |
| | **Units** | **MAC** | **IMAC** | **AO** | | | | |
| **Metals - Total** | | | | | | | | |
| * Aluminum | mg/L | | | 0.1/0.2 | 0.012 | <0.010 | <0.0010 | 0.01 |
| * Arsenic | mg/L | 0.01 | | | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| * Barium | mg/L | 1 | | | 0.535 | 0.499 | 0.553 | 0.622 |
| * Cadmium | mg/L | 0.005 | | | <0.002 | <0.002 | <0.002 | <0.002 |
| * Chromium | mg/L | 0.05 | | | <0.002 | <0.002 | <0.002 | <0.002 |
| * Copper | mg/L | | | <=1.0 | 0.003 | <0.002 | <0.002 | <0.002 |
| * Iron | mg/L | | | <=0.3 | 0.875 | 0.773 | 0.732 | 0.813 |
| * Lead | mg/L | 0.01 | | | <0.001 | <0.001 | <0.001 | 0.0002 |
| * Manganese | mg/L | | | <=0.05 | 0.11 | 0.094 | 0.107 | 0.114 |
| * Mercury | mg/L | 0.001 | | | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| * Selenium | mg/L | 0.01 | | | <0.0010 | <0.0010 | <0.0010 | <0.0010 |
| * Uranium | mg/L | | 0.02 | | <0.100 | <0.100 | <0.100 | <0.100 |
| * Zinc | mg/L | | | <=5.0 | 0.004 | 0.002 | <0.001 | 0.016 |

**Table B-3: Fort Liard Well 2**

| Sample ID | | | | | Alpha Labs | 28250-2 | 30348-002 | Well 2 |
|---|---|---|---|---|---|---|---|---|
| Date | | | | | 14/09/2005 | 27/09/2007 | 30/11/2008 | 10/02/2010 |
| Laboratory | | | | | Alpha Laboratory Services LTD. (Edmonton) | Alpha Laboratory Services LTD. (Edmonton) | Alpha Laboratory Services LTD. (Edmonton) | Alpha Laboratory Services LTD. (Edmonton) |
| | | GCDWQ | | | Value | Value | Value | Value |
| | Units | MAC | IMAC | AO | | | | |
| **Physicals** | | | | | | | | |
| * pHec | | | | 6.5 - 8.5 | 7.8 | 7.95 | 8.04 | 7.66 |
| * True Colour | TCU | | | <=15 | 15 | 15 | 35 | 20 |
| * Turbidity | NTU | 0.3/1.0/0.1 | | | 0.29 | 2.1 | 3.5 | 2.7 |
| **Nutrients** | | | | | | | | |
| * Nitrate-N | mg/L | 45 | | | <0.05 | <0.05 | <0.05 | <0.05 |
| * Total Dissolved Solidsa | mg/L | | | | 307 | 7 | 330 | 340 |
| **Organics** | | | | | | | | |
| * Cyanide | mg/L | 0.2 | | | <0.01 | <0.01 | <0.01 | <0.01 |
| * THM-Bromodichloromethane | mg/L | | | | 0.65 | | <1 | <.001 |
| * Total Trihalomethanes (THM's) | mg/L | 0.1 | | | | | | |
| **Major Ions** | | | | | | | | |
| * Chloride | mg/L | | | <=250 | 7 | 8.9 | 9.9 | 11 |
| * Fluoride | mg/L | 1.5 | | | 0.12 | 0.11 | <0.10 | 0.13 |
| * Sodium | mg/L | | | <=200 | 12 | 15 | 15 | 17 |
| * Sulphate | mg/L | | | <=500 | 23 | 24 | 26 | 25 |

**Table B-3: Fort Liard Well 2**

| Sample ID | | | | | Alpha Labs | 28250-2 | 30348-002 | Well 2 |
|---|---|---|---|---|---|---|---|---|
| Date | | | | | 14/09/2005 | 27/09/2007 | 30/11/2008 | 10/02/2010 |
| Laboratory | | | | | Alpha Laboratory Services LTD. (Edmonton) | Alpha Laboratory Services LTD. (Edmonton) | Alpha Laboratory Services LTD. (Edmonton) | Alpha Laboratory Services LTD. (Edmonton) |
| | | GCDWQ | | | Value | Value | Value | Value |
| | Units | MAC | IMAC | AO | | | | |
| **Metals - Total** | | | | | | | | |
| * Aluminum | mg/L | | | 0.1/0.2 | 1.31 | <0.010 | <0.010 | <0.010 |
| * Arsenic | mg/L | 0.01 | | | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| * Barium | mg/L | 1 | | | 0.416 | 0.48 | 0.551 | 0.589 |
| * Cadmium | mg/L | 0.005 | | | <0.002 | <0.002 | <0.002 | <0.002 |
| * Chromium | mg/L | 0.05 | | | <0.002 | <0.002 | <0.002 | <0.002 |
| * Copper | mg/L | | | <=1.0 | 0.002 | <0.002 | <0.002 | <0.002 |
| * Iron | mg/L | | | <=0.3 | 0.752 | 0.716 | 0.808 | 0.73 |
| * Lead | mg/L | 0.01 | | | <0.001 | <0.001 | <0.001 | 0.0001 |
| * Manganese | mg/L | | | <=0.05 | 0.086 | 0.106 | 0.117 | 0.124 |
| * Mercury | mg/L | 0.001 | | | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| * Selenium | mg/L | 0.01 | | | <0.0010 | <0.0010 | <0.0010 | <0.0010 |
| * Uranium | mg/L | | 0.02 | | <0.100 | <0.100 | <0.100 | <0.100 |
| * Zinc | mg/L | | | <=5.0 | 0.02 | 0.004 | 0.003 | 0.009 |

**Table B-4: Nahanni Butte Groundwater Well**

| Sample ID | | | | | 950124 | 960214 | 970489 | 234544 | L434037-3 | L588913-1 | M35959 | R10019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | | | | | 20/02/1995 | 20/03/1996 | 08/04/1997 | 01/12/2003 | 13/09/2006 | 18/12/2007 | 20/10/2008 | 05/10/2009 |
| Laboratory | | | | | Taiga Environmental Laboratory (Yellowknife) | Taiga Environmental Laboratory (Yellowknife) | Taiga Environmental Laboratory (Yellowknife) | Taiga Environmental Laboratory (Yellowknife) | ALS Laboratory (Edmonton) | ALS Laboratory (Edmonton) | Central Steam Plant (Fort Simpson) | Central Steam Plant (Fort Simpson) |
| | | GCDWQ | | | Value | Value | Value | Value | Value | Value | Value | Value |
| | Units | MAC | IMAC | AO | | | | | | | | |
| **Physicals** | | | | | | | | | | | | |
| * Alkalinity | mg/L | ND | | | 383 | 821 | 200 | 397 | | | | |
| * Conductivity | umhos/cm | ND | | | 780 | 797 | 738 | 761 | | | | |
| * Turbidity | | | | | | | | | 65 | 80 | 35 | 65 |
| * pHec | | | | 6.5 - 8.5 | 7.38 | 7.6 | 7.73 | 7.5 | 7.7 | 7.8 | 8.1 | 8.14 |
| * True Colour | TCU | | | <=15 | | | | 35 | <2.5 | <2 | 4 | 2 |
| **Nutrients** | Units | | | | | | | | | | | |
| Ammonia | mg/L | ND | | | 0.511 | 0.691 | 6.95 | 0.421 | | | | |
| * Dissolved Organic Carbon | mg/L | ND | | | | | | 71.2 | | | | |
| * Nitrate + Nitrite as Na | mg/L | | | | 0.008 | 0.008 | 0.008 | 0.008 | <0.05 | <0.05 | 0.012 | 0.04 |
| * Total Dissolved Solids | mg/L | | | | 461 | 454 | 427 | 408 | 266 | 398 | 400 | 330 |
| * Total Organic Carbon | mg/L | ND | | | | | | 71.8 | | | | |
| * Total Suspended Solids | mg/L | | | | 10 | 8 | 12 | 12 | | | | |
| * Phosphorous | | | | | | 0.007 | 0.014 | | | | | |
| **Organics** | | | | | | | | | | | | |
| * Cyanide | mg/L | 0.2 | | | | | | 0.01 | <0.002 | <0.002 | <0.001 | <0.001 |
| * Total Trihalomethanes (THM's) | mg/L | | | | | | | | <0.005 | | | |
| * THM-Bromodichloromethane | mg/L | | | | | | | | | | | |
| **Major Ions** | | | | | | | | | | | | |
| * Calcium | mg/L | ND | | | 93.6 | 155 | 124 | 113 | | | | |
| * Chloride | mg/L | | | <=250 | | 16.1 | 4.65 | 1.5 | 6 | 3 | 5 | 2 |
| * Fluoride | mg/L | 1.5 | | | | 0.28 | | 0.13 | 0.07 | 0.14 | 0.06 | 0.14 |
| * Magnesium | mg/L | ND | | | 26.6 | 30.5 | 27.7 | 23.3 | | | | |
| * Potassium | mg/L | ND | | | | 2.11 | 1.83 | 1.68 | | | | |
| * Sodium | mg/L | | | <=200 | | 20.8 | 9.52 | 5.95 | 5 | 6 | 4.9 | 5.1 |
| * Sulphate | mg/L | | | <=500 | | 57 | 20 | 4 | 8.4 | 5.8 | <1 | 6 |
| Sulphide | mg/L | | | <=0.05 | | | | 0.05 | | | | |
| * Total Hardness | mg/L | ND | | | 343 | 513 | | 379 | | | | |
| Reac-Silica | mg/L | | | | 2.257 | | | | | | | |

**Table B-4: Nahanni Butte Groundwater Well**

| Sample ID | | | | | 950124 | 960214 | 970489 | 234544 | L434037-3 | L588913-1 | M35959 | R10019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | | | | | 20/02/1995 | 20/03/1996 | 08/04/1997 | 01/12/2003 | 13/09/2006 | 18/12/2007 | 20/10/2008 | 05/10/2009 |
| Laboratory | | | | | Taiga Environmental Laboratory (Yellowknife) | Taiga Environmental Laboratory (Yellowknife) | Taiga Environmental Laboratory (Yellowknife) | Taiga Environmental Laboratory (Yellowknife) | ALS Laboratory (Edmonton) | ALS Laboratory (Edmonton) | Central Steam Plant (Fort Simpson) | Central Steam Plant (Fort Simpson) |
| | | GCDWQ | | | Value | Value | Value | Value | Value | Value | Value | Value |
| | Units | MAC | IMAC | AO | | | | | | | | |
| **Metals - Total** | | | | | | | | | | | | |
| *Aluminum | mg/L | | | | | | | | <0.01 | 0.01 | <0.04 | <0.04 |
| * Arsenic | mg/L | 0.01 | | | 0.007 | | | 0.017 | 0.011 | 0.0077 | 0.016 | 0.015 |
| * Barium | mg/L | | | | | | | | 0.463 | 0.343 | 0.54 | 0.55 |
| * Cadmium | mg/L | 0.005 | | | 0.0001 | 0.0001 | 0.0001 | 0.0001 | <0.0001 | <0.0001 | <0.0002 | 0.000009 |
| * Chromium | mg/L | 0.05 | | | 0.0079 | 0.0035 | 0.0033 | 0 | 0.0009 | 0.0006 | <0.01 | <0.01 |
| * Cobalt | mg/L | ND | | | 0.0023 | 0.0002 | 0.0008 | 0.0015 | | | | |
| * Copper | mg/L | | | <=1.0 | 0.0008 | 0.0015 | 0.0011 | 0.0007 | 0.148 | 0.469 | 0.0045 | 0.0002 |
| * Iron | mg/L | | | <=0.3 | 4.94 | 2.22 | 3.04 | 8.306 | 6.62 | 4.76 | 4.8 | <0.06 |
| * Lead | mg/L | 0.01 | | | 0.0009 | 0.0009 | 0.0002 | 0.0009 | 0.0043 | 0.0035 | 0.0006 | <0.0002 |
| * Manganese | mg/L | | | <=0.05 | 0.0761 | 0.0266 | 0.041 | 0.101 | 0.27 | 0.085 | 0.1 | 0.052 |
| * Mercury | mg/L | | | | | | | | | <0.0002 | 0.000016 | 0.006 |
| * Nickel | mg/L | ND | | | 0.0023 | 0.002 | 0.003 | 0.0029 | | | | |
| Selenium | mg/L | | | | | | | | 0.0008 | 0.0005 | <0.0002 | <0.0002 |
| Uranium | mg/L | | | | | | | | 0.0017 | 0.0019 | 0.0026 | 0.0025 |
| * Zinc | mg/L | | | <=5.0 | 0.0041 | 0.0217 | 0.0104 | 0.02 | 0.122 | 0.082 | 0.015 | 0.006 |

# APPENDIX C

## Surface Water and Groundwater Data Sources

# TECHNICAL MEMORANDUM

**DATE** February 18, 2016 **PROJECT No.** 1547195

**TO** Meghan Beveridge
ENR-GNWT

**CC** Nicole Dion, ENR-GNWT

**FROM** Robin Bourke **EMAIL** Robin_Bourke@golder.com

**RE: RESOURCE LISTS FOR LIARD AND PETITOT BASIN LEARNING PLANS**

## Introduction

This memo is submitted in fulfillment of Deliverable #2 (Resource List) of Project Event ID: 00000000018, Learning Plans for the Liard and Petitot River Basins (Learning Plans), between the Government of the Northwest Territories (GNWT) and Golder Associates Ltd (Golder).

The Resource List is a list of sources for each Learning Plan that includes information on existing environmental conditions, water uses, land use, surface water quality and quantity data, and groundwater quality and quantity data.

Potential data sources were described in the Proposal for Project Event ID: 00000000018, Learning Plans for the Liard and Petitot River Basins. In addition to these sources, component specific sources are included in the five separate resource list tables of this report.

## Resource List Components

Resource lists were compiled separately for available information on surface water and groundwater components to be used in the two Learning Plans.

Information required for the Resource List for the Liard-Petitot Surface Water Learning Plan comprises the following components:

- available information and resources to describe the **physical components** of the Petitot River and Liard River basins including climate, topography, geomorphology, geology and vegetation;
- available information and resources regarding the documentation of **past, current, and proposed land use** activities and development for the Liard and Petitot rivers;
- available information pertaining to **water uses** including: water licences and other authorized water withdrawals; traditional/cultural uses; community water supplies; and tourism and recreational uses;
- available **water quality** data to evaluate status and trends of routine parameters (physicals, major ions nutrients and metals) **and water quantity** (status and trends) of the Liard and Petitot rivers; and
- available **water and suspended sediment quality** data (and information), to describe the status of organic compounds (pesticides, herbicides, polychlorinated biphenyls and polycyclic aromatic hydrocarbons) of the Liard and Petitot Rivers.

Information required for the Resource List for the Liard-Petitot Basins Groundwater Learning Plan comprises the following components:

- available information and resources to describe the **hydrologic, geological, and geographic framework** including watershed characteristics, spatial information on surficial and geological units, and current and proposed developments and activities and human pressures;
- available information to complete an assessment of **current and future groundwater uses** and demands;
- available **water quality and quantity** data; and
- available information and resources of **other influences affecting groundwater quality and quantity** including: authorized water withdrawals; waste discharges; future land developments; and the potential for cumulative effects.

## Resource List Tables

Resources have been compiled into five separate tables based on the above described components:

- Table 1: Resource List for Physical Components of the Liard and Petitot River Basins, including Climate, Topography, Geomorphology, Geology and Vegetation;
- Table 2: Resource List for Land Use, Water Use, and Development for the Liard and Petitot River Basins, including Traditional Knowledge;
- Table 3: Resource List for Water Quality and Quantity Data, including Routine Parameters and Organic Compounds;
- Table 4: Resource List for Liard and Petitot Groundwater Basin Data, including Uses and Demands; and
- Table 5: Resource List for Cumulative Effects on Water Quality and Quantity in Liard and Petitot River Basins, and Other Additional Resources.

**Table 1: Resource List for Physical Components of the Liard and Petitot River Basins, including Climate, Topography, Geomorphology, Geology and Vegetation**

| No. | Title | File / Document Name | File Type | Date / Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 1 | Environment Canada | Climate Normals for Fort Liard, Fort Nelson, Tetsa River, and Watson Lake Stations | Excel Data | 2016 | Environment Canada. 2015. Environment Canada Climate Normals. Available at: http://climate.weather.gc.ca/climate_normals/index_e.html. Accessed: February 2016. | Climate Normals Spanning 1961-2010 with in study area |
| 2 | Mammals of Canada | Mammals of Canada | Publication | 1974 | Banfield, 1974. Mammals of Canada. University of Toronto Press. | Book |
| 3 | NWT Species at Risk | NWT Species at Risk | Registry | 2016 | http://www.nwtspeciesatrisk.ca/ | On-line species at risk registry |
| 4 | Federal Species at Risk | Federal Species at Risk | Registry | 2016 | http://www.registrelep-sararegistry.gc.ca/default.asp?lang=En&n=24F7211B-1 | On-line species at risk registry |
| 5 | Digital Elevation Model | *RASTER.SDE.CAN_TOPOGRAPHY_GEOBASE_CDED_50K_DEM* | GIS File | 2015 | Centre for Topographic Information - Geomatics Canada – obtained from GeoGratis, © Department of Natural Resources Canada. All rights reserved. | - |
| 6 | Watershed boundaries | *canadwscssda_p* | GIS File | 2008 | Atlas of Canada - Natural Resources Canada - obtained from GeoGratis, © Department of Natural Resources Canada. All rights reserved. | - |
| 7 | Bedrock Geology | *AB.SDE.GEOLOGY_AGS_BEDROCK_GEOLOGY_1_1_MILLION* | GIS File | 2013 | Alberta Geological Survey (AGS) - G.J. Prior and R. Elgr compiled and edited the data for 1 000 000 scale. | - |
| 8 | Bedrock Geology | *BC_bedrocks_ll83* | GIS File | 2005 | BCGeologyMap - Ministry of Energy and Mines | - |
| 9 | Bedrock Geology | bedrock geology | GIS File | - | | - |
| 10 | Bedrock Geology | Bedrock_Geology | GIS File | 2016 | GeoYukon Map Service - Gov of Yukon | - |
| 11 | Geological Faults | fltcan | GIS File | 2004 | Natural Resources Canada | - |
| 12 | Surficial Geology | [GSC] Surficial Geology of Canada - 5 Mill | GIS File | 2014 | Geological Survey of Canada | - |
| 13 | Soil Landscapes of Canada | ca_all_slc_v3r2 | GIS File | 2010 | Soil Landscapes of Canada Working Group, 2010. Soil Landscapes of Canada version 3.2. Agriculture and Agri-Food Canada. | - |
| 14 | Fire History | NFDB_poly_20140210 | GIS File | - | Department of Natural Resources | - |
| 15 | Land cover classification (AVHRR) | canada20 polygon | GIS File | 1992 | Department of Natural Resources | - |
| 16 | Ecoregions | CAN.SDE.LANDCOVER_AAFC_ECOREGIONS | GIS File | - | Agriculture and Agri-Food Canada (AAFC) | - |
| 17 | NWT Ecoregions | FMD_NWT_EcoRegions | GIS File | - | Department of Environment and Natural Resources, Government of the NWT | - |
| 18 | Natural Resources Canada | Quaternary geology of Fort Liard map area, Northwest Territories | GIS File | 2008 | Natural Resources Canada. 2015. Quaternary geology of Fort Liard map area, Northwest Territories. Available at: http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=225608. Accessed: February 2016 | - |
| 19 | DEM | *RASTER.SDE.CAN_TOPOGRAPHY_GEOBASE_CDED_50K_DEM* | GIS File | - | Centre for Topographic Information - Geomatics Canada | - |
| 20 | Watershed boundaries | *canadwscssda_p* | GIS File | - | Atlas of Canada - Natural Resources Canada | - |
| 21 | Bedrock Geology | *AB.SDE.GEOLOGY_AGS_BEDROCK_GEOLOGY_1_1_MILLION* | GIS File | - | Alberta Geological Survey (AGS) - G.J. Prior and R. Elgr compiled and edited the data for 1 000 000 scale. | - |
| 22 | Bedrock Geology | *BC_bedrocks_ll83* | GIS File | - | BCGeologyMap - Ministry of Energy and Mines | - |
| 23 | Bedrock Geology | bedrock geology | GIS File | - | Can we provide a link / url here? | - |
| 24 | Bedrock Geology | Bedrock_Geology | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 25 | Geological Faults | fltcan | GIS File | - | Natural Resources Canada | - |
| 26 | Surficial Geology | [GSC] Surficial Geology of Canada - 5 Mill | GIS File | - | Geological Survey of Canada | - |
| 27 | Soil Landscapes of Canada | ca_all_slc_v3r2 | GIS File | - | Soil Landscapes of Canada Working Group, 2010. Soil Landscapes of Canada version 3.2. Agriculture and Agri-Food Canada. | - |

Note: "-" = not applicable.

**Table 2: Resource List for Land Use, Water Use, and Development for the Liard and Petitot River Basins, including Traditional Knowledge**

| No. | Title | File Name | File Type | Date / Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 1 | BC Land Act Permits Shapefile | ILRR - Land Act Permits | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, ILRR - Land Act Permits. Available at: http://catalogue.data.gov.bc.ca/dataset/ilrr-land-act-permits. Accessed: February 2016. | Published by the Ministry of Forests, Lands and Natural Resource Operations - GeoBC - Pending the release from the BC Data Catalogue - Awaiting Approval |
| 2 | BC Oil and Gas Pipeline Temporary Permit Shapefile | OIL AND GAS PIPELINE TEMPORARY PERMIT (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, OIL AND GAS PIPELINE TEMPORARY PERMIT (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/oil-and-gas-pipeline-temporary-permit-ilrr. Accessed: February 2016. | |
| 3 | BC Oil and Gas Other Temporary Permit Shapefile | OIL AND GAS OTHER TEMPORARY PERMIT (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, OIL AND GAS OTHER TEMPORARY PERMIT (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/oil-and-gas-other-temporary-permit-ilrr. Accessed: February 2016. | |
| 4 | BC Oil and Gas Facility Temporary Permit Shapefile | OIL AND GAS FACILITY TEMPORARY PERMIT (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, OIL AND GAS FACILITY TEMPORARY PERMIT (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/oil-and-gas-facility-temporary-permit-ilrr. Accessed: February 2016. | |
| 5 | BC Mining Lease Shapefile | MINING LEASE (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, MINING LEASE (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/mining-lease-ilrr. Accessed: February 2016. | |
| 6 | BC Drilling License Shapefile | DRILLING LICENSE (ILRR | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, DRILLING LICENSE (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/drilling-licence-ilrr. Accessed: February 2016. | |
| 7 | BC Miscellaneous Land Use Permit Shapefile | MISCELLANEOUS LAND USES PERMIT (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, MISCELLANEOUS LAND USES PERMIT (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/miscellaneous-land-uses-permit-ilrr. Accessed: February 2016. | |
| 8 | BC Community Permit Shapefile | COMMUNITY PERMIT (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, COMMUNITY PERMIT (ILRR). Available at:http://catalogue.data.gov.bc.ca/dataset/community-permit-ilrr. Accessed: February 2016. | |
| 9 | BC Energy Production Permit Shapefile | ENERGY PRODUCTION PERMIT (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, ENERGY PRODUCTION PERMIT (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/energy-production-permit-ilrr. Accessed: February 2016. | |
| 10 | Alberta Land Use Permitting Database | GLIMPS | Database | 09/24/15 | Alberta Environment and Parks. 2015. GLIMPS. Available at: http://aep.alberta.ca/forms-maps-services/industry-online-services/glimps/default.aspx. Accessed: February 2016. | Email Correspondence with Jeff.Poeckens@gov.ab.ca. Summary sheet available for a quarterly fee through third party consultant. |
| 11 | Mackenzie Valley Land and Water Board - Land Use and Water License Data | NWT Permits_Licences File List_MVLWB_2016-2-8 | Registry | 02/08/16 | Mackenzie Valley Land and Water Board. 2016. Land Use and Water License Data. Sahtu land and Water Board, Fort Good Hope, NWT, Canada. | In addition to active and expired WL and LUP, it also includes the closed MVLWB files. Received from: jacqueline.ho@slwb.com |
| 13 | Yukon Government | Mining Map Viewer | Online File | 2016 | Yukon Government - Energy, Mines and Resources. 2015. Mining Map Viewer. Available at: http://mapservices.gov.yk.ca/Mining/. Accessed: February 2016. | An online tool which provides information available in a Geographic Information System for mineral and land tenure, mining and land uses activities, First Nation Traditional Territories and Settlement Land, parks and protected areas, base map and imagery. |
| 14 | Yukon Water Board | Water Use by Industry | Online File | 2014 | Yukon Water Board. 2014. Water Use by Industry. Available at: http://www.yukonwaterboard.ca/stats.htm. Accessed: February 2016. | An overview how water was allocated to the various industries in the Yukon in 2014. It needs to be noted that these are authorized amounts of water and are not necessarily reflective of the actual amounts being used. |
| 15 | Protected Areas | CAN.SDE.BOUNDARIES_CARTS_PROTECTED_AREAS | GIS File | - | Canadian Council on Ecological Areas | - |
| 16 | NWT Existing Protected Areas | multiple files | GIS File | - | NWT Centre for Remote Sensing, Department of Resources, Wildlife and Economic Development (RWED), Government of the Northwest Territories (GNWT), 1997 | - |
| 17 | Land Withdrawals (withdrawn from staking) | Areas_Withdrawn_from_Staking_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 18 | Candidate Areas | multiple files | GIS File | - | Northwest Territories Protected Areas Strategy (NWT-PAS), Department of Resources, Wildlife and Economic Development (RWED), Government of the Northwest Territories (GNWT), 2002 | - |
| 19 | Candidate Areas Interim Protection | multiple files | GIS File | - | | - |
| 20 | High pressure pipelines | AB.SDE.GEOLOGY_IHS_HIGHPRESSURE_PIPELINES | GIS File | - | IHS Inc. / IHS Energy Inc. / IHS Energy (Canada) Inc. | - |
| 21 | Low pressure pipelines | AB.SDE.GEOLOGY_IHS_LOWPRESSURE_PIPELINES | GIS File | - | IHS Inc. / IHS Energy Inc. / IHS Energy (Canada) Inc. | - |
| 22 | Existing pipelines | PIPELN_RW_polygon | GIS File | - | BC Agency - Oil and Gas Commission | - |
| 23 | Economy Data (pipelines, oil and gas, etc.) | | GIS File | - | NWT Centre for Geomatics, Informatics Shared Service Centre, Government of the Northwest Territories, 2015-2016 | - |
| 24 | Seismic Lines | Oil_and_Gas_Seismic_Lines | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 25 | Oil and gas wells | AB.SDE.GEOLOGY_IHS_SURFACE_WELLS | GIS File | - | IHS Inc. / IHS Energy Inc. / IHS Energy (Canada) Inc. | - |
| 26 | Oil and gas wells | SUR_HOL_ST_point | GIS File | - | BC Agency - Oil and Gas Commission | - |
| 27 | Oil and gas wells | Oil_and_Gas_Wells_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 28 | Oil sands | AB.BOUNDARIES_IHS_OILSANDS_AREAS | GIS File | - | IHS Inc. / IHS Energy Inc. / IHS Energy (Canada) Inc. | - |
| 29 | Oil and gas fields | OG_FIELDS_polygon | GIS File | - | BC Agency - Oil and Gas Commission | - |



Golder Associates

**Table 2: Resource List for Land Use, Water Use, and Development for the Liard and Petitot River Basins, including Traditional Knowledge**

| No. | Title | File Name | File Type | Date / Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 30 | AltaLIS DIDS | AB.SDE.LANDUSE_ALTALIS_DIDS | GIS File | - | AltaLIS Ltd. / Spatial Data Warehouse Ltd. | - |
| 31 | Mineral claims | MTA_AT_PLY_polygon | GIS File | - | Ministry of Energy and Mines | - |
| 32 | Mining Leases | MiningLeases | GIS File | - | NWT Centre for Geomatics | - |
| 33 | Mineral Claims | MineralClaims | GIS File | - | NWT Centre for Geomatics | - |
| 34 | Quartz Leases | Quartz_Leases_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 35 | Quartz Claims | Quartz_Claims_1M | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 36 | Mineral Claims | Mineral_Claims_Polygon_Surveyed | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 37 | Coal Leases | Coal_Leases_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 38 | Historic mineral claims | Historical_Mineral_Claims_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 39 | Placer operations | Placer_Operations_250k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 40 | Mineral showings/occurrences | MINFILE_point | GIS File | - | Ministry of Energy and Mines | - |
| 41 | Mineral showings/occurrences | Showings | GIS File | - | NWT Geoscience Office | - |
| 42 | Mineral showings/occurrences | Mineral_Occurrences_250k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 43 | BC Points of Diversion with Water License Information Shapefile | BC Points of Diversion with Water License Information | Online File | 01/11/16 | Government of British Colombia. 2015. Data Catalogue, BC Points of Diversion with Water License Information. Available at: http://catalogue.data.gov.bc.ca/dataset/bc-points-of-diversion-with-water-licence-information. Accessed: February 2016. | Published by the Ministry of Forests, Lands and Natural Resource Operations - Water Management |
| 44 | NWT Land Use and Water License Data | NWT Permits_Licences File List_MVLWB_2016-2-8 | Registry | 02/08/16 | Mackenzie Valley Land and Water Board. 2016. Land Use and Water License Data. Sahtu land and Water Board, Fort Good Hope, NWT, Canada. | Received from: jacqueline.ho@slwb.com |
| 45 | Surface and Groundwater Diversions Authorizations | Alberta GW_SW Licenses | Excel File | 02/10/16 | Alberta Environment and Parks. 2016. Surface and Groundwater Diversions Authorizations. Peace Region Department, Edmonton, AB, Canada. | Received From: Naba.Adhikari@gov.ab.ca |
| 46 | Yukon Water Licenses | Yukon WL.csv | Excel File | February 2016 | Yukon Government. 2014. Yukon Water Board Division. Whitehorse, YK, Canada. | Received from Kim.Hobus@gov.yk.ca |
| 47 | Yukon Environmental Assessment Board | YESAB_Projects_Liard.gdb | Database | February 2016 | Yukon Environmental and Socio-Economic Assessment Board. 2015. Summary of Liard River Projects. Whitehorse, YK, Canada. | Received from Erin.Spiewak@yesab.ca |
| 48 | Background Water Quality Resources from GNWT | REPORT - LIARD RIVER - Acquisition of Traditional Environmental Knowledge in the Lower Liard River Basin | Publication | 1995 | *MacDonald Environmental Sciences Ltd. 1995. LIARD RIVER - Acquisition of Traditional Environmental Knowledge in the Lower Liard River Basin. Water Resources Division, Indian and Northern Affairs Canada. Ottawa, On., Canada.* | - |
| 49 | Site C Project EIS | Site C Project Environmental Impact Statement, Volume 5 | Publication | 02/16/16 | BC Hydro. 2013. Site C Clean Energy Project Environmental Impact Statement. Available at: http://www.ceaa-acee.gc.ca/050/document-eng.cfm?document=85328. Accessed February 2016. | Provides traditional/cultural use information for Aboriginal communities with territory overlapping the Liard/Petitot watersheds |
| 50 | Fort Nelson Land and Resource Management Plan | Fort Nelson Land and Resource Management Plan | Publication | 02/16/16 | Government of British Columbia. 2007. Fort Nelson Land and Resource Management Plan. Available at: http://muskwa-kechika.com/uploads/documents/LRMPs/Fort%20Nelson%20LRMP.pdf. Accessed February 2016. | TLU information of Liard River Corridor (BC portion) |
| 51 | Annex XVIII - Traditional Knowledge and Traditional Land Use Baseline | Annex XVIII - Traditional Knowledge and Traditional Land Use Baseline | Publication | 02/16/16 | Golder Associates Ltd. 2014. Annex XVII: Traditional Land Use and Traditional Knowledge Baseline Report for the Jay Project. Available at: http://reviewboard.ca/upload/project_document/EA1314-01_17_Annex_XVII_Traditional_Land_Use_and_Traditional_Knowledge_Baseline.PDF. Accessed February 2016. | TK Information pertaining to water in NWT |
| 52 | NOVA Gas Transmission Ltd. Horn River Project | NOVA Gas Transmission Ltd. Horn River Project Environmental and Socio-economic ESA | Publication | 02/16/16 | TERA Environmental Consultants. 2010. Environmental and Socio-Economic Impact Assessment for the NOVA Gas Transmission Ltd. Horn River Mainline Project. Available at: https://docs.neb-one.gc.ca/ll-eng/llisapi.dll?func=ll&objId=600712&objAction=browse&viewType=1. Accessed February 2016. | TLU study summaries for Fort Nelson FN, Prophet River FN and Dene Tha' FN |
| 53 | Acho Dene Koe and Fort Liard Metis Traditional Use Study - Final Report (Short Version) | Acho Dene Koe and Fort Liard Metis Traditional Use Study - Final Report (Short Version) | Publication | 02/16/16 | DM Cultural Services Ltd. 2012. Acho Dene Koe and Fort Liard Metis Traditional Use Study - Final Report (Short Version). Available at: https://docs.neb-one.gc.ca/ll-eng/llisapi.dll/fetch/2000/90464/90550/554112/666941/737909/784861/856084/855550/C-20-3C__-_Written_Evidence_Schedule_A_Traditional_Use_Study_-_A2Z2D3.pdf?nodeid=855554&vernum=-2. Accessed February 2016. | TLU study includes Liard River |
| 54 | Fortune Creek Gas Plant BC Environmental Assessment Certificate Application | Fortune Creek Gas Plant BC Environmental Assessment Certificate Application | Publication | 02/16/16 | Quicksilver Resources. 2013. Fortune Creek Gas Plant British Columbia Environmental Assessment Certificate Application Pursuant to the British Columbia *Environmental Assessment Act.* Available at: http://a100.gov.bc.ca/appsdata/epic/html/deploy/epic_document_379_35279.html. Accessed February 2016. | Appendix L - Findings Summary of FNFN TK/TUS Study of Proposed Creek Gas Plant Area<br>Appendix M - Dene Tha' Traditional Land Use on the mbe chon ii linnah (Lower Petitot River)<br>Appendix N - Acho Dene Koe and Fort Liard Métis Traditional Ecological Knowledge of Quicksilver Resources Canada Inc, Fortune Creek Project |
| 55 | Protected Areas | CAN.SDE.BOUNDARIES_CARTS_PROTECTED_AREAS | GIS File | - | Canadian Council on Ecological Areas http://www.ccea.org/carts/ | - |
| 56 | NWT Existing Protected Areas | multiple files | GIS File | - | NWT Centre for Remote Sensing, Department of Resources, Wildlife and Economic Development (RWED), Government of the Northwest Territories (GNWT), 1997 | - |

**Table 2: Resource List for Land Use, Water Use, and Development for the Liard and Petitot River Basins, including Traditional Knowledge**

| No. | Title | File Name | File Type | Date / Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 57 | Land Withdrawals (withdrawn from staking) | Areas_Withdrawn_from_Staking_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 58 | Candidate Areas | multiple files | Publication | - | Northwest Territories Protected Areas Strategy (NWT-PAS), Department of Resources, Wildlife and Economic Development (RWED), Government of the Northwest Territories (GNWT), 2002 | - |
| 59 | Candidate Areas Interim Protection | multiple files | Publication | - | Northwest Territories Protected Areas Strategy (NWT-PAS), Department of Resources, Wildlife and Economic Development (RWED), Government of the Northwest Territories (GNWT), 2002 | - |
| 60 | High pressure pipelines | AB.SDE.GEOLOGY_IHS_HIGHPRESSURE_PIPELINES | GIS File | - | IHS Inc. / IHS Energy Inc. / IHS Energy (Canada) Inc. | - |
| 61 | Low pressure pipelines | AB.SDE.GEOLOGY_IHS_LOWPRESSURE_PIPELINES | GIS File | - | IHS Inc. / IHS Energy Inc. / IHS Energy (Canada) Inc. | - |
| 62 | Existing pipelines | PIPELN_RW_polygon | GIS File | - | BC Agency - Oil and Gas Commission | - |
| 63 | Economy Data (pipelines, oil and gas, etc.) | Economy Data | GIS File | - | NWT Centre for Geomatics, Informatics Shared Service Centre, Government of the Northwest Territories, 2015-2016 | - |
| 64 | Seismic Lines | Oil_and_Gas_Seismic_Lines | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 65 | Oil and gas wells | AB.SDE.GEOLOGY_IHS_SURFACE_WELLS | GIS File | - | IHS Inc. / IHS Energy Inc. / IHS Energy (Canada) Inc. | - |
| 66 | Oil and gas wells | SUR_HOL_ST_point | GIS File | - | BC Agency - Oil and Gas Commission | - |
| 67 | Oil and gas wells | Oil_and_Gas_Wells_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 68 | Oil sands | AB.SDE.BOUNDARIES_IHS_OILSANDS_AREAS | GIS File | - | IHS Inc. / IHS Energy Inc. / IHS Energy (Canada) Inc. | - |
| 69 | Oil and gas fields | OG_FIELDS_polygon | GIS File | - | BC Agency - Oil and Gas Commission | - |
| 70 | AltaLIS DIDS | AB.SDE.LANDUSE_ALTALIS_DIDS | GIS File | - | AltaLIS Ltd. / Spatial Data Warehouse Ltd. | - |
| 71 | Mineral claims | MTA_AT_PLY_polygon | GIS File | - | Ministry of Energy and Mines | - |
| 72 | Mining Leases | MiningLeases | GIS File | - | NWT Centre for Geomatics | - |
| 73 | Mineral Claims | MineralClaims | GIS File | - | NWT Centre for Geomatics | - |
| 74 | Quartz Leases | Quartz_Leases_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 75 | Quartz Claims | Quartz_Claims_1M | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 76 | Mineral Claims | Mineral_Claims_Polygon_Surveyed | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 77 | Coal Leases | Coal_Leases_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 78 | Historic mineral claims | Historical_Mineral_Claims_50k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 79 | Placer operations | Placer_Operations_250k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |
| 80 | Mineral showings/occurrences | MINFILE_point | GIS File | - | Ministry of Energy and Mines | - |
| 81 | Mineral showings/occurrences | Showings | GIS File | - | NWT Geoscience Office | - |
| 82 | Mineral showings/occurrences | Mineral_Occurrences_250k | GIS File | - | GeoYukon Map Service - Gov of Yukon | - |

Note: “-“ = not applicable.

**Table 3: Resource List for Water Quality and Quantity Data, including Routine Parameters and Organic Compounds**

| No. | Title | File Name | File Type | Date / Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 1 | BC Environmental Monitoring Locations Types Shapefile | BC Environmental Monitoring Location Types | Online File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, BC Environmental Monitoring Location Types. Available at: http://catalogue.data.gov.bc.ca/dataset/bc-environmental-monitoring-location-types. Accessed: February 2016. | Published by the Ministry of Environment - Environmental Quality |
| 2 | BC Oil and Gas Commission | Northeast Water Tool | Online File | 2016 | BC Oil and Gas Commission. 2015. Water Information - Northeast Water Tool (NEWT). Available at: https://www.bcogc.ca/public-zone/water-information. Accessed: February 2016. | Water Licenses Locator |
| 3 | BC Ministry of Forest, Lands and Natural Resource Operations | Water Portal | Online File | 2016 | BC Ministry of Forest, Lands and Natural Resource Operations. 2015. Water Portal. Available at: http://waterportal.geoweb.bcogc.ca/#5/55.318/-126.710. Accessed: February 2016. | Stream and Well Quantity, Surface and Ground Quality and Climate Data |
| 4 | Yukon Water Resources Data | Yukon Data (Folder) | Excel File | 02/11/16 | Yukon Government. 2014. Water Resources Branch, Department of Environment. Whitehorse, YK, Canada. | Received From: Tyler.Williams@gov.yk.ca Received By: Robin Bourke |
| 5 | Background Water Quality Resources from GNWT | Liard River WQ Data - Compilation of WQ Excel spreadsheets | Excel File | 2001-2015 | Government of the Northwest Territories. 2016. Liard River WQ Data. Environment and Natural Resources Department. Yellowknife, NWT, Canada. | Nicole Dion (GNWT) provided a flash drive of resources to Golder for Water Quality as well as Liard River Data on February 5. |
| | | Miscellaneous Studies Liard River Corridor Provincial Park and Protected Area Pointed Mountain Site C | Publication | 2010 | Government of the Northwest Territories. 2016. Miscellaneous Studies Liard River Corridor Provincial Park and Protected Area Pointed Mountain Site C. Environment and Natural Resources Department. Yellowknife, NWT, Canada. | |
| | | Overview of the Hydrology in the Deh Cho Region - NWT | Publication | 2002 | Faria, D. 2002.Overview of the Hydrology in the Deh Cho Region - NWT. Indian and Northern Affairs Canada - Water Resources Division.1-40. | |
| | | Reconnaissance Profile Petitot River | Publication | 1992 | Government of the Northwest Territories. 1992. Reconnaissance Profile Petitot River. Environment and Natural Resources Department. Yellowknife, NWT, Canada. | |
| | | REPORT - Data on the Proximate Composition Contaminants and Tainting for Fish from Fisherman Lake NWT | Publication | 1988 | *Lockhart, W.L., et al. 1988.Data on the Proximate Composition Contaminants and Tainting for Fish from Fisherman Lake NWT. Department of Fisheries and Oceans, Winnipeg, Man. Canada.* | |
| | | REPORT - LIARD RIVER - An Historic NWT Flood 1988 Flooding | Publication | 1992 | *Jasper J.N., Kerr J.A. 1992. LIARD RIVER - An Historic NWT Flood 1988 Flooding. Environment Canada. Yellowknife, NWT, Canada.* | |
| | | REPORT - LIARD RIVER - Liard River Environmental Quality Monitoring Program - Final Report | Publication | 1998 | Taylor B.R., Sanderson J and Lafontaine C. 1998. Liard River Environmental Quality Monitoring Program - Final Report. Indigenous and Northern Affairs Canada. Yellowknife, NWT, Canada | |
| | | REPORT - LIARD RIVER - Liard River Basin Spring Flood | Publication | 1981 | Grey B.J. et al. 1981. Liard River Basin Spring Flood. Environmental Management Service, Environment Canada. Hull, QC, Canada | |
| | | REPORT - LIARD RIVER - Liard River Hydroelectric Development Studies of Migratory Fish and Downstream Aquatic Impacts | Publication | 1979 | R.L.&L. Environmental Services Ltd. 1979. Liard River Hydroelectric Development Studies of Migratory Fish and Downstream Aquatic Impacts. GNWT Department of Renewable Resources Library. Yellowknife, NWT, Canada. | |
| | | REPORT - Liard River Hydroelectric Development Impacts on Mackenzie and Liard River Transportation | Publication | 1981 | Hirst S.M., Morgan M.J. 1981.Liard River Hydroelectric Development Impacts on Mackenzie and Liard River Transportation. Department of Indian and Northern Affairs. Yellowknife, NWT, Canada. | |
| | | State of the Aquatic Knowledge - Mackenzie River Basin - Liard Sub-Basin | Publication | 2003 | Mackenzie River Basin Board. 2003. State of the Aquatic Knowledge Report. Liard Sub-Basin 115-132 | |
| 6 | Federal freshwater Quality Monitoring and Surveillance | Liard River at Upcrossing - Westbank (YT10AA0005) | Online File | 1983-1994 | Government of Canada. 2014. Freshwater Quality Monitoring and Surveillance - Online Data. Available at: http://aquatic.pyr.ec.gc.ca/webdataonlinenational/en/SiteDetails/YT10AA0005/Projects/PYLTM/Regions/0. Accessed: February 2016. | Transboundary Water Quality Testing - Federal Government |
| 7 | Federal freshwater Quality Monitoring and Surveillance | Liard River at Upper Crossing (YT10AA0001) | Online File | 1991-2015 | Government of Canada. 2014. Freshwater Quality Monitoring and Surveillance - Online Data. Available at: http://aquatic.pyr.ec.gc.ca/webdataonlinenational/en/SiteDetails/YT10AA0001/Projects/PYLTM/Regions/0 Accessed: February 2016. | |
| 8 | Federal freshwater Quality Monitoring and Surveillance | Liard River at Lower Crossing (BC10BE0005) | Online File | 1984-1994 | Government of Canada. 2014. Freshwater Quality Monitoring and Surveillance - Online Data. Available at: http://aquatic.pyr.ec.gc.ca/webdataonlinenational/en/SiteDetails/BC10BE0005/Projects/PYLTM/Regions/0 Accessed: February 2016. | |
| 9 | Federal freshwater Quality Monitoring and Surveillance | Liard River at Fort Liard (NW10ED0001) | Online File | 1984-1997 | Government of Canada. 2014. Freshwater Quality Monitoring and Surveillance - Online Data. Available at: http://aquatic.pyr.ec.gc.ca/webdataonlinenational/en/SiteDetails/NW10ED0001/Projects/PYLTM/Regions/0 Accessed: February 2016. | |

**Table 3: Resource List for Water Quality and Quantity Data, including Routine Parameters and Organic Compounds**

| No. | Title | File Name | File Type | Date / Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 10 | Ministry of Energy and Mines | Regional Geochemistry | Online File | June 2005 | Government of British Colombia. 2015. Ministry of Energy and Mines - Regional Geochemistry. Available at: http://www.empr.gov.bc.ca/Mining/Geoscience/Geochemistry/RegionalGeochemistry/Pages/default.aspx. Accessed: February 2016. | In 1976, the British Columbia Geological Survey, in partnership with the Geological Survey of Canada, initiated reconnaissance stream sediment and water surveys across the province. Originally referred to as the Uranium Reconnaissance Program (URP), the program was renamed the Regional Geochemical Survey (RGS) in 1978. In 1987, the British Columbia Geological Survey began to administer the surveys independently, as part of Canada's National Geochemical Reconnaissance (NGR) program. Starting in 2006, samples from new surveys and archived samples were analyzed by Geoscience BC, and the results incorporated into the RGS database. |
| 11 | Uncertainty in the impacts of projected climate change on the hydrology of a subarctic environment: Liard River Basin | Uncertainty in the impacts of projected climate change on the hydrology of a subarctic environment: Liard River Basin | Publication | 5/17/2011 | Thorne R. 2011.Uncertainty in the impacts of projected climate change on the hydrology of a subarctic environment: Liard River Basin. Hydrology and Earth System Science, 15, 1483-1492. | From Hydrology and Earth System Science - School of Geography and Earth Sciences - McMaster University |
| 12 | Liard River Environmental Quality Monitoring Program – Summary Report | Liard River Environmental Quality Monitoring Program – Summary Report | Publication | March 1998 | Taylor B.R., Sanderson J and Lafontaine C. 1998. Liard River Environmental Quality Monitoring Program – Summary Report. Indigenous and Northern Affairs Canada. Yellowknife, NWT, Canada | - |
| 13 | Site-Specific Water Quality Guidelines for the Liard River at Upper Crossing for the Purpose of National Reporting | Site-Specific Water Quality Guidelines for the Liard River at Upper Crossing for the Purpose of National Reporting | Publication | May 2005 | Tri-Star Environmental Consulting. 2005. Site-Specific Water Quality Guidelines for the Liard River at Upper Crossing for the Purpose of National Reporting. Environment Canada. BC, Canada. | THIS DOCUMENT is one in a series that presents ambient site-specific water quality guidelines (SSGs) for British Columbia and the Yukon. This Executive Summary includes tables listing site-specific water quality guidelines (SSGs) for the purpose of reporting on one water use: protection of aquatic life. The main report presents the details of the water quality assessment for the Liard River, and forms the basis of the recommendations and site-specific guidelines presented here. |
| 14 | Northwest Territories Water Monitoring Inventory | Northwest Territories Water Monitoring Inventory | Publication | November 2013 | NWT Water Stewardship. 2013. Northwest Territories Water Monitoring Inventory. Government of the Northwest Territories. Yellowknife, NWT, Canada. | The NWT Water Monitoring Inventory includes information on current water monitoring programs led by Aboriginal, federal and territorial governments, communities, industry, and others. |
| 15 | Liard & Horn River Basin Water Monitoring | Liard & Horn River Basin Water Monitoring | Publication | 2013 | Fort Nelson First Nation Lands Department. 2013. Liard & Horn River Basin Water Monitoring. Available at:http://lands.fnnation.ca/project/Liard-horn-river-basin-water-monitoring. Accessed: February 2016. | Pending approval from Fort Nelson First Nation Lands Department |
| 16 | Current State of Surface Water Quality and Aquatic Ecosystem Health in Alberta-Northwest Territories Transboundary Waters | Current State of Surface Water Quality and Aquatic Ecosystem Health in Alberta-Northwest Territories Transboundary Waters | Publication | March 2009 | Hatfield Consultant. 2009. Current State of Surface Water Quality and Aquatic Ecosystem Health in Alberta-Northwest Territories Transboundary Waters. Alberta Government. Edmonton, AB, Canada | - |
| 17 | Mackenzie Gas Project - EIS Supplemental Information - Northwestern Alberta - Water Quality | Mackenzie Gas Project - EIS Supplemental Information - Northwestern Alberta - Water Quality | Publication | 12/01/04 | Mackenzie Gas Project. 2004. Water Quality. EIS Supplemental Information - Northwestern Alberta. 6.1-6.12. Available at: http://www.mackenziegasproject.com/theProject/regulatoryProcess/applicationSubmission/Documents/MGP_EIS_NWAlta_Section_6.pdf | Includes DO, pH, Conductance, Temp and Turbidity, watercourses NWML05-NWML28 within the Petitot watershed |
| 18 | A project: Baseline Surface Water Quality of River and Streams in the Petitot River Basin: Examining Potential Impacts of Shale Gas Development in the Horn River Basin, British Columbia. | A project: Baseline Surface Water Quality of River and Streams in the Petitot River Basin: Examining Potential Impacts of Shale Gas Development in the Horn River Basin, British Columbia. | Publication | 08/01/13 | Energy and Mines Ministers' Conference. 2013. Responsible Shale Development – Enhancing the Knowledge Base on Shale oil and Gas in Canada. Annex B, Pg. 6. Available at:https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/www/pdf/publications/emmc/AnnexB_Shale_Compemdium_e.pdf | Complete key findings will be disclosed at the project end date (March 31, 2016). Preliminary results might be disclosed prior to this end date. Contact: Bev McNaughton Environment Canada, PY Water Quality Monitoring and Surveillance, Tel: 604 664 4054, e-mail: beverly.mcnaughton@ec.gc.ca |

**Table 3: Resource List for Water Quality and Quantity Data, including Routine Parameters and Organic Compounds**

| No. | Title | File Name | File Type | Date / Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 19 | Background Water Quality Resources from GNWT | Characterizing the under Ice Suspended Sediment Plume During Northern River Breakup | Report | 1995 | Milburn D, Prowse T.D. 1995. Characterizing the under Ice Suspended Sediment Plume During Northern River Breakup. Indian Affairs and Northern Development/National Hydrology Research Institute. 1-20. | - |
| | | Observations on Some Physical-Chemical Characteristics of River-Ice Breakup | Report | 2000 | Milburn D, Prowse T.D. 2000. Observations on Some Physical-Chemical Characteristics of River-Ice Breakup. Journal of Cold Regions Engineering. 214-223. | - |
| | | Open Water Versus under Ice Rating Curves for Suspended Sediment an example from a Large Northern River | Report | 1996 | Milburn D, Prowse T.D. 1996. Open Water Versus under Ice Rating Curves for Suspended Sediment an example from a Large Northern River. Indian Affairs and Northern Development/National Hydrology Research Institute. 1-20. | - |
| | | REPORT - LIARD RIVER - An assessment of ambient environmental conditions in the Liard River Basin | Report | 1993 | *MacDonald Environmental Sciences Ltd. 1993. LIARD RIVER - An assessment of ambient environmental conditions in the Liard River Basin. Water Resources Division, Indian and Northern Affairs Canada. Yellowknife, NWT, Canada.* | - |
| | | REPORT - LIARD RIVER - Liard River Environmental Quality Monitoring Program - Final Report | Report | 1998 | Taylor B.R., Sanderson J and Lafontaine C. 1998. Liard River Environmental Quality Monitoring Program - Final Report. Indigenous and Northern Affairs Canada. Yellowknife, NWT, Canada | - |
| | | State of the Aquatic Knowledge - Mackenzie River Basin - Liard Sub-Basin | Report | 2003 | Mackenzie River Basin Board. 2003. State of the Aquatic Knowledge Report. Liard Sub-Basin 115-132 | - |
| | | The Effect of River-Ice Break-Up on Suspended Sediment and Select Trace-Element Fluxes | Report | 1994 | Milburn D, Prowse T.D. 1996. The Effect of River-Ice Break-Up on Suspended Sediment and Select Trace-Element Fluxes. Nordic Hydrology. 27, 69-84. | - |
| 20 | Hydrometric Data - WSC | Hydrometric Data from Water Survey of Canada (historic and real-time) for 7 Liard River stations and 1 Petitot River station. | Excel File | 2/12/2016 | http://wateroffice.ec.gc.ca/# | - |
| 21 | Hydrometric Data - other | Hydrometric Data from other sources, including 11 stations off main-stems of Liard and Petitot but within the drainage basins | Excel File | 2/12/2013 | http://wateroffice.ec.gc.ca/# | - |
| 22 | Hydrometric Data - Yukon Government | Liard Metadata.xlxs | Excel File | 2/11/2016 | Received by Robin Bourke via email From: Tyler.Williams@gov.yk.ca on Feb 11 2016 | - |

Note: “-“ = not applicable.

**Table 4: Resource List for Liard and Petitot Groundwater Basin Data, including Uses and Demands**

| No. | Title | File Name | File Type | Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 1 | Surface and Groundwater Diversions Authorizations | Alberta GW_SW Licenses | Publication | 02/10/16 | Alberta Environment and Parks. 2016. Surface and Groundwater Diversions Authorizations. Peace Region Department, Edmonton, AB, Canada. | Received from Naba.Adhikari@gov.ab.ca |
| 2 | BC Points of Diversion with Water License Information Shapefile | BC Points of Diversion with Water License Information | Online File | 01/11/16 | Government of British Colombia. 2015. Data Catalogue, BC Points of Diversion with Water License Information. Available at: http://catalogue.data.gov.bc.ca/dataset/bc-points-of-diversion-with-water-licence-information. Accessed: February 2016. | Published by the Ministry of Forests, Lands and Natural Resource Operations - Water Management |
| 3 | NWT Land Use and Water License Data | NWT Permits_Licences File List_MVLWB_2016-2-8 | Publication | 02/08/16 | Mackenzie Valley Land and Water Board. 2016. Land Use and Water License Data. Sahtu land and Water Board, Fort Good Hope, NWT, Canada. | In addition to active and expired WL and LUP, it also includes the closed files. Received from: jacqueline.ho@slwb.com |
| 4 | BC Oil and Gas Commission | Northeast Water Tool | Online File | 2016 | BC Oil and Gas Commission. 2015. Water Information - Northeast Water Tool (NEWT). Available at: https://www.bcogc.ca/public-zone/water-information. Accessed: February 2016. | Water Licenses Locator |
| 5 | Yukon Government | Mining Map Viewer | Online File | 2016 | Yukon Government - Energy, Mines and Resources. 2015. Mining Map Viewer. Available at: http://mapservices.gov.yk.ca/Mining/. Accessed: February 2016. | This online tool provides information available in a Geographic Information System for mineral and land tenure, mining and land uses activities, First Nation Traditional Territories and Settlement Land, parks and protected areas, base map and imagery. |
| 6 | Yukon Water Board | Water Use by Industry | Online File | 2014 | Yukon Water Board. 2014. Water Use by Industry. Available at: http://www.yukonwaterboard.ca/stats.htm. Accessed: February 2016. | Below is an overview how water was allocated to the various industries in the Yukon in 2014. It needs to be noted that these are authorized amounts of water and are not necessarily reflective of the actual amounts being used. |
| 7 | BC Government - The Map Place | Mineral Title Map | Online File | 1/12/2005 | Government of British Colombia. 2015. The MapPlace - mineral Titles Map. Available at: http://www.empr.gov.bc.ca/MINING/GEOSCIENCE/MAPPLACE/MAINMAPS/Pages/mtitles.aspx. Accessed: February 2016. | Legacy MiDA Mineral, Placer and Coal tenures (before January 12, 2005) and Mineral and Placer Mineral Titles Online (MTO) tenures (after January 12, 2005) are displayed on this map. |
| 8 | BC Water Resources | BC Water Resources Atlas | Online File | 2016 | Government of British Colombia. 2015. Ministry of Environment - BC Water Resources Atlas. Available at: http://maps.gov.bc.ca/ess/sv/wrbc/. Accessed: February 2016. | Water Well Use, Observation Wells, WQ, Hydrometrics, Etc. |
| 9 | GIN Database | Bistcho Lake Area/BC/YK GW Wells Records | Online File | 2014 | G.I.N. 2016. GIN Basic Map Viewer. Available at: http://gin.gw-info.net/service/api_ngwds:gin2/en/wmc/standard.html?BBOX=-126.136,57.62564,-114.65,61.72357. Retrieved: February 2016. | Water quality is not something we addressed in GIN but Alberta has a database of water quality. See No. 2 for data. |
| 10 | Groundwater Quality Summary for NW Alberta | GW WQ_NW Alberta_Hay Basin | Publication | 02/09/16 | Alberta Renewables and Environment. 2016. Groundwater Quality Summary for NW Alberta. Edmonton, AB, Canada. | Received from Steve.Clare@gov.ab.ca; Coordinates can be found using Well IDs in the spreadsheet with the following database: http://groundwater.alberta.ca/WaterWells/d/ |
| 11 | Subsurface Aquifer Study to Support Liard Basin Unconventional Gas and Oil Development, Northeastern B.C. (NTS 094J, K, N, O). | Subsurface Aquifer Study to Support Liard Basin Unconventional Gas and Oil Development, Northeastern B.C. (NTS 094J, K, N, O). | Publication | 01/22/14 | Geoscience BC. 2014. Geoscience BC Report 2014-02. Available at: http://www.geosciencebc.com/s/NewsReleases.asp?reportid=620593&hilite=liard&ver=BASIC&w=liard&op=ANDANYORDER&mindate=&maxdate=&o=DATE&dsp=SITEMAP&summ=T&summLen=300&rt=&rtNm=&prid=&pridNm=&mx=20&ecc=ver%3DBASIC%26w%3Dliard%26op%3. Retrieved: February 2016. | Can be released via: www.geosciencebc.com/s/DataReleases.asp. |
| 12 | Groundwater Observation Well Network | GOWN Chemistry Wells/Alberta Water Well Information Database | Online File | 07/08/2005 | Alberta Environment and Parks. 2016. Groundwater Observation Well Network. Available at: http://esrd.alberta.ca/water/programs-and-services/groundwater/groundwater-observation-well-network/default.aspx. Retrieved: February 2016. | The Groundwater Observation Well Network (GOWN) is an Alberta Government owned network of groundwater monitoring wells located in various aquifers throughout the province. Most wells are fitted with data loggers and sensors that continually record groundwater levels. In addition, many of these well are periodically pumped and sampled for water quality analysis. |
| 13 | Ministry of Energy and Mines | Regional Geochemistry | Online File | June 2005 | Government of British Colombia. 2015. Ministry of Energy and Mines - Regional Geochemistry. Available at: http://www.empr.gov.bc.ca/Mining/Geoscience/Geochemistry/RegionalGeochemistry/Pages/default.aspx. Accessed: February 2016. | In 1976, the British Columbia Geological Survey, in partnership with the Geological Survey of Canada, initiated reconnaissance stream sediment and water surveys across the province. Originally referred to as the Uranium Reconnaissance Program (URP), the program was renamed the Regional Geochemical Survey (RGS) in 1978. In 1987, the British Columbia Geological Survey began to administer the surveys independently, as part of Canada's National Geochemical Reconnaissance (NGR) program. Starting in 2006, samples from new surveys and archived samples were analyzed by Geoscience BC, and the results incorporated into the RGS database. |
| 14 | BC Oil and Gas Commission | Water Portal | Online File | 2016 | BC Ministry of Forest, Lands and Natural Resource Operations. 2015. Water Portal. Available at: http://waterportal.geoweb.bcogc.ca/#5/55.318/-126.710. Accessed: February 2016. | Stream and Well Quantity, Surface and Ground Quality and Climate |
| 15 | BC Ministry of Energy and Mines Geoscience Reports | Collaborative interagency water projects in British Columbia: introduction to the Northeast British Columbia Aquifer Project and Streamflow Modelling Decision Support Tool | Publication | 2012 | Wilford, D., et al. (2012): Collaborative interagency water projects in British Columbia: introduction to the Northeast British Columbia Aquifer Project and Streamflow Modelling Decision Support Tool; in Geoscience Reports 2012, British Columbia Ministry of Energy and Mines, pages 79-89 | This NEBC Aquifer Project does not appear to have online data, some follow-up later may reveal publically-available data, collected for its project area (includes the Liard Basin, Horn River Basin, Cordova Embayment, from south of Dawson Creek to Yukon and NWT boundaries). |
| 16 | Hydrogeology of the Zama-Bistcho Lakes Area, Alberta | Hydrogeology of the Zama-Bistcho Lakes Area, Alberta | Publication | 1980 | Borneuf D., Pretula B. 1980. Hydrogeology of the Zama-Bistcho Lakes Area, Alberta. Alberta Research Council, Pg. 1-10. | - |

**Table 4: Resource List for Liard and Petitot Groundwater Basin Data, including Uses and Demands**

| No. | Title | File Name | File Type | Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 17 | BC Ministry of Energy and Mines | Geospatial Data Downloads | GIS File | Bed Rock Geology/ Climate | Government of British Colombia. 2015. Geospatial Data Downloads- Ministry of Energy and Mines Available at: hhttp://www.empr.gov.bc.ca/MINING/GEOSCIENCE/MAPPLACE/GEODATA/Pages/default.aspx. Accessed: February 2016. | - |
| 18 | Yukon Government | Mining Map Viewer | GIS File | 2016 | Yukon Government - Energy, Mines and Resources. 2015. Mining Map Viewer. Available at: http://mapservices.gov.yk.ca/Mining/. Accessed: February 2016. | Look especially for placer and quartz mine locations in south-east Yukon and around Frances Lake. |
| 19 | Federal Government | Federal Contaminated Sites Inventory | Online File | 2/10/2016 | Government of Canada. 2016. Treasury Board of Canada Secretariat - Find Contaminated Sites by Location. Available at: http://www.tbs-sct.gc.ca/fcsi-rscf/location-emplacement-eng.aspx?clear=1. Accessed: February 2016. | For all jurisdictions |
| 20 | Biodivcanada | Technical Thematic Report No. 9. - Trends in permafrost conditions and ecology in northern Canada | Publication | 4/16/2015 | Biodivcanada.ca. 2015. Technical Thematic Report No. 9. - Trends in permafrost conditions and ecology in northern Canada. Available at: http://www.biodivcanada.ca/default.asp?lang=En&n=3ED0C589-1&offset=3&toc=hide. Accessed: February 2016. | Trends in Permafrost Conditions in the Taiga Plains Ecozone |
| 21 | Groundwater Information  Network | Permafrost | Online File | 2014 | G.I.N. 2014. Permafrost. Available at: http://gin.gw-info.net/service/api_ngwds:gin2/en/hydroreg/pfrost.html;jsessionid=17EF5DAF32F9A693D4394AFE74FE2C3D. Accessed: February 2016. | Review of Permafrost regions |
| 22 | Natural Resources Canada | Permafrost Map | Publication | 1978-1995 | Government of Canada. 2015. The North - Physical Geography. Available at: http://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada/selected-thematic-maps/16886#physicalgeography. Accessed: February 2016. | Contained within the 5th Edition (1978 to 1995) of the National Atlas of Canada has a large that shows the extent of permafrost and abundance of ground ice; mapping units are based on physiographic regions. Point data on map give permafrost temperature and thickness for specific sites. The second, smaller, map shows the mean annual ground temperatures. Graphs show four shallow temperature profiles (to 25 meters depth), and four deep temperature profiles (to several hundred meters depth). |
| 23 | Natural Resources Canada | Potential changes in permafrost distribution in the Fort Simpson and Norman Wells regions | Publication | 2000 | Natural Resources Canada. 2015. Potential changes in permafrost distribution in the Fort Simpson and Norman Wells regions. Available at: http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=211930 Accessed: February 2016. | Modelling that predicts permafrost distribution and thickness in equilibrium with a given mean annual air temperature is applied to the Norman Wells and Fort Simpson regions. The model predicts the likelihood of permafrost, based on values of thermal conductivity for the various surficial materials in each study area and a factor which describes the insulating property of ground-surface vegetation and snow cover. Estimates of permafrost thickness are obtained for various combinations of terrain characteristics. Using maps of vegetation and surficial geology, these combinations can be compiled for each study area and used to map both permafrost thickness and extent, using a geographic information system. This technique predicts that, under an increase in mean annual air temperature of 2°C, permafrost extent decreases slightly and thickness decreases markedly for the Norman Wells area. For the same temperature increase at Fort Simpson, permafrost almost completely disappears. |
| 24 | Yukon Permafrost Network | Permafrost Related links | Publication | 2016 | Government of Yukon. 2011. Yukon Permafrost Network. Available at: http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=211930 Accessed: February 2016. | Verity of Permafrost related links for the Yukon Region |
| 25 | Yukon Permafrost Probability Map | Impacts of mean annual air temperature change on a regional permafrost probability model for the southern Yukon and northern British Columbia, Canada | Publication | 2013 | Bonnaventure P. P., Lewkowicz A. G. 2013. Impacts of mean annual air temperature change on a regional permafrost probability model for the southern Yukon and northern British Columbia, Canada. The Cryosphere, 7, 935-946. | The permafrost probability model for the southern Yukon and northern British Columbia is a interpolative combination of seven local high-resolution empirical-statistical models (30 x 30 m grid cells), each developed by using the measured temperature at the bottom of the snowpack (BTS) in winter and by verification of frozen-ground  in summer. |

**Table 4: Resource List for Liard and Petitot Groundwater Basin Data, including Uses and Demands**

| No. | Title | File Name | File Type | Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 26 | Recent trends from Canadian permafrost thermal monitoring network sites | Recent trends from Canadian permafrost thermal monitoring network sites | Publication | 5/14/2005 | Smith S.L, et al. 2005. Recent trends from Canadian permafrost thermal monitoring network sites. Permafrost and Periglacial Processes, 16, 1, 19-30. | The Geological Survey of Canada (GSC), in collaboration with other government partners, has been developing and maintaining a network of active-layer and permafrost thermal monitoring sites which contribute to the Canadian Permafrost Monitoring Network and the Global Terrestrial Network for Permafrost. Recent results from the thermal monitoring sites maintained by the GSC and other federal government agencies are presented. These results indicate that the response of permafrost temperature to recent climate change and variability varies across the Canadian permafrost region. Warming of shallow permafrost temperatures of between 0.3 and 0.6°C per decade has occurred since the mid- to late 1980s in the central and northern Mackenzie region in response to a general increase in air temperature. No significant warming (less than 0.1°C per decade) of permafrost is observed in the southern Mackenzie valley. Warming of shallow permafrost of between 1.0 and 4.0°C per decade is also observed in the eastern and high Arctic, but this mainly occurred in the late 1990s. These trends in permafrost temperature are consistent with trends in air temperature observed since the 1970s. Local conditions however, influence the response of the permafrost thermal regime to these changes in air temperature. |
| 27 | BC Waste Discharge Authorizations | BC Waste Discharge Authorizations | Publication | February 2016 | Government of British Colombia. 2016. BC Waste Discharge Authorizations. Ministry of Environment - Environmental Protection Division. Victoria, BC, Canada. | Received from Michele.Bell@gov.bc.ca - Check Metadata tab for information |

Note: “-“ = not applicable.

**Table 5: Resource List for Cumulative Effects on Water Quality and Quantity in Liard and Petitot River Basins, and Other Additional Resources**

| No. | Title | File Name | File Type | Version | Reference | Comments |
|---|---|---|---|---|---|---|
| 1 | BC Commercial Recreation Permit Shapefile | COMMERCIAL RECREATION PERMIT (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, COMMERCIAL RECREATION PERMIT (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/commercial-recreation-permit-ilrr. Accessed: February 2016. | Published by the Ministry of Forests, Lands and Natural Resource Operations - GeoBC |
| 2 | BC Recreational Area Shapefile | RECREATION AREA (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, RECREATION AREA (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/8e2c9a7a-a01e-415c-9089-1c2c533c65e6. Accessed: February 2016. | |
| 3 | BC Environmental Permit Shapefile | ENVIRONMENT PERMIT (ILRR) | GIS File | 12/22/15 | Government of British Colombia. 2015. Data Catalogue, ENVIRONMENT PERMIT (ILRR). Available at: http://catalogue.data.gov.bc.ca/dataset/environment-permit-ilrr. Accessed: February 2016. | |
| 4 | Addressing Cumulative Effects in Natural Resource Decision-Making | Addressing Cumulative Effects in Natural Resource Decision-Making | Publication | 02/01/14 | Government of British Colombia. 2014. Data Catalogue, Addressing Cumulative Effects in Natural Resource Decision Making. Available at: http://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/cumulative-effects/overview_report_addressing_cumulative_effects.pdf. Accessed: February 2016. | CEF Overview Report February 2014 - CumulativeEffects@gov.bc.ca |
| 5 | Managing the Cumulative Effects of Natural Resource Development in B.C. | Managing the Cumulative Effects of Natural Resource Development in B.C. | Publication | 05/26/15 | Office of the Auditor General of BC. 2015. Managing the Cumulative Effects of Natural Resource Development in B.C. Available at: https://www.bcauditor.com/pubs/2015/managing-cumulative-effects-natural-resource-development-bc. Accessed: February 2016. | Looks at government’s management of cumulative effects, which are changes to the environment caused by the combined impact of past, present and potential future activity. |

## Closure

We trust the above meets your present requirements. If you have any questions or require additional details, please contact Robin Bourke at robin_bourke@golder.com or 867-873-6319.

# APPENDIX D

## Risk Assessment Approach: Problem Formulation and Conceptual Models

# 1.0 INTRODUCTION

An objective of the State of Knowledge Report is to evaluate the potential for risk to human and ecological receptors that use or come into contact with groundwater or surface water from the Study Area. Three components must be present for risks to exist: 1) contaminant(s) present at concentrations greater than regulatory standards or guidelines; 2) a receptor; and 3) an exposure pathway by which the receptor comes into contact with the contaminant. To determine whether these conditions are present, the first step of a risk assessment, the problem formulation, is conducted and includes the development of conceptual models. The other three steps in a risk assessment following the problem formulation are: exposure assessment, toxicity assessment, and risk characterization.

Information summarized by other State of Knowledge Report components form the basis of the problem formulation, including but not limited to: water uses, influence on water resources, ambient environmental conditions, traditional knowledge, and aquatic ecosystem information.

A search of water licenses and other authorized water withdrawals and return flows indicated that the main users of surface water in the Liard and Petitot River Basin are private industries (e.g. mining, oil and gas, hydroelectric power), and private residential water supply activities (Section 3.2 of the main report). Mineral leases, oil and gas leases, forestry, and communities of Watson Lake and Lower Post (Yukon) tend to cluster in the Upper Liard (Liard River above Watson Lake) and in the Middle Liard (Liard River between Watson Lake and Fort Liard). These land uses, activities, and communities have the potential to represent non- or point-sources that may influence water quality in this river. In the Lower Liard (Liard River between Fort Liard and Fort Simpson), forestry and the communities of Fort Liard and Nahanni Butte (NWT) may also represent non- or point-sources that could influence water quality in the lower reach. Mineral and oil and gas activities had the most potential within the Petitot Basin to influence water quality in the Petitot River.

Based on land-use and development identified within the Liard River Basin in Section 4 of the main report, metals, nutrients, and organic constituents such as polycyclic aromatic hydrocarbons and petroleum hydrocarbons are most relevant for inclusion in this assessment where data are available. Constituents of potential concern (COPCs) will be identified based on screening the available data for the Liard River.

# 2.0 IDENTIFICATION OF CONSTITUENTS OF POTENTIAL CONCERN

## 2.1 Screening Approach

Datasets were compiled for seven surface water quality monitoring stations situated along the Liard River and three surface water quality monitoring stations located on a major tributary (Petitot River), as described in Section 5.2 of the main report. Four groundwater aquifers were identified in the region however there are limited groundwater quality data (Section 5.4 of the main report) from the Study Area.

Of the seven surface water quality monitoring stations situated along the Liard River (Table B-1; Figure 2; Map A-18) water quality data from Upper Crossing (excluding Upper Crossing-West Bank), Fort Liard, and Fort Simpson water quality monitoring stations were compared to aquatic life water quality guidelines (WQG), and drinking WQGs. These three water quality monitoring stations were chosen because collectively the majority of water samples have been collected at these stations over an extended time period (since 1960 at Fort Liard and Fort Simpson, and since 1991 at Upper Crossing), recent data were available, and the stations were spatially distributed along the Liard River to correspond to the different portions of the river (i.e., Upper Liard, Middle Liard and Lower Liard). As described in Section 5.2 of the main report, there were substantially fewer data available for the Petitot River. The three surface water quality monitoring stations situated along the Petitot River (ordered from upstream to downstream) are located just downstream of the Tsea River, upstream of Fortune Creek, and downstream of Highway No. 77.

Maximum water concentrations at Upper Crossing, Fort Liard, and Fort Simpson were compared to CCME short- and long-term water quality guidelines (WQGs) and BC MOE maximum and 30-day freshwater WQGs to identify COPCs to aquatic life (Table D-1), and BC MOE wildlife WQGs to determine COPCs to wildlife (Table D-2). Maximum water concentrations were compared to Health Canada Drinking Water Guidelines to determine COPCs to human health (Table D-3). Based on information presented in Section 4.1 and Section 3.2 of the main report, livestock watering and crop irrigation were not identified as receiving water uses for the Liard or Petitot Rivers given that the limited agricultural activity in the watershed was concentrated around the Fort Nelson Area.

Maximum water concentrations measured in the Petitot River were also compared to aquatic life WQGs, drinking water guidelines, and wildlife WQGs to identify COPCs according to the approach below. No exceedances were noted for aquatic, human and wildlife receptors in the Petitot River. As such, water screening results pertaining only to the Liard River are shown below.

Although the main groundwater well uses in the Study area noted in Table 12 of the main report are private domestic use, followed by water supply systems, and unknown uses; it is presently unclear what the uses were for the groundwater wells with measured groundwater data. In addition, due to the paucity of the groundwater data available (five wells for a total of seven samples that were analyzed between 1995 and 2009 in Table 41 of the main report) and the absence of more recent and relevant data, the groundwater data has not been used to determine COPCs for aquatic life, wildlife or human health receptors.

As discussed in Section 5.6 of the main report there were no bottom sediment data available for the Liard and Petitot, rather sediment data were limited to suspended sediments. Suspended sediments are not directly comparable to provincial or federal sediment quality guidelines and so the data were only referred to qualitatively in this assessment where relevant to support the assessment of surface water quality.

For freshwater aquatic life, applicable guidelines for surface water were CCME (1999) WQGs for the Protection of Freshwater Aquatic Life and BC MOE approved (2016) and working (2015) water quality guidelines. It should be noted that these national and provincial guidelines are generic and apply across these jurisdictions and as such do not specifically consider site-specific conditions in the Liard River. Given that the Liard River flows across provincial and territorial boundaries the BC water quality guidelines are only directly applicable to the section of the river that flows through BC but do provide additional context for the remainder of the river length. CCME water quality guidelines apply to the entire length of the river.

For wildlife receptors, the applicable guidelines for surface water are provided by BC MOE approved (2016) and working (2015) water quality guidelines. Where WQGs for wildlife receptors were not available, livestock WQGs were used.

Constituents of potential concern for human health were selected based on comparison to Health Canada's Drinking Water Quality Guidelines (Health Canada 2017; DWQG).

## 2.2 Conventional Parameters and Organics

Maximum detected parameter concentrations at Upper Crossing, Fort Liard, and Fort Simpson (Tables D-1 to D-3) were compared to CCME and BC MOE long-term/30-day and/or short-term/maximum freshwater aquatic life WQGs. If the maximum concentration measured during any of the sampling events did not exceed the guidelines, then the 95% upper confidence limit of the mean (UCLM) concentration of that parameter was not calculated. Where the maximum concentration measured during any of the sampling events exceeded at least one of the guidelines, the 95% upper confidence limit of the mean (UCLM) of a particular parameter was calculated using water quality data from the last five years (2011 – 2015) (Tables D-1 to D-3) as this was considered representative of the current conditions. If the 95% UCLM concentration was greater than any of the relevant guidelines, the parameter was considered a COPC.

Many environmental decisions are based on calculating appropriate statistical parameters (e.g. 95% UCLMs) to describe and compare environmental concentrations to a criteria. Typically, environmental concentrations often have small sample sizes and/or skewed distributions (i.e. many concentrations based on detection limits and few detected concentrations), and popular statistical methods (e.g. Student's t-statistic, Central Limit Theorem-UCL) do not provide the desired coverage of the population mean (US EPA 2013).

The 95% UCLM is considered representative of the upper limit conditions that receptors may be exposed to while taking into consideration non-detected concentrations was calculated because the maximum concentration samples at one point in time may not represent the actual concentrations receptors are exposed for the majority of the year. Where a parameter was less than the detection limit, the full detection limit was used to calculate the 95% UCLM. If there were less than ten detected values (e.g., nitrite and anthracene) or if the data range was limited (e.g., fluoride), then the 95$^{th}$ percentile concentration was calculated.

## 2.3 Total and Dissolved Metals

If the 95% UCLM concentration for total metals exceeded any of the guidelines, then its corresponding 95% UCLM dissolved metal concentration was calculated and compared to guidelines. As discussed in Section 5.3 of the main report, total metal concentrations in surface waters can be highly influenced by high total suspended solids (TSS) concentrations. For example, elevated TSS levels typically occur during the spring freshet due to higher water flows and volumes occurring over a shorter period of time, thus mobilizing more particulates through erosion and scouring. The total metal concentration may not be indicative of the concentration bioavailable for uptake by aquatic organisms for some metals because a proportion of the total concentration is preferentially bound to particles. Dissolved metal concentrations are generally more indicative of the metal concentration potentially bioavailable to aquatic organisms. The suspended sediment data described in Section 5.6 of the main report showed that suspended sediments did have elevated concentrations of some metals and PAHs in the Liard and Petitot Rivers.

Therefore, the 95% UCLM dissolved metal concentration (subject to data availability) was calculated and compared to guidelines. If the 95% UCLM dissolved metal concentration exceeded any of the total or dissolved metal guidelines, then the relevant parameter was considered a COPC.

## 2.4 Constituents of Potential Concern for Aquatic Life Receptors

Parameters that exceeded at least one of the CCME and BC MOE long-term/30-day and/or short-term/maximum aquatic life WQGs are shown in Table D-1.

**Table D-1: Summary of Exceedances in Surface Water Compared to Freshwater Aquatic Life Water Quality Guidelines**

| Parameter | Freshwater Aquatic Life WQG | | Maximum (All Data) | | | 95% UCLM (2011-2015) | | | Aquatic Life COPC? [m] |
|---|---|---|---|---|---|---|---|---|---|
| | CCME Long-term (Short-term) [a] | BC MOE 30-day (Max) [b] | Upper Crossing (n=196-367) | Fort Liard (n=22-253) | Fort Simpson (n=22-295) | Upper Crossing (n=34 - 37) | Fort Liard (n=10 - 23) | Fort Simpson (n=12 - 25) | |
| ***Conventional Parameters (mg/L)*** [k] | | | | | | | | | |
| pH | 6.5 - 9.0 | 6.5 - 9.0 | 8.6 | **9.0** | **9.1** | <GL | 8.2 | 8.2 | No |
| Fluoride | 0.12 | (0.73 – 1.7) [c] | **0.2** | **0.23** | **0.3** | 0.09 | 0.09 | 0.1 [e] | No |
| Nitrate | 2.9 (124) | 3.0 (33) | 0.36 | **3.6** | 0.5 | <GL | 0.17 | <GL | No |
| Nitrite | 0.06 | 0.02 – 0.2 (0.06 – 0.6) | 0.009 | **0.03** | **1.3** | <GL | 0.02 [e] | <0.01 [e] | No |
| Dissolved Oxygen | 6.5 | 8.0 (5.0) | - | **6.0** [min] | 9.3 [min] | - | 9.0 [f] | >GL | No |
| ***Total Metals (µg/L)*** | | | | | | | | | |
| Aluminum | 100 | - | **2,150** | **21,400** | **65,100** | **283** | **3,581** | **2,286** | **Yes** |
| Arsenic | 5 | (5) | 2.3 | **20** | **8.0** | <GL | 3.3 | 2.2 | No |
| Barium | - | 1,000 | 105 | **1,050** | 773 | <GL | 327 | <GL | No |
| Beryllium | - | 0.13 | **0.14** | **1.3** | **1.6** | 0.022 | **0.34** | **0.23** | See dissolved |
| Cadmium | 0.046 – 0.34 (0.46 – 5.3) [c] | - | **0.9** | **17** | **11** | 0.028 | **0.53** [g] | **0.37** [h] | See dissolved |
| Chromium | 1.0 | 1.0 | **3.8** | **8,530** | **32** | 0.6 | **6.7** | **4.4** | See dissolved |
| Cobalt | - | 4.0 (110) | 2.0 | **22** | **22** | <GL | **6.0** | 3.7 | See dissolved |
| Copper | 2.0 – 4.0 | 2.0 – 9.9 (4.1 – 25) [c] | **4.6** | **54** | **132** | 1.2 | **15** [g] | **9.8** [h] | See dissolved |
| Iron | 300 | (1,000) | **3,990** | **57,600** | **93,500** | **613** | **10,965** | **6,982** | See dissolved |
| Lead | 1.0 – 7.0 | 3.8 – 13 (12 – 260) [c] | **3.3** | **33** | **33** | 0.5 | **8.6** [g] | 5.7 [h] | See dissolved |
| Selenium | 1.0 | 2.0 | 0.9 | **12** | **1.1** | <GL | 0.9 | 0.8 | No |
| Silver | 0.25 | 0.05 – 1.5 (0.1 – 3.0) [c] | 0.1 | **0.55** | **0.9** | <GL | 0.16 [g] | **0.08** [h] | See dissolved |
| Zinc | 30 | 7.5 – 126 (33 – 152) [c] | **15** | **209** | **388** | 3.0 | **56** [g] | **41** [h] | See dissolved |
| ***Dissolved Metals (µg/L)*** | | | | | | | | | |
| Aluminum | - | 50 (100) [d] | - | **803** [l] | **196** [l] | - | 40 | **73** | **Yes** |
| Arsenic | - | - | - | NA | NA | - | - [j] | - [j] | - |
| Barium | - | - | - | NA | NA | - | - [j] | - [j] | - |
| Beryllium | - | 0.13 [i] | - | NA | NA | - | 0.007 | 0.009 | No |

**Table D-1: Summary of Exceedances in Surface Water Compared to Freshwater Aquatic Life Water Quality Guidelines**

| Parameter | Freshwater Aquatic Life WQG | | Maximum (All Data) | | | 95% UCLM (2011-2015) | | | Aquatic Life COPC? [m] |
|---|---|---|---|---|---|---|---|---|---|
| | CCME Long-term (Short-term) [a] | BC MOE 30-day (Max) [b] | Upper Crossing (n=196-367) | Fort Liard (n=22-253) | Fort Simpson (n=22-295) | Upper Crossing (n=34 - 37) | Fort Liard (n=10 - 23) | Fort Simpson (n=12 - 25) | |
| Cadmium | 0.046 – 0.34 (0.46 – 5.3) [c,i] | - | - | NA | NA | - | 0.025 [g] | 0.036 [h] | No |
| Chromium | 1.0 [i] | 1.0 [i] | - | NA | NA | - | 0.17 | 0.17 | No |
| Cobalt | - | 4.0 (110) [i] | - | NA | NA | - | 0.12 | 0.10 | No |
| Copper | 2.0 – 4.0 [i] | 2.0 – 9.9 (4.1 – 25) [c,i] | - | NA | NA | - | 3.2 [g] | 2.2 [h] | No |
| Iron | - | (350) | - | **1,980** [l] | 350 [l] | - | 112 | <GL | No |
| Lead | 1.0 – 7.0 [i] | 3.8 – 13 (12 – 260) [c,i] | - | NA | NA | - | 0.09 [g] | 0.10 [h] | No |
| Selenium | - | - | - | NA | NA | - | - [j] | - [j] | - |
| Silver | 0.25 [i] | 0.05 – 1.5 (0.1 – 3.0) [c,i] | - | NA | NA | - | 0.002 [g] | 0.002 [h] | No |
| Zinc | 30 [i] | 7.5 – 126 (33 – 152) [c,i] | - | NA | NA | - | 3.8 [g] | 10 [h] | No |
| ***Polycyclic Aromatic Hydrocarbons (µg/L)*** | | | | | | | | | |
| Anthracene | 0.012 | 0.1 | - | **0.034** | *<0.02* | - | *<0.02* [e] | *<0.061* [e] | No |
| Fluoranthene | 0.04 | 0.2 | - | 0.028 | **0.068** | - | <GL | 0.007 | No |
| Pyrene | 0.025 | 0.02 | - | **0.059** | **0.15** | - | **0.027** | 0.009 | **Yes** |

Notes:

**Bolded value** = Exceeds at least one freshwater aquatic life guideline; *italicized value* = Detection limit exceeds at least one of the applicable guidelines;

<GL = Maximum concentration was less than guideline, 95% UCLM concentration is not shown; >GL = Greater than guideline (i.e., for dissolved oxygen), value is not shown; "-" = Not measured or unavailable; COPC = Constituent of potential concern; Min = Minimum value shown; n = number of samples available for calculating 95% UCLMs; NA = Not applicable, maximum dissolved metal concentration not shown because it is not used to compare against applicable guidelines; UCLM = Upper confidence limit of the mean

a) Canadian Council of Ministers of the Environment (CCME) long-term and short-term (in parentheses) Freshwater Aquatic Life Guidelines (CCME 1999). Accessed May 2016. Available online at: http://st-ts.ccme.ca/en/index.html?chems=all

b) British Columbia Ministry of Environment (BC MOE) 30-day and maximum (in parentheses) Approved (BC MOE 2016b) and Working (BC MOE 2015) Freshwater Aquatic Life Water Quality Guidelines (WQG). Accessed May 2016. Available online at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines

c). Guideline is hardness-dependent; range applies to all data at Upper Crossing, Ford Liard and At Mouth.

d) Guideline is pH-dependent, range applies to all data at Upper Crossing, Fort Liard and At Mouth.

e) 95% UCLM could not be calculated because the data set contained less than 10 detected values or the range of data was limited, the 95th percentile value is shown instead.

f) 95% UCLM is not applicable, the 5th percentile value is shown.

g) A median hardness of 153 mg/L as $CaCO_3$ from the 2011 to 2015 data at Fort Liard was used to calculate the applicable guidelines.

h) A median hardness of 160 mg/L as $CaCO_3$ from the 2011 to 2015 data at At Mouth was used to calculate the applicable guidelines.

i) Guideline for total metals shown as a comparison.

j) 95% UCLM total metal concentration do not exceed guidelines, therefore the 95% UCLM dissolved concentrations are not shown.

k) No units for pH; units for nitrate and nitrite are in mg/L of N (nitrogen), all other conventional parameters shown are in mg/L.

l) Maximum dissolved metal concentrations are shown because dissolved metal guidelines are available.

m) The maximum concentration is compared to their applicable guidelines, where the maximum concentration exceeds at least one of the guidelines, a 95% UCLM concentration is shown. If the maximum concentration does not exceed any of the guidelines, "<GL" is shown and the 95% UCLM is not calculated. For conventional parameters, if the 95% UCLM concentration exceeds at least one of the guidelines, then it is considered a COPC for aquatic life receptors. For total metals, if the 95% UCLM total metal concentration exceeds at least one of the guidelines, then its corresponding 95% UCLM dissolved concentration is calculated and compared to the same guidelines. If the 95% UCLM dissolved concentration exceeds at least one of the guidelines, then the total and dissolved form of the metal is considered a COPC for aquatic life receptors. If the 95% UCLM total metal concentration or the 95% UCLM dissolved metal concentration is less than their applicable guidelines, the metal is not considered a COPC for aquatic life.

The 95% UCLM concentrations for several total metals (beryllium, cadmium, chromium, cobalt, copper, iron, lead, silver, and zinc) were greater than at least one of the aquatic life WQGs, however, corresponding 95% UCLM dissolved metal concentrations were all less than the aquatic life WQGs. As such, beryllium, cadmium, chromium, cobalt, copper, iron, lead, silver, and zinc were not identified as aquatic life COPCS. The 95% UCLM total aluminum concentration exceeded the CCME aquatic life long-term WQG of 100 µg/L at Upper Crossing, Fort Liard, and Fort Simpson and the 95% UCLM dissolved aluminum concentration exceeded the BC MOE 30-day (50 µg/L) and maximum (100 µg/L) dissolved WQGs at Fort Simpson. The maximum and 95% UCLM pyrene concentrations exceeded both CCME (0.025 µg/L) and BC MOE (0.02 µg/L) long-term/30-day WQGs at Fort Liard. Aluminum and pyrene were therefore identified as aquatic life COPCs but a further assessment is required to determine whether aluminum and pyrene are a cause for concern for freshwater aquatic life.

The 95% UCLM concentration for pyrene at Fort Liard (0.027 mg/L) was only slightly elevated above the CCME (0.025 mg/L) and BC MOE WQGs (0.02 mg/L). It should be noted that the 95% UCLM concentration for pyrene was calculated based on 10 samples, of which four were less than the detection limit (<0.0039 µg/L) and the other six samples were greater than the detection limit. In addition, only two of the 10 samples in June 2012 and May 2013 were greater than the CCME and BC MOE WQGs but the most recent sample taken in October 2014 was less than the detection limit. Although the 95% UCLM calculation takes into account non-detected values, the full detection limit was used and the 95% UCLM can be influenced by detection limit value(s) especially when there are few detected values. More detected data values would be needed to calculate the 95% UCLM pyrene concentration at Fort Liard with more certainty.

## 2.5 Constituents of Potential Concern for Wildlife Receptors

Parameters that exceeded wildlife WQGs are shown in Table D-2. Where wildlife WQGs were not available for a parameter, livestock WQGs were shown. Based on the screening approach as outlined in Section 2.1, there were no COPCs identified for wildlife receptors.

**Table D-2: Summary of Exceedances in Surface Water Compared to Wildlife Water Quality Guidelines**

| Parameter | Wildlife WQG | | Maximum (All Data) | | | 95% UCLM (2011-2015) | | | Wildlife COPC? [c] |
|---|---|---|---|---|---|---|---|---|---|
| | BC MOE Maximum Wildlife WQG [a] | BC MOE 30-day Wildlife WQG [a] | Upper Crossing (n=196-367) | Fort Liard (n=22-253) | Fort Simpson (n=22-295) | Upper Crossing (n=34 - 37) | Fort Liard (n=10 - 23) | Fort Simpson (n=12 - 25) | |
| ***Total Metals (µg/L)*** | | | | | | | | | |
| Aluminum | 5,000 | - | 2,150 | **21,400** | **65,100** | <GL | 3,581 | 2,286 | No |
| Chromium | - | 50 [b] | 3.8 | **8,530** | 32 | <GL | 6.7 | <GL | No |
| Selenium | - | 2.0 | 0.9 | **12** | 1.1 | <GL | 0.9 | <GL | No |

Notes:
**Bolded value** = Exceeds the BC MOE acute and/or chronic wildlife guidelines
<GL Maximum concentration is less than guideline, 95% UCLM concentration is not shown; COPC = Constituent of potential concern; n = number of samples available for calculating 95% UCLMs; UCLM = Upper confidence limit of the mean; WQG = Water Quality Guidelines
a) British Columbia Ministry of Environment (BC MOE). BC MOE Approved (BC MOE 2016b) and Working (BC MOE 2015) Acute and Chronic Wildlife Guidelines Accessed May 2016. Available online at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines. Where acute/chronic wildlife guidelines are not available, acute/chronic livestock watering guidelines are shown.
b) BC MOE working livestock water quality guidelines
c) The maximum concentration is compared to their applicable guidelines, if the maximum concentration exceeds at least one of the guidelines, its 95% UCLM concentration is calculated. If the maximum concentration does not exceed any of the guidelines, then "<GL" is shown and its 95% UCLM is not calculated. If the 95% UCLM metal concentration is less than its applicable guidelines, then the metal is not considered a COPC for wildlife receptors.

## 2.6 Constituents of Potential Concern for Human Receptors

Parameters that exceeded Health Canada Drinking WQGs are shown in Table D-3. The total aluminum drinking WQG was exceeded at Upper Crossing, Fort Liard and Fort Simpson, while the total zinc drinking WQG was exceeded at Fort Liard and Fort Simpson. However, the total aluminum and zinc drinking WQGs are based on an operational and aesthetic objective, respectively, and are not based on a health objective. In addition, drinking water would be treated to remove total suspended solids and so total concentrations of these metals would decrease accordingly. Total aluminum and zinc were identified as drinking water COPCs based on a comparison of surface water in the Liard River to relevant drinking WQGs but in consideration of the above considerations.

**Table D-3: Summary of Exceedances in Surface Water Compared to Health Canada Drinking Water Quality Guidelines**

| Parameter | Health Canada Drinking WQG [a] | Surface Water | | | | | | Drinking Water COPC? [g] |
|---|---|---|---|---|---|---|---|---|
| | | Maximum (All Data) | | | 95% UCLM (2011-2015) | | | |
| | | Upper Crossing (n=196-367) | Fort Liard (n=22-253) | Fort Simpson (n=22-295) | Upper Crossing (n=34 - 37) | Fort Liard (n=10 - 23) | Fort Simpson (n=12 - 25) | |
| ***Conventional Parameters (mg/L)* [b]** | | | | | | | | |
| Nitrite | 1.0 | 0.009 | 0.03 | **1.3** | <GL | <GL | <0.01 [c] | No |
| ***Total Metals (µg/L)*** | | | | | | | | |
| Aluminum | 100 [d] | **2,150** | **21,400** | **65,100** | **283** | **3,581** | **2,286** | **Yes** |
| Arsenic | 10 | 2.3 | **20** | 8.0 | <GL | 3.3 | <GL | No |
| Barium | 1,000 | 105 | **1,050** | 773 | <GL | 327 | <GL | No |
| Cadmium | 5.0 | 0.9 | **17** | **11** | <GL | 0.53 | 0.37 | No |
| Chromium | 50 | 3.8 | **8,530** | 32 | <GL | 6.7 | <GL | No |
| Lead | 10 | 3.3 | **33** | **33** | <GL | 8.6 | 5.7 | No |
| Zinc | 30 [e] | 15 | **209** | **388** | <GL | **56** | **41** | **Yes** |

Notes:

**Bolded value** = Exceeds the drinking water guidelines

<GL = Maximum concentration is less than guideline, 95% UCLM concentration is not shown; COPC = Constituent of potential concern; DW = Drinking water; n = number of samples available for calculating 95% UCLMs; NM = Not measured; UCLM = Upper confidence limit of the mean; WQG = water quality guideline

a) Health Canada. 2017. Health Canada Guidelines for Canadian Drinking Water Quality – Summary Table. Accessed March 2017. Available online at: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sum_guide-res_recom/index-eng.php

b) No units for pH; units for nitrite is in mg/L of N (nitrogen).

c) 95% UCLM not calculated due to a limited data set, the 95$^{th}$ percentile is shown instead.

d) Drinking water guideline for aluminum is an operational guideline; "There is no consistent, convincing evidence that aluminum in drinking water causes adverse health effects in humans." (Health Canada 2014)

e) Drinking water guideline for zinc is an aesthetic objective: "Water with zinc levels above the aesthetic objective tends to be opalescent and develops a greasy film when boiled…" (Health Canada 2014)

f). Drinking WQG is not health-based; parameter is not considered a COPC.

g) The maximum concentration is compared to their applicable guidelines, if the maximum concentration exceeds at least one of the guidelines, its 95% UCLM concentration is calculated. If the maximum concentration does not exceed any of the guidelines, then "<GL" is shown and the 95% UCLM is not calculated. If the 95% UCLM concentration is less than its applicable guideline, then the parameter is not considered a COPC for human receptors.

# 3.0 IDENTIFICATION OF RECEPTORS OF CONCERN

## 3.1 Ecological Receptors

Potential ecological receptors were considered those that could come into direct or indirect contact with groundwater, surface water or sediment in the Study Area. Based on the information available on the river and the surrounding area, ecological receptors could include aquatic organisms, and aquatic and terrestrial wildlife.

With respect to ecological receptors, it was not possible to directly assess the risk for each individual species because a functional ecosystem involves interaction of multiple species and each species responds differently to COPCs. Rather, the ecosystem was divided into components (e.g., aquatic plants, benthic invertebrates, birds, and mammals), and a limited number of representative species or ecological communities (such as benthic invertebrates) were selected from each of these components.

Several factors were considered in the selection of appropriate ecological receptors, including the following.

- *Ecological relevance*: The selected receptors should play a measurable role in the functioning of the ecosystem.
- *Relevance from a human perspective*: The selected receptors should have importance with regard to traditional use or non-traditional use.
- *Representative of different exposure pathways*: Organisms are exposed through a number of pathways, the selected receptors should represent the major exposure pathways.
- *Species at risk*: Species at risk are assessed in a similar manner as other species, however a more stringent level of protection should be afforded.

Based on information provided in Sections 5.7.2 and 5.7.3 of the main report, ecosystem components and surrogate receptors of concern selected for aquatic and terrestrial wildlife are shown in Table D-4.

**Table D-4: Candidate Aquatic and Terrestrial Wildlife Receptors**

| Receptor Group | Feeding Guild | Candidate Receptors |
|---|---|---|
| Aquatic plants | Primary Producer | algal communities |
| Aquatic invertebrates | Various | benthic invertebrate communities |
| Fish | Various | small and large-bodied fish populations |
| | | Threatened or endangered species (e.g., bull trout, dolly varden, arctic cisco, lake cisco, spotted shiner), and species hunted for sustenance (e.g., arctic grayling, burbot, lake trout, lake whitefish, longnose sucker, mountain whitefish, northern pike, walleye, white sucker) |
| Mammalian | Insectivore | American water shrew |
| | Herbivore | moose, woodland caribou |
| | Piscivore | American mink, North American river otter |
| | Omnivore | American black bear |
| Avian | Insectivore | rusty blackbird, harlequin duck, common nighthawk |
| | Herbivore | mallard |
| | Piscivore | osprey, bald eagle |
| | Omnivore | sandhill crane |

## 3.2 Human Receptors

Several communities were identified within the Study Area in BC (Lower Post, Fort Nelson, Trutch and Dease Lake), Yukon (Watson Lake, Rancheria and Frances Lake) and in the NWT (Fort Liard and Fort Simpson); no established communities were identified in Alberta (as described in Sections 2.2 and 2.3 of the main report). However, of the communities located within the Study Area, the following communities are directly influenced by either the Liard or Petitot Rivers: Watson Lake, Lower Post, Fort Liard, Nahanni Butte, and Fort Simpson.

In addition to the communities identified in the Study area, multiple Aboriginal groups identified as having territory used, or valued for traditional purposes in Section 3.1 of the main report, specifically: Acho Dene Koe First Nation, Blueberry River First Nations, Deh Cho First Nations, Dene Tha First Nation, Kaska Dena, Fort Liard Métis, Fort Nelson First Nation, Members of Treat 8 Tribal Association (including Doig River First Nation, Halfway River First Nation, Prophet River First Nation, and West Moberly First Nations), Tahltan Central Government, and Teslin Tlingit Council. Traditional activities such as hunting, trapping, fishing, plant gathering, travel and practicing culturally important activities at selected sites and areas currently take place within the Study area.

Tourism and recreation are sources of income for the communities and First Nation groups in the area. During the summer, water-based tourist recreational activities include: fishing, swimming, canoeing, kayaking, and rafting and winter activities that take place in or near the water include ice-fishing and trapping.

Oil and gas, forestry and mining activities are known to occur in the Study Area and as such, camp workers will reside in the Study Area for part of the year.

# 4.0 EXPOSURE PATHWAYS OF POTENTIAL CONCERN

## 4.1 Ecological Pathways

Exposure pathways for ecological receptors are routes by which receptors could potentially be exposed to COPCs in environmental media. Potential pathways for surface water and sediment that could be applied to receptors could include but may not be limited to:

- direct contact and uptake of surface water by wildlife;
- ingestion of dietary items exposed to surface water; and
- direct contact and incidental ingestion of sediment.

There is no direct exposure pathway for groundwater and aquatic receptors, however the surface water in the river would integrate with groundwater that's discharging directly into the river.

## 4.2 Human Health Pathways

The objective of the exposure pathway screening process is to identify potential routes by which people could be exposed to COPCs in surface water, sediment and groundwater under current and future conditions, and the relative significance of these pathways to the total exposure. A COPC is considered to represent a potential health risk only if it could reach receptors through an exposure pathway at a concentration that could potentially lead to adverse effects (i.e., greater than guidelines). If there is no pathway for a COPC to reach a receptor, then there cannot be a risk, regardless of the COPC concentration. Potential human health exposure pathways include but may not be limited to:

- Community Residents:
  - ingestion of ground/surface water (i.e., drinking water source);
  - direct skin contact with surface water while swimming or wading;
  - incidental ingestion of surface water while swimming;
  - ingestion of dietary items (e.g., fish, plants) exposed to ground/surface water; and
  - direct contact, incidental ingestion and dermal contact of sediment while swimming.
- First Nations Communities:
  - ingestion of ground/surface water (i.e., drinking water source);
  - direct skin contact with surface water while swimming or wading;
  - incidental ingestion of surface water while swimming;
  - ingestion of dietary items (e.g., fish, plants) exposed to ground/surface water; and
  - direct contact, incidental ingestion and dermal contact of sediment while swimming.
- Camp Workers
  - Ingestion of ground/surface water (i.e., drinking water source).
- Seasonal Recreational Users
  - direct skin contact with surface water while swimming or wading;
  - incidental ingestion of surface water while swimming; and
  - direct contact, incidental ingestion and dermal contact of sediment while swimming.

Drinking water for Fort Nelson and Fort Simpson is sourced from surface water, and drinking water for Fort Liard, Nahanni Butte, and Watson Lake is sourced from groundwater wells.

# 5.0 CONCEPTUAL MODELS

Three conceptual models for aquatic, wildlife and human receptors are shown in Figures D-1 to D-3, respectively. These models provide a visual depiction showing COPCs in various environmental media, potential direct and indirect (i.e., treated drinking water) exposure pathways, and human and ecological receptors.

- A conceptual model for aquatic receptors such as aquatic plants, benthic invertebrates and fish is shown in Figure D-1. The conceptual model applies to the entire Study Area because receptors remain largely the same along the length of the two rivers. For the most part there were no discernible differences in surface water quality along the length of the two rivers, identified by the Problem Formulation and the Surface Water Assessment (Section 5.3 of the main report), that would warrant an alternative approach. Due to a lack of available bottom sediment data, it is unclear whether there is a spatial distribution of COPCs in sediment along the two rivers. Exposure to COPCs was primarily evaluated through the surface water pathway because surface water quality data collected reflects parameter concentrations aquatic life are exposed to after upstream surface water and groundwater inputs to the river have mixed.. There was insufficient data to evaluate the potential presence of COPCs in groundwater.

- Figure D-2 shows the conceptual model for wildlife receptors. Livestock were not identified as receptors based on the available information. No COPCs for wildlife receptors were noted in surface water, therefore there is no operable exposure pathway for surface water. Whether there are COPCs in bottom sediments for wildlife receptors remains to be determined due to limited data. The conceptual model applies to the entire Study Area because it is expected wildlife will be found throughout the Study Area and exposure scenarios are assumed to be the same *in lieu* of sufficient groundwater and bottom sediment chemistry data.
- Human receptors residing at different locations may be exposed to a different suite of COPCs but because more specific data regarding human receptors were not available, the conceptual model for human receptors shown in Figure D-3 is relevant to the entire Study Area. In addition, due to insufficient groundwater and bottom sediment chemistry data, a data gap was identified for the two media.

Should more data be available in the future, these conceptual models could be updated to account for spatial differences along the length of the two rivers. Furthermore as discussed in Section 4.1.6 of the main report, should the limited agricultural activity in the watershed, that is currently concentrated around the Fort Nelson Area, expand then the wildlife conceptual model could be revisited as to whether livestock should be included.

The conceptual models show that the COPCs are limited to only a few parameters, with aluminium the one parameter consistently identified as a COPC both in total and dissolved forms. Elevated concentrations of total aluminum would be largely associated with elevated TSS loadings that are seasonally present in the river. While total aluminum data were available for all three stations on the Liard River; dissolved concentrations were only available for the mid- and downstream stations and not the Upper Crossing station. To evaluate spatial changes in aluminum and potential bioavailability to aquatic biota along the Liard River, dissolved concentrations of aluminum (and other metals) should be measured and reported at the Upper Crossing station. TSS data also appeared to be limited in recent years at the Upper Crossing station (Appendix B). Supporting parameters that facilitate the interpretation of contaminant data including but not limited to TSS, pH, chloride, hardness, and dissolved organic carbon should be measured at every station where total and dissolved metals are being measured.

# 6.0 REFERENCES

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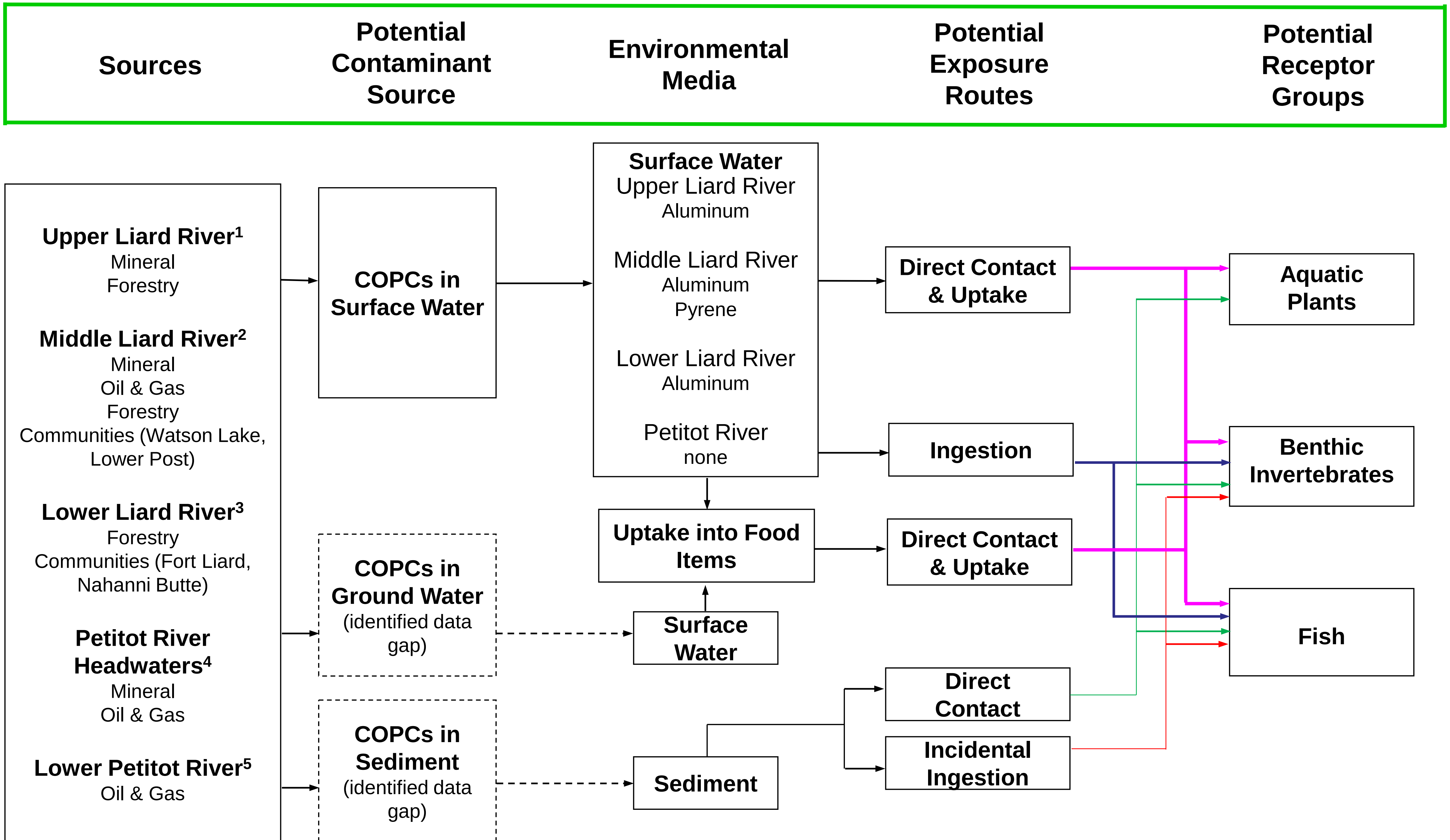



**Conceptual Model for Ecological Aquatic Receptors**
Liard and Petitot Rivers Surface and Groundwater Learning Plan
**ENR-GNWT**

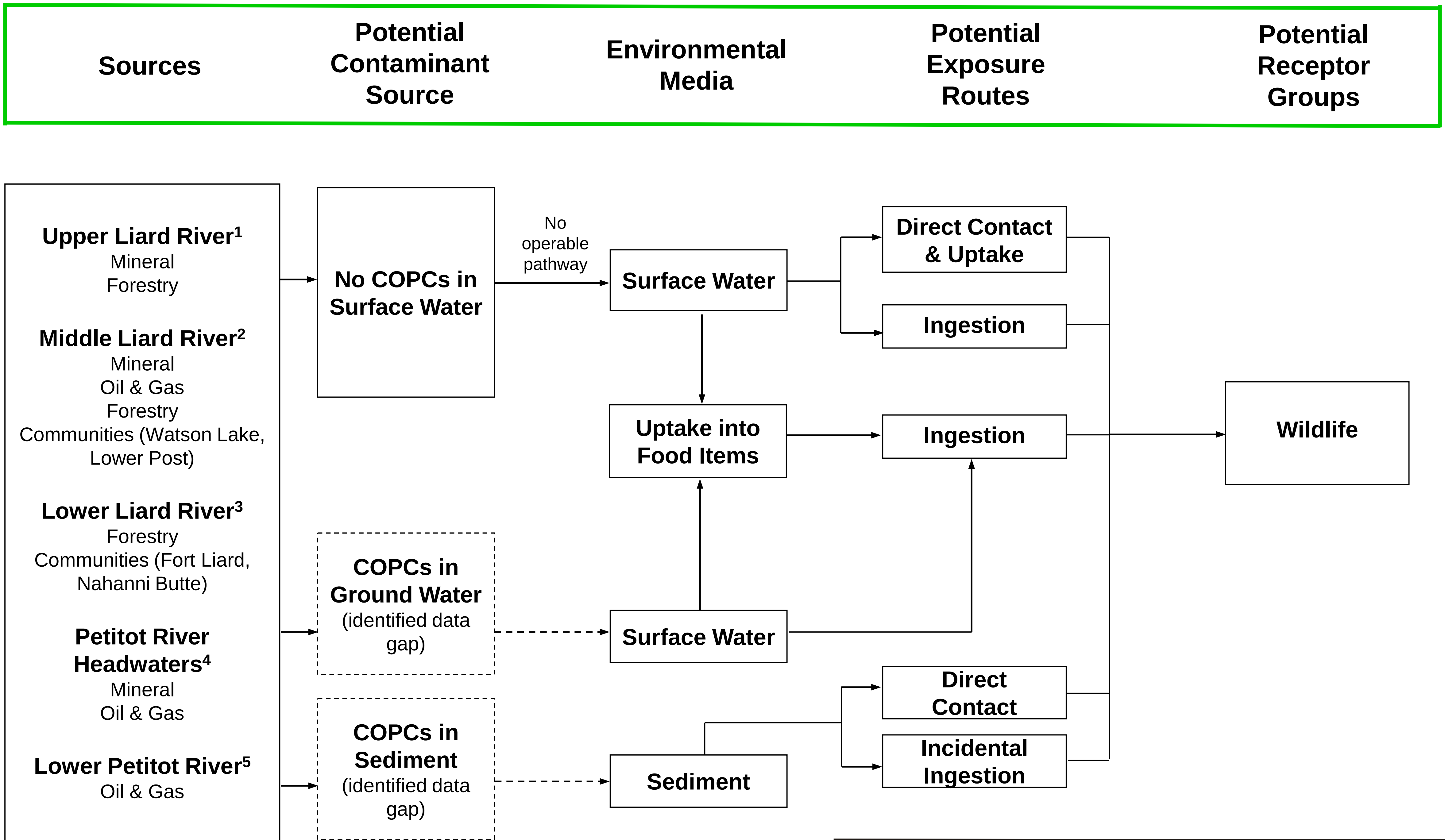
Golder Associates

| PROJECT No. 1547195 | | | FILE No. ---- | |
|---|---|---|---|---|
| DESIGN | SK | 24MAY16 | SCALE NTS | REV. |
| CADD | -- | | **FIGURE D-1** | |
| CHECK | EI | 27MAY16 | | |
| REVIEW | CAT | 02JUN16 | | |

Note: Colours are used to differentiate the potential exposure pathways only
1. Upper Liard River is upstream of Watson Lake
2. Middle Liard River is between Watson Lake and Ford Liard
3. Lower Liard River is between Fort Liard and Fort Simpson
4. Petitot River Headwaters in Alberta
5. Lower Petitot River in British Columbia

Legend
→ Potential Pathway
- - → Data Gap

Filepath – https://capws.golder.com/sites/1547195LiardpetitotLearningPlans/4_Deliverable_Multiuser/Forms/AllItems.aspx




Note: Colours are used to differentiate the potential exposure pathways only

1. Upper Liard River is upstream of Watson Lake
2. Middle Liard River is between Watson Lake and Ford Liard
3. Lower Liard River is between Fort Liard and Fort Simpson
4. Petitot River Headwaters in Alberta
5. Lower Petitot River in British Columbia

Legend

——→ Potential Pathway

- - - → Data Gap

**Conceptual Model for Ecological Wildlife Receptors**

Liard and Petitot Rivers Surface and Groundwater Learning Plan

**ENR-GNWT**

Golder Associates

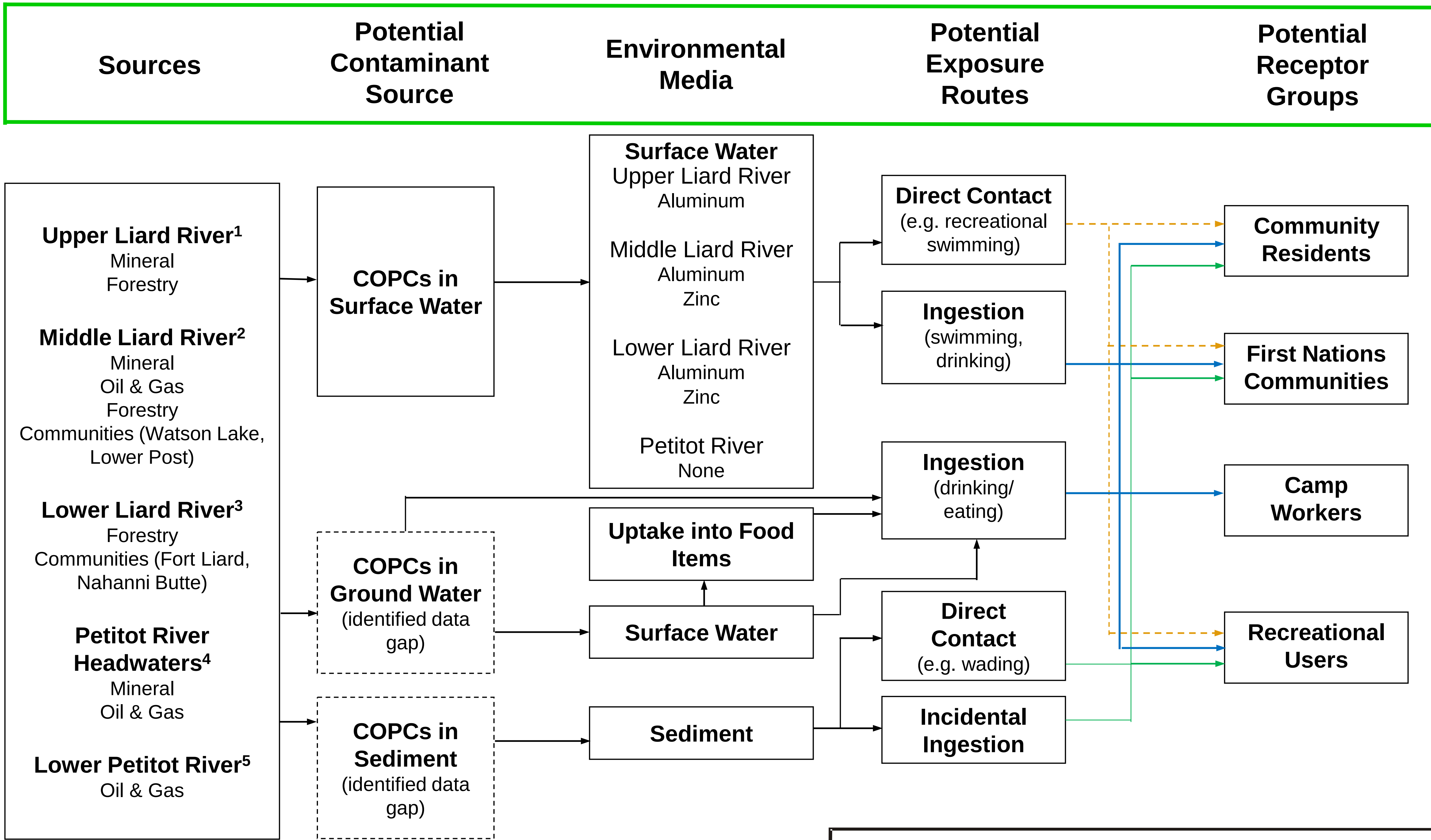
PROJECT No. 1547195 | FILE No. ----

| | | |
|---|---|---|
| DESIGN | SK | 24MAY16 |
| CADD | -- | |
| CHECK | EI | 27MAY16 |
| REVIEW | CAT | 02JUN16 |

SCALE NTS | REV.

**FIGURE D-2**

Filepath – https://capws.golder.com/sites/1547195LiardpetitotLearningPlans/4_Deliverable_Multiuser/Forms/AllItems.aspx




**Conceptual Model for Human Receptors**
Liard and Petitot Rivers Surface and Groundwater Learning Plan
**ENR-GNWT**

| | | | | |
|---|---|---|---|---|
| PROJECT No. 1547195 | | | FILE No. ---- | |
| DESIGN | SK | 24MAY16 | SCALE NTS | REV. |
| CADD | -- | | **FIGURE D-3** | |
| CHECK | EI | 27MAY16 | | |
| REVIEW | CAT | 02JUN16 | | |

Legend
→ Potential Pathway
- - - → Data Gap

Note: Colours are used to differentiate the potential exposure pathways only
1. Upper Liard River is upstream of Watson Lake
2. Middle Liard River is between Watson Lake and Ford Liard
3. Lower Liard River is between Fort Liard and Fort Simpson
4. Petitot River Headwaters in Alberta
5. Lower Petitot River in British Columbia

# APPENDIX E

## Hydrographs

*Figure E-1: Mean, Maximum and Minimum Daily Discharges at Station 10AA001, Laird River at Upper Crossing, 1960 to 2014*

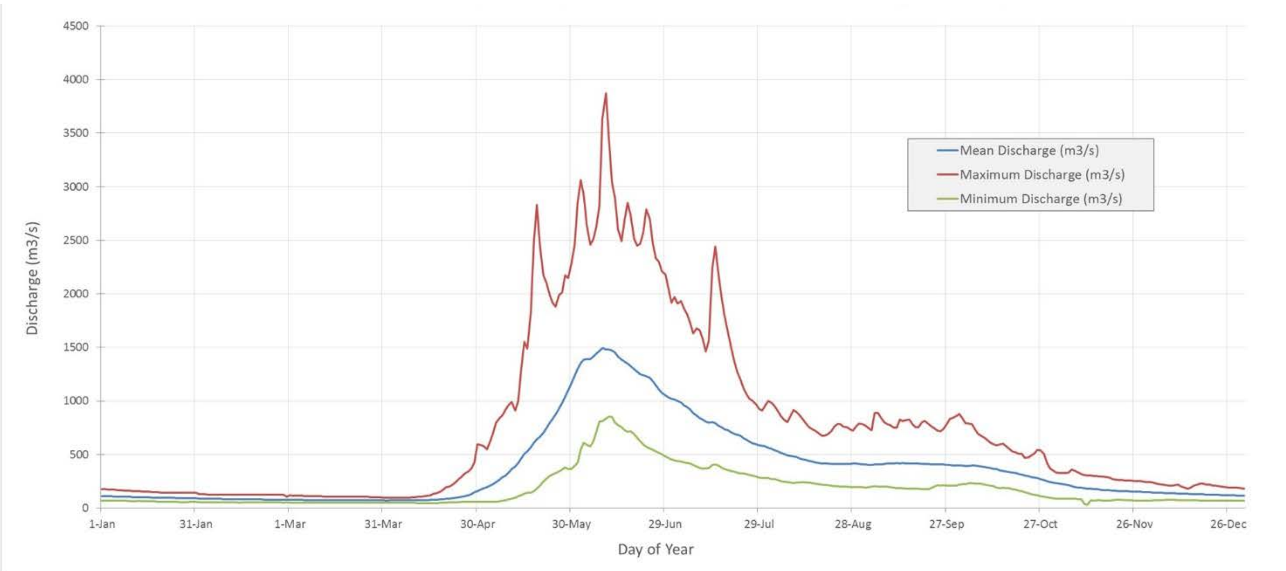



*Figure E-2: Mean, Maximum and Minimum Daily Discharges at Station 10BE001, Laird River at Lower Crossing, 1944 to 2014*

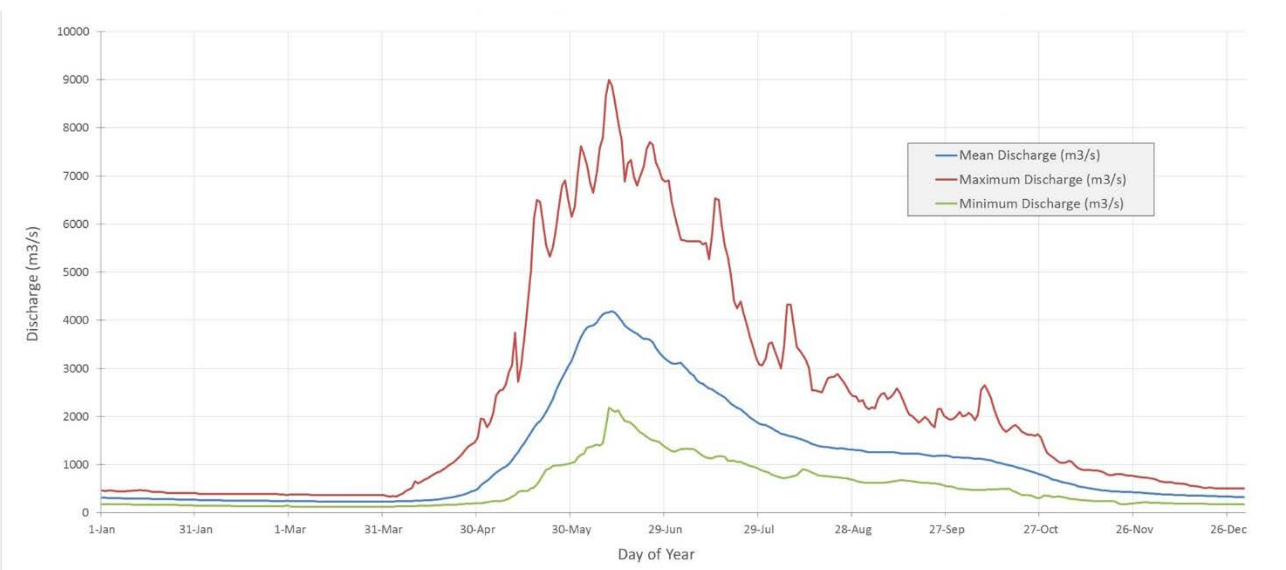


*Figure E-3: Mean, Maximum and Minimum Daily Discharges at Station 10BE005, Laird River above Beaver River, 1968 to 1995*

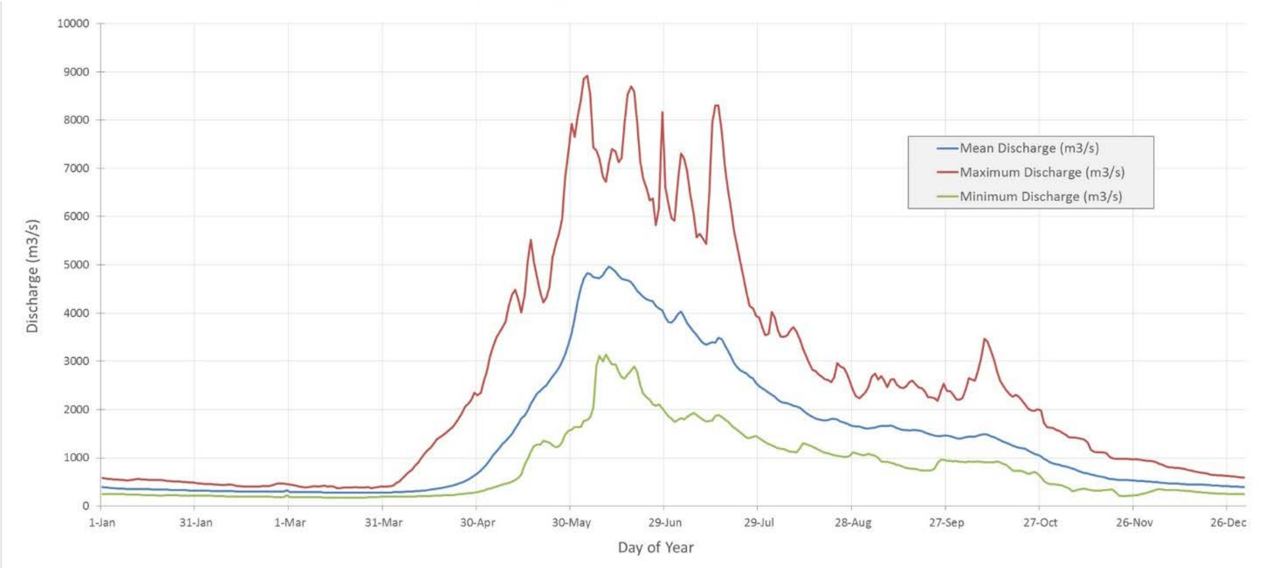



*Figure E-4: Mean, Maximum and Minimum Daily Discharges at Station 10BE006, Laird River above Kechika River, 1969 to 1995*

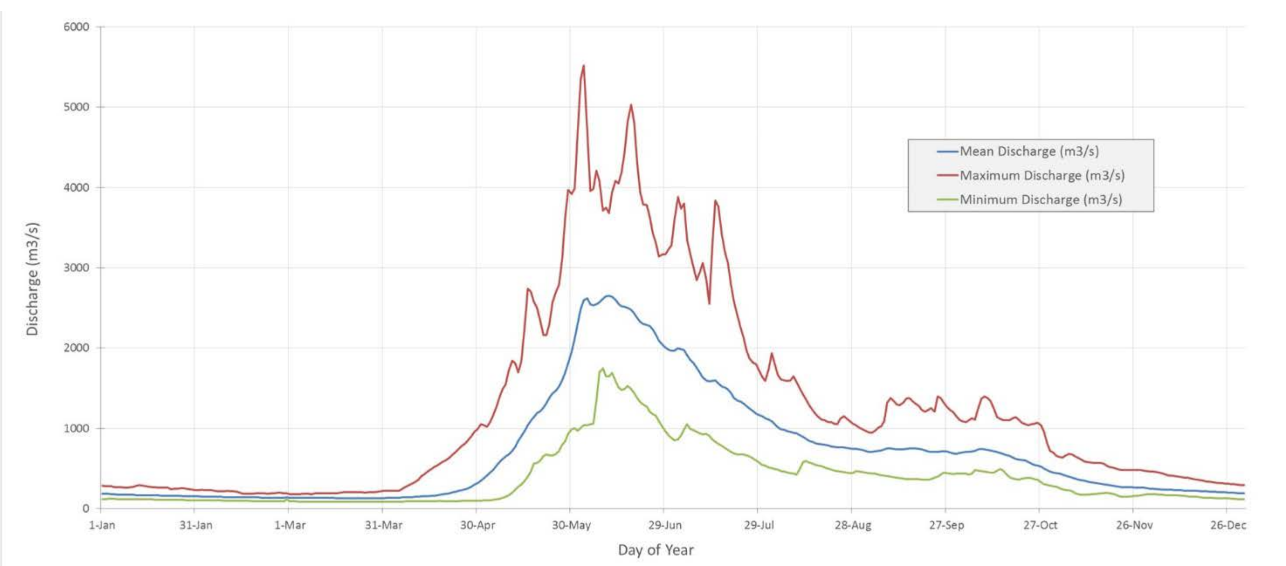


*Figure E-5: Mean, Maximum and Minimum Daily Discharges at Station 10ED001, Laird River at Fort Laird, 1942 to 2014*

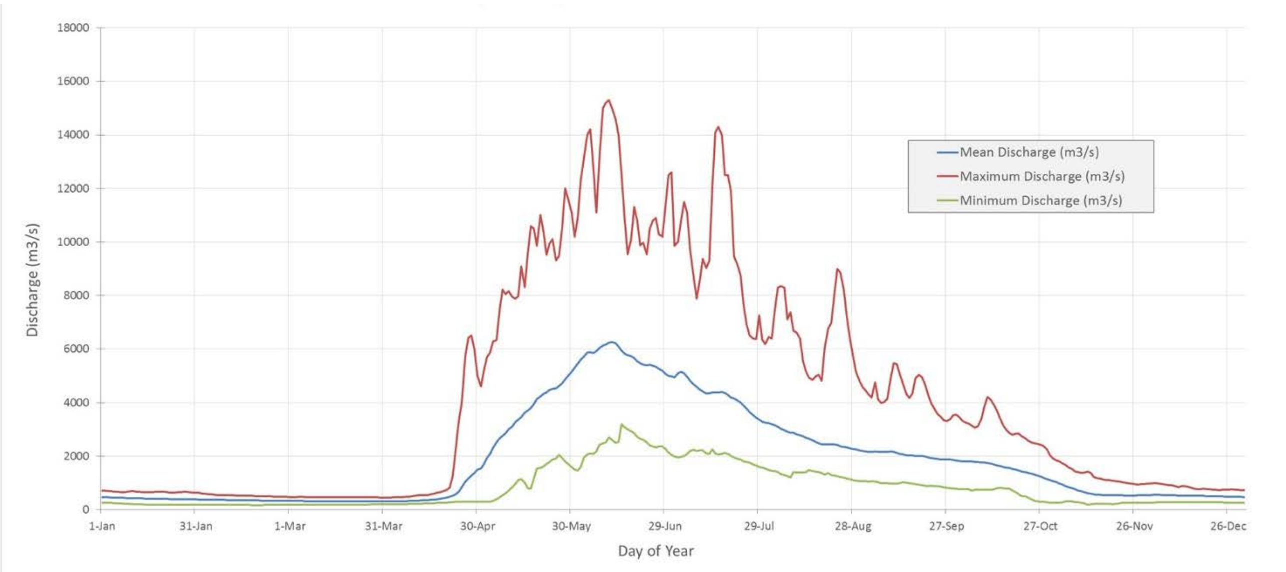



*Figure E-6: Mean, Maximum and Minimum Daily Discharges at Station 10ED002, Laird River near Mouth, 1972 to 2014*

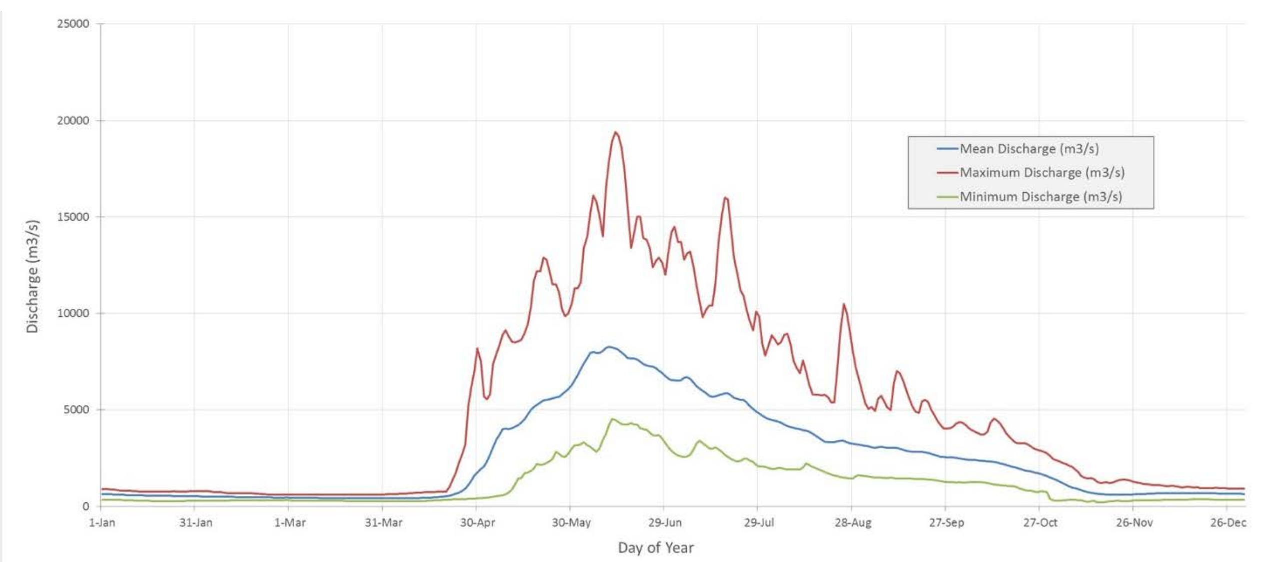


*Figure E-7: Mean, Maximum and Minimum Daily Discharges at Station 10ED008, Laird River at Lindberg Landing, 1991 to 1996*

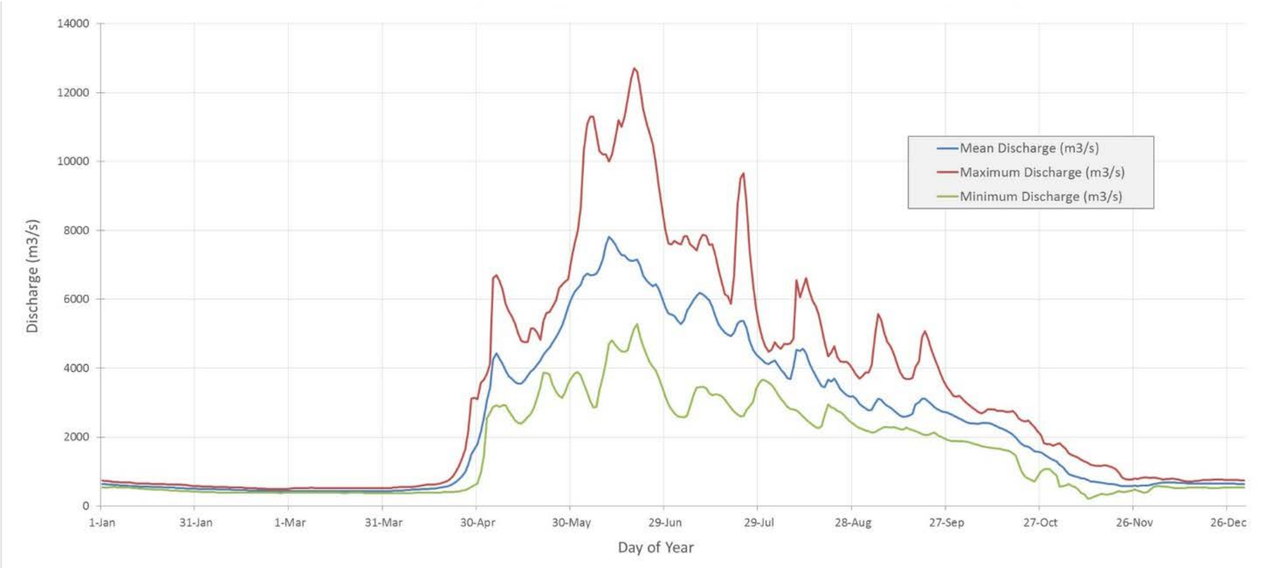
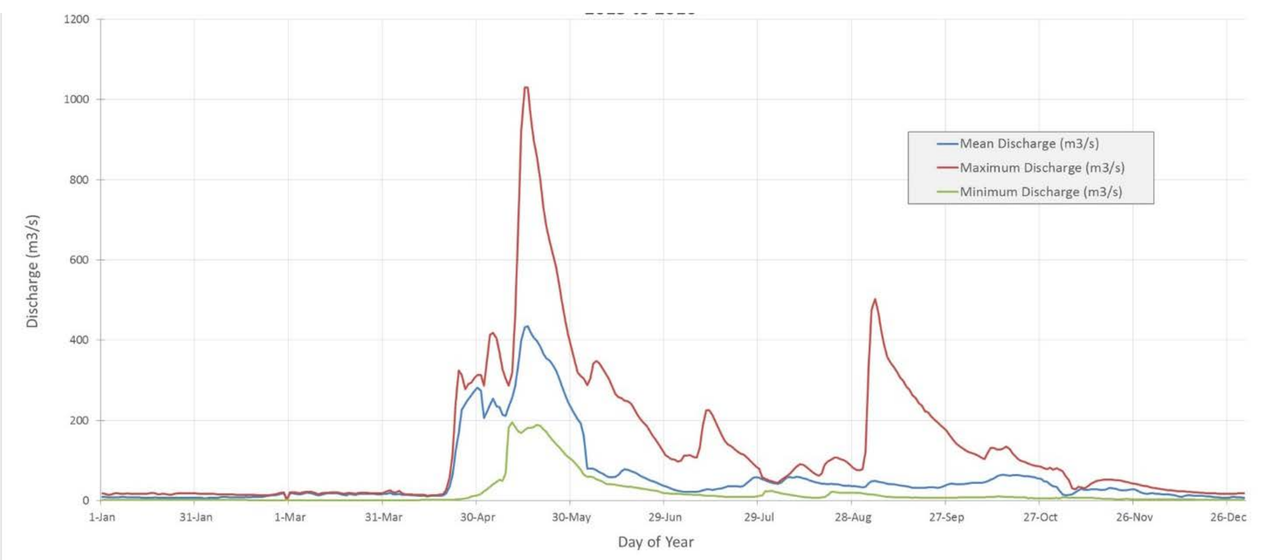



*Figure E-8: Mean, Maximum and Minimum Daily Discharges at Station 10DA001, Petitot River below Highway 7, 1995, 1996 and 2013 to 2016*



# APPENDIX F

## Suspended Sediment Quality Data Summary

**Table F1: Summary of AXYS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2013 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics 2013 - 2015 | | | | % Above Guideline | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCME ISQG | CCME PEL | BC MOE SQG[a] | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG[a] |
| **Parent PAHs** | | | | | | | | | | | |
| Naphthalene | µg/g | 0.035 | 0.39 | 0.02 | 0.021[B] | 0.035[I, B] | 0.11[I, B] | 8 | 50 | 0 | 100 |
| Acenaphthylene | µg/g | 0.0059 | 0.13 | - | <0.00005 | 0.00011 | 0.0013 | 8 | 0 | 0 | - |
| Biphenyl | µg/g | - | - | - | 0.0089 | 0.01 | 0.033 | 8 | - | - | - |
| Acenaphthene | µg/g | 0.0067 | 0.089 | 0.24 | <0.00011 | 0.0015 | 0.0039 | 8 | 0 | 0 | 0 |
| Fluorene | µg/g | 0.021 | 0.14 | 0.3 | 0.0051 | 0.0086 | 0.023[I] | 8 | 13 | 0 | 0 |
| Phenanthrene | µg/g | 0.042 | 0.52 | 0.06 | 0.034 | 0.053[I, B] | 0.15[I, B] | 8 | 75 | 0 | 88 |
| Anthracene | µg/g | 0.047 | 0.25 | 0.9 | <0.00032 | 0.0009 | 0.055[I] | 8 | 13 | 0 | 0 |
| Dibenzothiophene | µg/g | - | - | - | <0.000026 | <0.0003 | 0.0098 | 8 | - | - | - |
| Pyrene | µg/g | 0.053 | 0.88 | - | 0.011 | 0.019 | 0.04 | 8 | 0 | 0 | - |
| Fluoranthene | µg/g | 0.11 | 2.4 | 3 | 0.006 | 0.0096 | 0.021 | 8 | 0 | 0 | 0 |
| Benzo(a)anthracene | µg/g | 0.032 | 0.39 | 0.3 | 0.0027 | 0.0048 | 0.011 | 8 | 0 | 0 | 0 |
| Benzo(b)fluoranthene | µg/g | - | - | - | 0.0086 | 0.015 | 0.034 | 8 | - | - | - |
| Benzo(j,k)fluoranthenes | µg/g | - | - | - | <0.00021 | 0.0033 | 0.022 | 8 | - | - | - |
| Chrysene | µg/g | 0.057 | 0.86 | - | 0.018 | 0.027 | 0.069[I] | 8 | 13 | 0 | - |
| 1-Methyl-7-isopropyl-phenanthrene (Retene) | µg/g | - | - | - | 0.035 | 0.062 | 0.32 | 8 | - | - | - |
| Benzo(a)pyrene | µg/g | 0.032 | 0.0942 | 0.09 | 0.0032 | 0.0072 | 0.015 | 8 | 0 | 0 | 0 |
| Benzo(e)pyrene | µg/g | - | - | - | 0.019 | 0.029 | 0.076 | 8 | - | - | - |
| Perylene | µg/g | - | - | - | 0.059 | 0.11 | 0.25 | 8 | - | - | - |
| Benzo(g,h,i)perylene | µg/g | - | - | - | 0.018 | 0.03 | 0.076 | 8 | - | - | - |
| Indeno(c,d-123)pyrene | µg/g | - | - | - | <0.000088 | 0.0055 | 0.013 | 8 | - | - | - |
| Dibenzo(a,h)anthracene | µg/g | 0.0062 | 0.14 | - | <0.00008 | 0.0032 | 0.0075[I] | 8 | 13 | 0 | - |
| **Alkylated PAHs** | | | | | | | | | | | |
| 2-Methylanthracene | µg/g | - | - | - | <0.000036 | 0.00087 | 0.0021 | 8 | - | - | - |
| 1-Methylnaphthalene | µg/g | - | - | - | 0.036 | 0.055 | 0.16 | 8 | - | - | - |
| 2-Methylnaphthalene | µg/g | 0.02 | 0.2 | - | 0.042[I] | 0.068[I] | 0.21[I, P] | 8 | 100 | 13 | - |
| 1,2-Dimethylnaphthalene | µg/g | - | - | - | 0.0084 | 0.013 | 0.035 | 8 | - | - | - |
| 2,6-Dimethylnaphthalene | µg/g | - | - | - | 0.026 | 0.038 | 0.11 | 8 | - | - | - |
| 2,3,5-Trimethylnaphthalene | µg/g | - | - | - | 0.024 | 0.034 | 0.097 | 8 | - | - | - |

**Table F1: Summary of AXYS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2013 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics 2013 - 2015 | | | | % Above Guideline | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCME ISQG | CCME PEL | BC MOE SQG[a] | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG[a] |
| 2,3,6-Trimethylnaphthalene | µg/g | - | - | - | 0.025 | 0.038 | 0.096 | 8 | - | - | - |
| 1,4,6,7-Tetramethylnaphthalene | µg/g | - | - | - | <0.000066 | <0.00056 | 0.011 | 8 | - | - | - |
| 1-Methylphenanthrene | µg/g | - | - | - | 0.017 | 0.026 | 0.096 | 8 | - | - | - |
| 2-Methylphenanthrene | µg/g | - | - | - | 0.019 | 0.032 | 0.091 | 8 | - | - | - |
| 3-Methylphenanthrene | µg/g | - | - | - | 0.015 | 0.026 | 0.078 | 8 | - | - | - |
| 9/4-Methylphenanthrene | µg/g | - | - | - | 0.022 | 0.037 | 0.11 | 8 | - | - | - |
| 1,7-Dimethylphenanthrene | µg/g | - | - | - | 0.0099 | 0.015 | 0.044 | 8 | - | - | - |
| 1,8-Dimethylphenanthrene | µg/g | - | - | - | 0.003 | 0.0041 | 0.0097 | 8 | - | - | - |
| 2,6-Dimethylphenanthrene | µg/g | - | - | - | 0.0051 | 0.0077 | 0.012 | 8 | - | - | - |
| 3,6-Dimethylphenanthrene | µg/g | - | - | - | <0.000056 | <0.00024 | <0.00065 | 8 | - | - | - |
| 1,2,6-Trimethylphenanthrene | µg/g | - | - | - | 0.0024 | 0.0038 | 0.0079 | 8 | - | - | - |
| 2-Methylfluorene | µg/g | - | - | - | 0.0027 | 0.006 | 0.012 | 8 | - | - | - |
| 1,7-Dimethylfluorene | µg/g | - | - | - | <0.000067 | 0.0027 | 0.023 | 8 | - | - | - |
| 2/3-methyldibenzothiophenes | µg/g | - | - | - | 0.0049 | 0.0073 | 0.02 | 8 | - | - | - |
| 2,4-Dimethyldibenzothiophene | µg/g | - | - | - | <0.000044 | <0.00053 | 0.005 | 8 | - | - | - |
| 1-Methylchrysene | µg/g | - | - | - | 0.0046 | 0.0065 | 0.017 | 8 | - | - | - |
| 5/6-Methylchrysenes | µg/g | - | - | - | 0.0028 | 0.0041 | 0.0098 | 8 | - | - | - |
| 5,9-Dimethylchrysene | µg/g | - | - | - | 0.0042 | 0.007 | 0.019 | 8 | - | - | - |
| 7-Methylbenzo(a)pyrene | µg/g | - | - | - | 0.002 | 0.0035 | 0.011 | 8 | - | - | - |
| 3-methylfluoranthene / benzo(a)fluorene | µg/g | - | - | - | 0.025 | 0.042 | 0.11 | 8 | - | - | - |
| C1 substituted acenaphthenes | µg/g | - | - | - | 0.00046 | 0.00093 | 0.017 | 8 | - | - | - |
| C1 substituted phenanthrenes/anthracenes | µg/g | - | - | - | 0.074 | 0.12 | 0.38 | 8 | - | - | - |
| C2 substituted phenanthrenes/anthracenes | µg/g | - | - | - | 0.067 | 0.1 | 0.28 | 8 | - | - | - |
| C3 substituted phenanthrenes/anthracenes | µg/g | - | - | - | 0.043 | 0.07 | 0.15 | 8 | - | - | - |
| C4 substituted phenanthrenes/anthracenes | µg/g | - | - | - | 0.11 | 0.19 | 0.49 | 8 | - | - | - |
| C1 substituted benzo(a)anthracenes/chrysenes | µg/g | - | - | - | 0.029 | 0.045 | 0.13 | 8 | - | - | - |
| C2 substituted benzo(a)anthracenes/chrysenes | µg/g | - | - | - | 0.021 | 0.041 | 0.1 | 8 | - | - | - |
| C3 substituted benzo(a)anthracenes/chrysenes | µg/g | - | - | - | 0.0034 | 0.0072 | 0.03 | 8 | - | - | - |
| C4 substituted benzo(a)anthracenes/chrysenes | µg/g | - | - | - | 0.00083 | 0.0026 | 0.016 | 8 | - | - | - |

**Table F1: Summary of AXYS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2013 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2013 - 2015 | | | | | | |
| | | | | | | | | | % Above Guideline | | |
| | | CCME ISQG | CCME PEL | BC MOE SQG(a) | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG(a) |
| C1 substituted benzofluoranthenes/benzopyrenes | µg/g | - | - | - | 0.046 | 0.068 | 0.19 | 8 | - | - | - |
| C2 substituted benzofluoranthenes/benzopyrenes | µg/g | - | - | - | 0.012 | 0.022 | 0.075 | 8 | - | - | - |
| C1 substituted biphenyls | µg/g | - | - | - | 0.015 | 0.02 | 0.056 | 8 | - | - | - |
| C2 substituted biphenyls | µg/g | - | - | - | 0.013 | 0.021 | 0.048 | 8 | - | - | - |
| C1 substituted fluoranthenes/pyrenes | µg/g | - | - | - | 0.07 | 0.12 | 0.29 | 8 | - | - | - |
| C2 substituted fluoranthenes/pyrenes | µg/g | - | - | - | 0.073 | 0.13 | 0.34 | 8 | - | - | - |
| C3 substituted fluoranthenes/pyrenes | µg/g | - | - | - | 0.021 | 0.053 | 0.18 | 8 | - | - | - |
| C4 substituted fluoranthenes/pyrenes | µg/g | - | - | - | 0.0086 | 0.023 | 0.04 | 8 | - | - | - |
| C1 substituted fluorenes | µg/g | - | - | - | 0.016 | 0.035 | 0.078 | 8 | - | - | - |
| C2 substituted fluorenes | µg/g | - | - | - | 0.029 | 0.045 | 0.12 | 8 | - | - | - |
| C3 substituted fluorenes | µg/g | - | - | - | 0.03 | 0.05 | 0.12 | 8 | - | - | - |
| C1 substituted naphthalenes | µg/g | - | - | - | 0.078 | 0.12 | 0.37 | 8 | - | - | - |
| C2 substituted naphthalenes | µg/g | - | - | - | 0.13 | 0.2 | 0.56 | 8 | - | - | - |
| C3 substituted naphthalenes | µg/g | - | - | - | 0.12 | 0.17 | 0.47 | 8 | - | - | - |
| C4 substituted naphthalenes | µg/g | - | - | - | 0.068 | 0.091 | 0.24 | 8 | - | - | - |
| C1 substituted dibenzothiophenes | µg/g | - | - | - | 0.017 | 0.024 | 0.061 | 8 | - | - | - |
| C2 substituted dibenzothiophenes | µg/g | - | - | - | 0.026 | 0.038 | 0.11 | 8 | - | - | - |
| C3 substituted dibenzothiophenes | µg/g | - | - | - | 0.018 | 0.028 | 0.077 | 8 | - | - | - |
| C4 substituted dibenzothiophenes | µg/g | - | - | - | 0.0091 | 0.012 | 0.042 | 8 | - | - | - |
| **Naphthenic Acids** | | | | | | | | | | | |
| $C_{12}H_{18}O_2$ | µg/g | - | - | - | 0.0021 | 0.0064 | 0.0092 | 6 | - | - | - |
| $C_{12}H_{20}O_2$ | µg/g | - | - | - | 0.014 | 0.031 | 0.043 | 6 | - | - | - |
| $C_{12}H_{22}O_2$ | µg/g | - | - | - | 0.0081 | 0.018 | 0.035 | 6 | - | - | - |
| $C_{12}H_{24}O_2$ | µg/g | - | - | - | 0.0079 | 0.016 | 0.036 | 6 | - | - | - |
| $C_{13}H_{20}O_2$ | µg/g | - | - | - | 0.005 | 0.0091 | 0.014 | 6 | - | - | - |
| $C_{13}H_{22}O_2$ | µg/g | - | - | - | 0.019 | 0.031 | 0.06 | 6 | - | - | - |
| $C_{13}H_{24}O_2$ | µg/g | - | - | - | 0.012 | 0.021 | 0.036 | 6 | - | - | - |
| $C_{13}H_{26}O_2$ | µg/g | - | - | - | <0.00065 | <0.0007 | <0.0052 | 6 | - | - | - |
| $C_{14}H_{20}O_2$ | µg/g | - | - | - | 0.012 | 0.021 | 0.028 | 6 | - | - | - |

**Table F1: Summary of AXYS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2013 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics 2013 - 2015 | | | | % Above Guideline | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCME ISQG | CCME PEL | BC MOE SQG[(a)] | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG[(a)] |
| $C_{14}H_{22}O_2$ | µg/g | - | - | - | 0.0077 | 0.017 | 0.087 | 6 | - | - | - |
| $C_{14}H_{24}O_2$ | µg/g | - | - | - | 0.021 | 0.029 | 0.077 | 6 | - | - | - |
| $C_{14}H_{26}O_2$ | µg/g | - | - | - | 0.011 | 0.021 | 0.034 | 6 | - | - | - |
| $C_{14}H_{28}O_2$ | µg/g | - | - | - | <0.00065 | <0.00074 | <0.0011 | 6 | - | - | - |
| $C_{15}H_{18}O_2$ | µg/g | - | - | - | 0.0082 | 0.012 | 0.018 | 6 | - | - | - |
| $C_{15}H_{20}O_2$ | µg/g | - | - | - | 0.011 | 0.017 | 0.028 | 6 | - | - | - |
| $C_{15}H_{22}O_2$ | µg/g | - | - | - | 0.016 | 0.024 | 0.033 | 6 | - | - | - |
| $C_{15}H_{24}O_2$ | µg/g | - | - | - | 0.023 | 0.034 | 0.049 | 6 | - | - | - |
| $C_{15}H_{26}O_2$ | µg/g | - | - | - | 0.03 | 0.053 | 0.099 | 6 | - | - | - |
| $C_{15}H_{28}O_2$ | µg/g | - | - | - | <0.0007 | 0.016 | 0.034 | 6 | - | - | - |
| $C_{15}H_{30}O_2$ | µg/g | - | - | - | <0.0007 | <0.00074 | <0.045 | 6 | - | - | - |
| $C_{16}H_{20}O_2$ | µg/g | - | - | - | 0.02 | 0.03 | 0.05 | 6 | - | - | - |
| $C_{16}H_{22}O_2$ | µg/g | - | - | - | 0.013 | 0.018 | 0.033 | 6 | - | - | - |
| $C_{16}H_{24}O_2$ | µg/g | - | - | - | <0.0007 | 0.0046 | 0.02 | 6 | - | - | - |
| $C_{16}H_{26}O_2$ | µg/g | - | - | - | 0.014 | 0.026 | 0.044 | 6 | - | - | - |
| $C_{16}H_{28}O_2$ | µg/g | - | - | - | 0.023 | 0.046 | 0.077 | 6 | - | - | - |
| $C_{16}H_{30}O_2$ | µg/g | - | - | - | <0.00065 | <0.00074 | <0.00084 | 6 | - | - | - |
| $C_{16}H_{32}O_2$ | µg/g | - | - | - | <0.0007 | <0.001 | <0.003 | 6 | - | - | - |
| $C_{17}H_{22}O_2$ | µg/g | - | - | - | 0.014 | 0.021 | 0.037 | 6 | - | - | - |
| $C_{17}H_{24}O_2$ | µg/g | - | - | - | 0.013 | 0.018 | 0.032 | 6 | - | - | - |
| $C_{17}H_{26}O_2$ | µg/g | - | - | - | 0.016 | 0.028 | 0.034 | 6 | - | - | - |
| $C_{17}H_{28}O_2$ | µg/g | - | - | - | 0.013 | 0.019 | 0.04 | 6 | - | - | - |
| $C_{17}H_{30}O_2$ | µg/g | - | - | - | 0.014 | 0.022 | 0.039 | 6 | - | - | - |
| $C_{17}H_{32}O_2$ | µg/g | - | - | - | <0.00065 | <0.00074 | <0.0017 | 6 | - | - | - |
| $C_{17}H_{34}O_2$ | µg/g | - | - | - | <0.00084 | <0.0048 | <0.016 | 6 | - | - | - |
| $C_{18}H_{24}O_2$ | µg/g | - | - | - | 0.0084 | 0.017 | 0.037 | 6 | - | - | - |
| $C_{18}H_{26}O_2$ | µg/g | - | - | - | 0.0098 | 0.018 | 0.035 | 6 | - | - | - |
| $C_{18}H_{28}O_2$ | µg/g | - | - | - | <0.0007 | 0.0032 | 0.0094 | 6 | - | - | - |
| $C_{18}H_{30}O_2$ | µg/g | - | - | - | 0.016 | 0.041 | 0.094 | 6 | - | - | - |

**Table F1: Summary of AXYS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2013 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2013 - 2015 | | | | | | |
| | | | | | | | | | % Above Guideline | | |
| | | CCME ISQG | CCME PEL | BC MOE SQG[(a)] | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG[(a)] |
| $C_{18}H_{32}O_2$ | µg/g | - | - | - | 0.016 | 0.045 | 0.16 | 6 | - | - | - |
| $C_{18}H_{34}O_2$ | µg/g | - | - | - | <0.00065 | <0.00074 | <0.0013 | 6 | - | - | - |
| $C_{18}H_{36}O_2$ | µg/g | - | - | - | <0.0007 | <0.00077 | <0.0015 | 6 | - | - | - |
| $C_{19}H_{26}O_2$ | µg/g | - | - | - | 0.024 | 0.035 | 0.055 | 6 | - | - | - |
| $C_{19}H_{28}O_2$ | µg/g | - | - | - | 0.015 | 0.027 | 0.037 | 6 | - | - | - |
| $C_{19}H_{30}O_2$ | µg/g | - | - | - | 0.017 | 0.03 | 0.065 | 6 | - | - | - |
| $C_{19}H_{32}O_2$ | µg/g | - | - | - | 0.018 | 0.031 | 0.053 | 6 | - | - | - |
| $C_{19}H_{34}O_2$ | µg/g | - | - | - | 0.014 | 0.022 | 0.031 | 6 | - | - | - |
| $C_{19}H_{36}O_2$ | µg/g | - | - | - | <0.00065 | <0.00074 | 0.038 | 6 | - | - | - |
| $C_{19}H_{38}O_2$ | µg/g | - | - | - | 0.066 | 0.084 | 0.11 | 6 | - | - | - |
| $C_{20}H_{28}O_2$ | µg/g | - | - | - | <0.0048 | 0.0069 | 0.015 | 6 | - | - | - |
| $C_{20}H_{30}O_2$ | µg/g | - | - | - | 0.25 | 0.36 | 0.83 | 6 | - | - | - |
| $C_{20}H_{32}O_2$ | µg/g | - | - | - | 0.068 | 0.12 | 0.19 | 6 | - | - | - |
| $C_{20}H_{34}O_2$ | µg/g | - | - | - | 0.082 | 0.12 | 0.39 | 6 | - | - | - |
| $C_{20}H_{36}O_2$ | µg/g | - | - | - | 0.01 | 0.023 | 0.073 | 6 | - | - | - |
| $C_{20}H_{38}O_2$ | µg/g | - | - | - | 0.023 | 0.031 | 0.039 | 6 | - | - | - |
| $C_{21}H_{30}O_2$ | µg/g | - | - | - | 0.02 | 0.024 | 0.027 | 6 | - | - | - |
| $C_{21}H_{32}O_2$ | µg/g | - | - | - | 0.014 | 0.033 | 0.044 | 6 | - | - | - |
| $C_{21}H_{34}O_2$ | µg/g | - | - | - | 0.014 | 0.025 | 0.026 | 5 | - | - | - |
| $C_{21}H_{36}O_2$ | µg/g | - | - | - | 0.012 | 0.02 | 0.025 | 6 | - | - | - |
| $C_{21}H_{38}O_2$ | µg/g | - | - | - | 0.0062 | 0.032 | 0.043 | 6 | - | - | - |
| $C_{21}H_{40}O_2$ | µg/g | - | - | - | <0.0007 | 0.0051 | 0.052 | 6 | - | - | - |
| **PCBs** | | | | | | | | | | | |
| Aroclor 1254 | µg/g | 0.06 | 0.34 | - | 0.0000026 | 0.0000027 | 0.0000078 | 3 | 0 | 0 | - |
| Total PCBs | µg/g | 0.034 | 0.28 | 0.03 | 0.000025 | 0.000033 | 0.000068 | 3 | 0 | 0 | 0 |
| **Pesticides/Herbicides** | | | | | | | | | | | |
| 2,4,5-T | µg/g | - | - | - | <0.000013 | <0.000018 | <0.000022 | 6 | - | - | - |
| 2,4,5-TP (SILVEX) | µg/g | - | - | - | <0.000017 | <0.000056 | <0.00021 | 6 | - | - | - |
| 2,4-D | µg/g | - | - | - | <0.00013 | <0.00019 | <0.00029 | 6 | - | - | - |

**Table F1: Summary of AXYS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2013 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics 2013 - 2015 | | | | % Above Guideline | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCME ISQG | CCME PEL | BC MOE SQG[(a)] | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG[(a)] |
| 2,4-DB | µg/g | - | - | - | <0.00012 | <0.00026 | <0.00056 | 6 | - | - | - |
| 2,4'-DDD | µg/g | 0.00354 | 0.00851 | - | <0.0000037 | <0.0000052 | <0.00003 | 6 | 0 | 0 | - |
| 4,4'-DDD | µg/g | 0.00354 | 0.00851 | - | <0.0000042 | 0.000012 | 0.000016 | 6 | 0 | 0 | - |
| 2,4'-DDE | µg/g | 0.00142 | 0.00675 | - | <0.0000037 | <0.0000048 | <0.00011 | 6 | 0 | 0 | - |
| 4,4'-DDE | µg/g | 0.00142 | 0.00675 | - | 0.000008 | 0.000031 | <0.00015 | 6 | 0 | 0 | - |
| 4,4'-DDT | µg/g | 0.00119 | 0.00477 | - | <0.0000069 | 0.000031 | 0.000071 | 6 | 0 | 0 | - |
| 2,4'-DDT | µg/g | 0.00119 | 0.00477 | - | <0.0000042 | <0.00001 | <0.000078 | 6 | 0 | 0 | - |
| Aldrin | µg/g | - | - | - | <0.000001 | <0.000004 | <0.000007 | 6 | - | - | - |
| alpha-Endosulphan | µg/g | - | - | - | <0.0000094 | <0.000023 | <0.000099 | 6 | - | - | - |
| beta-Endosulphan | µg/g | - | - | - | <0.0000094 | 0.000035 | <0.0002 | 6 | - | - | - |
| *cis*-Chlordane | µg/g | 0.0045 | 0.00887 | - | <0.0000037 | <0.0000042 | <0.000055 | 6 | 0 | 0 | - |
| *trans*-Chlordane | µg/g | 0.0045 | 0.00887 | - | <0.0000037 | <0.0000042 | <0.000059 | 6 | 0 | 0 | - |
| oxychlordane | µg/g | 0.0045 | 0.00887 | - | <0.0000037 | <0.0000042 | <0.000075 | 6 | 0 | 0 | - |
| Dicamba | µg/g | - | - | - | <0.000011 | 0.000017 | 0.00007 | 6 | - | - | - |
| Dichlorprop | µg/g | - | - | - | <0.000022 | <0.000091 | <0.00014 | 6 | - | - | - |
| Dieldrin | µg/g | 0.0029 | 0.0067 | - | <0.0000092 | <0.000011 | <0.000032 | 6 | 0 | 0 | - |
| Endosulphan sulphate | µg/g | - | - | - | <0.0000094 | <0.000031 | <0.00016 | 6 | - | - | - |
| Endrin | µg/g | 0.0027 | 0.062 | - | <0.0000092 | <0.000013 | <0.000036 | 6 | 0 | 0 | - |
| Endrin aldehyde | µg/g | - | - | - | <0.0000092 | <0.00001 | <0.000028 | 4 | - | - | - |
| Endrin ketone | µg/g | - | - | - | <0.0000094 | <0.000011 | <0.00016 | 6 | - | - | - |
| alpha-HCH | µg/g | - | - | - | <0.0000042 | 0.000013 | 0.000021 | 6 | - | - | - |
| beta-HCH | µg/g | - | - | - | <0.0000037 | <0.0000042 | <0.000038 | 6 | - | - | - |
| delta-HCH | µg/g | - | - | - | <0.0000092 | <0.000011 | <0.000035 | 6 | - | - | - |
| Heptachlor | µg/g | 0.0006 | 0.0027 | - | <0.000002 | <0.0000038 | <0.0000042 | 6 | 0 | 0 | - |
| Heptachlor epoxide | µg/g | - | - | - | <0.0000092 | <0.000011 | <0.000043 | 6 | - | - | - |
| Hexachlorobenzene | µg/g | - | - | - | 0.000033 | 0.000049 | 0.000072 | 6 | - | - | - |
| Lindane | µg/g | 0.00094 | 0.0014 | - | <0.0000037 | 0.0000051 | <0.000032 | 6 | 0 | 0 | - |
| MCPA | µg/g | - | - | - | <0.000021 | 0.00012 | 0.00023 | 6 | - | - | - |
| MCPP (Mecoprop) | µg/g | - | - | - | <0.000021 | 0.000035 | <0.000089 | 6 | - | - | - |

**Table F1: Summary of AXYS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2013 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics 2013 - 2015 | | | | % Above Guideline | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCME ISQG | CCME PEL | BC MOE SQG[a] | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG[a] |
| Methoxychlor | µg/g | - | - | - | <0.00002 | <0.000071 | <0.00024 | 6 | - | - | - |
| Mirex | µg/g | - | - | - | <0.0000037 | <0.0000042 | <0.000012 | 6 | - | - | - |
| *cis*-Nonachlor | µg/g | - | - | - | <0.0000037 | <0.0000042 | <0.000045 | 6 | - | - | - |
| *trans*-Nonachlor | µg/g | - | - | - | <0.0000037 | <0.0000042 | <0.000054 | 6 | - | - | - |
| Octachlorostyrene | µg/g | - | - | - | <0.0000001 | <0.0000038 | <0.000019 | 5 | - | - | - |
| Technical Toxaphene | µg/g | 0.0001 | - | - | <0.000063 | <0.00011[DL>I] | 0.00019[I] | 4 | 0 | - | - |
| Triclopyr | µg/g | - | - | - | <0.000013 | <0.000027 | <0.000044 | 6 | - | - | - |

[a] Guidelines are based on median value (1.6%) of total organic carbon content from ALS laboratory results.
Values in shaded cells are higher than sediment quality guidelines:
[I] = value higher than the CCME ISQG.
[P] = value higher than the CCME PEL.
[B] = value higher than the BC MOE SQG.
Sediment quality data shown in this table were rounded to reflect laboratory precision *after* comparisons to guidelines. Therefore, values slightly above guidelines may be displayed as being equal to the guidelines and identified as exceedances. Measured concentrations equal to the guideline values were not identified as exceedances.
BC MOE = British Columbia Ministry of Environment; CCME = Canadian Council of of Ministers of the Environment; ISQG = interim sediment quality guideline; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; PEL= probable effect level; SQG = sediment quality guideline; µg/g = mg/kg; - = no guideline or data.

**Table F2: Summary of ALS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2001 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2001 - 2015 | | | | | | |
| | | | | | | | | | % Above Guideline | | |
| | | CCME ISQG | CCME PEL | BC MOE SQG | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG |
| **Carbon Content** | | | | | | | | | | | |
| Total organic carbon | % | - | - | - | 1.3 | 1.6 | 2.4 | 9 | - | - | - |
| $CaCO_3$ equivalent | % | - | - | - | 8.6 | 10 | 12 | 8 | - | - | - |
| Inorganic carbon | % | - | - | - | 1.0 | 1.3 | 1.3 | 9 | - | - | - |
| Inorganic carbon (as $CaCO_3$ equivalent) | % | - | - | - | 9.2 | - | 9.6 | 2 | - | - | - |
| Total carbon by combustion | % | - | - | - | 2.5 | 2.7 | 3.7 | 9 | - | - | - |
| **Particle Size And Moisture Content** | | | | | | | | | | | |
| Clay | % | - | - | - | 22 | 27 | 43 | 5 | - | - | - |
| Sand | % | - | - | - | 10 | 26 | 34 | 5 | - | - | - |
| Silt | % | - | - | - | 43 | 47 | 53 | 5 | - | - | - |
| **Total Metals** | | | | | | | | | | | |
| Aluminum | µg/g | - | - | - | 10,500 | 11,400 | 15,500 | 7 | - | - | - |
| Antimony | µg/g | - | - | - | <0.2 | 0.65 | 0.82 | 8 | - | - | - |
| Arsenic | µg/g | 5.9 | 17 | - | 8.3[I] | 9.2[I] | 9.9[I] | 8 | 100 | 0 | - |
| Barium | µg/g | - | - | - | 222 | 328 | 396 | 10 | - | - | - |
| Beryllium | µg/g | - | - | - | 0.56 | 0.71 | <1.0 | 10 | - | - | - |
| Bismuth | µg/g | - | - | - | <0.2 | 0.22 | 0.27 | 6 | - | - | - |
| Boron | µg/g | - | - | - | 6.1 | - | 11 | 2 | - | - | - |
| Boron (hot water extraction) | µg/g | - | - | - | 0.22 | 0.35 | 0.56 | 6 | - | - | - |
| Cadmium | µg/g | 0.6 | 3.5 | - | <0.5 | 0.7[I] | 0.9[I] | 10 | 90 | 0 | - |
| Calcium | µg/g | - | - | - | 28,200 | 33,400 | 38,200 | 8 | - | - | - |
| Chromium | µg/g | 37.3 | 90 | - | 17 | 24 | 30 | 10 | 0 | 0 | - |
| Cobalt | µg/g | - | - | - | 7.0 | 9.3 | 12 | 10 | - | - | - |
| Copper | µg/g | 36 | 197 | - | 19 | 22 | 25 | 10 | 0 | 0 | - |
| Iron | µg/g | - | - | - | 16,500 | 23,900 | 24,900 | 8 | - | - | - |
| Lead | µg/g | 35.7 | 91 | - | 8.0 | 12 | 14 | 10 | 0 | 0 | - |
| Lithium | µg/g | - | - | - | 17 | 17 | 19 | 6 | - | - | - |
| Magnesium | µg/g | - | - | - | 8,640 | 9,900 | 11,400 | 8 | - | - | - |
| Manganese | µg/g | - | - | - | 300 | 422 | 537 | 8 | - | - | - |

**Table F2: Summary of ALS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2001 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2001 - 2015 | | | | | | |
| | | | | | | | | | % Above Guideline | | |
| | | CCME ISQG | CCME PEL | BC MOE SQG | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG |
| Mercury | µg/g | 0.17 | 0.49 | - | 0.045 | 0.051 | 0.08 | 8 | 0 | 0 | - |
| Molybdenum | µg/g | - | - | - | 1.0 | 2.1 | 3.3 | 10 | - | - | - |
| Nickel | µg/g | - | - | - | 22 | 32 | 37 | 10 | - | - | - |
| Phosphorus | µg/g | - | - | - | 710 | 763 | 837 | 8 | - | - | - |
| Potassium | µg/g | - | - | - | 1,280 | 1,645 | 3,180 | 8 | - | - | - |
| Selenium | µg/g | - | - | - | 0.75 | 0.84 | 1.2 | 8 | - | - | - |
| Silver | µg/g | - | - | - | <0.2 | 0.25 | <1.0 | 10 | - | - | - |
| Sodium | µg/g | - | - | - | 100 | 120 | 193 | 8 | - | - | - |
| Strontium | µg/g | - | - | - | 64 | 87 | 111 | 8 | - | - | - |
| Thallium | µg/g | - | - | - | 0.17 | 0.23 | <1.0 | 10 | - | - | - |
| Tin | µg/g | - | - | - | <2.0 | 2.0 | 5.0 | 10 | - | - | - |
| Titanium | µg/g | - | - | - | 17 | 62 | 157 | 8 | - | - | - |
| Uranium | µg/g | - | - | - | 1.1 | 1.2 | <2.0 | 8 | - | - | - |
| Vanadium | µg/g | - | - | - | 25 | 35 | 45 | 10 | - | - | - |
| Zinc | µg/g | 123 | 315 | - | 95 | 106 | 130[I] | 10 | 10 | 0 | - |
| Zirconium | µg/g | - | - | - | 4.4 | - | 4.4 | 2 | - | - | - |
| **Parent PAHs** | | | | | | | | | | | |
| Naphthalene | µg/g | 0.035 | 0.39 | 0.01 - 0.02 | 0.017[B] | 0.04[I, B] | 0.045[I, B] | 3 | 67 | 0 | 100 |
| Acenaphthylene | µg/g | 0.0059 | 0.13 | - | <0.003 | <0.003 | <0.01[DL>I] | 3 | 0 | 0 | - |
| Acenaphthene | µg/g | 0.0067 | 0.089 | 0.2 - 0.36 | <0.003 | 0.004 | <0.01[DL>I] | 3 | 0 | 0 | 0 |
| Fluorene | µg/g | 0.021 | 0.14 | 0.3 - 0.5 | 0.006 | 0.015 | 0.02 | 3 | 0 | 0 | 0 |
| Phenanthrene | µg/g | 0.042 | 0.52 | 0.05 - 0.1 | 0.033 | 0.07[I, B] | 0.09[I, B] | 3 | 67 | 0 | 67 |
| Anthracene | µg/g | 0.047 | 0.25 | 0.8 - 1.4 | <0.003 | <0.003 | <0.01 | 3 | 0 | 0 | 0 |
| Pyrene | µg/g | 0.053 | 0.88 | - | 0.014 | 0.021 | 0.04 | 3 | 0 | 0 | - |
| Fluoranthene | µg/g | 0.11 | 2.4 | 3 - 5 | 0.007 | 0.012 | 0.02 | 3 | 0 | 0 | 0 |
| Benzo(a)anthracene | µg/g | 0.032 | 0.39 | 0.3 - 0.5 | <0.01 | 0.01 | 0.017 | 3 | 0 | 0 | 0 |
| Chrysene | µg/g | 0.057 | 0.86 | - | <0.01 | 0.01 | 0.015 | 3 | 0 | 0 | - |
| Benzo(a)pyrene | µg/g | 0.032 | 0.78 | 0.08 - 0.14 | <0.003 | 0.005 | <0.01 | 3 | 0 | 0 | 0 |
| Dibenzo(a,h)anthracene | µg/g | 0.0062 | 0.14 | - | <0.003 | <0.003 | <0.01[DL>I] | 3 | 0 | 0 | - |

**Table F2: Summary of ALS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2001 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics 2001 - 2015 | | | | % Above Guideline | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CCME ISQG | CCME PEL | BC MOE SQG | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG |
| **PCBs** | | | | | | | | | | | |
| Aroclor 1016 | µg/g | - | - | - | <0.01 | <0.01 | <0.01 | 4 | - | - | - |
| Aroclor 1221 | µg/g | - | - | - | <0.01 | <0.01 | <0.01 | 4 | - | - | - |
| Aroclor 1232 | µg/g | - | - | - | <0.01 | <0.01 | <0.01 | 4 | - | - | - |
| Aroclor 1242 | µg/g | - | - | - | <0.01 | <0.01 | <0.01 | 4 | - | - | - |
| Aroclor 1248 | µg/g | - | - | - | <0.01 | <0.01 | <0.01 | 4 | - | - | - |
| Aroclor 1254 | µg/g | 0.06 | 0.34 | - | <0.01 | <0.01 | <0.01 | 4 | 0 | 0 | - |
| Aroclor 1260 | µg/g | - | - | - | <0.01 | <0.01 | <0.01 | 4 | - | - | - |
| Aroclor 1262 | µg/g | - | - | - | <0.01 | <0.01 | <0.01 | 4 | - | - | - |
| Aroclor 1268 | µg/g | - | - | - | <0.01 | <0.01 | <0.01 | 4 | - | - | - |
| Total PCBs | µg/g | 0.034 | 0.28 | 0.03 - 0.05 | 0.00015 | - | 0.0013 | 2 | 0 | 0 | 0 |
| **Pesticides/Herbicides** | | | | | | | | | | | |
| 2,4-D | µg/g | - | - | - | <0.005 | <0.005 | <0.005 | 4 | - | - | - |
| 2,4'-DDD | µg/g | 0.00354 | 0.00851 | - | <0.0001 | - | <0.001 | 2 | 0 | 0 | - |
| 4,4'-DDD | µg/g | 0.00354 | 0.00851 | - | <0.0001 | - | <0.001 | 2 | 0 | 0 | - |
| 2,4'-DDE | µg/g | 0.00142 | 0.00675 | - | <0.0001 | - | <0.001 | 2 | 0 | 0 | - |
| 4,4'-DDE | µg/g | 0.00142 | 0.00675 | - | <0.0001 | - | <0.001 | 2 | 0 | 0 | - |
| 2,4'-DDT | µg/g | 0.00119 | 0.00477 | - | <0.0001 | - | <0.001 | 2 | 0 | 0 | - |
| 4,4'-DDT | µg/g | 0.00119 | 0.00477 | - | <0.0001 | - | <0.001 | 2 | 0 | 0 | - |
| Aldrin | µg/g | - | - | - | <0.0001 | <0.001 | <0.005 | 4 | - | - | - |
| Alpha-BHC | µg/g | - | - | - | <0.0001 | <0.0015 | <0.005 | 4 | - | - | - |
| Beta-BHC | µg/g | - | - | - | <0.0001 | <0.0015 | <0.005 | 4 | - | - | - |
| Bromoxynil | µg/g | - | - | - | <0.005 | <0.005 | <0.005 | 4 | - | - | - |
| *cis*-Chlordane | µg/g | 0.0045 | 0.00887 | - | <0.0001 | <0.001 | <0.005 | 4 | 0 | 0 | - |
| *trans*-Chlordane | µg/g | 0.0045 | 0.00887 | - | <0.0001 | <0.001 | <0.005 | 4 | 0 | 0 | - |
| Dicamba | µg/g | - | - | - | <0.005 | <0.005 | <0.005 | 4 | - | - | - |
| Dieldrin | µg/g | 0.0029 | 0.0067 | - | <0.0001 | <0.001 | <0.005(DL>I) | 4 | 0 | 0 | - |
| alpha-Endosulphan | µg/g | - | - | - | <0.0001 | <0.001 | <0.005 | 4 | - | - | - |
| beta-Endosulphan | µg/g | - | - | - | <0.0001 | <0.001 | <0.005 | 4 | - | - | - |

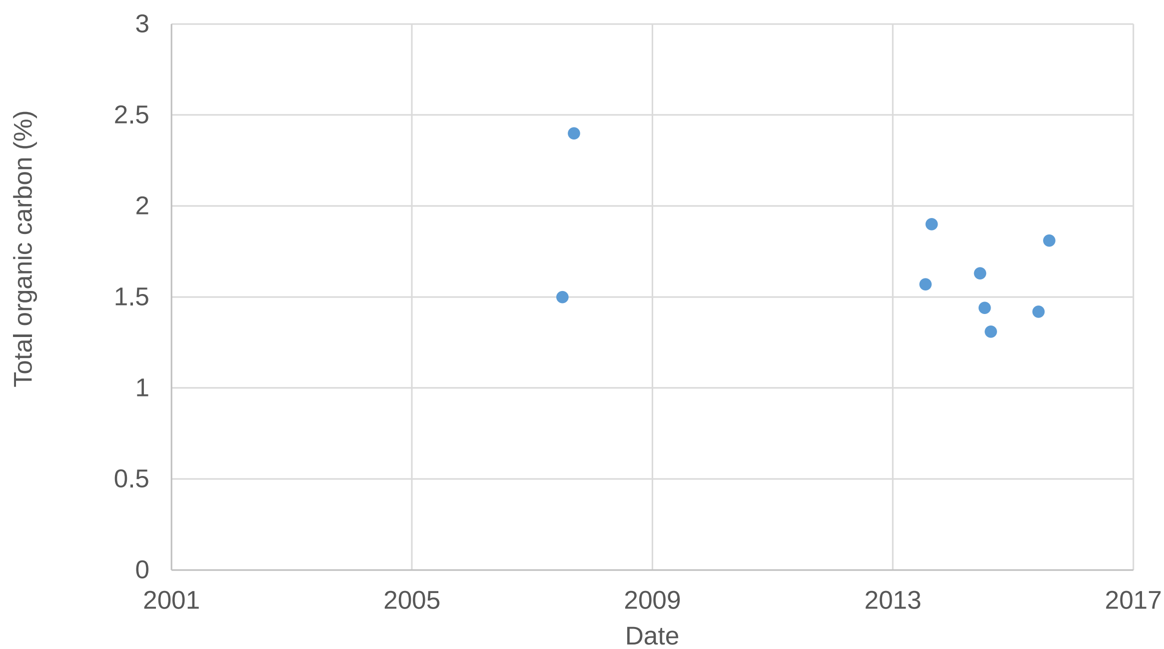
**Table F2: Summary of ALS Suspended Sediment Quality Data from the Liard River Upstream of the Kotaneelee River, 2001 to 2015**

| Parameter | Units (Dry Weight) | Guidelines | | | Summary Statistics | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2001 - 2015 | | | | | | |
| | | | | | | | | | % Above Guideline | | |
| | | CCME ISQG | CCME PEL | BC MOE SQG | Minimum | Median | Maximum | Count | CCME ISQG | CCME PEL | BC MOE SQG |
| Endrin | µg/g | 0.0027 | 0.062 | - | <0.0001 | <0.001 | <0.005(DL>I) | 4 | 0 | 0 | - |
| Heptachlor | µg/g | 0.0006 | 0.0027 | - | <0.0001 | <0.001(DL>I) | <0.005(DL>I, DL>P) | 4 | 0 | 0 | - |
| Lindane | µg/g | - | - | - | <0.0001 | <0.0015 | <0.005 | 4 | - | - | - |
| MCPA | µg/g | - | - | - | <0.005 | <0.005 | 0.0054 | 4 | - | - | - |
| MCPP (Mecoprop) | µg/g | - | - | - | <0.005 | <0.005 | <0.005 | 4 | - | - | - |
| Methoxychlor | µg/g | - | - | - | <0.0001 | <0.0015 | <0.005 | 4 | - | - | - |
| Mirex | µg/g | - | - | - | <0.0001 | <0.001 | <0.005 | 4 | - | - | - |
| Oxychlordane | µg/g | - | - | - | <0.0001 | <0.001 | <0.005 | 4 | - | - | - |
| Picloram | µg/g | - | - | - | <0.005 | <0.005 | <0.005 | 4 | - | - | - |
| Toxaphene | µg/g | 0.0001 | - | - | - | <0.1(DL>I) | - | 1 | 0 | - | - |

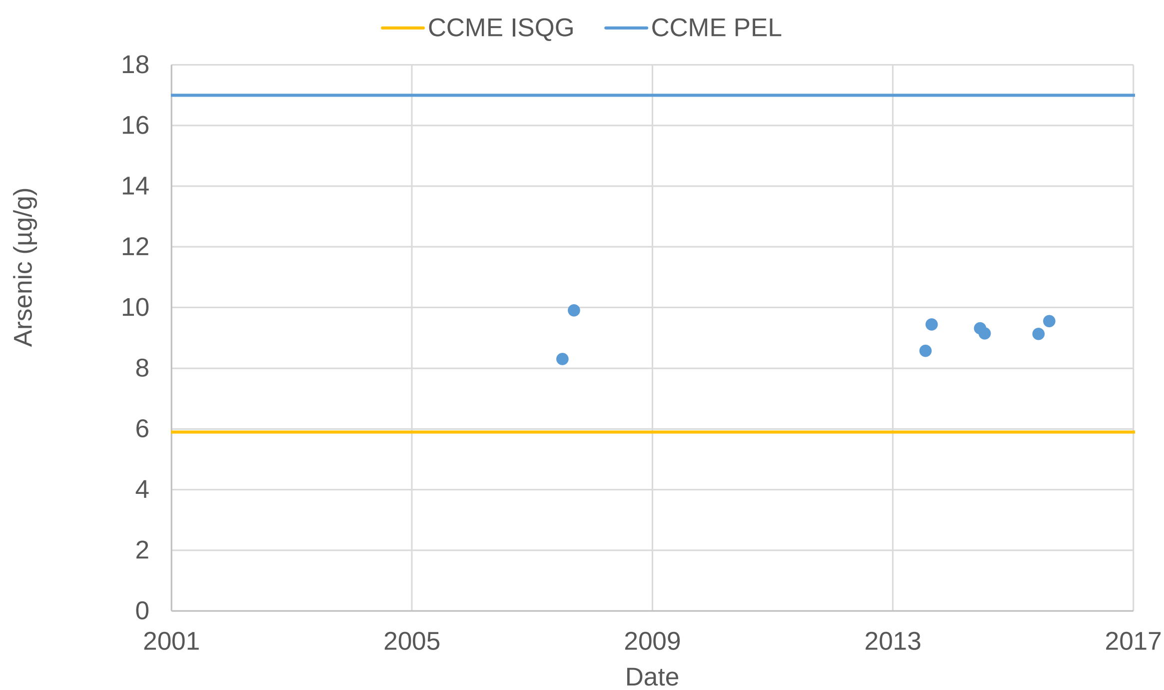
Values in shaded cells are higher than sediment quality guidelines:
(I) = value higher than the CCME ISQG.
(P) = value higher than the CCME PEL.
(B) = value higher than the BC MOE SQG.
Sediment quality data shown in this table were rounded to reflect laboratory precision *after* comparisons to guidelines. Therefore, values slightly above guidelines may be displayed as being equal to the guidelines and identified as exceedances. Measured concentrations equal to the guideline values were not identified as exceedances.
BC MOE = British Columbia Ministry of Environment; CCME = Canadian Council of of Ministers of the Environment; ISQG = interim sediment quality guideline; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; PEL= probable effect level; SQG = sediment quality guideline; µg/g = mg/kg. - = no guideline or data.

*Figure F-1: Suspended Sediment Concentrations in the Liard River Upstream of the Kotaneelee River, 2001 to 2015 (as dry weight)*

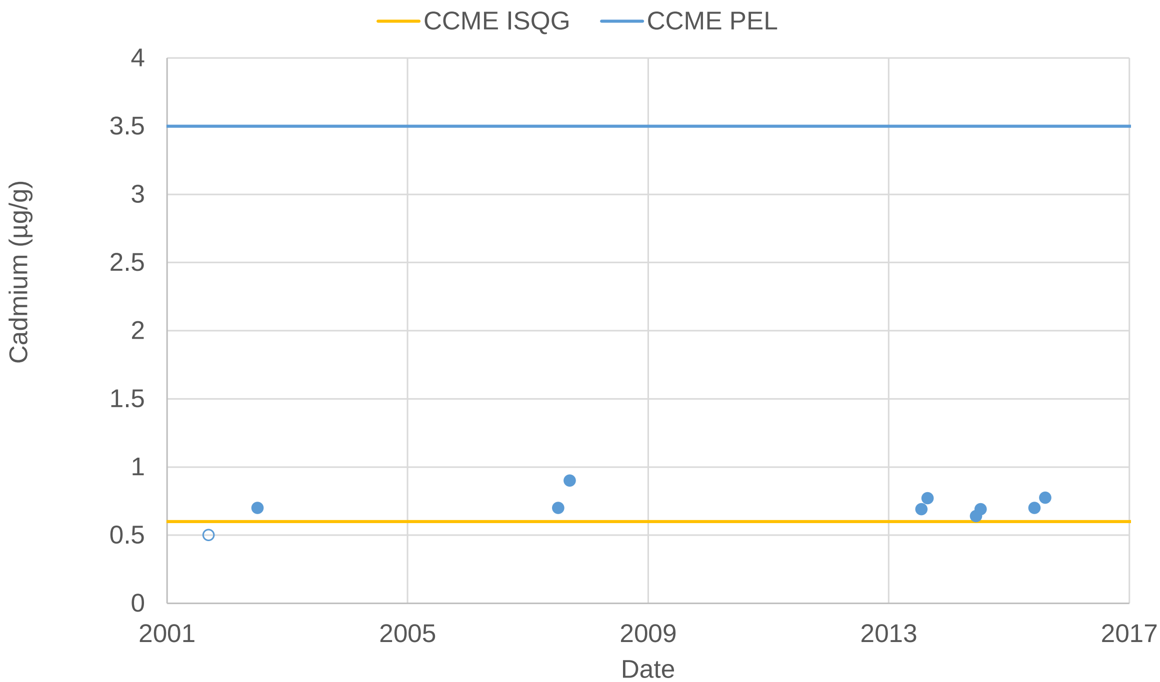
**(1) Total organic carbon**



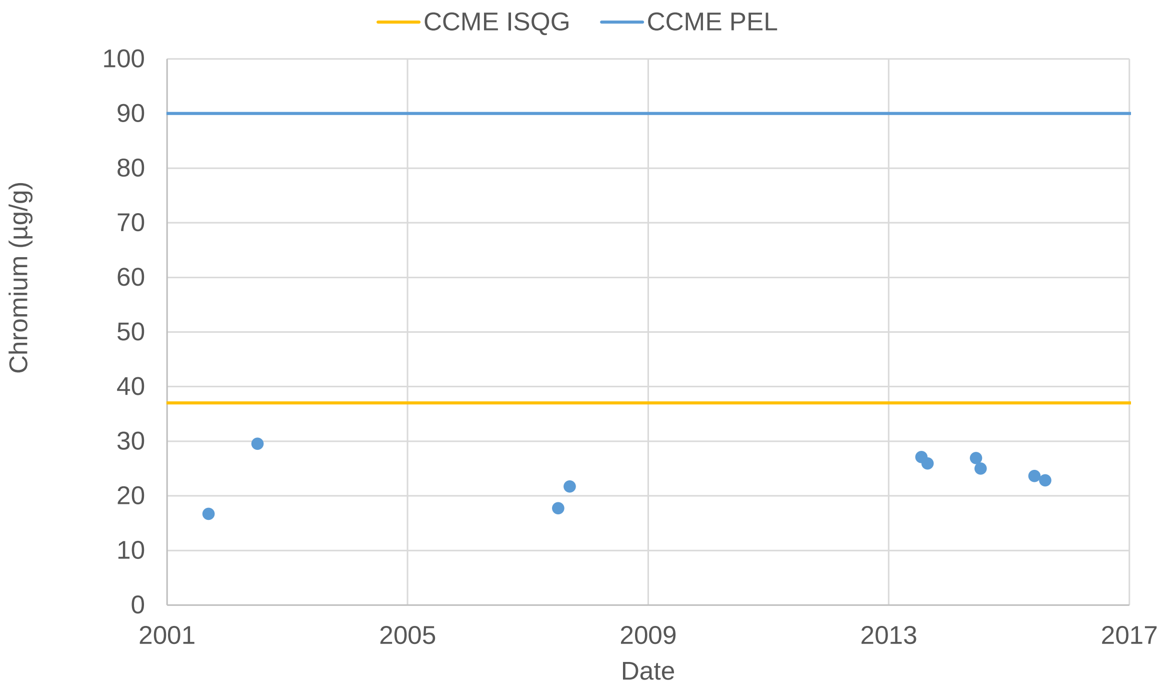

**(2) Arsenic**



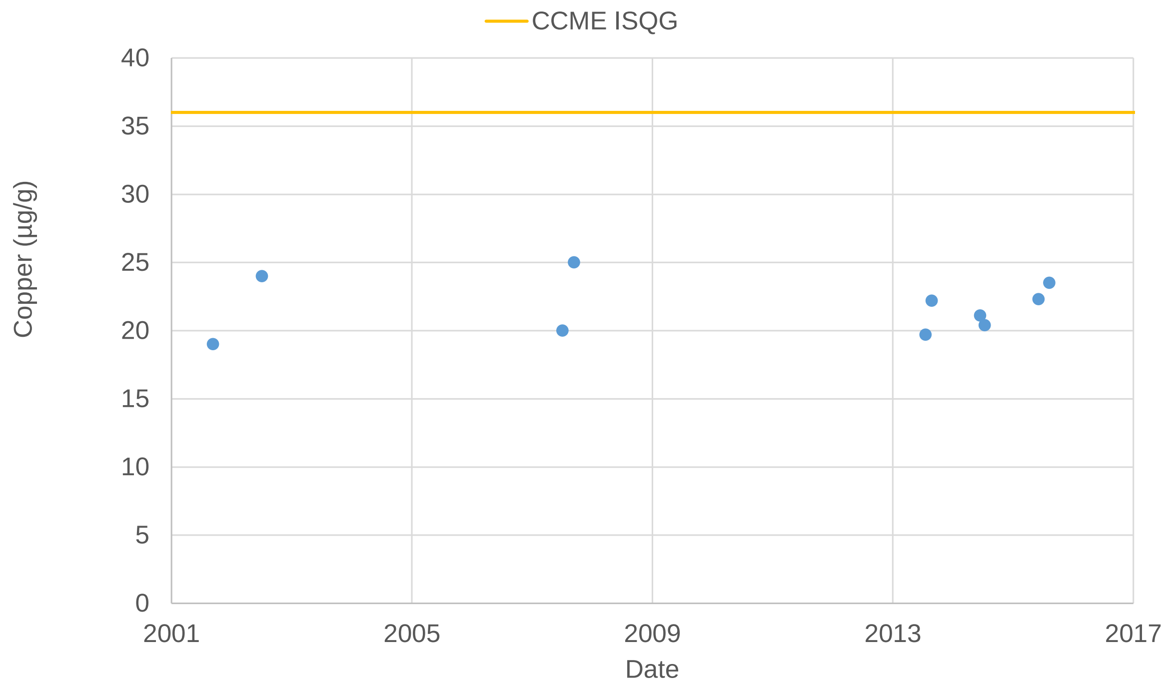
**(3) Cadmium**




**(4) Chromium**

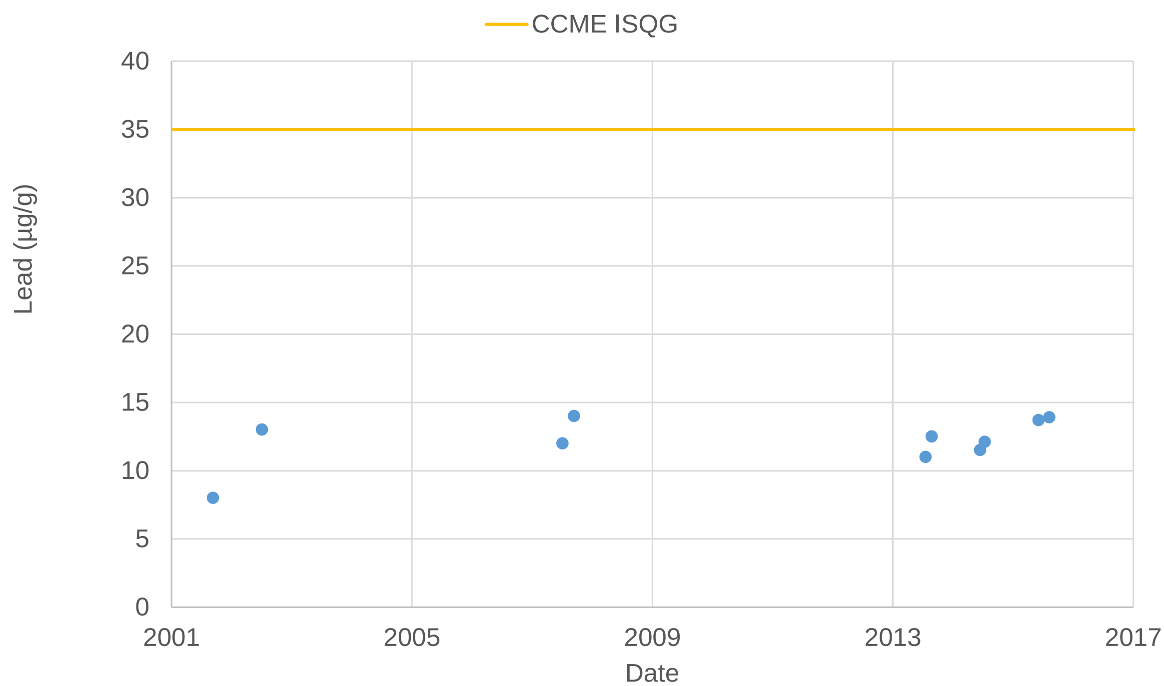


**(5) Copper**



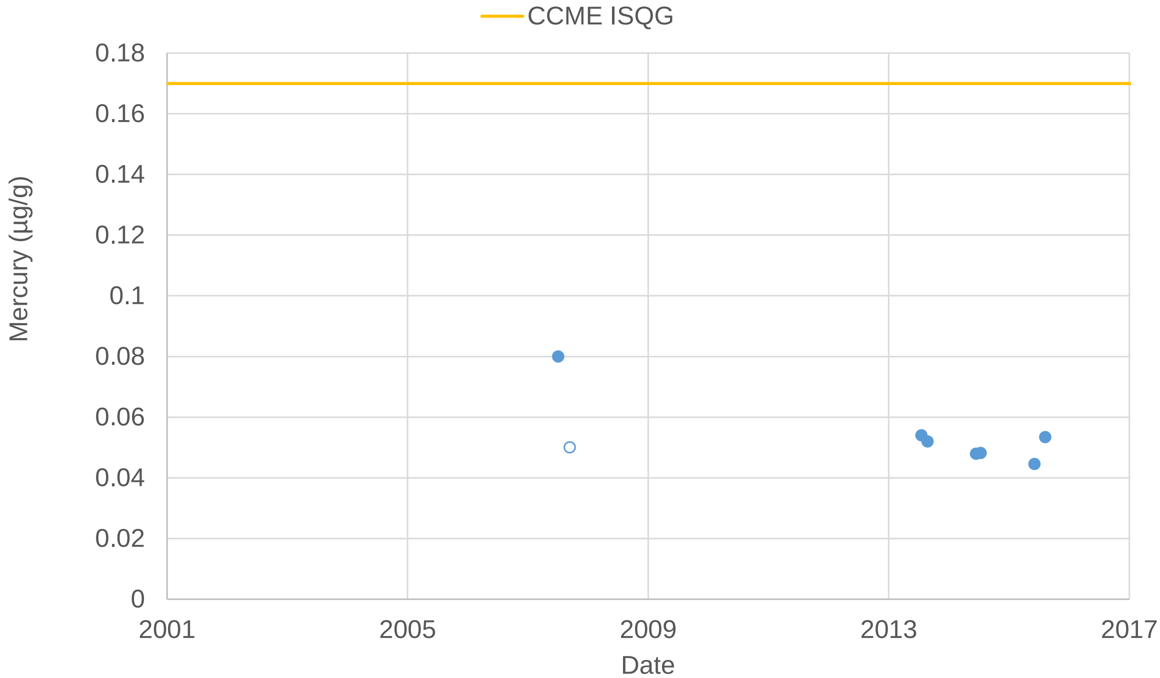

For the purposes of visually reviewing the data, the CCME PEL guideline (197 µg/g) is not shown.

**(6) Lead**



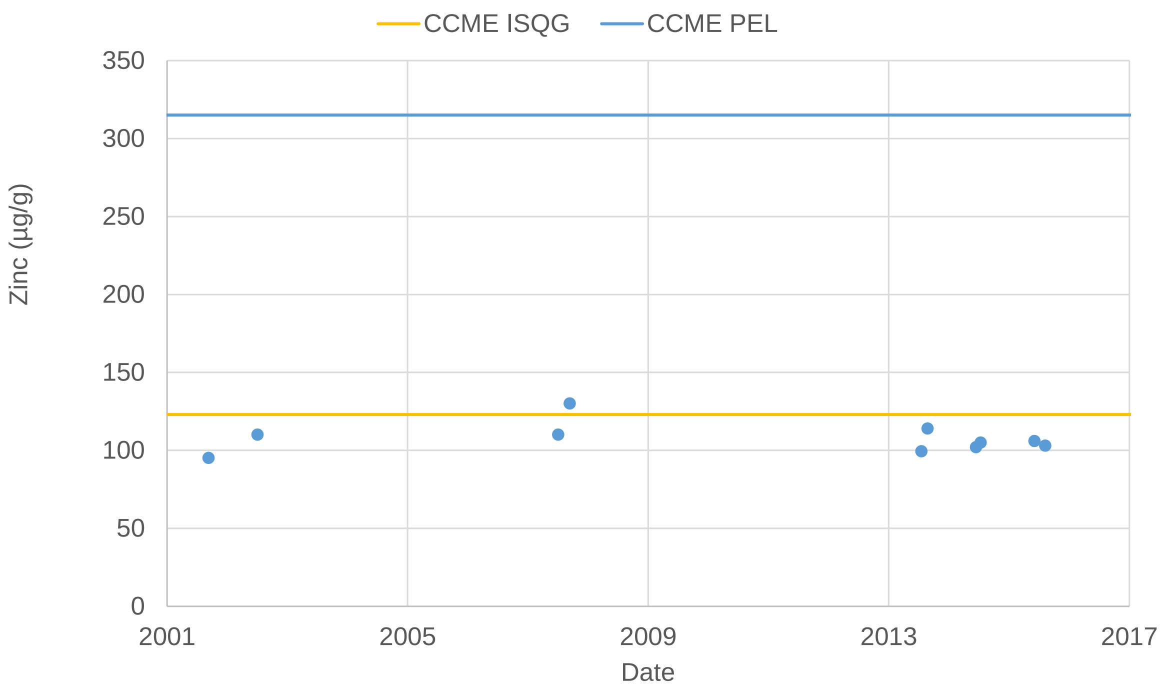

For the purposes of visually reviewing the data, the CCME PEL guideline (91 µg/g) is not shown.

**(7) Mercury**

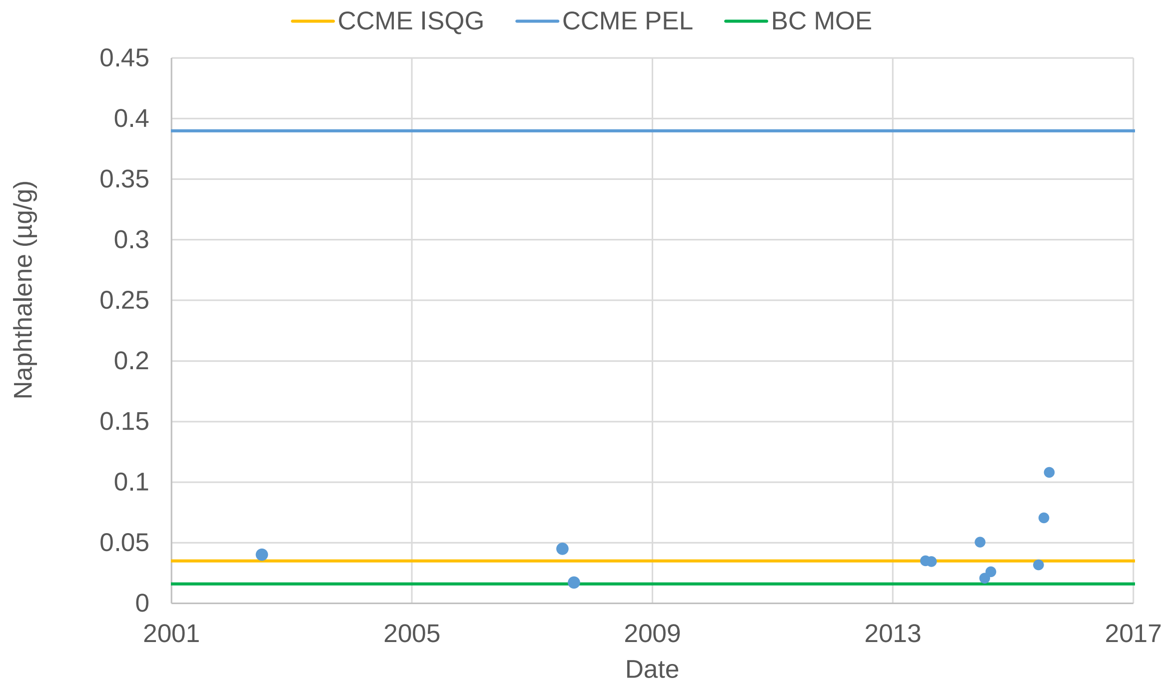



For the purposes of visually reviewing the data, the CCME PEL guideline (0.49 µg/g) is not shown.

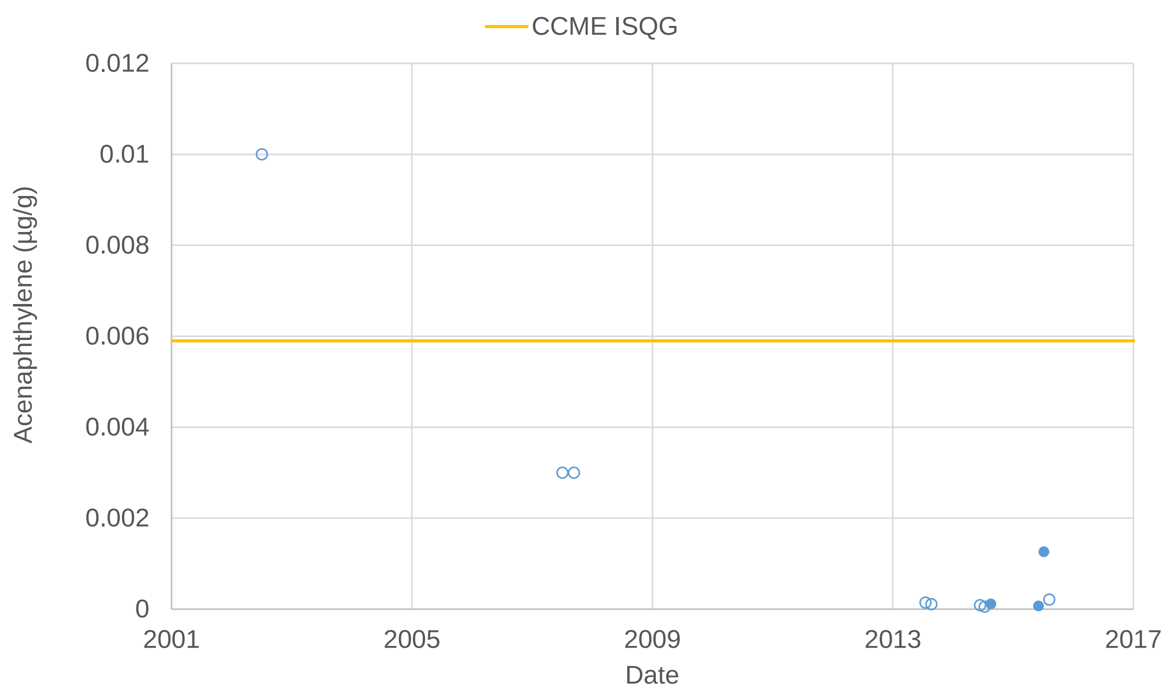
**(8) Zinc**



**(9) Naphthalene**

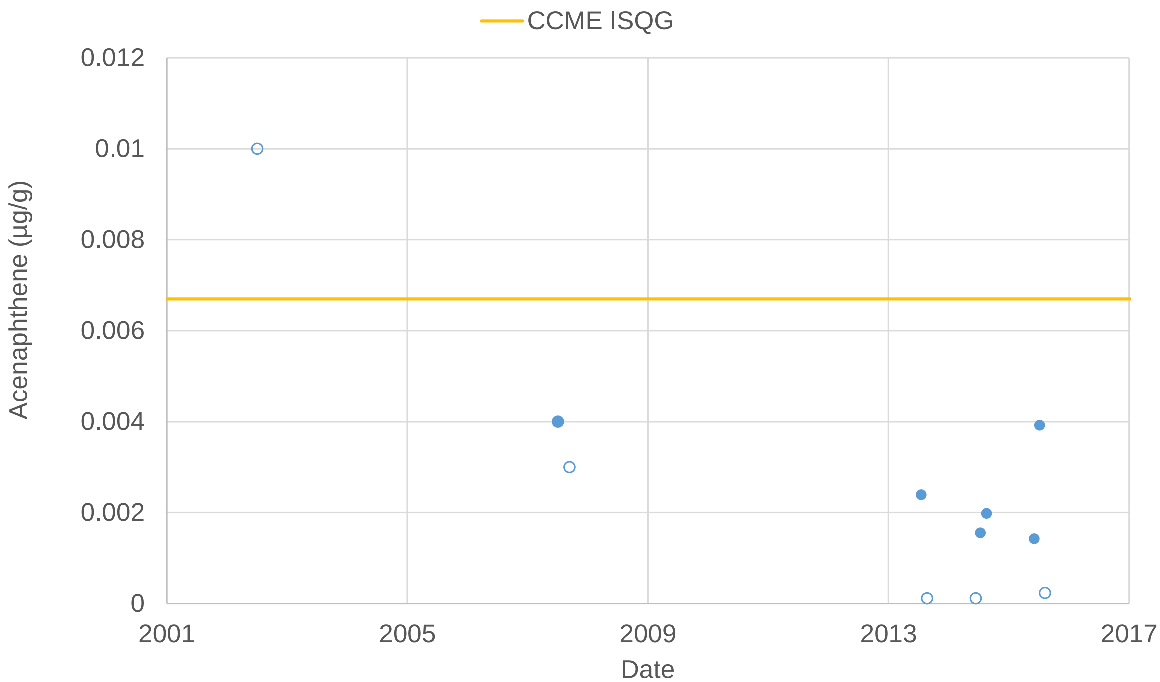



**(10) Acenaphthylene**



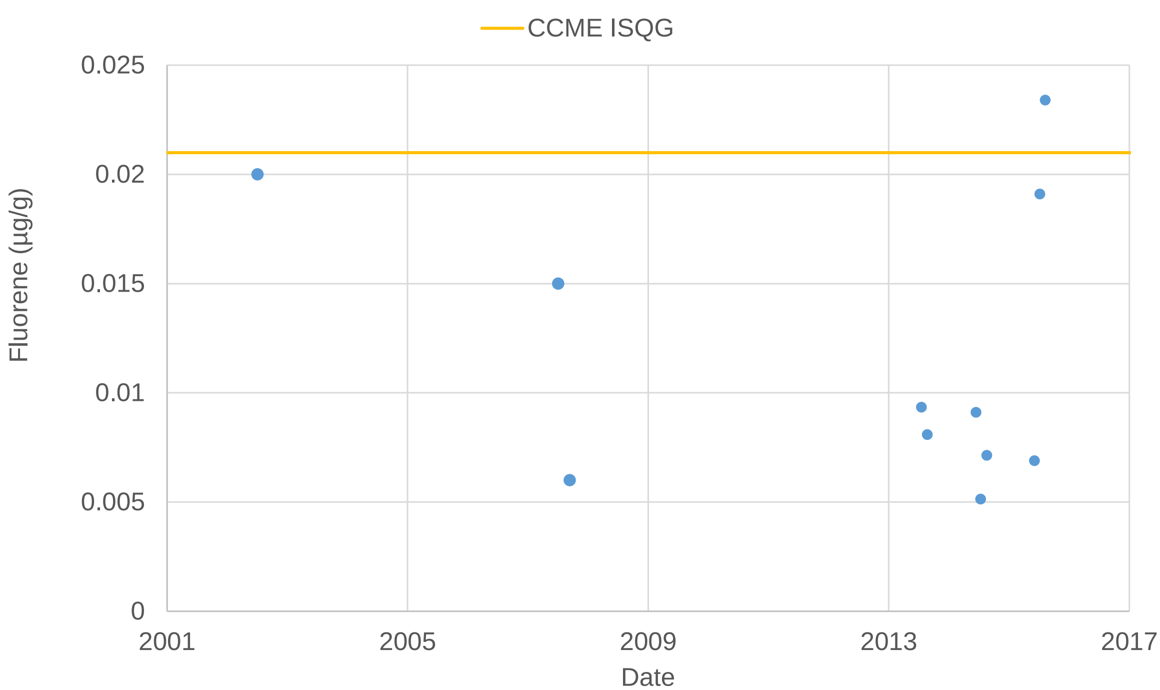

For the purposes of visually reviewing the data, the CCME PEL guideline (0.13 µg/g) is not shown.

**(11) Acenaphthene**



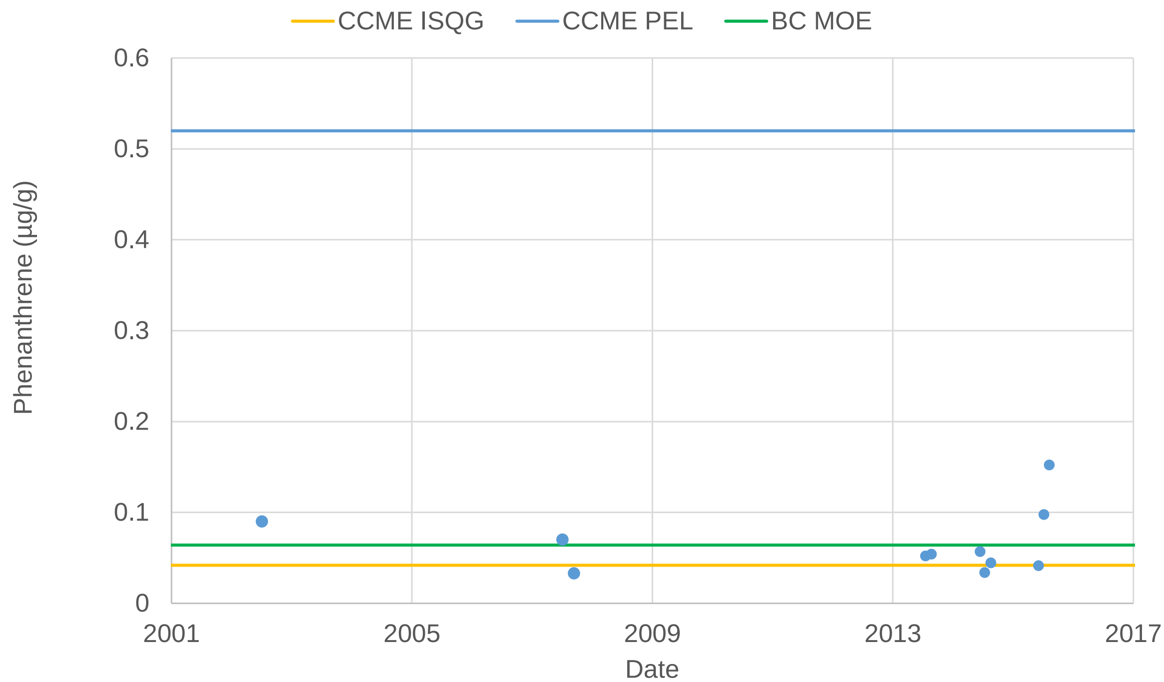

For the purposes of visually reviewing the data, the PEL (0.089 µg/g) and BC MOE (0.20 µg/g) guidelines are not shown.

**(12) Fluorene**

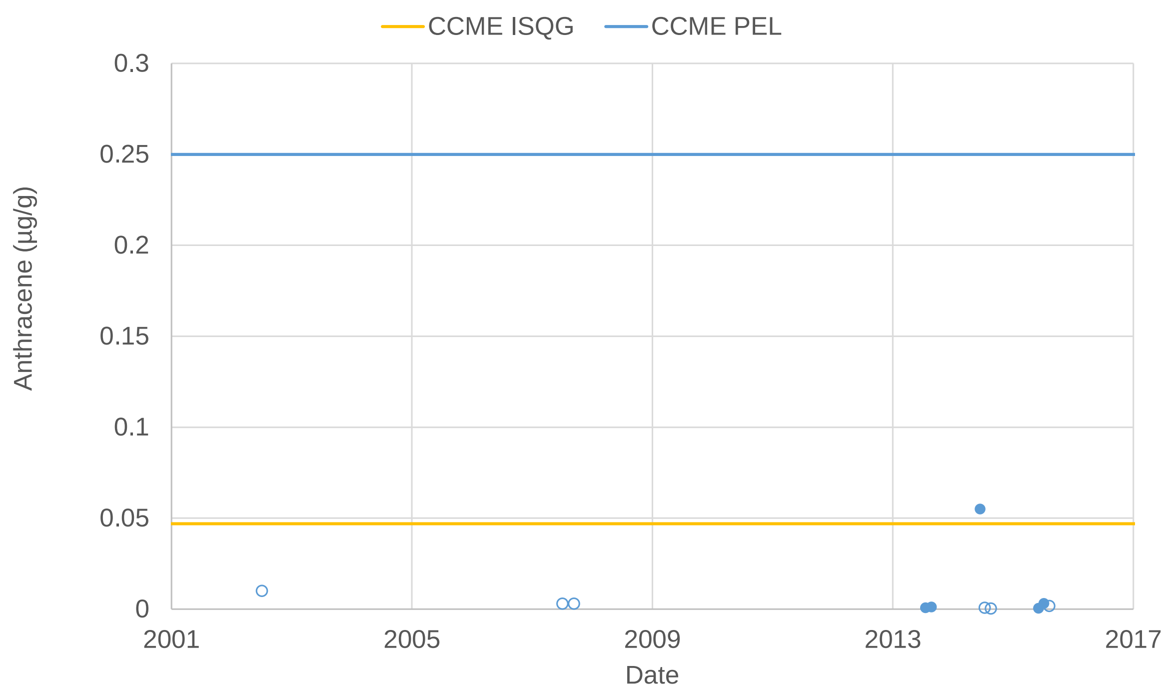



For the purposes of visually reviewing the data, the CCME PEL (0.14 µg/g) and BC MOE (0.3 µg/g) guidelines are not shown.

**(13) Phenanthrene**

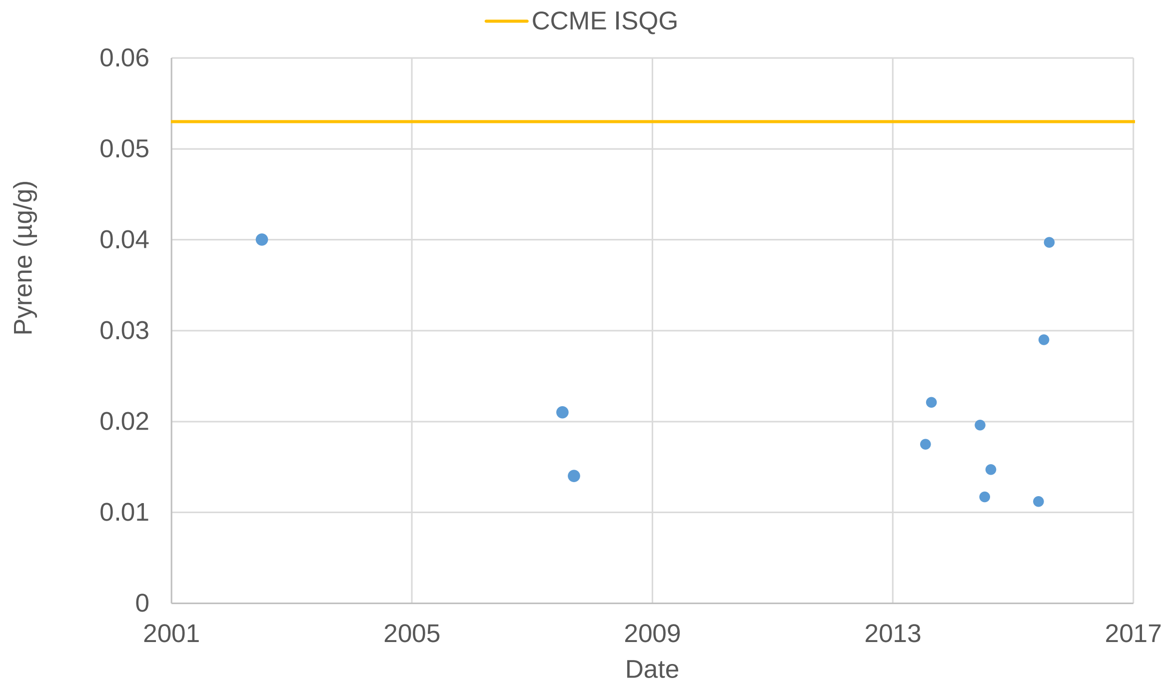



**(14) Anthracene**



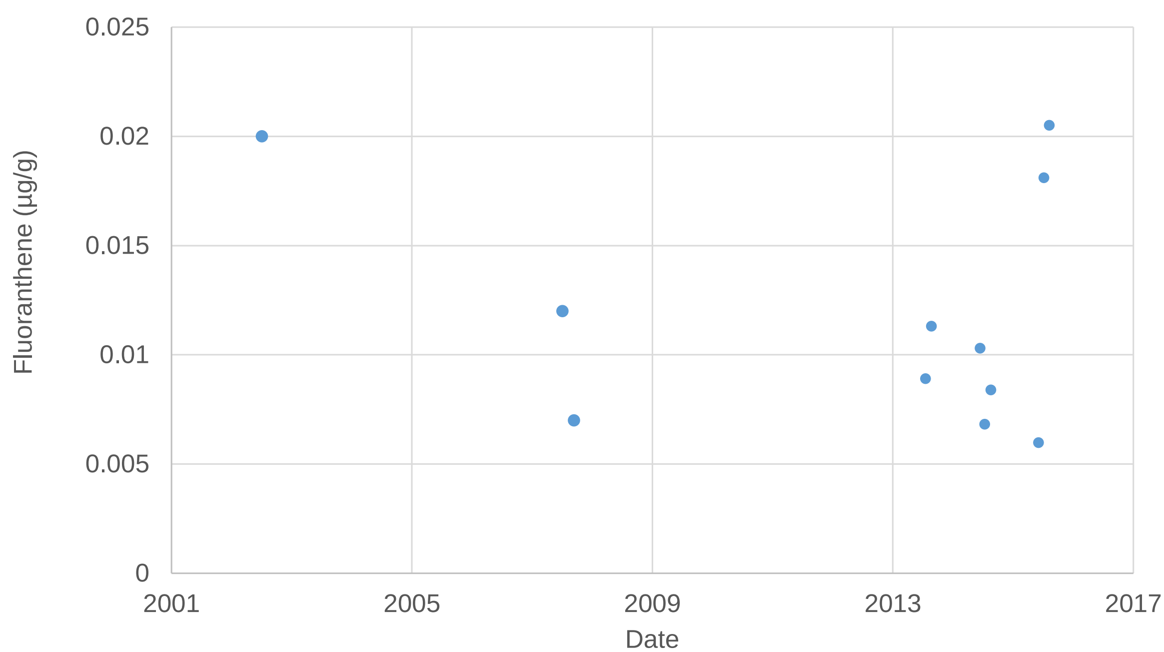

For the purposes of visually reviewing the data, the BC MOE (0.8 µg/g) guideline is not shown.

**(15) Pyrene**



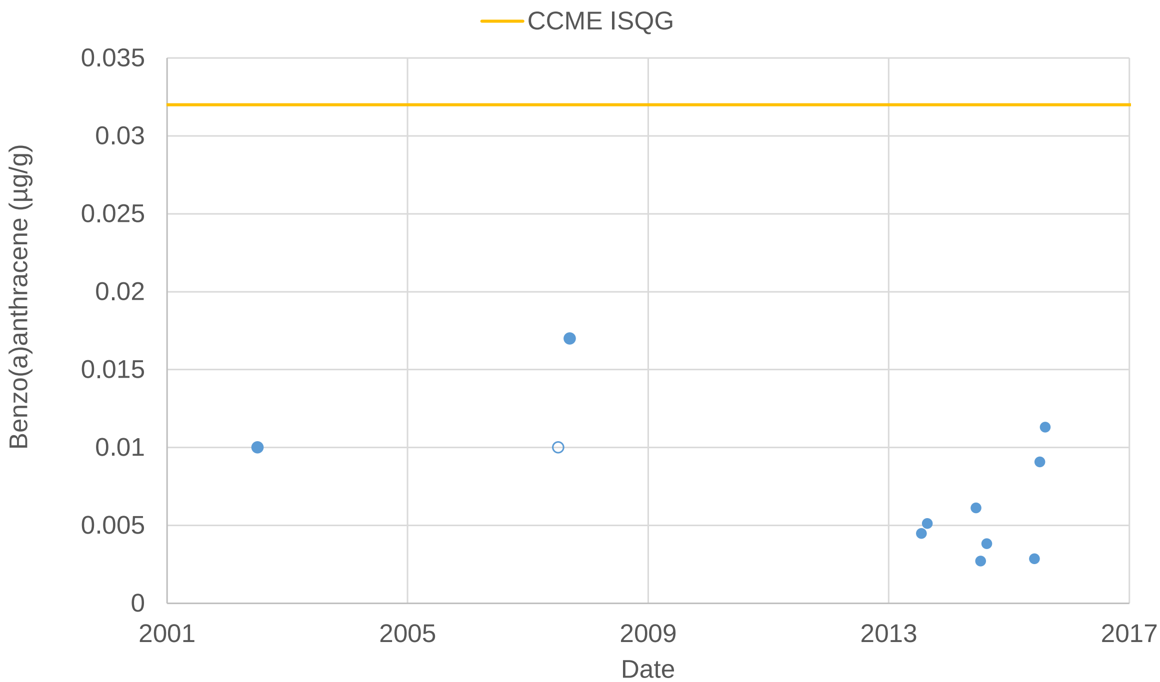

For the purposes of visually reviewing the data, the CCME PEL (0.88 µg/g) guideline is not shown.

**(16) Fluoranthene**



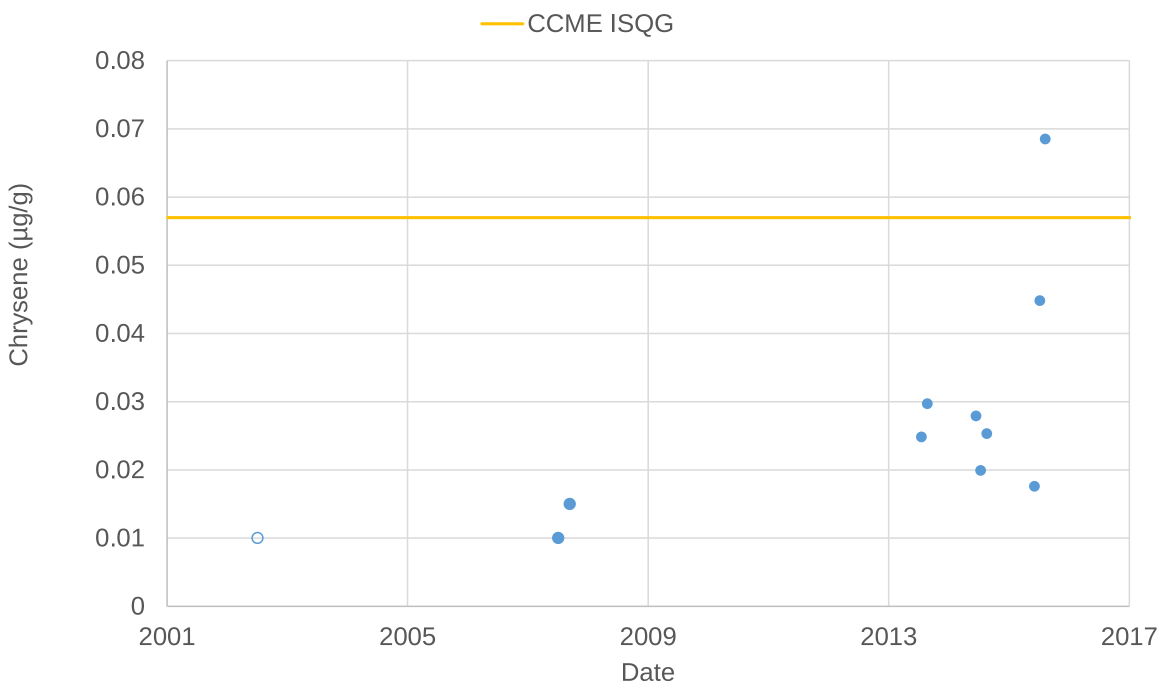

For the purposes of visually reviewing the data, the CCME ISQG (0.11 µg/g), CCME PEL (2.4 µg/g) guideline, and BC MOE (3 µg/g) guideline are not shown.

**(17) Benzo(a)anthracene**



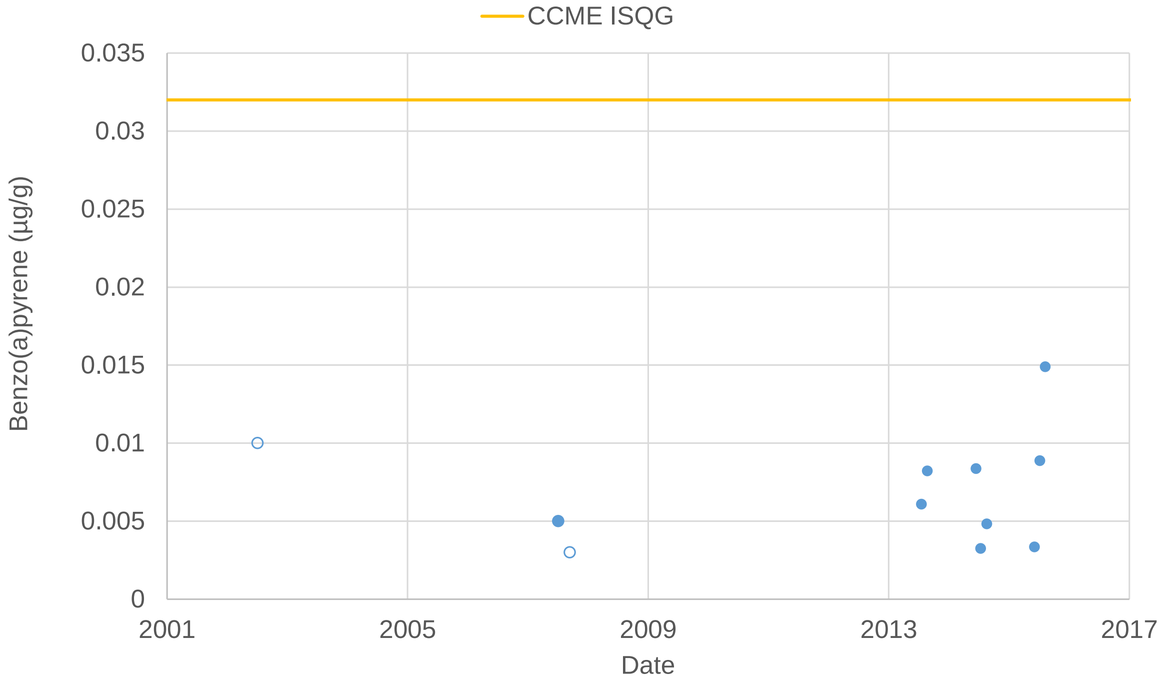

For the purposes of visually reviewing the data, the CCME PEL (0.39 µg/g) and BC MOE (0.3 µg/g) guidelines are not shown.

**(18) Chrysene**



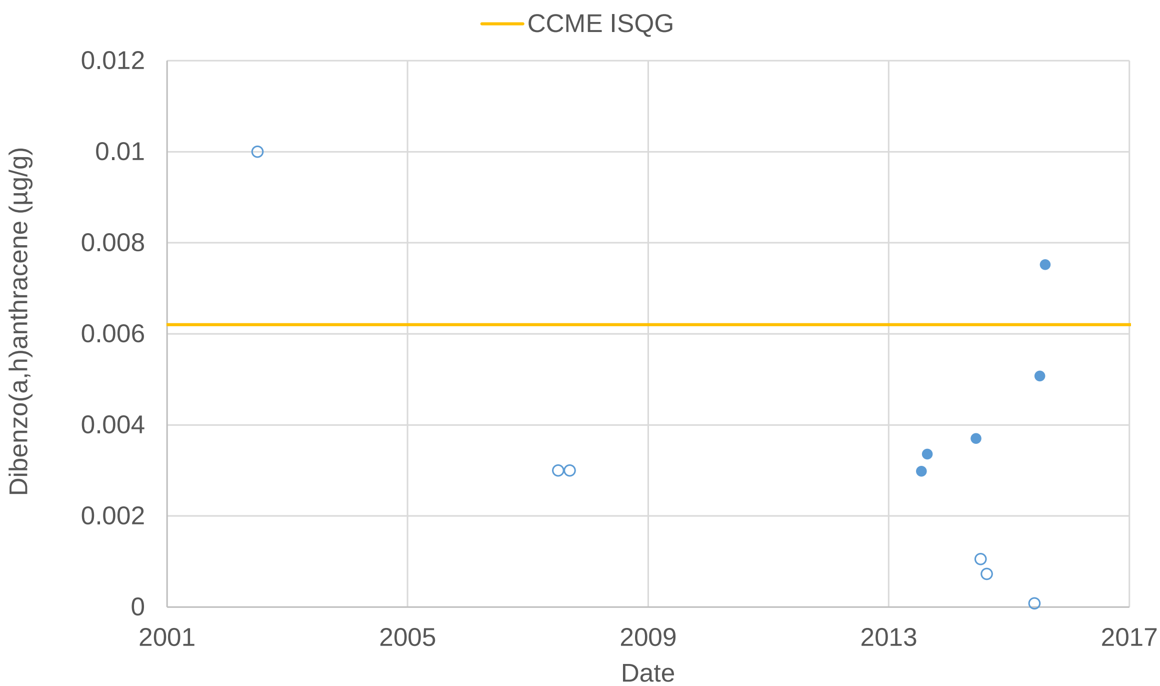

For the purposes of visually reviewing the data, the CCME PEL (0.86 µg/g) guideline is not shown.

**(19) Benzo(a)pyrene**



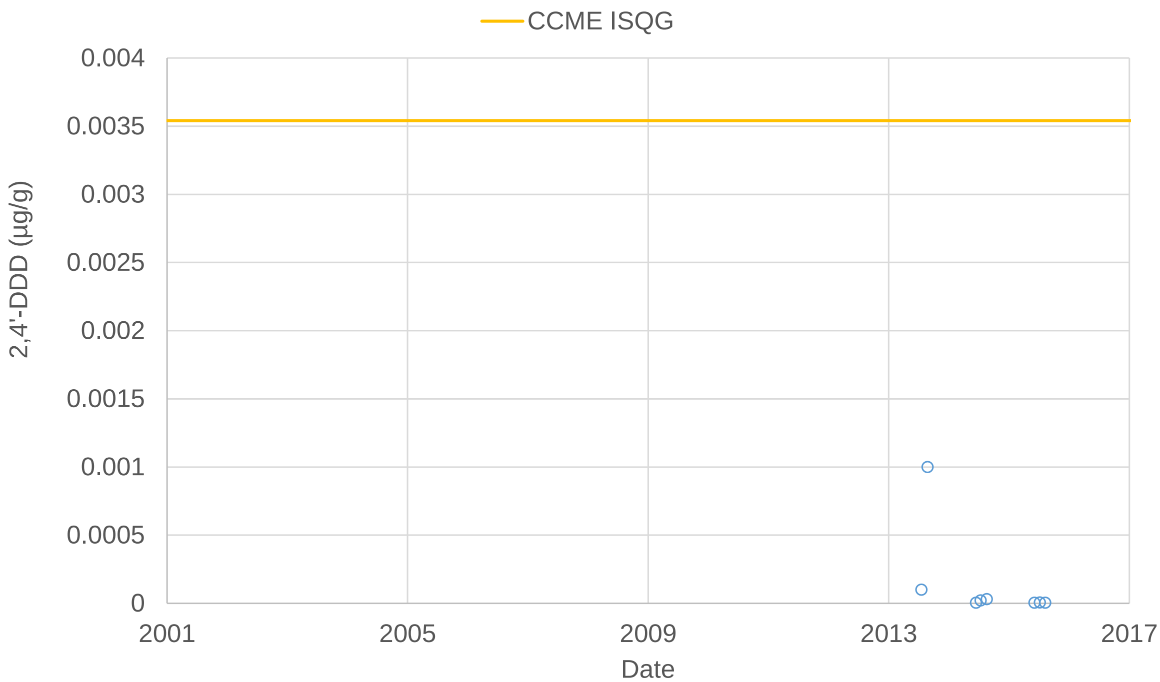

For the purposes of visually reviewing the data, the CCME PEL (0.78 µg/g) and BC MOE (0.08 µg/g) guidelines are not shown.

**(20) Dibenzo(a,h)anthracene**



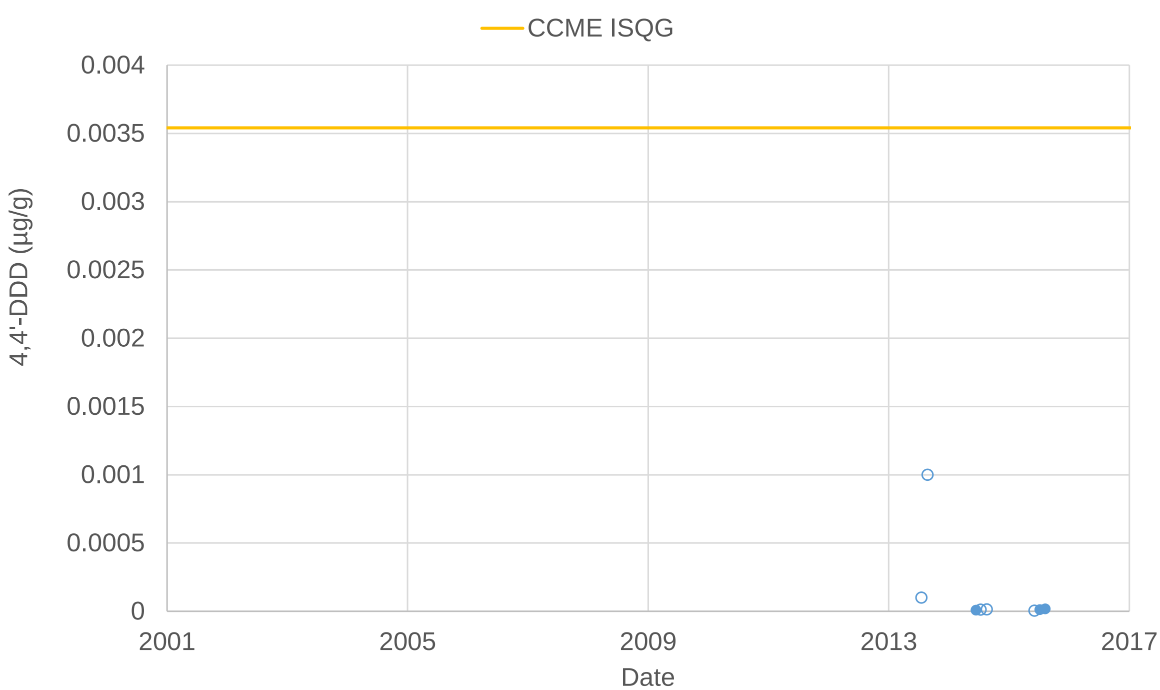

For the purposes of visually reviewing the data, the CCME PEL (0.14 µg/g) guideline is not shown.

**(21) 2,4'-DDD**



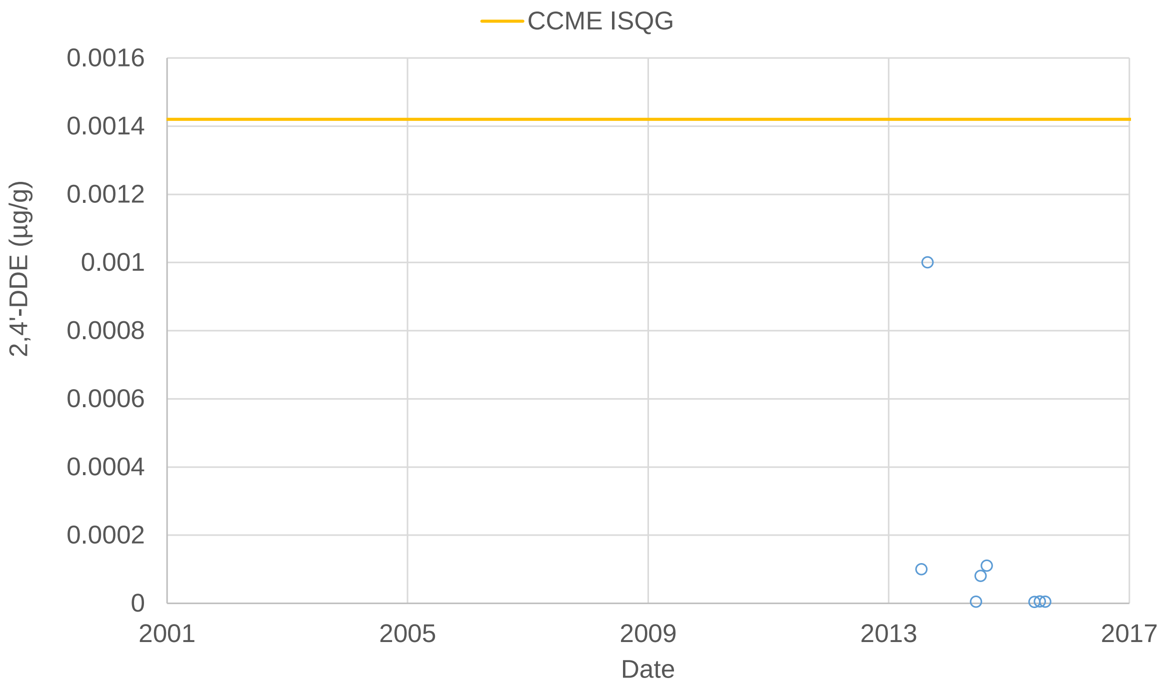

For the purposes of visually reviewing the data, the CCME PEL (0.00851 µg/g) guideline is not shown.

**(22) 4,4'-DDD**



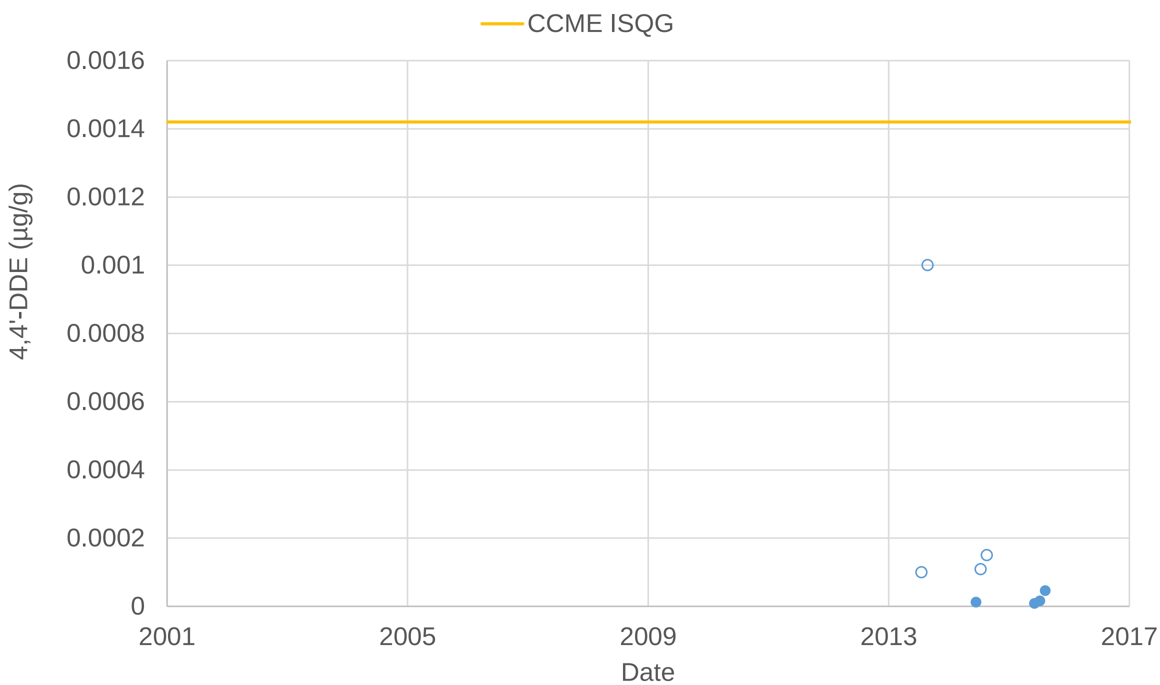

For the purposes of visually reviewing the data, the CCME PEL (0.00851 µg/g) guideline is not shown.

**(23) 2,4'-DDE**



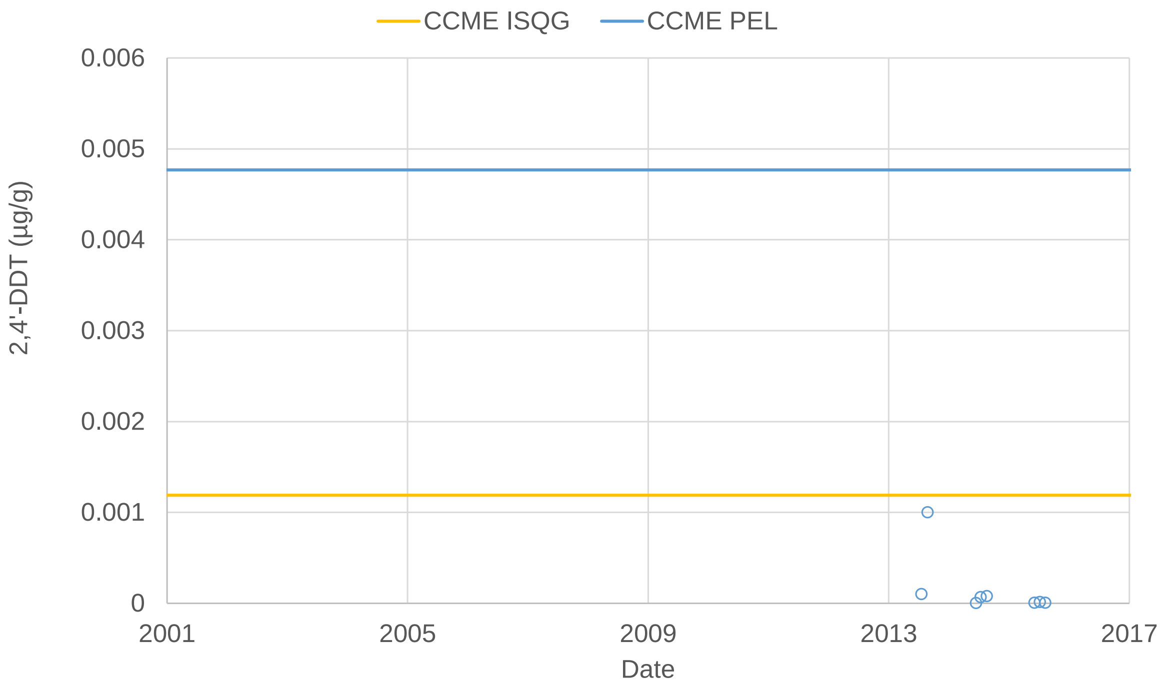

For the purposes of visually reviewing the data, the CCME PEL (0.00675 µg/g) guideline is not shown.

**(24) 4,4'-DDE**

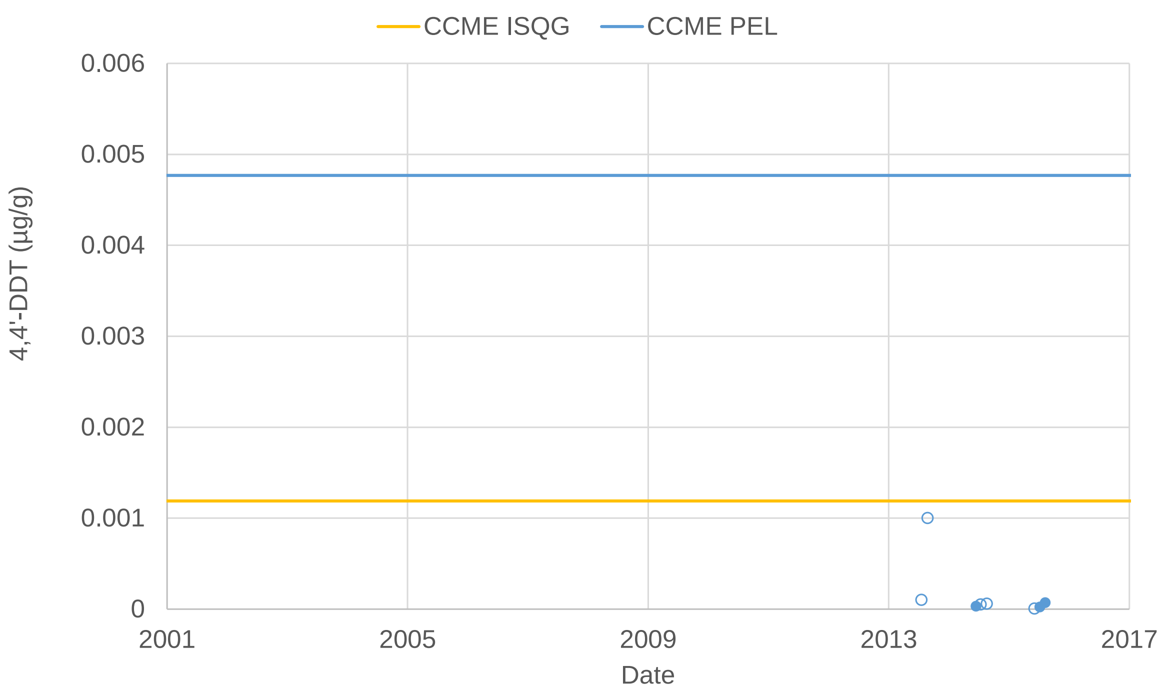



For the purposes of visually reviewing the data, the CCME PEL (0.00675 µg/g) guideline is not shown.

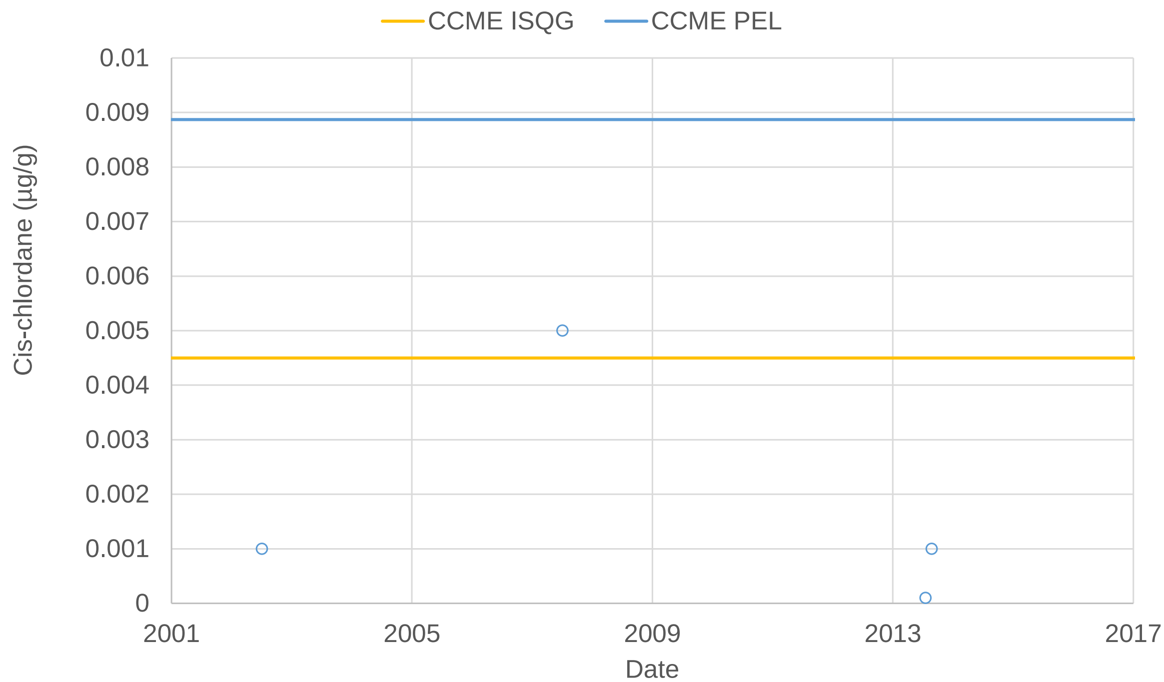
**(25) 2,4'-DDT**



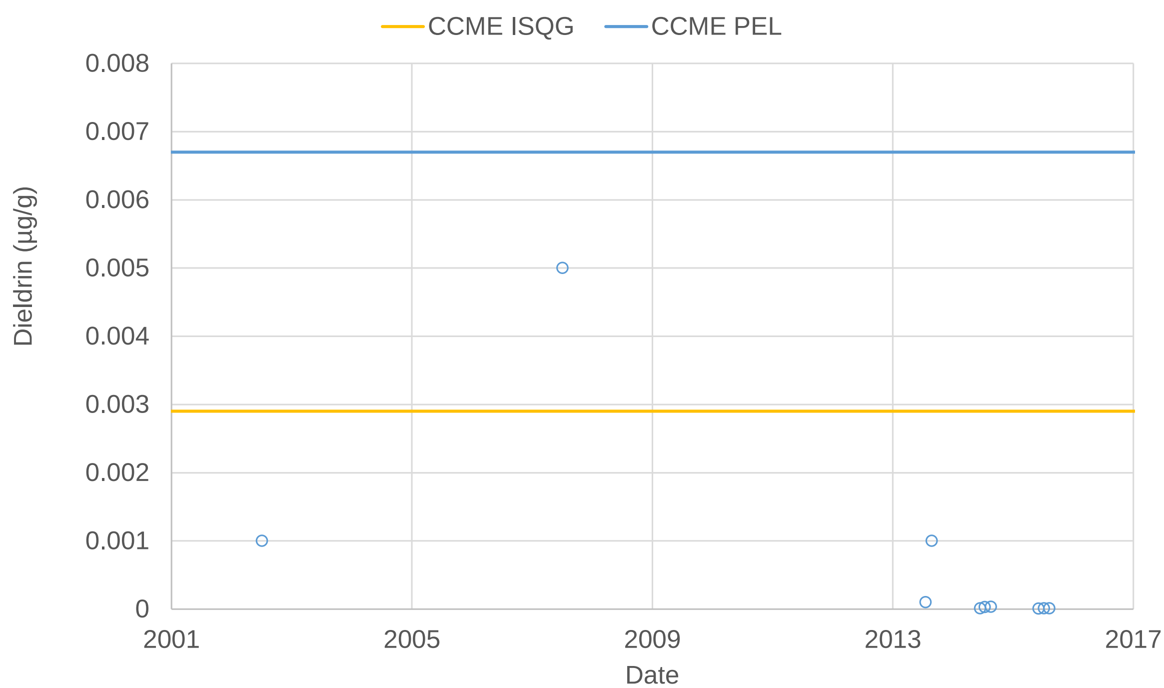

**(26) 4,4'-DDT**



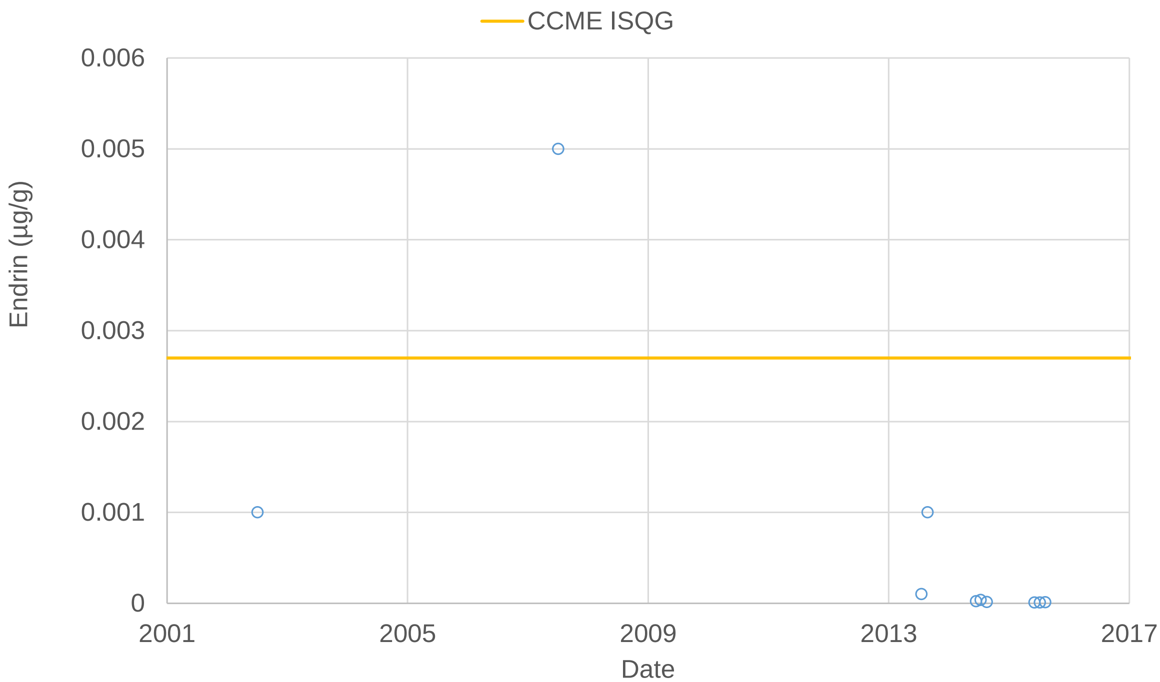
**(27) Cis-chlordane**




**(28) Dieldrin**

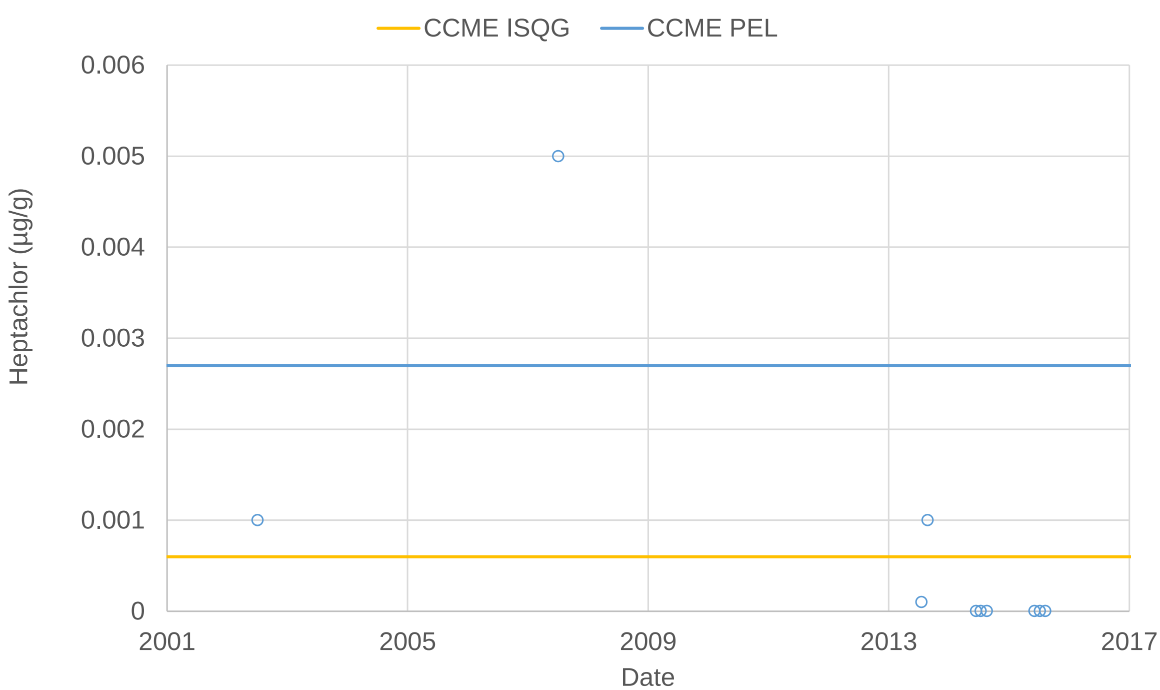


**(29) Endrin**

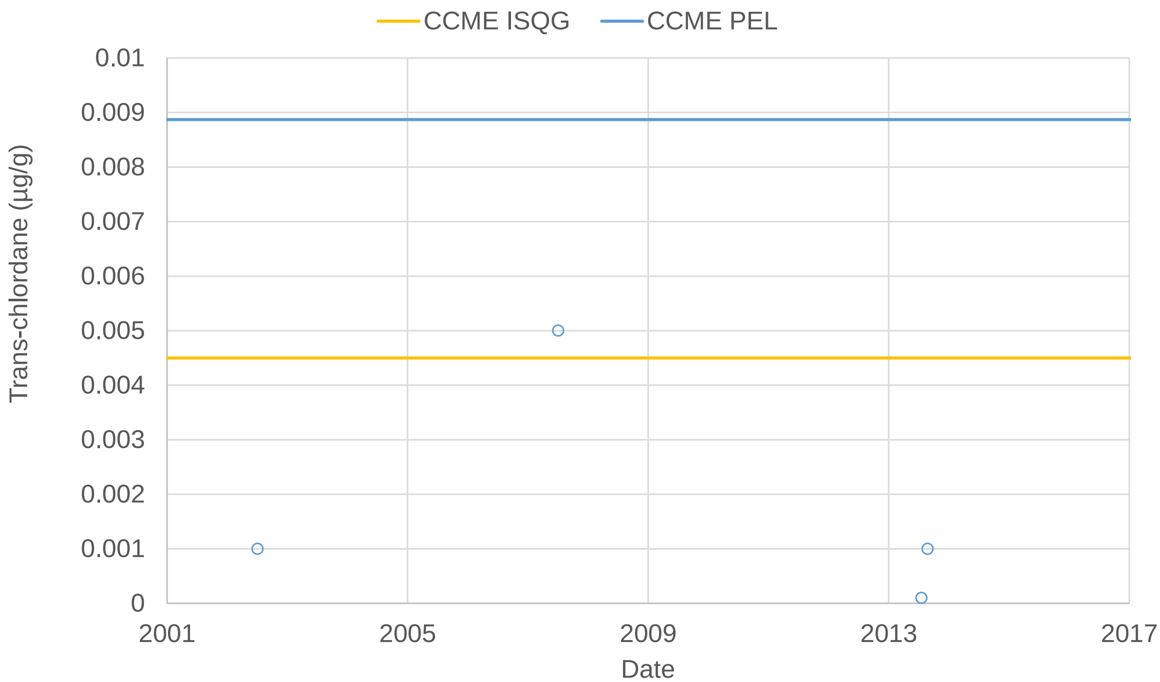



For the purposes of visually reviewing the data, the CCME PEL (0.062 µg/g) guideline is not shown.

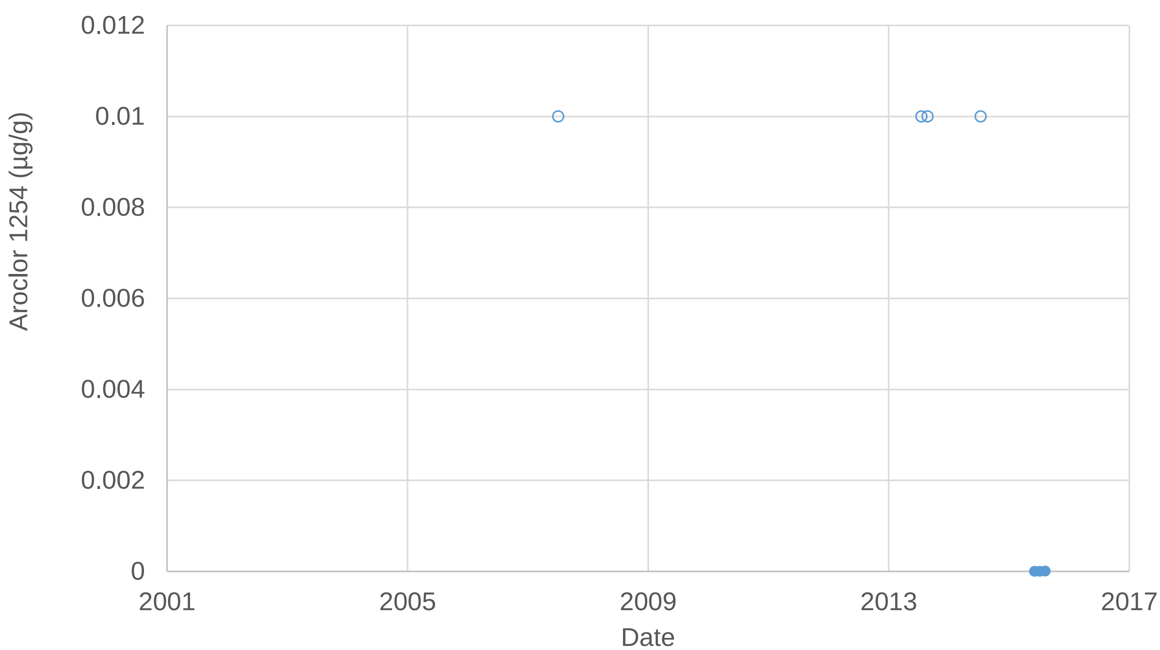
**(30) Heptachlor**



**(31) Trans-chlordane**

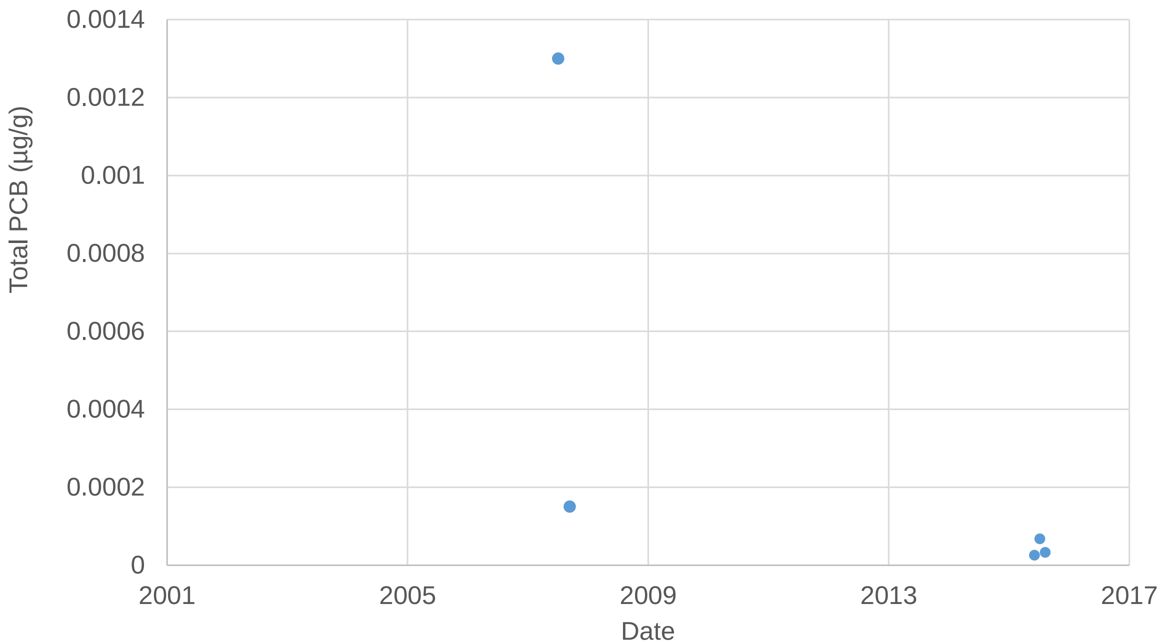



**(32) Aroclor 1254**



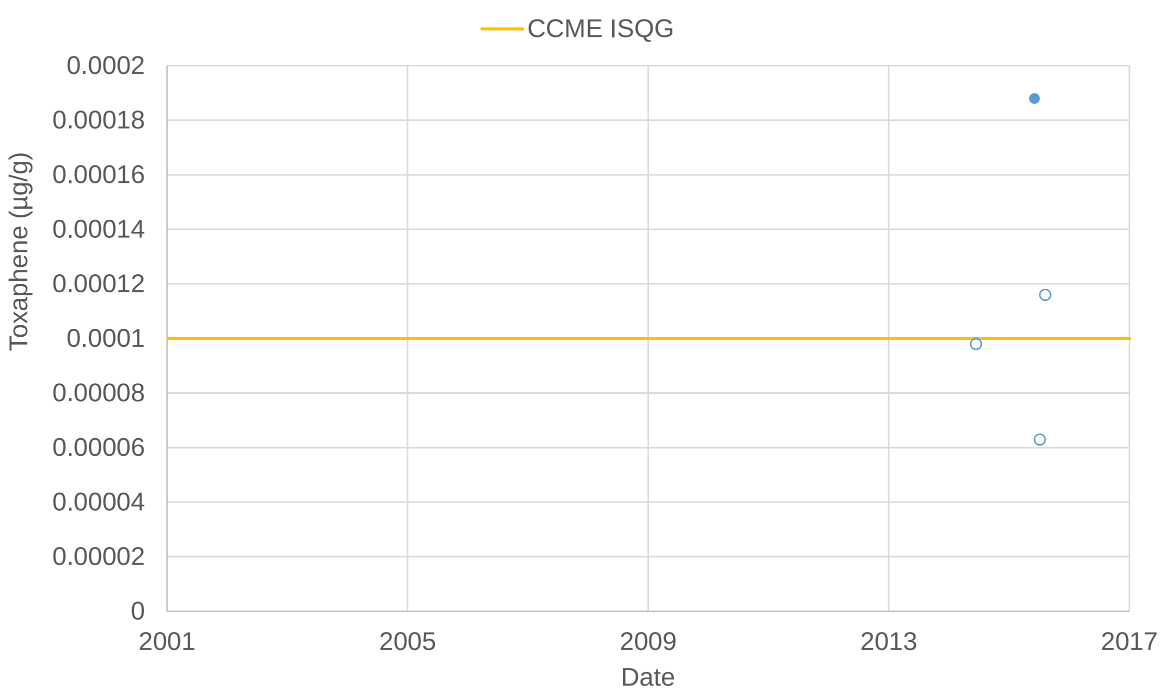

For the purposes of visually reviewing the data, the CCME ISQG (0.06 µg/g) and CCME PEL (0.34 µg/g) guideline are not shown.

**(33) Total PCB**

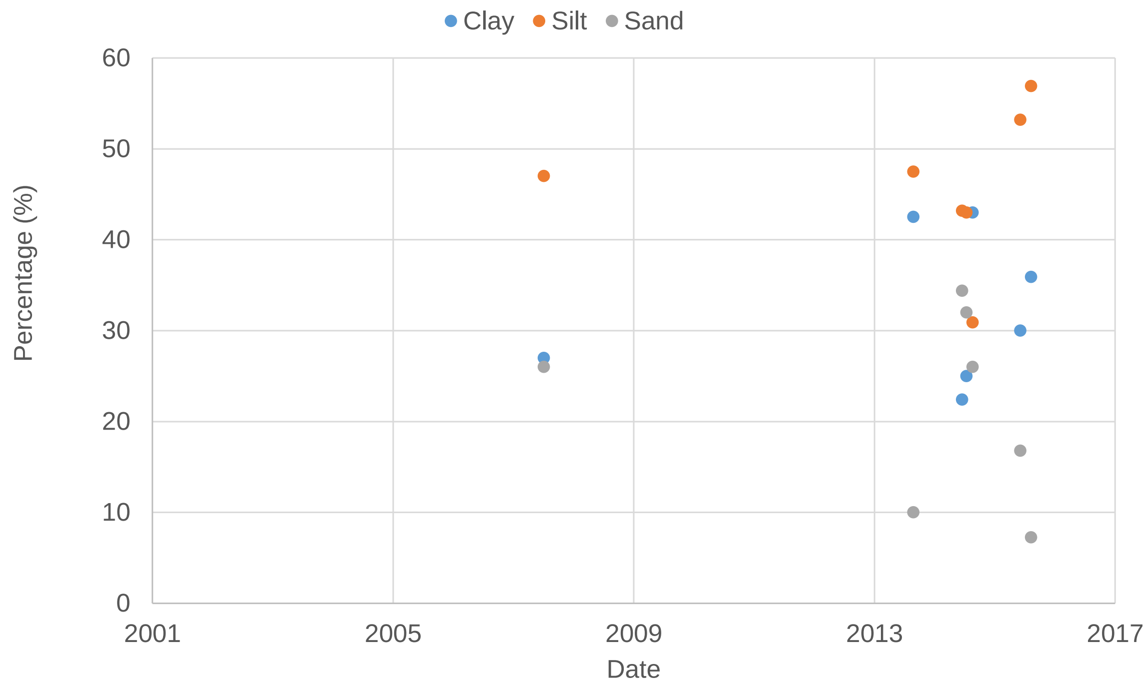



For the purposes of visually reviewing the data, the CCME ISQG (0.034 µg/g), the CCME PEL (0.28 µg/g) guideline, and the BC MOE (0.03 µg/g) guideline are not shown.

**(33) Toxaphene**



**(34) Particle Size**




Abbreviations: CCME = Canadian Council of Ministers of Environment; BC MOE = British Columbia Ministry of the Environment; ISQG = interim sediment quality guideline; PEL = probable effect level; PCB = polychlorinated biphenyl; TOC = total organic content; µg/g = micrograms per gram (equivalent to mg/kg [milligrams per kilogram]).

Notes: Values reported as less than the detection limit were plotted as open data points at the detection limit.

BC MOE guidelines were calculated based on the minimum suspended sediment TOC (1.3%).

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