

Peel River Basin Water Quality Report



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**Water Resources Division
Indian and Northern Affairs Canada
Yellowknife, NT
Canada**

**Water Quality Review (1980-1998) at *Peel River Above Fort McPherson*
Winter Water Quality and Flow throughout the Peel River Basin, March 1999**

PEEL RIVER BASIN

WATER QUALITY REPORT

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Executive Summary

The Peel River Basin March 1999 study was a successful project which provided information about winter water quality and quantity at remote sites throughout the basin. Examination of the March 1999 data as well as the twenty years of water quality and quantity data from *Peel River above Fort McPherson* indicates that river discharge and therefore water quality is intimately associated with seasonality. The most common seasonal trend observed was high concentrations of water quality parameters during freshet with decreasing concentrations throughout the recession and lowest values during baseflow. Parameters fitting this trend are those typically associated with particulate matter, including most metals. The second most common seasonal trend was the opposite, with parameter concentrations being highest during baseflow and lowest during the freshet. Dissolved constituents of water that remain in solution such as major ions are lowest during the freshet due to dilution.

Water quality data were compared to established water quality guidelines. Few exceedances were noted which is indicative of good water quality. Most parameters were at very low concentrations or not detected. In the absence of major development, any metals that were detected are probably natural in origin and are not likely to cause adverse effects. The baseline data collected and examined in this report can be used to monitor changes in water quality due to any future anthropogenic disturbances or natural phenomena.



The Bonnet Plume River, Yukon.

Paul von Baich

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Taiga Environmental Laboratory (of Yellowknife) performed the analysis of the March 1999 data. Kathleen Puznicki provided advice and scientific support. Historic data for *Peel River above Fort McPherson* was provided by Doug Halliwell of Environment Canada (EcoAtlas™). Thanks to Denise Bicknell of DIAND Water Resources (Yellowknife) for her map-making expertise.

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Finally, we are grateful to photographer Paul von Baich for allowing us to use his stunning photographs of the rivers of the Peel Basin.

Table of Contents

Executive Summary	i
Acknowledgements	ii
Table of Contents	iii
List of Figures	iv
List of Tables	iv
Introduction	1
Study Area	1
Sampling Program	2
Water Quantity	2
Water Quality	3
Data Handling and Statistics	5
Results and Discussion	10
Water Quantity	10
Water Quality	11
Physical Parameters	11
pH	11
Conductivity	11
Turbidity	12
Total Suspended Solids/Nonfilterable Residue (TSS/NFR)	13
Total Dissolved Solids/Filterable Residue (TDS/FR)	14
True Colour	14
Major Ions	16
Alkalinity	16
Hardness	17
Cations	19
Anions	21
Nutrients	24
Phosphorous	24
Ammonia	25
Nitrate/Nitrite	26
Reactive Silica	28
Carbon	29
Metals	30
Aluminum	32
Barium	33
Cadmium	34
Chromium	35
Copper	36
Iron	36
Lead	37
Manganese	38
Molybdenum	39
Nickel	39
Selenium	40
Silver	41
Zinc	41
Conclusions	44
References	46
Appendix A	i
Appendix B	iv

List of Figures

Figure 1. Peel River Basin with site locations	4
Figure 2. <i>Peel River above Fort McPherson</i> Hydrograph	7
Figure 3. Open water vs. under ice pH conditions at <i>Peel River above Fort McPherson</i> (1980-2000).....	9
Figure 4. Seasonal patterns of conductivity in grab samples at <i>Peel River above Fort McPherson</i> (1980-2000)	11
Figure 5. Seasonal patterns of turbidity in grab samples from <i>Peel River above Fort McPherson</i> (1980-2000)	12
Figure 6. Log-log relationship between discharge (Q) and concentration of total suspended solids (C_{TSS}) (1980-2000)	13
Figure 7. Concentration of TDS at 15 sites in the Peel River basin, March 1999.....	14
Figure 8. Seasonal patterns of dissolved calcium and sulphate from <i>Peel River above Fort McPherson</i> (1980-2000)	16
Figure 9. Alkalinity at <i>Peel River above Fort McPherson</i> (1980-2000)	17
Figure 10. Alkalinity results at 15 sites in the Peel River drainage basin, March 1999.....	17
Figure 11. Hardness at <i>Peel River above Fort McPherson</i> (1980-2000).....	18
Figure 12. Level of water hardness at 15 sites in the Peel River drainage basin, March 1999	18
Figure 13. Limestone pillars in the Peel River, Yukon, just past the confluence of the Peel and Bonnet Plume Rivers	19
Figure 14. Concentration of calcium at 15 sites in the Peel River drainage basin, March 1999.....	20
Figure 15. Concentration of magnesium at 15 sites in the Peel River drainage basin, March 1999	20
Figure 16. Seasonal Patterns of dissolved potassium in grab samples from <i>Peel River above Fort McPherson</i> (1980-2000).....	21
Figure 17. Concentration of sulphate at 15 sites in the Peel River drainage basin, March 1999	22
Figure 18. Total and dissolved phosphorous grab samples from <i>Peel River above Fort McPherson</i>	25
Figure 19. Dissolved ammonia concentrations from grab samples collected at <i>Peel River above Fort McPherson</i> (1980-2000)	26
Figure 20. NO_3+NO_2 concentrations from grab samples collected at <i>Peel River above Fort McPherson</i> (1980-2000)	27
Figure 21. Concentration of nitrate and nitrate/nitrite at 15 sites in the Peel River drainage basin, March 1999	27
Figure 22. Concentration of nitrate/nitrite at 15 sites in the Peel River drainage basin, March 1999	28
Figure 23. Reactive silica concentrations from grab samples collected at <i>Peel River above Fort McPherson</i> (1980-2000).....	28
Figure 24. Total cobalt concentrations at <i>Peel River above Fort McPherson</i> from 1980-2000	30
Figure 25. Northern Ogilvie Mountains at the headwaters of the Porcupine River, Yukon (early October)	32
Figure 26. Total barium concentrations from grab samples collected at <i>Peel River above Fort McPherson</i> (1980-2000).....	33
Figure 27. Concentration of total and dissolved barium at 15 sites in the Peel River watershed, March 1999	33
Figure 28. Levels of total cadmium throughout the Peel River Basin, March 1999	34
Figure 29. Concentration of total chromium at 15 sites in the Peel River drainage basin, March 1999	35
Figure 30. Concentration of total and dissolved copper at 15 sites in the Peel River drainage basin, March 1999	36
Figure 31. Concentration of total iron at 15 sites in the Peel River drainage basin, March 1999	36
Figure 32. Concentration of total and dissolved lead at 15 sites in the Peel River drainage basin, March 1999	37
Figure 33. Concentration of total and dissolved manganese at 15 sites in the Peel River drainage basin, March 1999	38
Figure 34. Concentration of total and dissolved molybdenum at 15 sites in the Peel River drainage basin, March 1999.....	39
Figure 35. Concentration of total and dissolved nickel at 15 sites in the Peel River drainage basin, March 1999.....	40
Figure 36. Concentration of total and dissolved selenium at 15 sites in the Peel River drainage basin, March 1999.....	41
Figure 37. Concentration of total and dissolved zinc at 15 sites in the Peel River drainage basin, March 1999.....	42

List of Tables

Table 1. Water quality station names and locations	2
Table 2. <i>Peel River above Fort McPherson</i> physical parameters raw data summary (1980-2000).....	5
Table 3. <i>Peel River above Fort McPherson</i> major ions raw data summary (1980-2000)	5
Table 4. <i>Peel River above Fort McPherson</i> nutrients raw data summary (1980-2000)	6
Table 5. <i>Peel River above Fort McPherson</i> metals raw data summary (1980-2000)	6
Table 6. Peel River Basin flow data (March 1999).....	10
Table 7. Seasonal variation of physical parameters at <i>Peel River above Fort McPherson</i> (means and medians by water-year).....	15
Table 8. Seasonal variation of major ions (mg/L) at <i>Peel River above Fort McPherson</i> (median and means by water-year).....	23
Table 9. Seasonal variation of nutrients (mg/L) in the Peel River (median and means by water-year)	29
Table 10. Spearman's correlation results of total suspended solids and various metals.....	31
Table 11. Seasonal variation of metals at <i>Peel River above Fort McPherson</i> (median and means by water-year)	42

Introduction

A survey of water chemistry and stream flow in the Peel River watershed was undertaken in March 1999 by the Department of Indian Affairs and Northern Development (DIAND) Water Resources staff from Yellowknife and Whitehorse. The Peel River Basin lies mainly in the northern Yukon, but the Peel River discharges through the Northwest Territories where it joins the Mackenzie River. Remote drainage basins in the north are difficult to monitor due to high logistical costs and poor access. As such, water quantity and quality information from northern Yukon and NWT watersheds is limited. Data collected in this study provides a snapshot of winter water quality in this remote basin. This report also examines historic water quality data collected at *Peel River above Fort McPherson* since 1980. Seasonal patterns are examined and compared to March 1999 data. The baseline data examined in this report can be used to monitor changes in water quality caused by anthropogenic disturbances or natural phenomena. Although the region has no major industrial development at present, there is potential for oil and gas exploration in the Yukon portion of the basin.

Study Area

The Peel River is a transboundary river that drains an area of approximately 70 600 km² (Hydat, 2001). The Peel River originates in the Yukon (YT) and drains the northern part of the territory between 64 and 67 degrees north and 131 and 140 degrees west. From its headwaters in the Ogilvie Mountains, the river flows eastward for 193 km to meet the Snake River. It then continues in a northerly course for 237 km to Fort McPherson in the Northwest Territories (NT). The river eventually empties into the Mackenzie River, approximately 65 km south of Aklavik, NT (MacDonald Environmental Sciences, 1994). Throughout its course, the Peel River is joined by six major tributaries, including the Ogilvie, Blackstone, Hart, Wind, Bonnet Plume and Snake Rivers. The smaller tributaries within this basin are the Caribou, Trail, Road, Satah, and Vittekwa Rivers (Figure 1).

The Peel River Basin spans two distinct ecozones. The headwaters of the Peel River Basin are located in the Taiga Cordillera Ecozone. This remote region contains the northernmost stretch of the Rocky Mountains, but also contains rolling foothills, upland plateaus, and low-lying basins. Sedimentary rocks like sandstone, shale, limestone and dolomite are abundant in the area, while more recent activity produced igneous mountain formations. The cold, humid climate promotes alpine and subalpine plant species, while the northernmost portion of the basin has vast wetlands of poplar, willow, and alder (Environment Canada, 2001). The northeast portion of the Peel Basin is part of the Taiga Plains Ecozone. A region of discontinuous and continuous permafrost, this ecozone is characterized of having short cool summers and long, very cold winters typical of a high subarctic ecoclimate. The mean annual temperature is approximately -7°C (summer mean 10°C; winter mean -24°C) (Environment Canada, 2001). Annual precipitation averages 300 mm. The geology is predominately sedimentary rock, such as limestone, shale and sandstone. Vegetation is predominately open stands of stunted black spruce and tamarack as well as dwarf birch, willow, shrubs, lichens and moss.

The water, wildlife and fisheries resources produced in the Peel Basin are used to support the traditional culture and subsistence lifestyle (hunting, trapping, and fishing) of numerous residents within the area (MacDonald Environmental Sciences, 1994). Residents include the Tetlit Gwich'in in Fort McPherson, the Inuvialuit in Aklavik, the Na-Cho Ny'a'k Dun in Mayo and the Tr'on Dek Hwech'in of Dawson City. Characteristic wildlife includes caribou (home range of the Porcupine Caribou herd), mountain goats, Dall's sheep, moose, grizzly bear, wolf, fox, hare and beaver as well as numerous species of birds and waterfowl. Some recreation and tourism activity is carried

out in the Peel River area (Environment Canada, 2001). The Dempster Highway connects the Mackenzie Delta communities in the Northwest Territories with the North American highway network through the Yukon Territory. The highway crosses the upper reaches of the basin providing limited road access and highway support facilities for work in this region.

Sampling Program

Two different sampling programs will be discussed as there were two different datasets to be examined: long term water quality data at *Peel River above Fort McPherson* (NW10MC0001) and water quality data collected in March 1999 at various sites throughout the basin. The water quality site names and locations are listed in Table 1.

Table 1. Water quality station names and locations

Letter Code	Water Quality Station	Location (Latitude, Longitude)
A	Ogilvie River above Engineer Creek	65°22'42"N 138°17'22"W
B	Ogilvie River near Mouth	65°52'00"N 137°16'00"W
C	Blackstone River near Champion Lake	64°52'03"N 138°17'14"W
D	Blackstone River near Mouth	65°51'00"N 137°15'00"W
E	Peel River above Hart River	65°51'00"N 136°25'00"W
F	Hart River near Hungry Lake	65°42'16"N 136°25'08"W
G	Peel River above Canyon Creek	65°53'40"N 136°02'20"W
H	Wind River near Mouth	65°49'50"N 135°17'08"W
I	Peel River above the Bonnet Plume River	65°55'00"N 135°04'00"W
J	Bonnet Plume River above Gillespie Creek	64°44'24"N 133°40'21"W
K	Bonnet Plume River above Mouth	65°52'00"N 134°55'00"W
L	Peel River above Snake River	65°58'00"N 134°15'00"W
M	Snake River above Mouth	65°58'10"N 134°01'40"W
N	Peel River above Caribou River	65°30'00"N 134°10'00"W
O	Peel River above Fort McPherson	67°13'60"N 134°54'00"W

Water Quantity

Water Survey of Canada (WSC) staff in Inuvik operate the *Peel River above Fort McPherson* hydrometric station (10MC002). The station is located at 67°14'56" N and 134°52'59" W and has been active since 1969. The gauge station measures a basin area of 70,600 km².

During the March 1999 study, flow measurements were carried out according to the WSC procedures. Holes were drilled in the ice across the river. Distances were measured using a 50m tape. Ice thickness and water depth were measured using the ice rod. Flow velocities were measured with a calibrated winter meter. Discharges were later calculated. Equipment for flow measurement using salt dilution was taken into the field although it was not used, as the smaller rivers did not have enough flow to measure.

Water Quality

As part of the NWT Water Quality Monitoring Network and through a cost-sharing agreement, Environment Canada (EC) in co-operation with the Water Resources Division of Indian and Northern Affairs Canada has collected water quality data at *Peel River above Fort McPherson* (67°13'60"N 134°54'00"W) sporadically from 1960 to 1979 and continuously since 1980. Routine parameters include physical parameters, nutrients, major ions, and total and extractable metals. EC has also collected data at *Peel River at Fort McPherson* (NW10MC0002). Data collected from this site is very sporadic (1969-1974, 1987, 1994) and will not be included in this report.

The Water Survey of Canada (WSC) staff in Inuvik carries out water quality collection at *Peel River above Fort McPherson*. Some sampling visits are opportunistic because of weather and availability of aircraft, but every effort has been made to visit the site regularly in May, June, August and January. Field quality assurance/quality control (QA/QC) sampling was carried out throughout most of the sampling period. QA/QC consisted of field triplicates, which ensure confirmation of repeatability and one field blank that confirms the lack of contamination during the collection and shipping of the sample to the laboratory.

In the open water season, grab samples are collected from a boat. In winter, samples are collected from an ice hole. WSC collection consists of water samples collected in five specially marked bottles which are tested respectively for physical parameters, nutrients, major ions, total metals and dissolved selenium and arsenic. All samples are kept in a cooler upon collection. A preservative supplied by the laboratory (5 mL, 20% concentration nitric acid) is added to the metals sample. Upon return from the field, samples are kept at 4°C until analysed at the laboratory. The Taiga Environmental Laboratory (TEL) of the Department of Indian Affairs and Northern Development in Yellowknife, NT, carried out the analyses of physical parameters and some nutrients. The National Laboratory of Environmental Testing (NLET) of Environment Canada in Burlington, Ontario carried out the analyses for major ions, nutrients (Particulate Organic Carbon, Particulate Organic Nitrogen), and metals.

The Department of Indian Affairs and Northern Development (DIAND) Water Resources staff from Yellowknife and Whitehorse carried out all March 1999 sampling. A survey of water chemistry in the Peel River watershed was undertaken March 9, 10, and 11th, 1999 to document under ice water quality conditions throughout the basin. March was selected as it was near the end of the winter period, prior to the beginning of freshet and sufficient daylight was available to allow efficient helicopter operations. Fifteen sampling sites were selected to provide representative water data for the Peel River and its tributaries (Figure 1). March data include results for physical parameters, nutrients, major ions, total metals and dissolved metals. A preservative supplied by the laboratory of 5 mL 1:1 nitric acid was added to the total and dissolved metals sample bottles. The samples were returned to the hotel. The dissolved metals samples were filtered through a prepackaged 0.45-micron filter into a new sample bottle. Samples were kept in a plastic Coleman cooler at all times. The temperatures of -20°C to -30°C in the field meant that some ice formed in the sample bottles but no bottle froze completely. All coolers were kept in a helicopter, warm vehicle and hotel room. Upon arrival in Whitehorse the samples were stored in a cooler at 4°C. The samples were shipped directly from Whitehorse to Yellowknife in the coolers. All analyses were carried out at TEL.

To conduct the March 1999 sampling, a base camp was established at the Eagle Plains Lodge (66°22'N, 136°43'W) on the Dempster Highway. Two Bell Long Ranger helicopters were used to move the crews to most of the sample sites. A vehicle was used for transportation to the two sites accessible from the road (*Ogilvie above Engineer Creek* and *Blackstone near Champion Lake*). A QA/QC program was carried out for the March study as well. Duplicate samples were collected at five of fifteen sites and a triplicate sample was collected at *Peel River above Fort McPherson* (Appendix 'A').

Data Handling and Statistics

Peel River above Fort McPherson water quality data were provided by Environment Canada (EcoAtlas™, 2001). Although data have been collected since 1960, only the results from 1980 to 2000 were analyzed because of changing analytical techniques, detection limits, and continuity of the data. Triplicate samples were reduced to single samples by calculating the median value for each parameter. Laboratory results are often expressed as less than the detection limit ("L"). Where this occurred, "less than" values were treated as results equal to the detection limit. All data were carefully reviewed and basic statistics were computed. Maximum, minimum, mean, median, standard deviation (SD), number of samples (n) and number of samples below detection (ndets) were determined for each parameter. The tenth and ninetieth percentile were also calculated. Percentiles are measures of location and spread. For a set of data arranged in rank order, the pth percentile is a number such that p% of the data is below and (100 - p)% of the data is above the pth percentile. The percentile calculations provide information on what we can expect in the future given past sample results. Raw data summaries are presented in Table 2 to 5.

Table 2. *Peel River above Fort McPherson* physical parameters raw data summary (1980-2000)

	units	n	ndets	mean	median	max	min	SD	90th	10th
pH	pH units	145	0	7.91	7.92	8.47	6.73	0.23	8.18	7.69
Colour True	TCU	135	31	22.3	10.0	160.0	5.0	28.3	60.0	5.0
Specific Conductance	uS/cm	144	0	360	385	516	166	71	435	247
Temperature Water	deg C	126	0	4.74	0.00	18.00	0.00	6.08	15.00	0.00
Total Dissolved Solids	mg/L	53	0	245.0	250.0	391.0	126.0	43.3	289.0	193.4
Total Suspended Solids	mg/L	143	22	168.1	16.0	1853.0	1.0	346.8	541.8	1.0
Turbidity	NTU	144	0	101.5	9.7	1210.0	0.6	207.0	335.4	1.0

Table 3. *Peel River above Fort McPherson* major ions raw data summary (1980-2000)

	units	n	ndets	mean	median	max	min	SD	90th	10th
Alkalinity Total CaCO ₃	mg/L	139	0	127.8	133.0	188.0	51.5	28.1	157.0	82.4
Calcium Dissolved/Filtered	mg/L	138	0	47.1	49.6	71.8	21.6	9.4	56.6	32.1
Chloride Dissolved	mg/L	138	0	2.84	2.80	10.90	0.82	1.54	4.20	1.27
Fluoride Dissolved	mg/L	138	2	0.1	0.1	0.8	0.01	0.1	0.1	0.1
Magnesium Dissolved/Filtered	mg/L	138	0	14.8	16.0	25.9	5.8	3.5	18.0	9.4
Potassium Dissolved/Filtered	mg/L	138	0	0.59	0.53	1.11	0.25	0.14	0.80	0.47
Sulphate Dissolved	mg/L	138	0	54.0	53.2	96.3	17.5	15.1	73.7	36.1
Strontium Dissolved	mg/L	48	0	0.169	0.170	0.222	0.103	0.20	0.190	0.149
Sodium Dissolved/Filtered	mg/L	138	0	4.68	4.80	9.96	1.89	1.37	6.09	2.70

Table 4. *Peel River above Fort McPherson* nutrients raw data summary (1980-2000)

	units	n	ndets	mean	median	max	min	SD	90th	10th
Ammonia Dissolved	mg/L	51	4	0.0244	0.0130	0.1710	0.0006	0.0345	0.0410	0.0050
Carbon Dissolved Inorganic	mg/L	12	0	32.0	34.0	39.3	17.0	6.3	37.4	24.9
Carbon Dissolved Organic	mg/L	131	0	3.3	2.4	13.7	0.3	2.5	6.7	1.1
Carbon Particulate Organic	mg/L	131	0	2.9	0.4	39.0	0.04	6.0	10.3	0.1
Nitrogen Dissolved NO ₃ and NO ₂	mg/L	131	0	0.1170	0.1030	0.2240	0.0200	0.0534	0.1900	0.0570
Nitrogen Particulate	mg/L	131	20	0.2541	0.0400	3.5000	0.0030	0.5055	0.8150	0.0100
Nitrogen Total Dissolved	mg/L	141	0	0.2394	0.2000	0.8550	0.0900	0.1381	0.4090	0.1300
Phosphorous Total	mg/L	142	3	0.154	0.027	1.360	0.002	0.275	0.499	0.005
Phosphorous Total Dissolved	mg/L	142	34	0.012	0.006	0.366	0.002	0.040	0.017	0.002
Reactive Silica	mg/L	138	0	3.46	3.53	5.10	1.82	0.58	4.17	2.64

Table 5. *Peel River above Fort McPherson* metals raw data summary (1980-2000)

	units	n	ndets	mean	median	max	min	SD	90th	10th
Aluminum Total	ug/L	47	0	1811.7	61.0	19900.0	11.0	4153.6	5264.0	25.6
Arsenic Dissolved	ug/L	148	30	0.3570	0.3000	4.6000	0.1000	0.4439	0.5000	0.1000
Barium Total	ug/L	139	22	125.4	99.0	413.0	50.0	67.3	216.8	80.0
Beryllium Total	ug/L	48	34	0.126	0.050	0.820	0.050	0.184	0.316	0.050
Boron Dissolved	ug/L	46	0	0.050	0.050	0.090	0.020	0.015	0.070	0.030
Cadmium Total	ug/L	141	68	0.6	0.2	5.2	0.10	0.7	1.0	0.1
Calcium Total	mg/L	48	0	53.2	54.5	75.0	25.6	8.4	60.9	44.8
Chromium Total	ug/L	48	6	3.1	0.5	29.8	0.2	6.2	9.1	0.2
Cobalt Total	ug/L	141	66	2.4	1.0	14.4	0.1	2.9	6.0	0.2
Copper Total	ug/L	140	16	5.6	2.1	57.0	0.2	9.1	16.2	0.5
Iron Total	mg/L	48	0	4.6	0.1	61.6	0.04	12.2	10.7	0.1
Lead Total	ug/L	140	54	2.9	1.3	22.8	0.2	3.7	6.1	0.2
Lithium Total	ug/L	48	3	12.6	9.3	53.9	5.6	9.7	20.3	6.7
Magnesium Total	mg/L	48	0	16.5	16.4	28.7	9.3	2.9	18.0	14.7
Manganese Total	ug/L	47	0	52.7	17.6	431.0	6.6	89.3	116.6	8.3
Mercury Total	ug/L	7	3	0.043	0.020	0.140	0.020	0.044	0.080	0.020
Molybdenum Total	ug/L	48	0	1.2	1.1	3.6	0.1	0.5	1.5	0.9
Nickel Total	ug/L	139	9	6.3	2.9	49.1	0.5	8.8	16.7	0.9
Potassium Total	mg/L	48	0	0.79	0.61	2.28	0.43	0.44	1.22	0.49
Selenium Dissolved	ug/L	142	12	0.6211	0.6000	1.2000	0.3000	0.1367	0.8000	0.5000
Silver Total	ug/L	16	14	0.1	0.1	0.1	0.1	0.0	0.1	0.1
Sodium Total	mg/L	48	0	3.98	4.02	6.79	1.20	1.14	5.10	2.41
Vanadium Total	ug/L	140	38	5.1	1.0	70.7	0.1	10.6	15.2	0.2
Zinc Total	ug/L	138	1	22.3	8.2	212.0	0.5	35.4	57.6	1.5

The data were organized according to the period of ice cover to compare “winter” water quality to “summer” water quality. The “under ice” period extends from approximately mid-October to mid-May while the “open water” period extends from approximately the mid-May to mid-October. Ice cover periods were based on historic hydrometric and site observations.

Without matching long-term water quality data to the hydrometric data, the influence of water discharge is unnoticed and the degree of data variability is exaggerated. To further investigate the influence of seasonality, the data were separated according to water-year. There are three main portions of the water-year; the spring freshet (high flow), the late summer and fall recession and the late winter baseflow (Halliwell, 1998). Portions of the water-year vary greatly with geography and hydrology. The annual freshet generally occurs in late May or June. The months of July, August and September constitute the recession, and October to early May constitutes the baseflow. Water-year estimations were made based on the daily mean discharge hydrograph (Figure 2), which illustrates the fluctuation in water discharge throughout the year. 1993-1999 datasets (excluding 1998) were used to produce the hydrograph. The year 1998 did not have a complete year of data. Temporal variability was examined by comparing water quality between water years.

The data from the March 1999 sampling period received from TEL were entered into spreadsheet format. After data entry, all data were verified against the laboratory sheets, and basic statistics were computed. Graphs and maps were generated to illustrate any spatial variation throughout the basin. Where duplicate or triplicate samples were taken, one sample was randomly chosen to represent the site. The raw data is included in Appendix B.

Parametric tests make certain assumptions about background populations from which samples are drawn. The most important assumptions are that the background populations are normally distributed and have equal variances. Most water quality data do not have a normal distribution, contain outliers and generally exhibit seasonal fluctuations. Statistical testing of sample distribution was carried out with Statgraphics™ Plus v.4.1. Methods used to test the data for normality include the Shapiro-Wilks test and the standardized skewness, which looks for lack of symmetry in the data. Sulphate was the only variable that was normally distributed. Because so many of the data sets were not normally distributed, non-parametric (distribution-free) statistics were used throughout this report (WER Agra, 1993). The use of non-parametric statistical methods does not require the assumption that the data follows any specific distribution (Gartner Lee, 2001).

The Mann-Whitney and Kruskal-Wallis tests are the non-parametric equivalent of the more familiar parametric t-test and one-way analysis of variance. These tests examine the hypothesis that the medians between 2 (Mann-Whitney) or more (Kruskal-Wallis) groups of data are equal versus the alternative hypothesis that they are not. The tests check for significant differences among the medians, due primarily to seasonality. Water quality between water-years were compared. All statistical analyses including Spearman's correlation were carried out with Statgraphics™ Plus v.4.1. The Spearman correlation coefficients range between -1 and 1 and measure the strength of the association between two variables. In contrast to the more common Pearson correlation, the non-parametric Spearman correlation coefficient (Spearman's 'rho') is computed from the ranks of the data values rather than from the values themselves. 95% confidence levels were used to determine significance. Microsoft® Excel 2000 was used to investigate the relationship between discharge and total suspended solids.

Seasonal trends were analyzed graphically by inspection of Box and Whisker plots (Figure 3). The central "box" covers the middle 50% of the data; the top and bottom of the box are the upper and lower quartiles (75%, 25% respectively). The horizontal line inside the box is the median (the mean is plotted as an "+"). The whiskers extend above and below the box. The lower whisker is drawn from the lower quartile to the smallest point within 1.5 interquartile ranges from the lower quartile. The upper whisker is drawn from the upper quartile to the largest point within 1.5 interquartile ranges from the upper quartile. Any values found beyond

the whiskers are considered extreme values (suspect outliers are plotted as an empty square box, 'confirmed' outliers are plotted with a "+" through the square box). Below (Figure 3) is an example of a box and whisker plot using actual pH results from *Peel River above Fort McPherson*. Here, 50% of the open water data lies between 7.86 (lower quartile) and 8.09 (upper quartile) which means that 25% of the data should fall below 7.86 and 25% should be greater than 8.06. The median is 8.00. There are three suspect outliers, one of which happens to be the maximum value of 8.47. There are two confirmed outliers, one of which happens to be the minimum value of the dataset reported at 6.73.

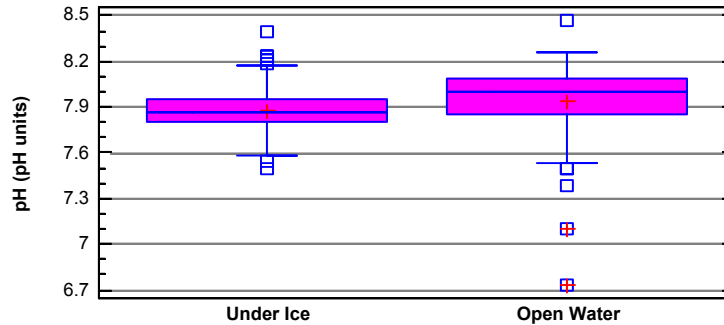


Figure 3. Open water vs. under ice pH conditions at *Peel River above Fort McPherson* (1980-2000)

Water quality data were compared to Health and Welfare Canada's *Canadian Water Quality Guidelines for Drinking Water* (CDWQ) and the Canadian Council of Ministers of the Environment (CCME) *Canadian Water Quality Guidelines for the Protection of Freshwater Aquatic Life* (CPFAL). Also used were the CCME *Aesthetic Objectives* that ensure water quality is of good aesthetic quality (appearance, smell and taste).

The CPFAL are based on a thorough review of information on the toxicity of different water quality parameters; however, as national guidelines, they may not reflect the specific conditions in northern ecosystems. The CDWQ are meant for use on drinking water after treatment. Not all water quality variables have an established guideline. The CDWQ and CPFAL provide a useful basis for comparison of the results collected in this study, but should be interpreted with care.

Results and Discussion

Water Quantity

Of the seven sites attempted, only four flow measurements were made during the March 1999 study. Frazil ice was encountered at the *Peel River above the Hart River*, so a flow measurement was not possible. The Bonnet Plume River is braided at its confluence with the Peel River and the channels were not frozen, thus a measurement could not be made. A measurement was not attempted at *Peel River above Canyon Creek*. As there is a very good correlation between this site and the *Peel River above Fort McPherson*, flow was calculated rather than measured. The measurement at the Snake River was not finished as bad weather moved in and precluded completion. Recorded measurements should be considered good estimates only. All stations and flow measurement results are listed in Table 6.

Table 6. Peel River Basin flow data (March 1999)

Station Name	Discharge (m ³ /s)
Peel River above Hart River (E)	n/a
Hart River near Hungry Lake (F)	13.1
Peel River above Canyon Creek (G)	20.5*
Bonnet Plume River above the mouth (K)	n/a
Snake River above Mouth (M)	4.9
Wind River near Mouth (H)	6.9
Peel River above Fort McPherson (O)	77.3

* indicates calculated number

The historical maximum and minimum flow rates in March at *Peel River above Fort McPherson* was 117 m³/s and 45.3m³/s, respectively. The mean flow rate for March is 76.4 ± 16.0 m³/s, which was very close to the flow rate recorded at Peel River above Fort McPherson in March, 1999. The maximum flow rate ever recorded was 8800 m³/s on May 29, 1992 during the freshet.

Water Quality

Physical Parameters

pH

pH is a measure of the balance between acids and bases in water. It is measured on a scale of 0-14 pH units, where 7 indicates a neutral condition (drinking water). Any value less than 7 is considered acidic and any value greater than 7 is considered basic. *Peel River above Fort McPherson* water was found to have a median pH value of 7.92. Laboratory measurements of pH ranged between 6.73 and 8.47 units (n=145), which is within the range of CDWQ aesthetic guidelines (6.5-8.5 pH units) and CPFAL guidelines (6.5-9.0). It should be noted that the minimum value of 6.73 is the only pH value less than 7.0. When the 6.73 value is removed from the dataset, the pH range at this site is 7.10 to 8.47.

All pH results from the March 1999 study fell within the historic range recorded at *Peel River above Fort McPherson* and were within the CPFAL and CDWQ guidelines.

Conductivity

Conductivity is a measure of the ability of an aqueous solution to conduct an electrical current and is a useful indicator of the degree of mineralization in a sample (Mg, Na, K, Cl, and dissolved metals). Specific conductance of natural surface water can range from 50 to 1500 $\mu\text{S}/\text{cm}$ (McNeely *et al.*, 1979). There are no guidelines for conductivity. Lab measurements from the Peel River ranged from 166 to 516 $\mu\text{S}/\text{cm}$ (n=144). Conductivity at Peel River above Fort McPherson is highest during baseflow when groundwater contributes the greatest proportion to streamflow and lowest during the spring freshet when the river water is diluted during the spring snowmelt (Figure 4). Winter concentrations of several variables are predictable based upon the relationship of those variables to conductivity (Whitfield *et al.*, 1995, 1996). Examination of the historic Peel River data revealed moderately strong positive correlations of conductivity with hardness (Spearman's $D=0.74$), alkalinity ($D=0.84$), dissolved calcium ($D=0.82$). These relationships are expected as conductivity is a measure of the dissolved constituents of water.

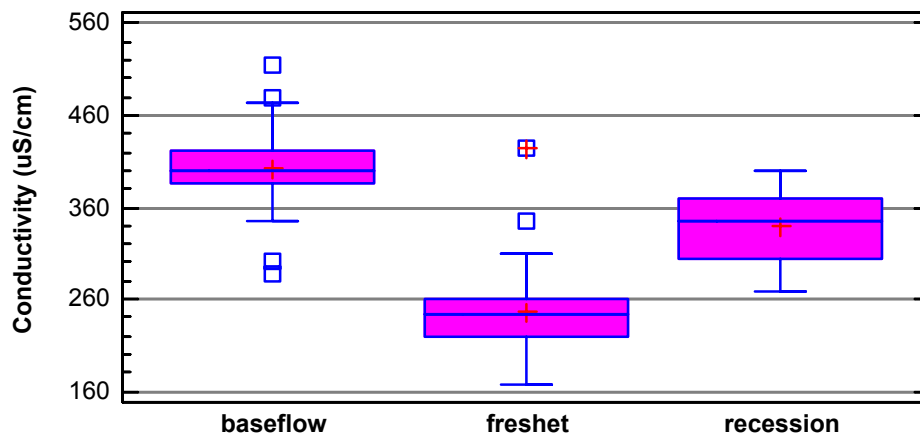


Figure 4. Seasonal patterns of conductivity in grab samples at *Peel River above Fort McPherson* (1980-2000)

Conductivity measurements during March 1999 ranged from 352 to 601 $\mu\text{S}/\text{cm}$. The lowest value of 352 $\mu\text{S}/\text{cm}$ was detected at *Wind River near the Mouth* (H) while 601 $\mu\text{S}/\text{cm}$ was detected at *Snake*

River above the Mouth (M). High conductivity results are expected during the baseflow, but some of these findings were out of the range of the historic data (Appendix 'B'). As conductivity is negatively correlated with flow, it is expected that the highest conductivities should be observed on the tributaries of the Peel River. In fact, the highest conductivity was observed at Site M, *Snake River above the Mouth*, which also had a low flow in March 1999.

Turbidity

Turbidity is a measure of the amount of suspended particles in water, such as silt, clay, organic matter, plankton and microscopic organisms. Turbidity is usually related to discharge because the amount of suspended particles depends primarily on flow (as well as surface runoff/land disturbances, instream erosion and algal growth). Turbidity is what gives rivers its “muddy” or “cloudy” appearance (*nephos* is Greek for cloud). Results in the Peel ranged from 0.6 to 1210 NTU (nephelometric turbidity units) (n=144). The CDWQ guideline is 1 NTU (90% of the samples exceeded this guideline) and the CDWQ aesthetic guideline is <5 NTU (53% of the samples exceeded this guideline). Turbidity concentrations rise sharply during spring freshet, then decrease during fall and winter low flows (Figure 5).

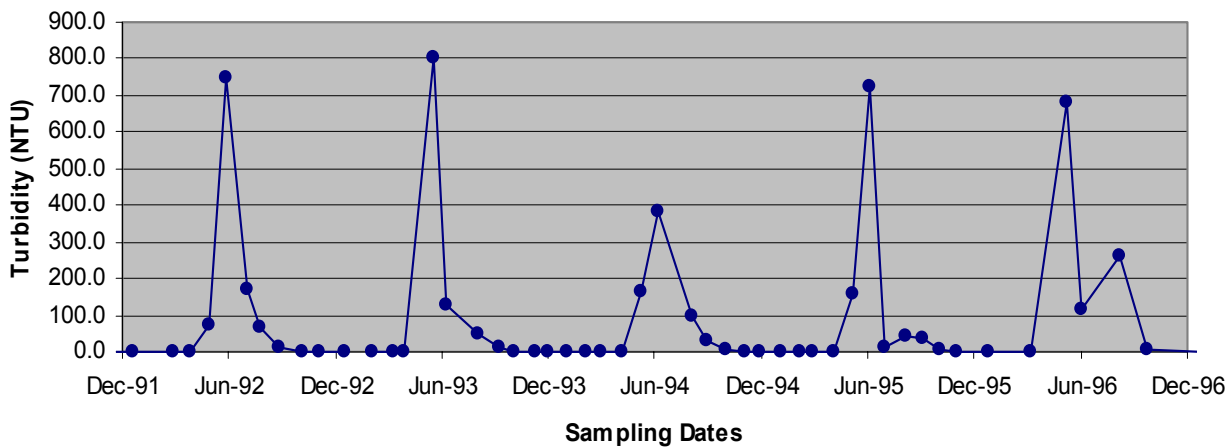


Figure 5. Seasonal patterns of turbidity in grab samples from *Peel River above Fort McPherson* (1980-2000) Turbidity values are highest during the spring freshet (late May and June) and lowest during the winter baseflow.

The rivers of the Peel River basin are at very low flow and ice covered for about eight months of the year. During this period turbidity, suspended solids and associated parameters would be expected to remain near detection levels. This is the case for all the stations except for *Peel River above Caribou River* (N), where the turbidity was measured at 127 NTU and total suspended solids were measured at 135 mg/L. This sample exceeded the CDWQ guideline of 1 NTU. The first attempt to collect a water sample from this site was not successful. The water collected was muddy (dirt was noted) and frazil ice was present. The second attempt was taken from the center of the channel, and although the water was noted to be brownish, the sample was used for this study. During the winter, as ice cover thickens, occasionally bottom sediments are excavated and deposited as the channel adapts to changing conditions. One example is the case of frazil ice, which is known to be an agent of sediment transport. This can occur both directly when sediment adheres to frazil ice particles, or indirectly when a frazil ice “dam” causes a concentration of flow and results in scouring of the riverbed (Prowse, 2000). While it is not possible to determine the exact cause of the sediment

release at *Peel River above Caribou River*, it has proven to be an interesting anomaly in the dataset that will be examined further in the rest of this report.

Total Suspended Solids/Nonfilterable Residue (TSS/NFR)

Total suspended solids (also called nonfilterable residue) is a measure of all the material, primarily silt and clay particles, suspended in the water column that will not pass through a 1.2 μm filter membrane. Suspended solids also consist of organic material such as plankton, bacteria and detritus that are washed into the river from the surrounding land. Both contribute to the turbidity of the water. TSS tends to be highest during the spring snowmelt or following large rain events, as water runs from the land into the water carrying with it inorganic and organic material. During periods of high flow, instream erosion can cause TSS levels to rise and can cause environmental problems such as loss of aquatic habitat, land loss, downstream sedimentation and problems with flooding. Suspended material can affect the suitability of drinking water and can clog fish gills. Suspended solids can also reduce light penetration, which reduces the ability of algae to produce food and oxygen.

Results from *Peel River above Fort McPherson* were found to have a mean TSS value of 168 mg/L and a range of 1 to 1853 mg/L ($n=143$). The maximum value (1853 mg/L) was detected on June 26, 1995. Suspended sediment concentrations are related to discharge, with peak concentrations of suspended sediment occurring during the rising hydrograph in June when water levels are high and sediment load is at its greatest. TSS was found to have a strong logarithmic correlation ($r^2=0.8772$) with flow (Figure 6). As expected in winter, during baseflow sediment loads are significantly lower because of the reduced supply of sediment and carrying capacity of the river (Table 7).

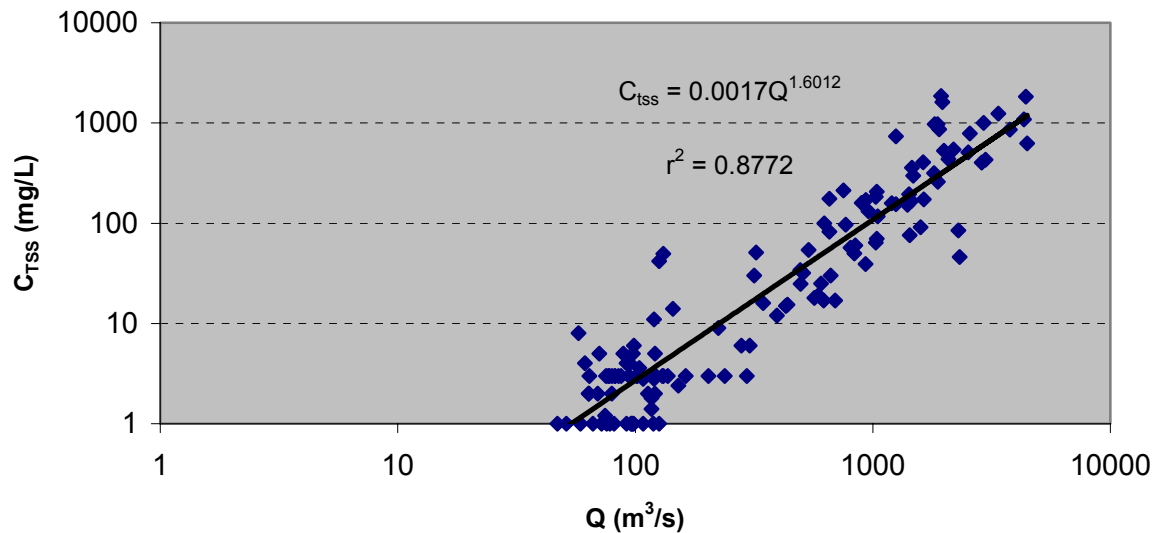


Figure 6. Log-log relationship between discharge (Q) and concentration of total suspended solids (C_{TSS}) (1980-2000)

All total suspended solids results sampled in March 1999 were very close to detection (3 mg/L) except the sample collected at *Peel River above Caribou River* (N), which was 135 mg/L, as discussed in "Turbidity".

Total Dissolved Solids/Filterable Residue (TDS/FR)

Total Dissolved Solids, like conductivity, measures the concentration of dissolved substances (in solution) in water. TDS is separated from TSS by filtration and includes dissolved inorganic ions as well as dissolved organic matter that will pass through the 0.45 μm porosity filter. The CDWQ aesthetic guideline for TDS is <500 mg/L. TDS in the Peel River ranged from 126 to 391 mg/L (n=53), all of which were below the recommended guideline. TDS remained relatively constant throughout the year (Table 7).

March 1999 total dissolved solids values ranged between 179 mg/L (Site H, *Wind River near Mouth*) and 370 mg/L (Site M, *Snake River above Mouth*) as shown in Figure 7. All values fell within the range of the historical range of data from *Peel River above Fort McPherson*, and were below the CDWQ aesthetic guideline.

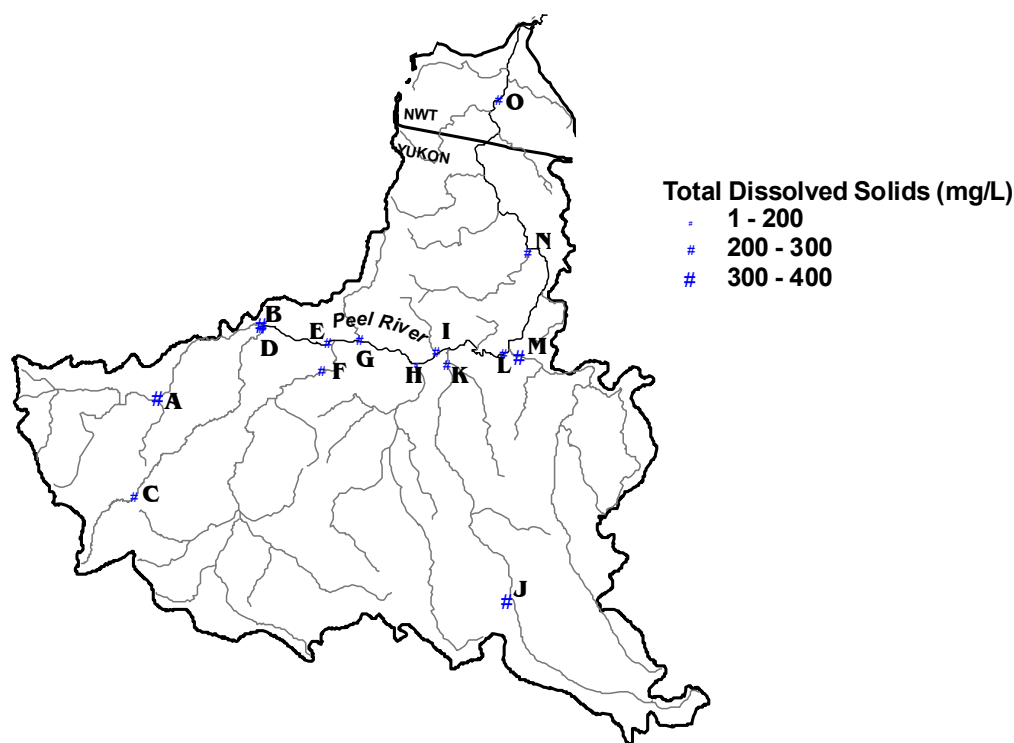


Figure 7. Concentration of TDS at 15 sites in the Peel River basin, March 1999

True Colour

True colour is a measure of the light absorption by the dissolved substances in water. True colour in the Peel River ranged from detection (5 true colour units) to 160 TCU (n=135) in early spring. While the concentration of other dissolved substances in water generally correlate negatively with flow (low concentration at freshet, high at baseflow), colour correlates positively with flow (Spearman's $\rho=0.83$). The high values for colour during freshet may be a result of snowmelt and rainfall washing highly coloured dissolved organic matter (such as tea-brown humic acid) into the river (Sanderson *et al.*, 1997).

All values sampled in March 1999 were less than the detection limit (5 TCU).

Table 7. Seasonal variation of physical parameters at *Peel River above Fort McPherson* (means and medians by water-year)

Parameter	Freshet	Recession	Baseflow
	median/mean	Median/mean	median/mean
pH* (pH units) (n, sd)	7.80/7.74 (25, 0.32)	8.02/8.04 (39, 0.16)	7.89/7.90 (81, 0.18)
Conductivity* (μ S/cm) (n, sd)	243/247 (25, 56)	344/338 (39, 39)	403/404 (80, 29)
Turbidity* (NTU) (n, sd)	288/336 (27, 226)	51/138 (38, 260)	1.8/4.9 (82, 7.8)
Total Suspended Solids* (mg/L) (n, sd)	436/553 (27, 422)	81/227 (38, 411)	3/6 (78, 9)
Total Dissolved Solids* (mg/L) (n, sd)	205/219 (11, 77)	239/235 (12, 31)	253/258 (30, 31)
True Colour* (TCU) (n, sd)	55/61 (27, 37)	20/25 (35, 20)	5/7 (73, 4.2)

* Calculated value for the Kruskal-Wallis test statistic is significant (95% confidence interval). Median values do differ significantly between water-years for all physical parameters.

Major Ions

The main source of ions in natural waters is from the weathering of rocks. Concentrations therefore vary according to geology. Major cations include calcium, magnesium, potassium, sodium and strontium and major anions include sulphate, fluoride, and chloride. Typically, an inverse relationship exists between ion concentration and discharge. Ion concentrations tend to be lowest during the high dilution period of the spring freshet (Figure 8). Concentrations rise until they peak in winter when the groundwater, most likely the major source of ions to the system, constitutes the highest proportion of flows (WER Agra, 1993). All major ion variables were tested (Kruskal-Wallis) to determine which variables differed significantly between the 3 portions of the water-year (freshet, recession, baseflow). All major ion results, other than potassium, were significantly lower during the spring freshet, and highest during the baseflow and recession. Seasonal variation of major ions in the Peel River is summarized in Table 8.

Example of Negative Flow Dependence (Dilution Effects)

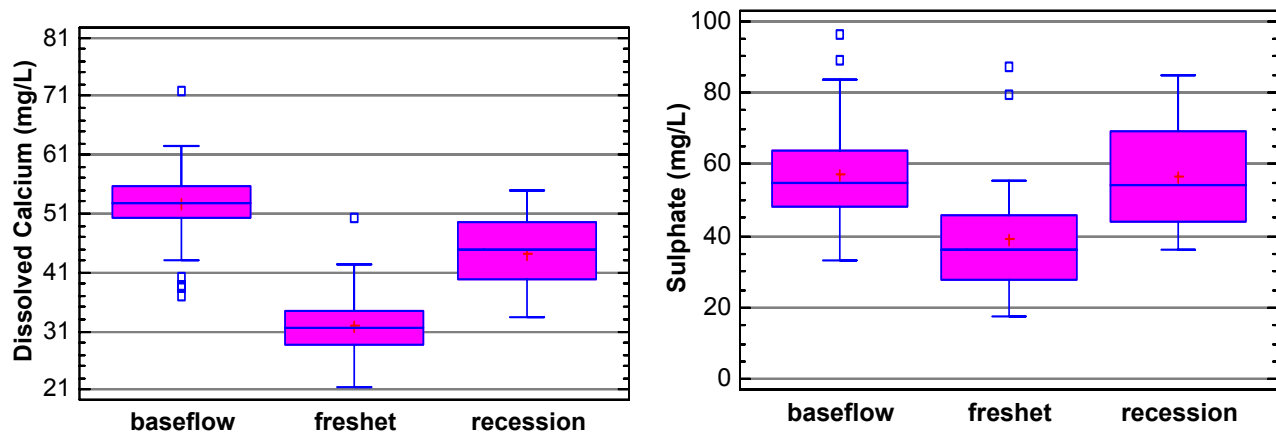


Figure 8. Seasonal patterns of dissolved calcium and sulphate from *Peel River above Fort McPherson* (1980-2000)

Alkalinity

Alkalinity refers to the capability of water to neutralize acid. It is really an expression of buffering capacity and is expressed in terms of CaCO_3 in mg/L. A buffer is a solution to which an acid can be added without changing the concentration of available H^+ ions (without changing the pH) appreciably. Results ranged from 52 to 188 mg/L ($n=139$). Percentile calculations indicated that 80% of all the data falls between 82 and 157 mg/L. Higher results were detected under ice than in open water ($\text{median}_{\text{ice}}=152$ mg/L, $\text{median}_{\text{open}}=111$ mg/L) as shown in Figure 9.

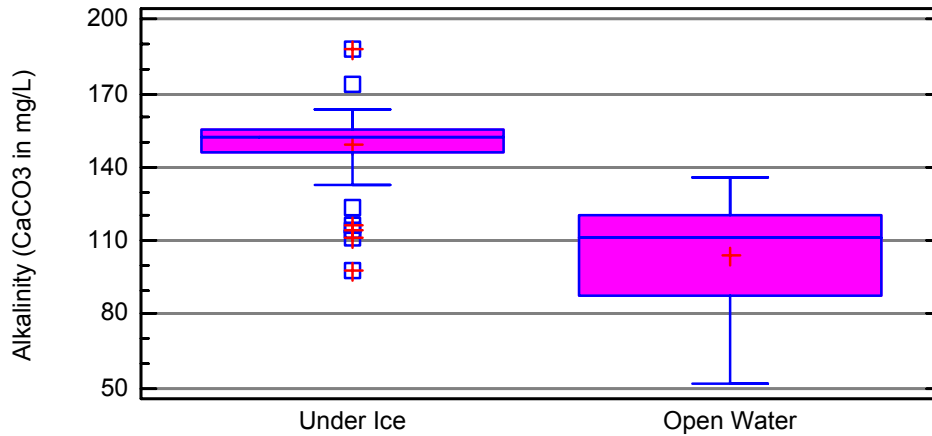
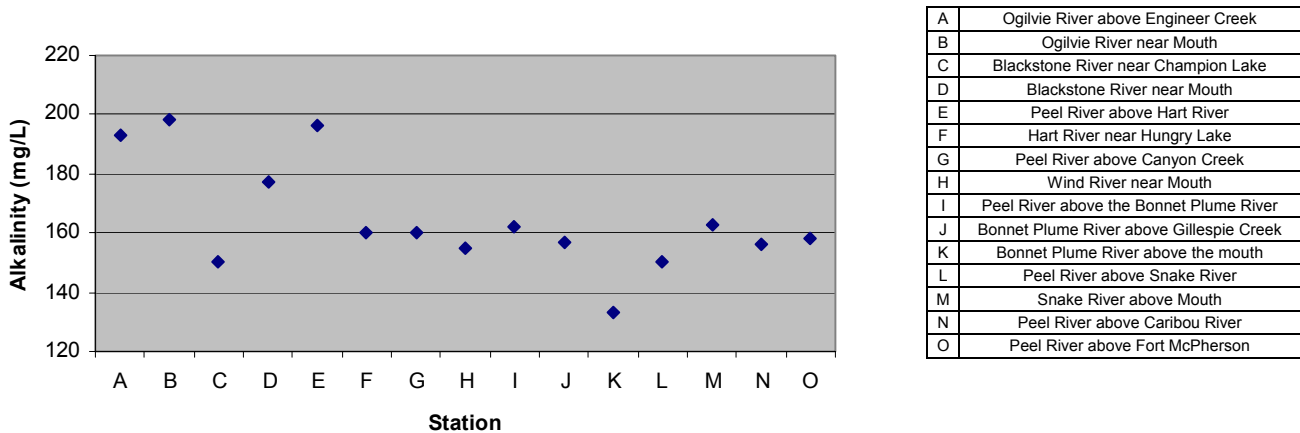


Figure 9. Alkalinity at Peel River above Fort McPherson (1980-2000)

March 1999 alkalinity results were high, as expected under ice. Values ranged from 150 to 198 mg/L (Figure 10).



A	Ogilvie River above Engineer Creek
B	Ogilvie River near Mouth
C	Blackstone River near Champion Lake
D	Blackstone River near Mouth
E	Peel River above Hart River
F	Hart River near Hungry Lake
G	Peel River above Canyon Creek
H	Wind River near Mouth
I	Peel River above the Bonnet Plume River
J	Bonnet Plume River above Gillespie Creek
K	Bonnet Plume River above the mouth
L	Peel River above Snake River
M	Snake River above Mouth
N	Peel River above Caribou River
O	Peel River above Fort McPherson

Figure 10. Alkalinity results at 15 sites in the Peel River drainage basin, March 1999

Hardness

Water hardness is defined as the sum of the calcium and magnesium concentrations and is expressed as an equivalent of calcium carbonate. Other constituents include iron, manganese and aluminum that may contribute to total hardness but are not normally present in appreciable amounts. Hardness is based on the ability of these ions to react with soap to form a precipitate or soap scum (McNeely *et al.*, 1979). Water hardness is a useful parameter for the interpretation of other water quality results as the toxicity of certain metals is dependent on water hardness. Water hardness was not a routine variable measured during EC’s monitoring program, nor was it measured in 1999 however a simple calculation can be performed to determine water hardness ($2.497 \cdot Ca + 4.117 \cdot Mg$) (Puznicki, pers. comm. 2001).

Water hardness ranged from 78 mg/L CaCO₃ (open water) and 286 mg/L CaCO₃ (under ice). Water hardness is expected to be higher under ice than in open water due to dilution effects on the dissolved ions (Figure 11). Hardness is primarily a function of the geology of the area with which the surface and ground water are associated. Given the underlying limestone in portions of the Peel River Basin it is not surprising to find “hard” water in this region (Figure 13). Mean water hardness above Fort McPherson was calculated as 179 mg/L (202 mg/L under ice; 153 mg/L open water). Based on this value, the Peel River is considered to have hard to very hard water.

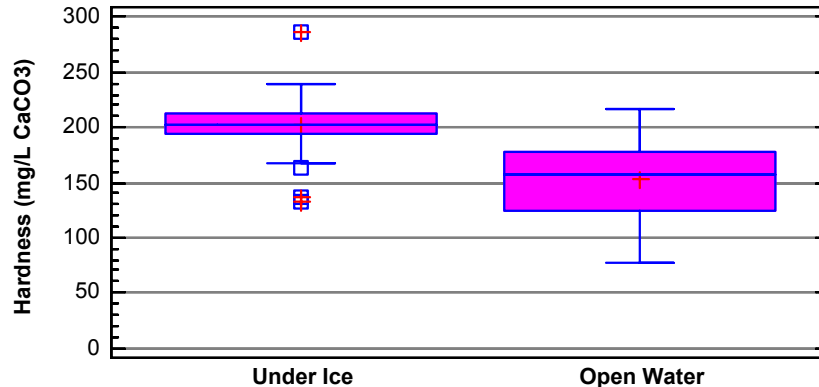


Figure 11. Hardness at *Peel River above Fort McPherson* (1980-2000)

The Mann-Whitney test confirmed a significant difference in water hardness between the under ice and open water season ($P < 0.05$).

Hardness was calculated for sites in the Peel River Basin, and like the historic data, was found to be quite high. As shown in Figure 12, the highest values were found to be at the *Bonnet Plume River above Gillespie Creek* (J) with a value of 332 mg/L and *Ogilvie River above Engineer Creek* (A) with a value of 328 mg/L.

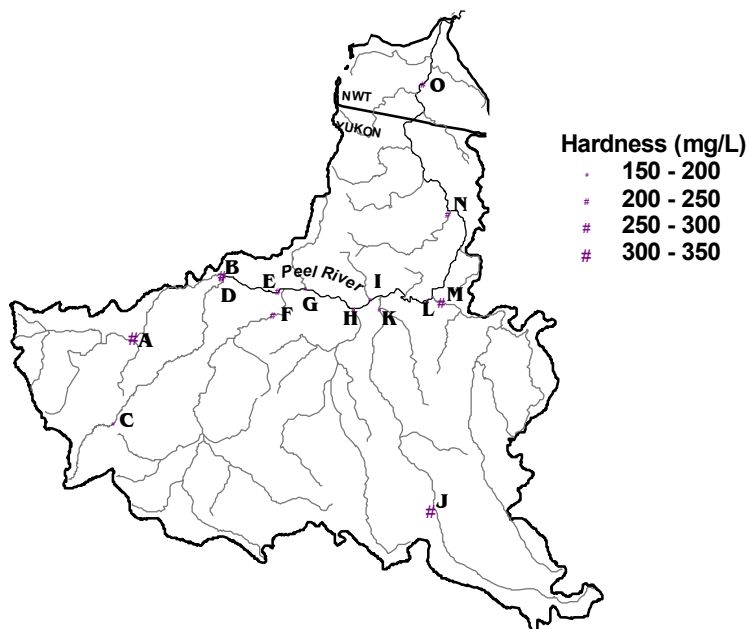
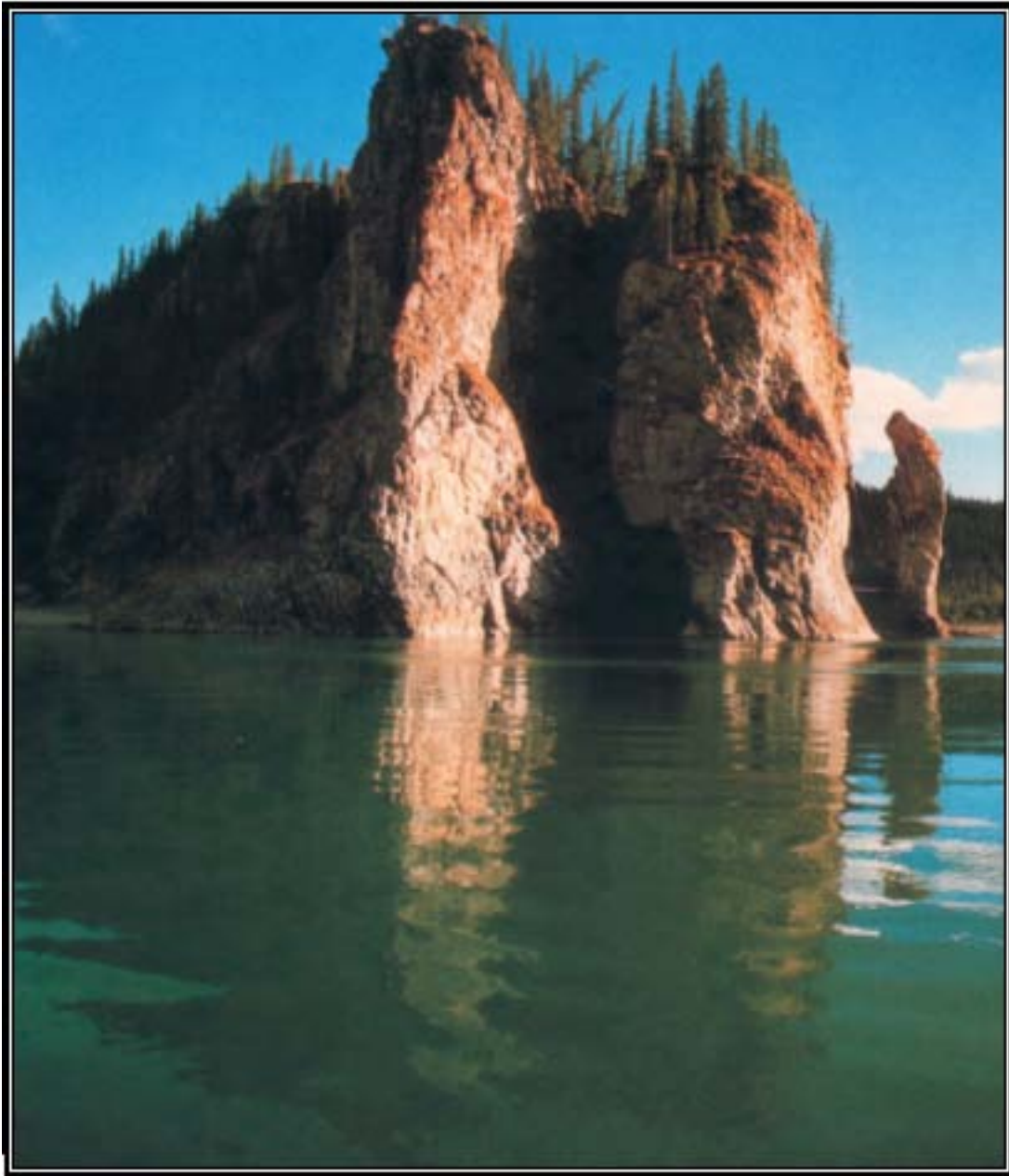


Figure 12. Level of water hardness at 15 sites in the Peel River drainage basin, March 1999



Paul von Baich

Figure 13. Limestone pillars in the Peel River, Yukon, just past the confluence of the Peel and Bonnet Plume Rivers

Cations

Calcium ions are among the most common ions occurring in nature (McNeely *et al.*, 1979). Calcium at *Peel River above Fort McPherson* ranged from 21.6 to 71.8 mg/L (n=138). The minimum value was detected during the freshet in May 1988 while the maximum value was detected during the recession in October 1999.

The highest calcium value (85.0 mg/L) throughout the basin in March 1999 was at *Ogilvie River near the Mouth* (B) while the lowest (43.4 mg/L) was detected at *Wind River near the Mouth* (H) as demonstrated in Figure 14.

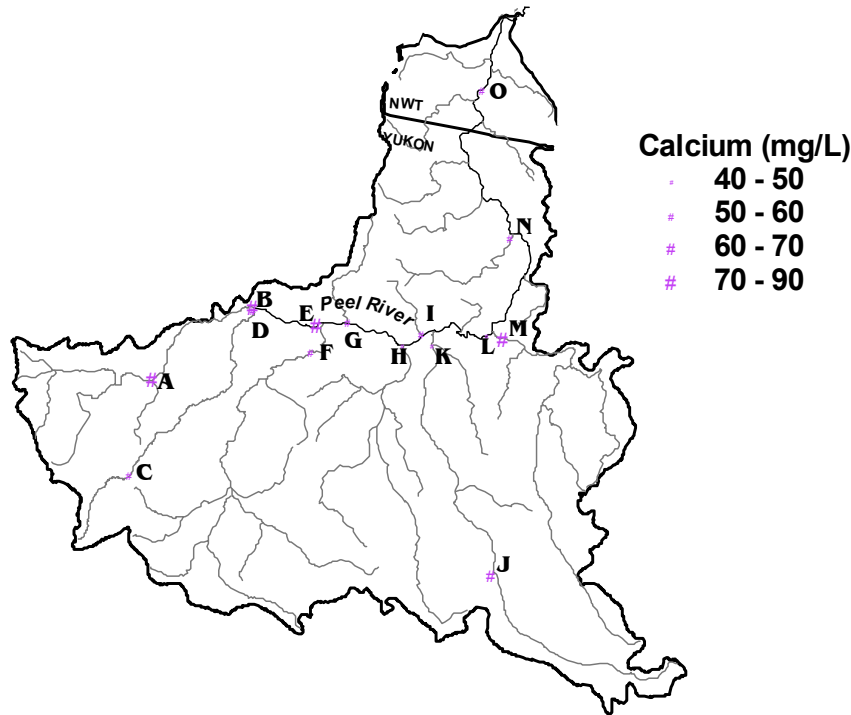


Figure 14. Concentration of calcium at 15 sites in the Peel River drainage basin, March 1999

Magnesium is widely distributed in ores and minerals. Magnesium is second to calcium as the most important contributor to water hardness (water hardness plays an important role in determining the toxicity of certain compounds). Concentrations between 5.8 mg/L (May 1988) and 25.9 mg/L (October 1999) were measured above Fort McPherson (n=138).

March 1999 results ranged from 15.0 mg/L (Site G, *Peel River above Canyon Creek*) to 38.2 mg/L (Site J, *Bonnet Plume River above Gillespie Creek*) as shown in Figure 15.

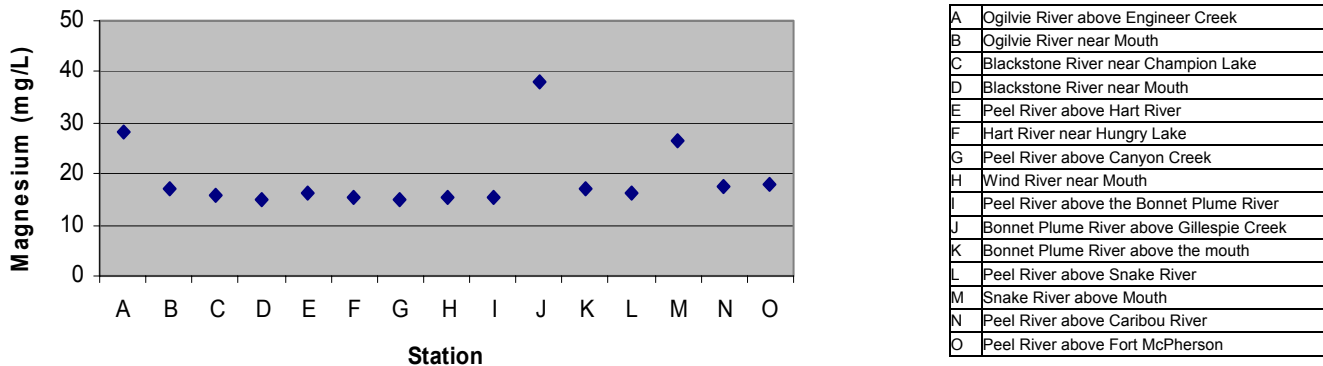


Figure 15. Concentration of magnesium at 15 sites in the Peel River drainage basin, March 1999

Strontium is an alkaline earth metal like calcium and magnesium. In most surface water, strontium is less abundant than calcium (McNeely *et al.*, 1979). Strontium does not occur freely in nature but primarily as a sulphate or in combination with other salt minerals. Strontium at *Peel River above McPherson* followed the typical trend for dissolved ions with concentrations highest during the winter baseflow and lowest during the spring freshet. Values for dissolved strontium ranged from 0.103 to 0.222 mg/L. In March 1999, samples taken in the Peel River Basin were high, with the maximum being observed at *Snake River above the Mouth* (M), a value of 0.366 mg/L.

Potassium is an essential nutrient for plant and animal growth. Concentrations are usually less than 10 mg/L in surface water (McNeely *et al.*, 1979). Values in the Peel River ranged from 0.25 to 1.11 mg/L (n=138). Potassium is the only major ion where concentrations were higher in the spring freshet than during recession and baseflow (Figure 16).

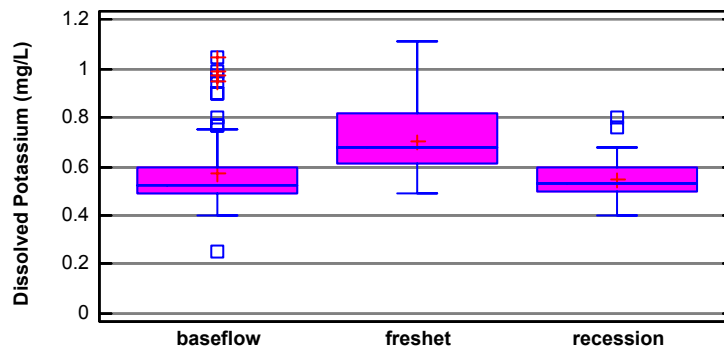


Figure 16. Seasonal Patterns of dissolved potassium in grab samples from *Peel River above Fort McPherson* (1980-2000)

All potassium results collected in March 1999 throughout the basin were below the baseflow maximum value at *Peel River above Fort McPherson*.

Sodium concentrations at *Peel River above Fort McPherson* ranged from 1.89 to 9.96 mg/L (n=138). The minimum value of 1.89 mg/L was detected in May 1988 while the maximum value of 9.96 mg/L was detected January 1992. The sodium concentration - discharge relationship was evident (low during freshet, high during baseflow). The CDWQ aesthetic guideline for sodium is <200 mg/L. All of the historic and the March 1999 sodium results were well below the CDWQ guideline. *Ogilvie River above Engineer Creek* (11.60 mg/L, Site A) was the only value that fell outside of the historic under ice range.

Anions

Sulphur is an essential plant nutrient. Aquatic organisms require sulphur, and reduced concentrations have a detrimental effect on algal growth. The most common form of sulphur in well-oxygenated waters is sulphate. When sulphate is less than 0.5 mg/L, algal growth will not occur. Sulphate is second to bicarbonate as the major anion in hard water. Of the 138 samples collected, the minimum value for sulphate was 17.5 mg/L (June 1990) while the maximum value was 96.3

mg/L (October 1999). Figure 8 shows the dilution effect clearly. The CDWQ guideline for sulphate is <500 mg/L.

Of the March 1999 samples, the maximum sulphate value (157 mg/L) was detected at *Snake River above the Mouth* (M) while the minimum (16 mg/L) was sampled at *Wind River near the Mouth* (H). Three samples were found to be higher than the range of the historic under ice data, which may be due to the reduced dilution along some of the tributaries of the Peel River (Figure 17).

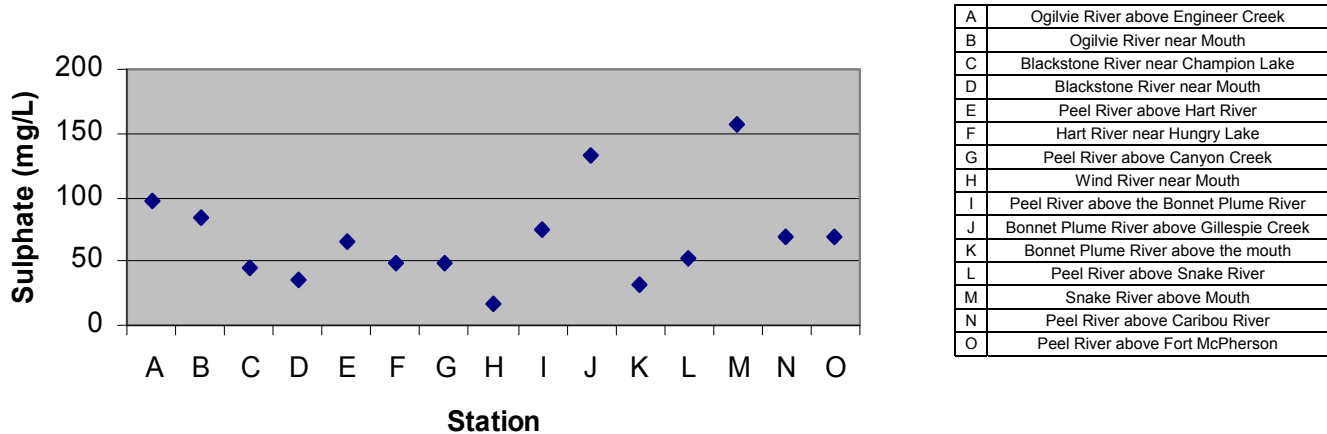


Figure 17. Concentration of sulphate at 15 sites in the Peel River drainage basin, March 1999

The primary source of fluoride in natural waters is from the weathering of igneous and sedimentary rocks, especially shales. Typical surface water concentrations are less than 1 mg/L but concentrations can be in excess of 50 mg/L (McNeely *et al.*, 1979). The CDWQ guideline for fluoride is 1.5 mg/L. Peel River fluoride values ranged from 0.01 to 0.8 mg/L (n=138).

All March 1999 fluoride values were within the historic range (under ice) measured at *Peel River above Fort McPherson*.

Concentrations of chloride ranged from 0.82 (June 2000) to 10.90 mg/L (January 1992) (n=138). Chloride values were highest under ice (median=3.70 mg/L) and lowest during the open water season (median=1.60 mg/L). When discharge is high (spring), there is a lot of dilution in the system, which results in the low chloride values (Table 8). Results are well below the CDWQ aesthetic guideline of 250 mg/L.

March 1999 results ranged from 0.5 mg/L (*Bonnet Plume River above Gillespie Creek*, Site J) to 8.5 mg/L (*Ogilvie River above Engineer Creek*, Site A). Four values exceeded the maximum chloride value measured at *Peel River above Fort McPherson* in March (4.6 mg/L).

Table 8. Seasonal variation of major ions (mg/L) at *Peel River above Fort McPherson* (median and means by water-year)

Parameter	Freshet	Recession	Baseflow
	median/mean (n, sd)	median/mean (n, sd)	median/mean (n, sd)
Alkalinity* (n, sd)	81.2/81.9 (22, 16.1)	114/113.4 (36, 11)	151/147 (81, 14.5)
Calcium* (n, sd)	31.4 / 32.0 (23,6.2)	44.8 / 44.3 (35, 5.33)	53.0 / 52.7 (80, 5.40)
Magnesium* (n, sd)	8.35 /9.25 (23,2.77)	14.20 / 14.00 (35, 2.00)	17.05 / 16.8 (80, 2.05)
Potassium* (n, sd)	0.68 / 0.70 (23, 0.16)	0.53 / 0.55 (35, 0.09)	0.52 / 0.57 (80, 0.14)
Strontium * (n, sd)	0.14, 0.13 (8, 0.06)	0.16, 0.17 (10, 0.02)	0.17, 0.17 (31, 0.01)
Sodium* (n, sd)	2.61 / 3.19 (23, 1.65)	4.30 / 4.23 (35, 0.93)	5.30 / 5.03 (80, 1.00)
Fluoride* (n, sd)	0.08 / 0.08 (23, 0.02)	0.08 / 0.09 (35, 0.02)	0.07 / 0.08 (80, 0.08)
Chloride* (n, sd)	1.40 / 1.30 (23, 1.30)	1.65 / 1.72 (35, 0.34)	3.63 / 3.68 (80, 1.39)
Sulphate* (n, sd)	36.2 / 39.3 (23, 16.80)	54.0 / 56.8 (35, 14.7)	54.8 / 57.1 (80, 12.2)

* Calculated value for the Kruskal-Wallis test statistic is significant (95% confidence interval). Median values do differ significantly between water-years for all major ion parameters.

Nutrients

Nutrients are required for plants to grow. Important macro-nutrients include phosphorous, nitrogen and carbon. Nutrients may exist in a number of chemical forms as they are cycled through the aquatic, terrestrial and atmospheric systems. Their source may be both inorganic and organic and they may be present in their dissolved or particulate form. Only those nutrients in their bio-available form can stimulate plant production, such as ortho-phosphorous, ammonia, nitrate and nitrite.

Phosphorous and nitrogen are particularly important water quality variables. When factors such as light and temperature that permit growth are right, limited amounts of nutrients including nitrogen and phosphorous can control the growth rate and abundance of aquatic plants. Certain nutrients at high concentrations may cause excessive plant growth. This can ultimately result in low oxygen levels due to aerobic respiration of microorganisms that feed on the dead or decaying plants. Dissolved oxygen is vital for freshwater aquatic life, especially fish. The biological effect of the addition of excessive nutrients to a water body is known as eutrophication.

Routine nutrient variables measured at *Peel River above Fort McPherson* include dissolved organic carbon, particulate organic carbon, dissolved inorganic carbon, ammonia, particulate nitrogen, dissolved nitrogen, nitrate/nitrite, total phosphorous and dissolved phosphorous. The March 1999 study measured total phosphorous, nitrate/nitrite, ammonia, and nitrate.

Phosphorous

Phosphorous is not commonly toxic to man, animals or fish and is a key element necessary for the growth of aquatic plants (McNeely *et al.*, 1979). Generally, phosphorous is the limiting nutrient in freshwater aquatic systems. That is, plant growth will discontinue if all phosphorous is used up, no matter how much nitrogen is available.

Phosphorous in freshwater systems exists in either a particulate or dissolved form. Together these forms constitute total phosphorous (TP). Total phosphorous includes all forms of phosphorous. TP at *Peel River above Fort McPherson* ranged from 0.002-1.36 mg/L (n=142). A seasonal trend was observed for total phosphorous, with high values in spring, which decreased through the summer and fall and dropped to low levels in the winter (Table 9). Dissolved phosphorous (DP) is phosphorous that will pass through a 0.45 µm porosity filter. DP ranged from 0.002-0.366 mg/L (n=142). Other than two high results reported in June 1998 (0.366 mg/L) and November 1995 (0.301 mg/L), dissolved phosphorous levels were fairly constant throughout the years (Figure 18). Presently, Canadian Water Quality Guidelines do not exist for total and dissolved phosphorous.

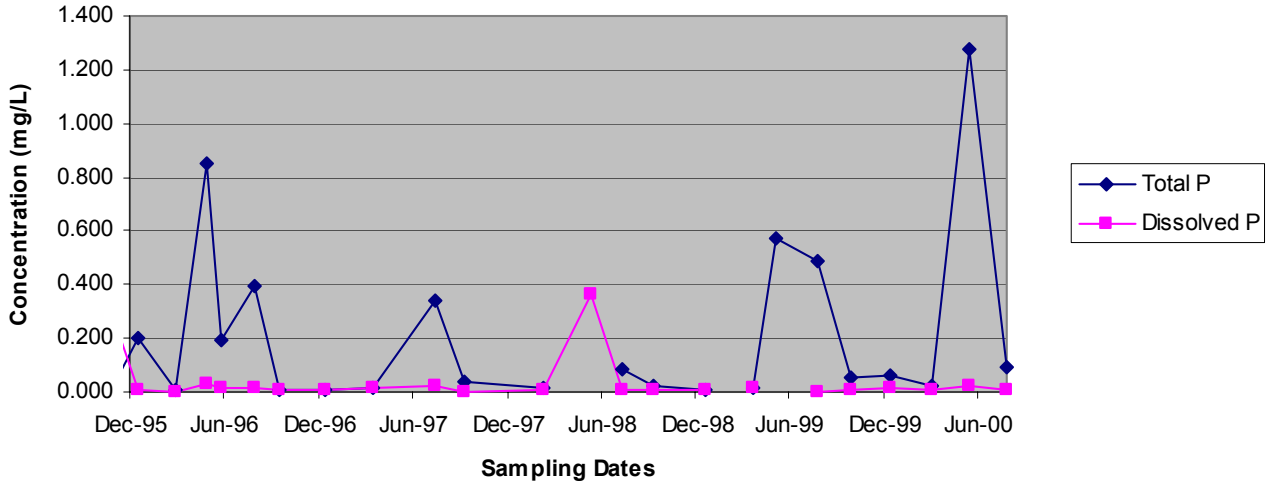


Figure 18. Total and dissolved phosphorous grab samples from *Peel River above Fort McPherson*.

Note the influence of flow on Total P, results were higher during the spring freshet and lowest during baseflow. (1995-2000).

March 1999 samples from 15 sites in the Peel River drainage basin were analyzed for total phosphorous. As expected, phosphorous concentrations were extremely low, with the highest result from the *Peel River above the Caribou River (N)*, measuring at 0.13 mg/L.

Nitrogen Cycle

Nitrogen is a major nutrient that affects the primary production of freshwaters. Forms of nitrogen in freshwater include dissolved molecular nitrogen (N_2), ammonia nitrogen (NH_3), nitrite (NO_2), nitrate (NO_3) and various organic nitrogen compounds (Wetzel, 1983).

The balance of nitrogen inputs and losses within an aquatic system is known as the nitrogen cycle – nitrogen fixation, nitrification and denitrification make up the three major processes of the cycle. Nitrogen inputs include nitrogen contained in particulate, precipitation, and nitrogen fixation both in the water and the sediments. Certain bacteria and blue-green algae carry out nitrogen fixation by extracting N_2 from the atmosphere and transforming it into organic nitrogen compounds. Nitrogen losses include outflow from the basin, reduction of NO_3 to N_2 by bacterial denitrification with loss of N_2 to the atmosphere, and nitrogen-containing compounds adsorbing to sediment (Wetzel, 1983). Bacterial denitrification is the reduction of oxidized nitrogen anions ($NO_3 + NO_2$) to gaseous nitrogen (N_2). Nitrification is the oxidation of ammonia into those nitrogen anions. Two groups of microorganisms are involved in nitrification. *Nitrosomonas* oxidizes ammonia to nitrite while *Nitrobacter* oxidizes nitrite ions to nitrate (Wetzel, 1983).

Ammonia

Ammonia is a large source of available nitrogen in the environment and its toxicity is dependent on water temperature and pH (CCME, 2000). Considering the temperature and pH values recorded from 1980-1998 (0-18°C and 7.10-8.47 pH units, respectively), the CPFAL for ammonia ranges between 0.137 mg/L (open water) and 18.48 mg/L (under ice). The open water CPFAL guideline

was exceeded on one occasion in August 1994 whereas the under ice CPFAL guideline has never been exceeded. The Kruskal-Wallis test ($P>0.05$) revealed that a significant difference did not exist for ammonia between water-years (freshet, baseflow and recession), indicating that ammonia is not greatly influenced by seasonality (Figure 19).

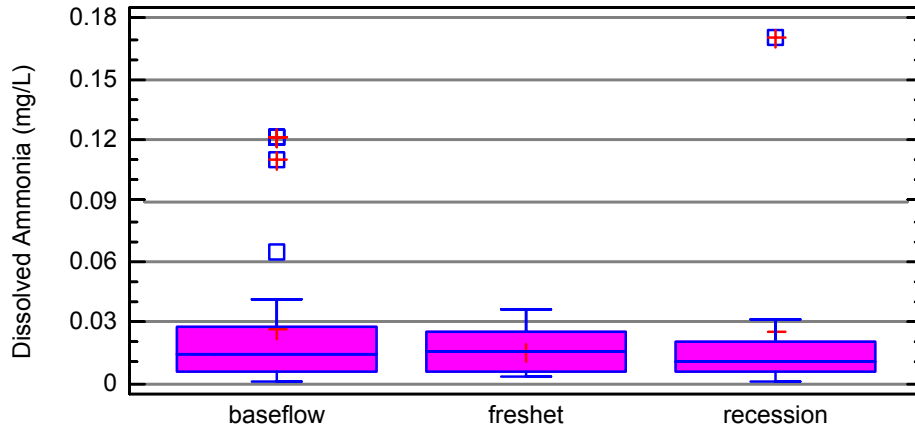


Figure 19. Dissolved ammonia concentrations from grab samples collected at *Peel River above Fort McPherson* (1980-2000)

Dissolved ammonia concentrations are not influenced by seasonality (Kruskal Wallis $P>0.05$).

Ammonia concentrations measured in March 1999 were quite low. Of the 15 sites sampled, 9 results were at or below the detection limit of 0.002 mg/L. The highest concentration of ammonia was 0.08 mg/L, observed at *Peel River above the Caribou River* (N).

Nitrate/Nitrite

Nitrite is readily oxidized to nitrate and is therefore rarely found in freshwater in significant concentrations. High nitrate concentrations, when consumed, can inhibit hemoglobin to bind and can reduce the oxygen-carrying capacity of the blood (Sanderson *et al.*, 1997). Throughout the study, nitrate and nitrite were analyzed together, not separately. Concentrations at *Peel River above Fort McPherson* ranged from 0.020 – 0.224 mg/L ($n=131$). The Kruskal-Wallis test indicated that significant differences between water year medians for nitrate/nitrite did exist. As the plot shows (Figure 20), highest values were reported during winter baseflow and lower values during the freshet and recession. There was little median difference between freshet and recession. This is a good example of where discharge has little influence on water quality. The lower values during freshet and recession are probably a result of biological uptake as summer progresses rather than the negative relationship with flow as is typical with other dissolved components (sulphate or calcium) (Halliwell, 1998).

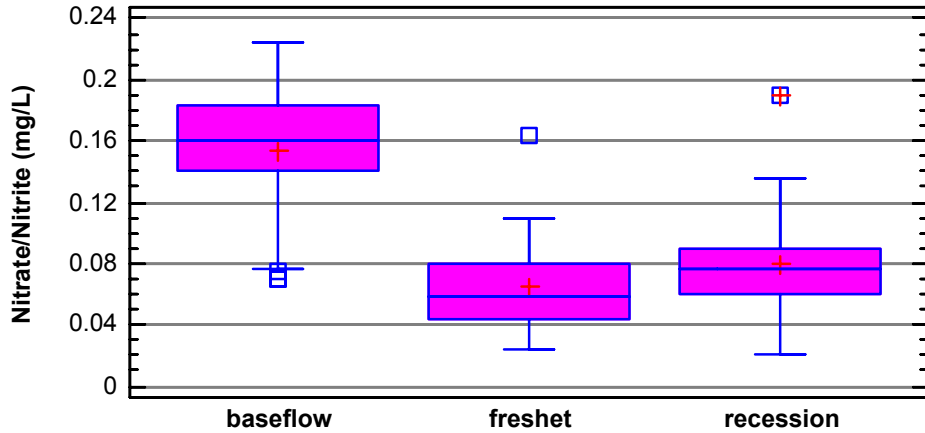


Figure 20. NO₃+NO₂ concentrations from grab samples collected at *Peel River above Fort McPherson* (1980-2000)

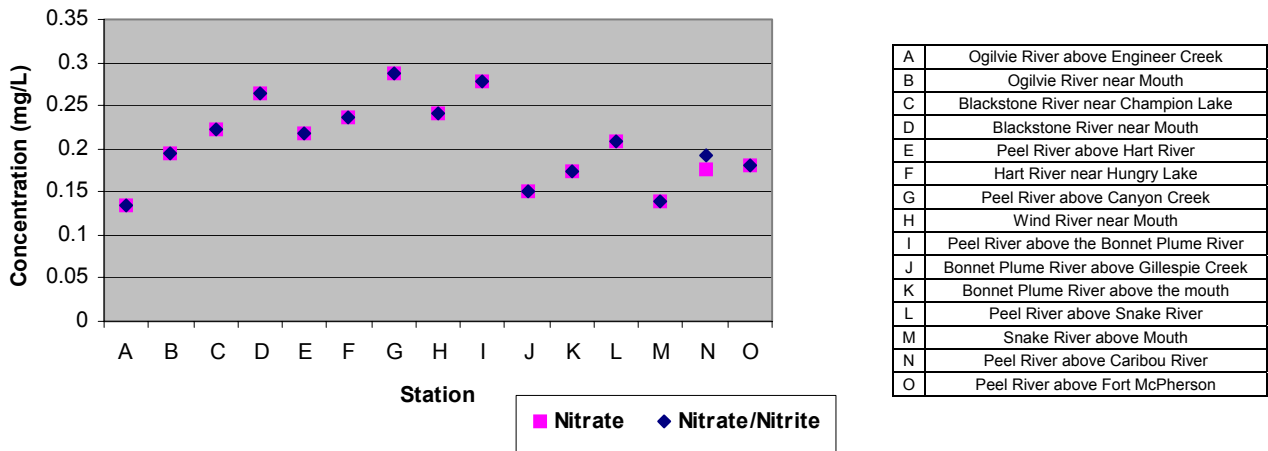


Figure 21. Concentration of nitrate and nitrate/nitrite at 15 sites in the Peel River drainage basin, March 1999

Peel River Basin samples from 15 sites were analyzed for nitrate/nitrite together, and nitrate separately. As evident in Figure 22, there appears to be very little nitrite present except for Site N, *Peel River above the Caribou River*. Five samples exceeded the upper range of the historic data from *Peel River above Fort McPherson*, with the highest sample at 0.288 mg/L from *Peel River above Canyon Creek* (G).

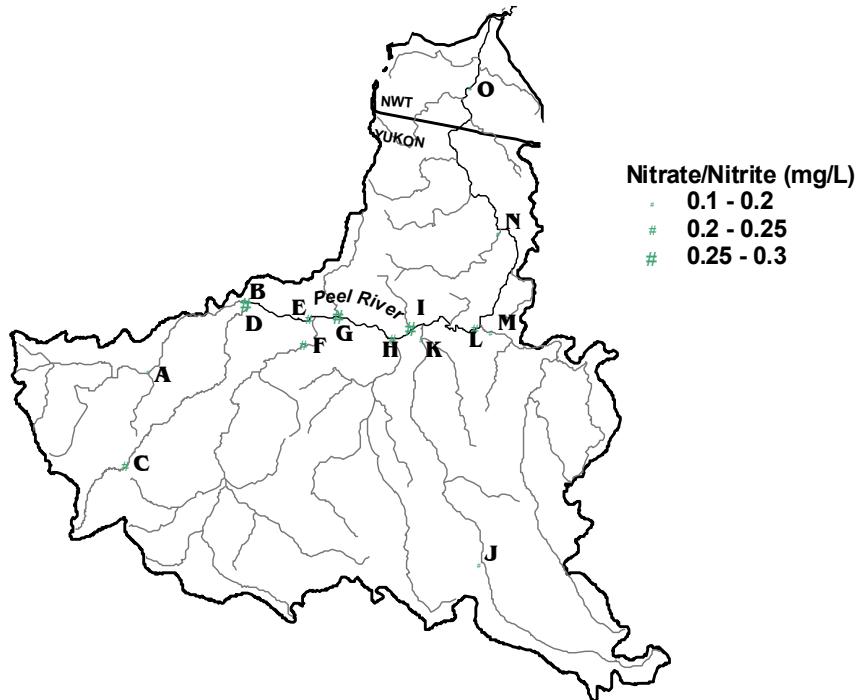


Figure 22. Concentration of nitrate/nitrite at 15 sites in the Peel River drainage basin, March 1999

Reactive Silica

Silica is second to oxygen as the most abundant element in the earth's crust. It is very important for certain algae (diatoms) for the synthesis of their frustules (the diatom's silicate shell). Most natural waters contain less than 5 mg/L of silica, although a range of 1 to 30 mg/L is not uncommon (McNeely *et al.*, 1979). Silica values from *Peel River above Fort McPherson* ranged from 1.82 – 5.10 mg/L (n=138). Highest values were recorded during the baseflow and lower results were found during the freshet and recession (Table 9). This trend is perhaps another example of biological uptake (Figure 23).

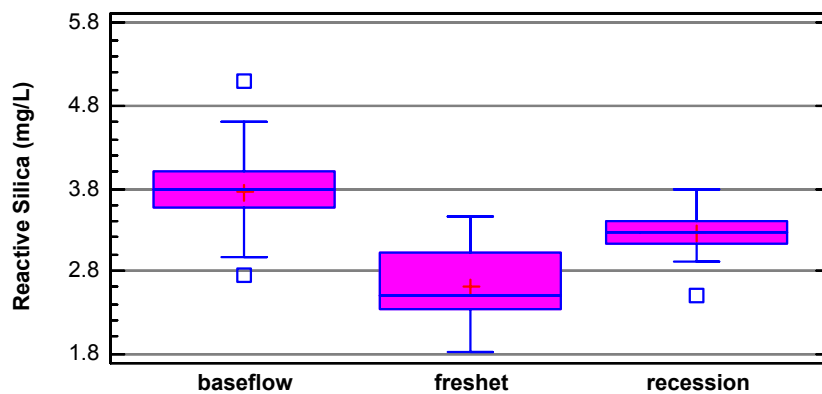


Figure 23. Reactive silica concentrations from grab samples collected at *Peel River above Fort McPherson* (1980-2000)

Carbon

Organic carbon compounds are created by photosynthesis in the aquatic environment (autochthonous sources), and can also be contributed from the biodegradation of plant and animal materials (allochthonous sources). Carbon is a required nutrient for biological systems, but the breakdown of organic carbon can rob waters of dissolved oxygen (McNeely *et al.*, 1979). Organic carbon is highest during freshet, when the input of organic material to the river from spring runoff is highest.

Organic carbon found in natural waters is almost always found as dissolved organic carbon (DOC) or particulate organic carbon (POC). DOC is separated from POC by filtration (through a 0.45µm membrane filter). According to Wetzel (1983), in stream systems, the ratio of DOC to POC is 10:1. Above Fort McPherson, this appears to only apply during the baseflow, when the DOC:POC ratio is 12:1 (median) or 9:1 (mean). During the recession and freshet, the DOC:POC ratio is much closer to 1:1. Seasonal results are presented in Table 9.

Dissolved Inorganic Carbon (DIC) includes the sum of carbonates, bicarbonates, and carbonic acid and is dependent on the pH of the water (Wetzel, 1983). The underlying limestone geology is a likely source of carbonates in the Peel Basin. Dissolved Inorganic Carbon is high during baseflow when groundwater inputs to the system are highest (Table 9).

Table 9. Seasonal variation of nutrients (mg/L) in the Peel River (median and means by water-year)

Parameter	Freshet	Recession	Baseflow
	median/mean	median/mean	median/mean
Total Phosphorous* (n, sd)	0.419/0.532 (26, 0.383)	0.097/0.182 (37, 0.217)	0.003/0.009 (78, 0.034)
Dissolved Phosphorous* (n, sd)	0.011/0.026 (26, 0.070)	0.008/0.011 (38, 0.013)	0.009/0.017 (79, 0.027)
Dissolved Ammonia-N (n, sd)	0.015/0.016 (10, 0.011)	0.012/0.026 (11, 0.049)	0.015/0.027 (30, 0.034)
Nitrate+Nitrite* (n, sd)	0.058/0.065 (25, 0.029)	0.076/0.080 (35, 0.03)	0.160/0.154 (71, 0.039)
Dissolved Nitrogen* (n, sd)	0.217/0.244 (26, 0.126)	0.15/0.198 (37, 0.133)	0.205/0.258 (78, 0.142)
Reactive Silica* (n, sd)	2.70 / 2.76 (14, 0.44)	3.27 / 3.26 (35, 0.25)	3.81 / 3.78 (80, 0.40)
Particulate Organic Nitrogen* (n, sd)	0.692/0.798 (22, 0.544)	0.174/0.401 (35, 0.681)	0.012/0.023 (74, 0.022)
Particulate Organic Carbon* (n, sd)	6.745/9.182 (22, 7.08)	2.14/4.53 (35, 7.81)	0.13/0.215 (74, 0.244)
Dissolved Organic Carbon* (n, sd)	6.53/6.76 (24, 2.98)	3.40/3.66 (34, 1.56)	1.52/1.97 (73, 1.36)
Dissolved Inorganic Carbon * (n, sd)	17.0/17.0 (1, 0.00)	25.80, 25.80 (2, 1.55)	35.0/35.1 (9, 2.55)

* Calculated value for the Kruskal-Wallis test statistic is significant (95% confidence). Median values do differ significantly between water-years for all nutrient parameters except ammonia.

Metals

Total and extractable metals data is available for *Peel River above Fort McPherson*. Total metal concentrations include metals found in both dissolved and particulate form (unfiltered). Dissolved metals are those metals in solution and the sample must be filtered to remove any suspended sediment. Extractable results are the combination of the dissolved concentration as well as a variable amount found in particulate form (the sediment is allowed to settle out and the decant is analyzed). The dissolved form is biologically available to aquatic organisms. Dissolved metal samples were collected during the March 1999 sampling program only, while they are not part of routine sampling at *Peel River above Fort McPherson*. Total metal results for the historic data are summarized in Table 11.

Filtering of water samples soon after collection is required for the analysis of dissolved metals. In March 1999, dissolved metals samples were filtered at the Eagle Plains Lodge at the end of the day due to below freezing field conditions. It would be expected that dissolved metals would be equal to or less than the total metals for each sample. However, in a number of cases, dissolved metals exceeded the concentration of total metals, specifically for chromium, copper, lithium, manganese, lead and antimony. This may be due in part to the fact that total and dissolved metals are collected in separate sample bottles and could be expected to show some variation. In addition, as the sample results get closer to the detection limit for a particular parameter, laboratory error is known to increase exponentially (Mueller *et al.*, 2001). Sampling error may also be responsible for a portion of the variation.

Although metals occur naturally in the aquatic environment, elevated levels of some metals can be harmful to certain biota. Metals may biomagnify in the food web and bioaccumulate in higher organisms. Elevated levels in fish tissue can cause health concerns for humans consuming those fish.

Most metals are associated with suspended sediment (Sanderson, 1997; Taylor, 1998). This association is a good example of positive flow dependence, as concentrations are high when sediment load is great and water levels are high. Total cobalt concentrations illustrate this clearly in Figure 24. Spearman's correlations revealed strong positive relationships of suspended sediment with several metals including aluminum, chromium, cobalt, copper, iron, lead, lithium, and nickel (Table 10). Certain metals in this basin naturally exceed the CPFAL and CDWQ guidelines.

Example of Positive Flow Dependence (Particulate Effects):

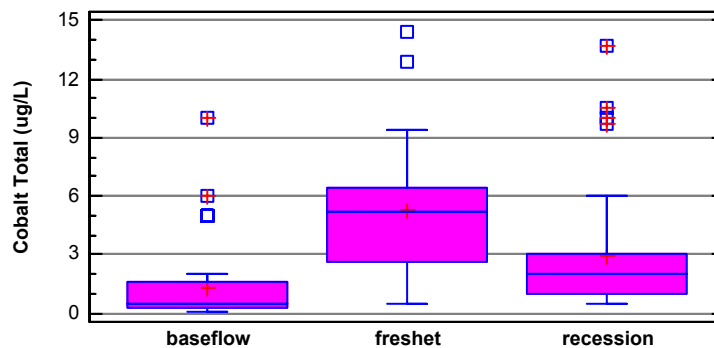


Figure 24. Total cobalt concentrations at *Peel River above Fort McPherson* from 1980-2000

Table 10. Spearman's correlation results of total suspended solids and various metals

METAL AND TSS	SPEARMAN'S 'RHO'
Aluminum and TSS	0.8407
Chromium and TSS	0.8824
Cobalt and TSS	0.8088
Copper and TSS	0.9276
Iron and TSS	0.8407
Lead and TSS	0.8933
Lithium and TSS	0.9276
Nickel and TSS	0.9276

The data from March 1999 are presented in detail below. Some notable features are high levels of most sediment-associated metals at *Peel River above the Caribou River (N)*, which also had high turbidity and total suspended solids. The water sample used for this study was noted to be brownish, as discussed in "Turbidity". While the data as presented are valuable, the metals data from that site should not be considered representative of the normal water quality within the basin. Otherwise, the levels of most parameters fell within the range of the historic data from *Peel River above Fort McPherson*.

Also, high levels of some metals were noted at the Ogilvie River sites when compared to other sites in the basin. Specifically, Copper, molybdenum, and zinc were elevated at *Ogilvie above Engineer Creek (A)* and lead was high at *Ogilvie River near Mouth (B)*. There are no anthropogenic sources of these metals in the Peel River basin, other than long-range atmospheric transport. During the baseflow winter months, under-ice water quality is primarily influenced by groundwater. The chemical composition of groundwater normally reflects the mineral composition of the rock or soils through which it moves. In areas underlain by inert bedrock of low solubility, groundwater typically has low concentrations of dissolved chemicals. In areas where base metal mineralization (Cu, Zn, Fe, etc.) occurs, groundwater may contain relatively high concentrations of those metals. Still elsewhere, where limestone and dolomite formations predominate, groundwater will have high calcium and magnesium carbonate content which imparts hardness to the water (Province of British Columbia, 1994). The underlying geology of the Ogilvie sub-basin would likely provide explanation for the winter water quality. Effects are not seen downstream as it is expected that the main stem of the Peel River would be more dilute and have different geological influences.



Paul von Baich

Figure 25. Northern Ogilvie Mountains at the headwaters of the Porcupine River, Yukon (early October)

Aluminum

Aluminum (Al) is a very abundant element in the earth's crust and the weathering of igneous and sedimentary rocks produces aluminum naturally. Aluminum concentrations in water can be high near areas where alum is used in water treatment, as well as downstream of areas where acid mine drainage is common (McNeely *et al.*, 1979). The guideline for freshwater aquatic life is 100 µg/L (for waters with a pH≥6.5, Diss Ca<4mg/L and DOC≥2mg/L). There are no CDWQ Guidelines for aluminum. Concentrations at *Peel River above Fort McPherson* are naturally high and ranged between 11 and 19,900 µg/L (n=48), the highest of which may result from an elevated sediment load. 40% of the samples exceeded the guideline for total aluminum. Highest values were recorded in the spring, with lowest concentrations during the baseflow (Table 11).

In the March 1999 data, throughout the basin, total aluminum concentrations were all less than detection (<10 µg/L), except for Site N (*Peel River above the Caribou*), which measured 6870 µg/L, and Site O (*Peel River above Fort McPherson*) with a value of 12 µg/L. Only Site N exceeded the CPFAL guideline. All dissolved aluminum concentrations were below the detection limit of 10 µg/L.

Barium

Barium (Ba) can be released by weathering of naturally occurring barite compounds, which are often associated with metallic ore deposits. Barium also has numerous industrial uses. Because of the insolubility of most of its compounds, it is not considered to be an ecological threat. It is found to occur naturally in almost all surface waters, in concentrations from 2 to 340 µg/L (USEPA, 2001). There are no CPFAL guidelines for barium. The CDWQ guideline for barium is 1000 µg/L. At *Peel River above Fort McPherson*, total barium ranged from 50 to 413 µg/L (n=139), median 99 µg/L. Highest concentrations were recorded at freshet, and lowest concentrations at baseflow (Figure 26).

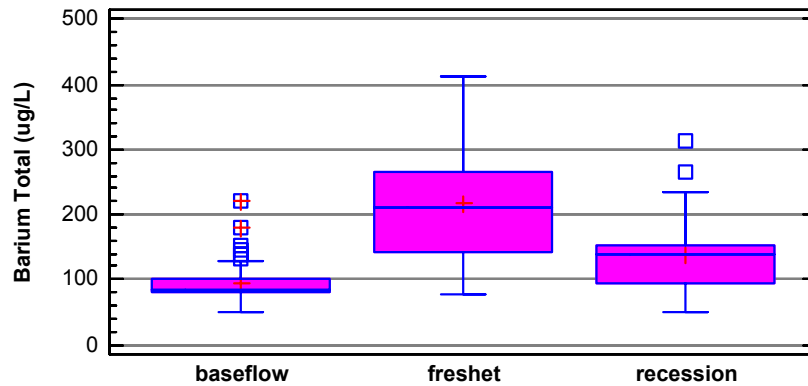


Figure 26. Total barium concentrations from grab samples collected at *Peel River above Fort McPherson* (1980-2000)

Barium was detected in the waters of the Peel River basin (Figure 27) during the March 1999 program. Total barium levels varied between 58.3 µg/L at *Snake River above Mouth* (M) and a maximum of 255 µg/L at *Peel River above the Caribou River* (N), with a mean of 104 µg/L over all sites. With the exception of Site N, all total barium levels fell into the historical baseflow range, at *Peel River above Fort McPherson*. Dissolved barium levels followed a similar pattern and varied from 65.9 µg/L at *Snake River above Mouth* (M) to 131 µg/L at *Blackstone River near Mouth* (D), with a mean of 92.6 µg/L. All samples were below the CDWQ guideline.

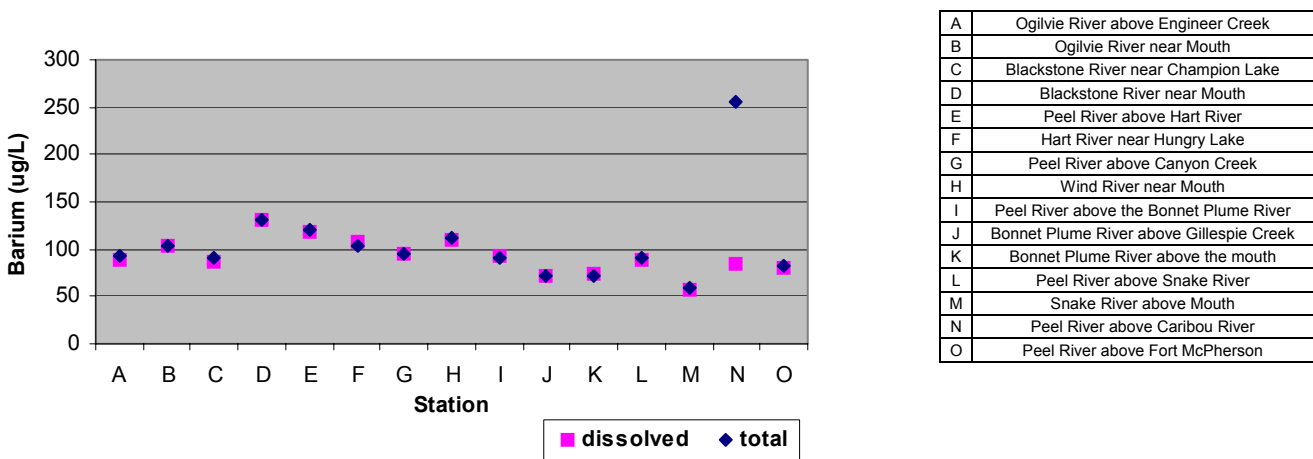


Figure 27. Concentration of total and dissolved barium at 15 sites in the Peel River watershed, March 1999

Cadmium

Cadmium (Cd) and cadmium compounds are usually present at low levels in natural waters, in the range of 0.1 to 10 µg/L. Cadmium salts can be present organically or inorganically which are absorbed on suspended particles or deposited on the bottom. The toxicity of cadmium is dependent on water hardness, pH and to a lesser extent zinc and cyanide (McNeely *et al.*, 1979). Aquatic biota show acute and chronic toxicities to cadmium in solution (CCME 1999). The interim CPFAL guideline for total cadmium is 0.05 µg/L (for water with a mean hardness value of 179 mg/L). Of the 52% of samples (n=141) which were detectable at Fort McPherson, only one value exceeded the CDWQ of 5 µg/L and all detectable results exceeded the interim CPFAL guideline of 0.05 µg/L. Metals tend to associate with sediment and therefore the availability for biotic uptake is minimal (Taylor *et al.*, 1998).

Levels of dissolved cadmium were detected in the Peel Basin from <0.01 µg/L to a maximum of 0.06 µg/L (Site A, *Ogilvie above Engineer Creek*). The average concentration over all sites was 0.017 µg/L. Two of the fifteen Peel River sites had total cadmium levels in exceedence of the CPFAL guideline of 0.05 µg/L, as shown on Figure 28. The highest recorded level (0.4 µg/L) was detected at *Peel River above the Caribou River* (N). All samples analyzed had cadmium levels below the CDWQ guideline of 5 µg/L.

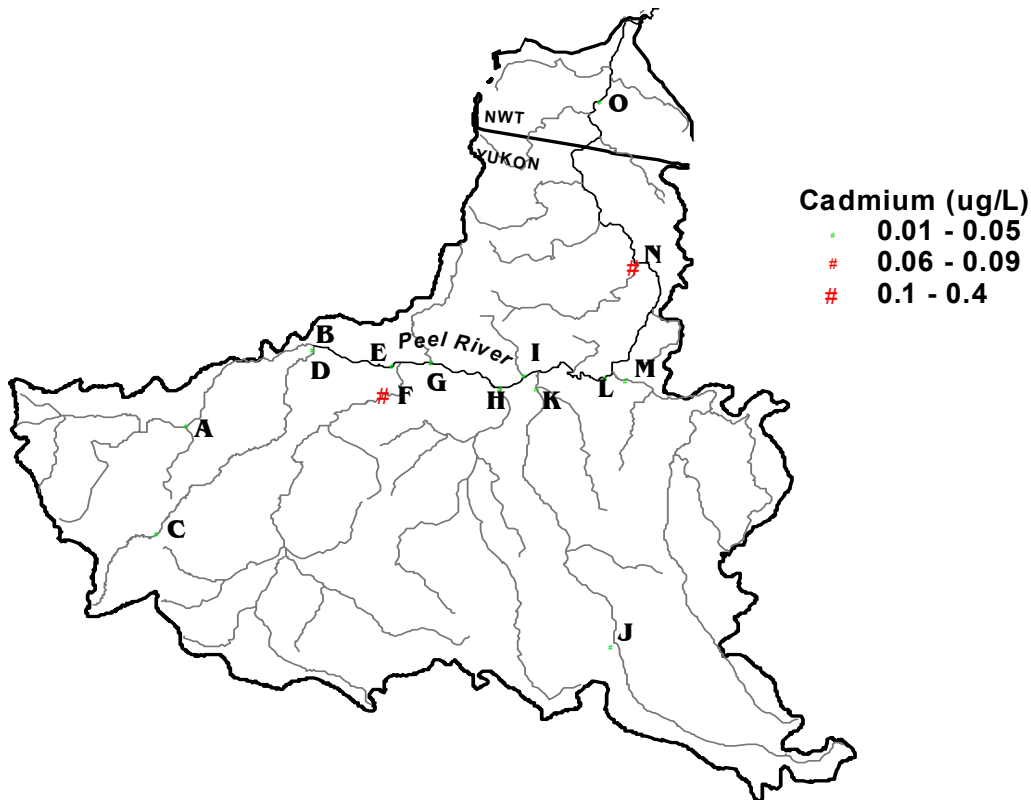


Figure 28. Levels of total cadmium throughout the Peel River Basin, March 1999
The CPFAL Guideline for cadmium is 0.05 µg/L, and has been exceeded at two sites

Chromium

Natural chromates are rare; because of this few water bodies contain chromium from natural sources. Chromium (Cr) toxicity to aquatic life is dependent on water temperature and pH (McNeely *et al.*, 1979). Concentrations of chromium in Canada's pristine lakes and rivers have been reported to be between <1 to 5 µg/L (CCME, 1999). Two types of chromium are of concern to the environment, trivalent and hexavalent. In natural waters trivalent chromium is not present in a stable form and slowly changes to the more toxic hexavalent form. Results for this study did not identify the state of the chromium. To be conservative, the more stringent CPFAL guideline for hexavalent chromium will be used (1.0 µg/L).

Chromium results from *Peel River above Fort McPherson* ranged from 0.2 to 29.8 µg/L (40% of the chromium results exceeded the CPFAL). None of the results exceeded the CDWQ of 50 µg/L.

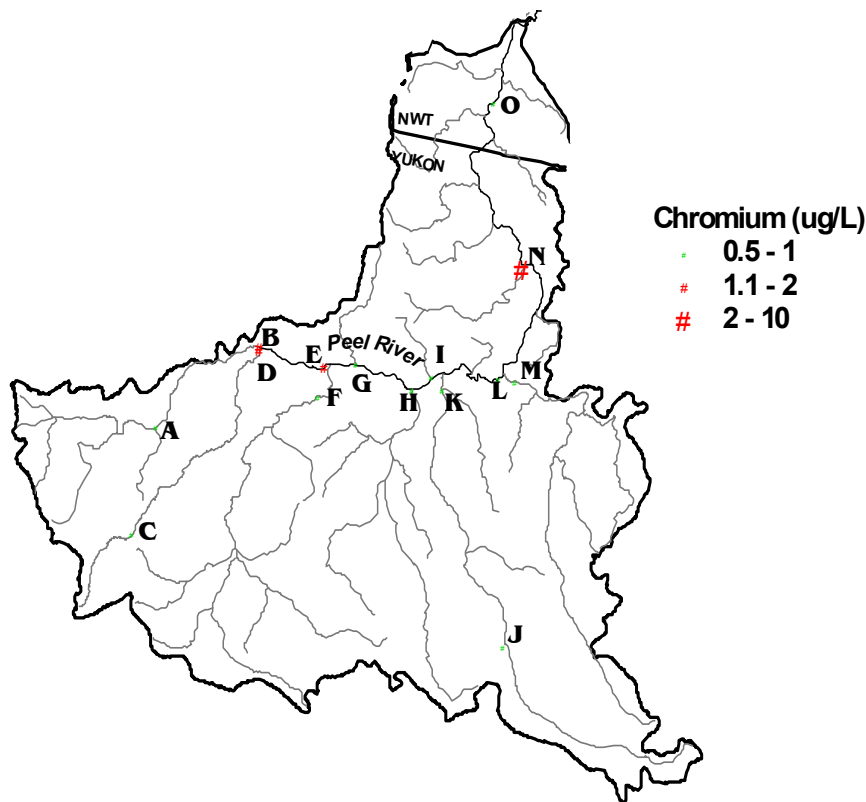
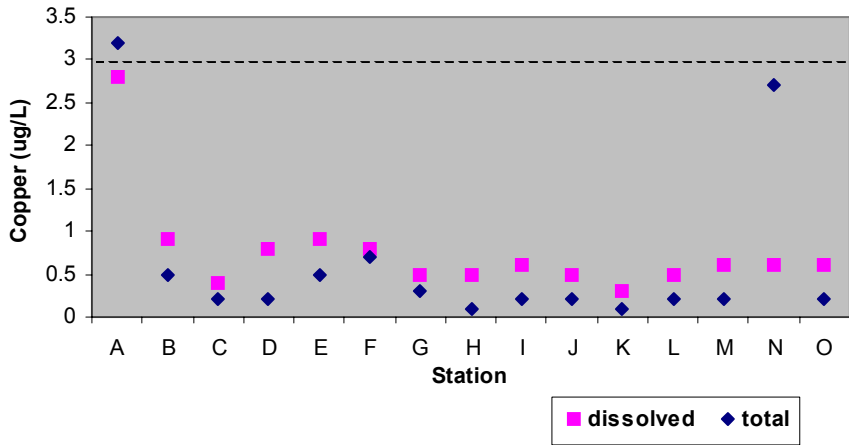


Figure 29. Concentration of total chromium at 15 sites in the Peel River drainage basin, March 1999

The CPFAL guideline for hexavalent chromium is 1.0 µg/L, and has been exceeded at four sites

The results for total chromium at the Peel River Basin ranged from 0.6 µg/L to 10 µg/L, and four (of fifteen) sites exceeded the CPFAL guideline of 1.0 µg/L, as shown in Figure 29. The total chromium concentration of 10 µg/L on the *Peel River above the Caribou River* (N) was substantially higher than all other sites sampled. Dissolved chromium over all sites averaged 1.2 µg/L, with the maximum value of 2 µg/L recorded at *Blackstone River near the Mouth* (D). It is noted in many cases that the concentration of dissolved chromium exceeded the concentration of total chromium.

Copper



A	Ogilvie River above Engineer Creek
B	Ogilvie River near Mouth
C	Blackstone River near Champion Lake
D	Blackstone River near Mouth
E	Peel River above Hart River
F	Hart River near Hungry Lake
G	Peel River above Canyon Creek
H	Wind River near Mouth
I	Peel River above the Bonnet Plume River
J	Bonnet Plume River above Gillespie Creek
K	Bonnet Plume River above the mouth
L	Peel River above Snake River
M	Snake River above Mouth
N	Peel River above Caribou River
O	Peel River above Fort McPherson

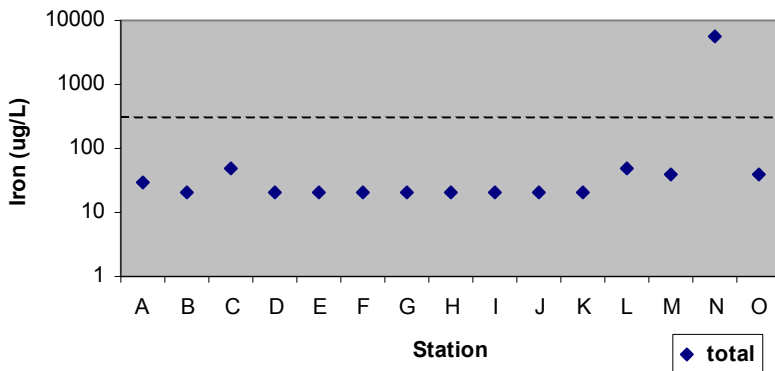
Figure 30. Concentration of total and dissolved copper at 15 sites in the Peel River drainage basin, March 1999

Dashed line indicates CPFAL guideline (3 µg/L).

Copper is a heavy metal that is common in natural waters. Plants and animals rely on copper as part of an essential nutrient. Natural surface waters contain trace amounts of the metal up to 50 µg/L. Temperature, turbidity and water hardness as well as the form of copper determine its toxicity to freshwater aquatic life. Since copper minerals are relatively insoluble little copper in water is of natural origin (McNeely *et al.*, 1979). The copper CPFAL guideline (for waters with water hardness between 120-180 mg/L) of 3 µg/L was exceeded 36% of the time, at *Peel River above Fort McPherson*, while there were no exceedences of the CDWQ guideline (1000 µg/L).

Throughout the Peel River basin, concentrations of total copper ranged from less than the detection limit (<0.1 µg/L) to a maximum of 3.2 µg/L at *Ogilvie River above Engineer Creek (A)*. This maximum value was the only exceedence of the CPFAL guideline. As shown in Figure 30, all dissolved copper levels were below 3 µg/L, with the maximum level measured at *Ogilvie River above Engineer Creek (A)* (2.8 µg/L).

Iron



A	Ogilvie River above Engineer Creek
B	Ogilvie River near Mouth
C	Blackstone River near Champion Lake
D	Blackstone River near Mouth
E	Peel River above Hart River
F	Hart River near Hungry Lake
G	Peel River above Canyon Creek
H	Wind River near Mouth
I	Peel River above the Bonnet Plume River
J	Bonnet Plume River above Gillespie Creek
K	Bonnet Plume River above the mouth
L	Peel River above Snake River
M	Snake River above Mouth
N	Peel River above Caribou River
O	Peel River above Fort McPherson

Figure 31. Concentration of total iron at 15 sites in the Peel River drainage basin, March 1999

Broken line indicates CPFAL guideline (300 µg/L). Data have been log transformed.

Iron (Fe) is the fourth most common element in the earth's crust. When mobile iron is present in water it is oxidized to a less mobile form and precipitates as ferric iron. Iron concentrations in surface waters are usually less than 0.5 mg/L. The growth cycles of freshwater algae and related aquatic microorganisms can greatly influence the concentration of iron in surface waters (McNeely *et al.*, 1979). Sampling for total iron began in 1993. Background iron concentrations are high. Since 1993, concentrations at *Peel River above Fort McPherson* ranged from 0.044 to 61.60 mg/L (n=48). The maximum value (61.60 mg/L) was detected during the spring freshet while the minimum value (0.044 mg/L) was detected during the baseflow matching the same kind of trend as in Figure 24. The CPFAL and CDWQ guidelines for total iron are 0.3 mg/L. These guidelines were exceeded approximately 40% of time.

In March 1999, total iron results for the Peel River Basin were all within 0.03 mg/L of the detection limit (0.02 mg/L). All results were below the CPFAL and CDWQ guidelines except for *Peel River above the Caribou River* (N) with a concentration of 5.43 mg/L. All dissolved iron concentrations were measured below the detection limit and were therefore not included in Figure 31.

Lead

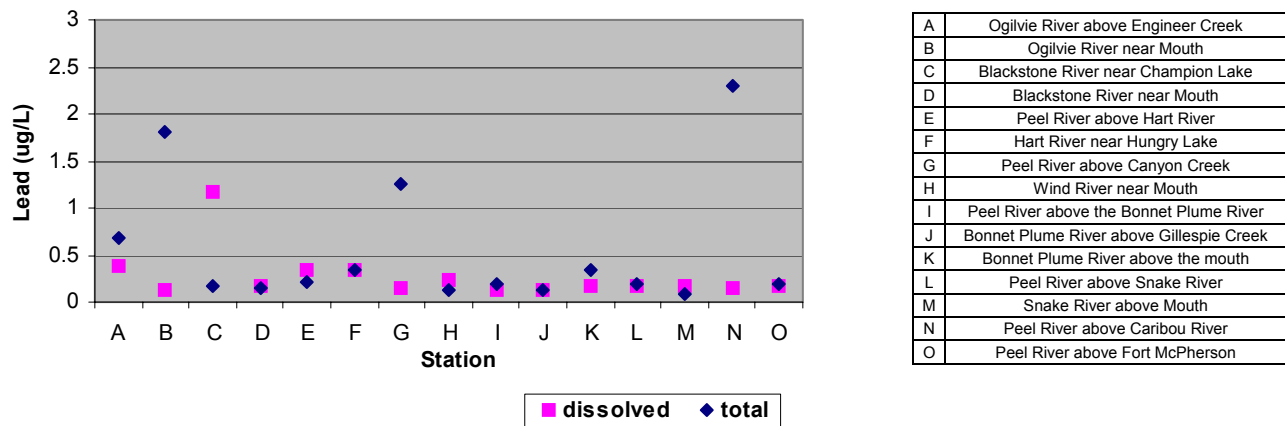


Figure 32. Concentration of total and dissolved lead at 15 sites in the Peel River drainage basin, March 1999

Lead can occur in low concentrations in the environment in both the soluble and suspended forms. The toxicity of lead is dependent on the hardness, pH, alkalinity, and dissolved oxygen content of the water. Lead does not often affect plants as it is strongly absorbed by soils, however lead can be toxic to animals, especially fish. Naturally small amounts of lead are produced, but humans produce much more through automobiles and industry which can impact waters through atmospheric transport and deposition (McNeely *et al.*, 1979).

The CPFAL guideline for lead depends on the hardness of the receiving water, as the toxicity of lead increases with decreasing hardness. The hardness of the receiving waters of the Peel River Basin averaged 179 mg/L, and the corresponding guideline for lead is 4 µg/L. The CDWQ guideline states that the maximum concentration of lead in human drinking water is 10 µg/L. Lead was detectable in 61% of the samples above Fort McPherson (n=140). Concentrations ranged between 0.2 and 22.8 µg/L. Highest values were recorded in the freshet (median=5.5 µg/L) and lowest values during the baseflow (median = 0.8 µg/L). The CDWQ was exceeded 4% of the time while the CPFAL was

exceeded 16% of the time, generally during freshet or recession when water levels and sediment load is greater than during the rest of the year.

All values detected during the March 1999 study were well below both the sets of guidelines (Figure 32). The concentrations of total lead in the Peel Basin ranged from 0.08 µg/L at *Snake River above Mouth* (M) to 2.3 µg/L at *Peel River above the Caribou River* (N). Dissolved lead concentrations were also low and ranged from 0.12 µg/L to 1.17 µg/L. It is noted that in some instances the value for dissolved lead exceeds that for total lead. As was the case with cadmium, it is possible that these results are skewed by human error and are not representative of actual conditions.

Manganese

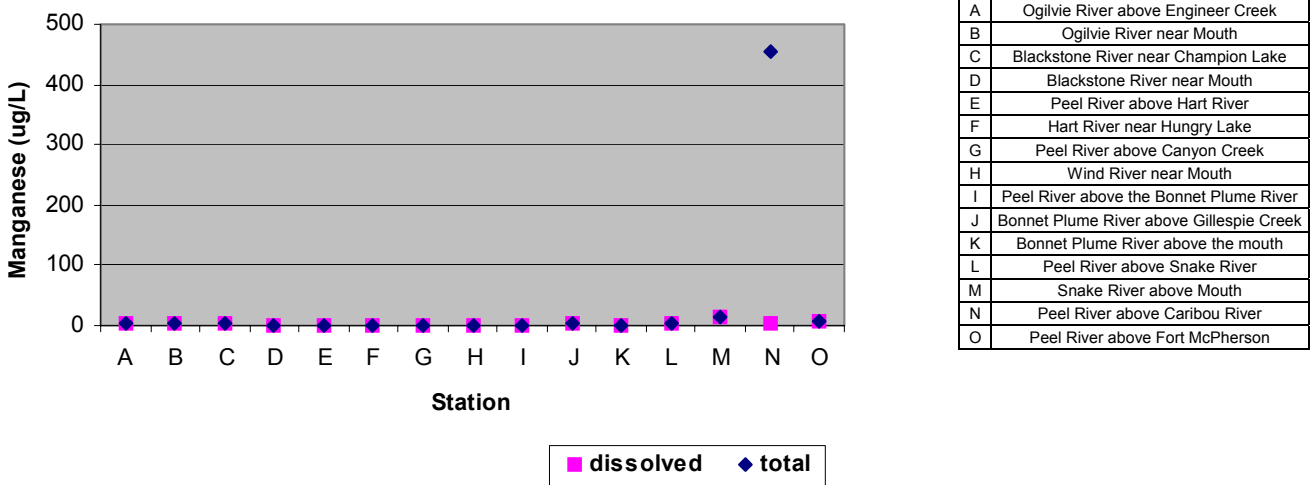


Figure 33. Concentration of total and dissolved manganese at 15 sites in the Peel River drainage basin, March 1999

Manganese (Mn) is an important element in soil fertility and plant and animal nutrition. Manganese seldom reaches concentrations of 1000 µg/L in natural waters and is usually present in quantities of 200 µg/L or less (CCREM, 1987). The CDWQ Aesthetic Guideline is 50 µg/L, and there are no CPFAL guidelines in place. Total manganese results above Fort McPherson ranged between 6.6 and 431 µg/L (n=47). The results collected throughout the Peel River Basin in March 1999 were low except for one value (453 µg/L) that was detected at *Peel River above the Caribou River* (N) (Figure 33). All however, fell within the historic range recorded at Fort McPherson. Dissolved manganese varied from 0.6 µg/L to 15.6 µg/L among the sites sampled in the Peel River Basin.

Molybdenum

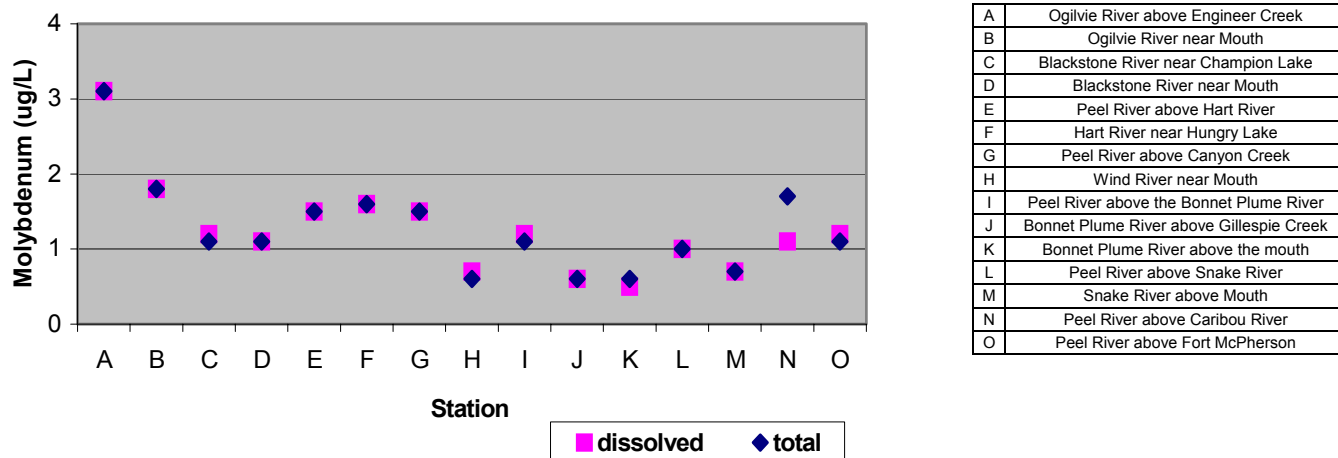


Figure 34. Concentration of total and dissolved molybdenum at 15 sites in the Peel River drainage basin, March 1999

Molybdenum (Mo) is a metal found in trace amounts in Canadian waters, in concentrations less than 0.01 $\mu\text{g/L}$ to as high as 500 $\mu\text{g/L}$. This element can enter the aquatic ecosystem through natural sources such as the weathering of rocks (especially shale), or from anthropogenic sources including atmospheric deposition from fossil fuel burning. Although molybdenum aids nitrogen fixation and is essential in trace amounts for the metabolism of aquatic plants, at high levels it can be toxic to freshwater fish. The interim CPFAL guideline has been set at 73 $\mu\text{g/L}$.

At *Peel River above Fort McPherson*, 100% of the results were above the detection limit. The maximum value of 3.6 $\mu\text{g/L}$ was detected during freshet. Average concentration at this station during baseflow is 1.1 $\mu\text{g/L}$ ($n=31$). All samples were substantially below the CPFAL Guideline of 73 $\mu\text{g/L}$. Results from the Peel River basin were also far below the CPFAL guideline; total molybdenum levels ranged from 3.1 $\mu\text{g/L}$ at *Ogilvie above Engineer Creek* (A) to 0.6 $\mu\text{g/L}$ at *Bonnet Plume above Gillespie Creek* (J) and *Bonnet Plume River at the Mouth* (K). Dissolved molybdenum concentrations followed a similar pattern to total, and the results as shown in Figure 34 indicate that most of the molybdenum is in the dissolved form.

Nickel

Nickel (Ni) is not often found in its native state, but can be part of many minerals and ores. Nickel present in waters because of weathering processes is usually insoluble, however soluble salts such as nickel ammonium sulphate, nickel nitrate, and chloride are found in water (McNeely *et al.*, 1979). Nickel is required as an enzyme cofactor in trace quantities, but it is toxic to most organisms at relatively low concentrations (CCREM, 1987).

The CPFAL guideline for nickel is reliant on water hardness, as the toxicity of nickel increases with decreasing hardness. Based on the hardness of the receiving waters of the Peel River Basin, the corresponding nickel guideline is 110 $\mu\text{g/L}$. At *Peel River above Fort McPherson*, total nickel concentrations ranged from detection (0.5 $\mu\text{g/L}$) to 49.1 $\mu\text{g/L}$ ($n=140$). During baseflow, the median concentration of total nickel was 1.3 $\mu\text{g/L}$ ($n=79$).

All total nickel measurements were below the CPFAL guideline by a substantial amount. The maximum value for total nickel was recorded at Site N, *Peel River above the Caribou River* (7.2 µg/L) and the minimum 0.8 µg/L at Site H, *Wind River near the Mouth*. Dissolved nickel concentrations follow a similar pattern to total, the exception being Site N where total nickel exceeds dissolved nickel by 5.4 µg/L (Figure 35).

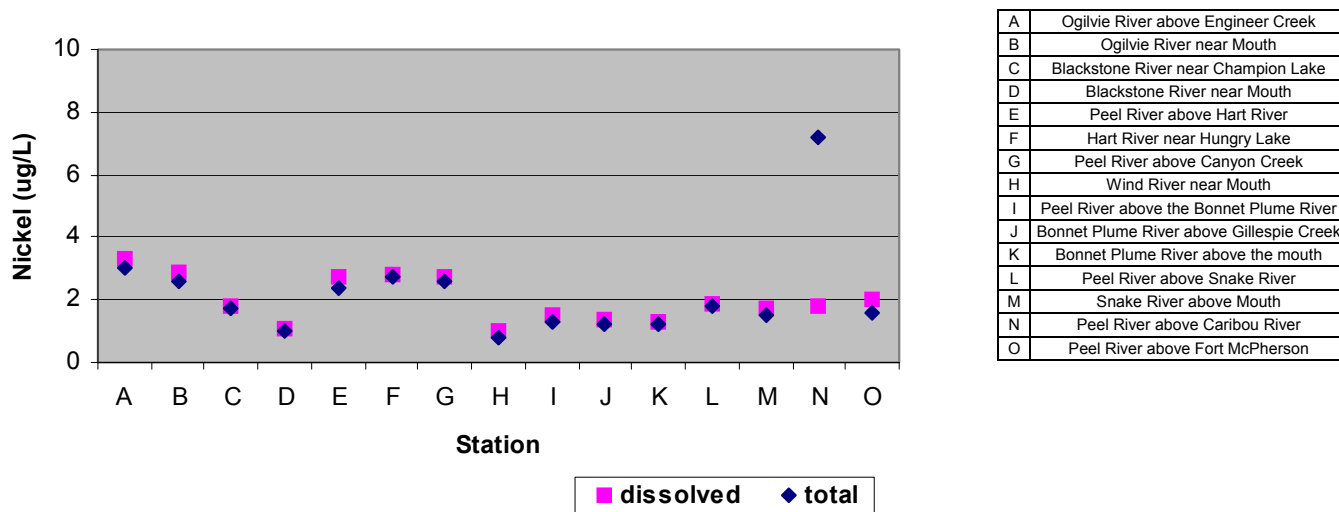


Figure 35. Concentration of total and dissolved nickel at 15 sites in the Peel River drainage basin, March 1999

Selenium

Selenium (Se) generally forms oxidized inorganic compounds in aqueous solution. Insoluble elemental selenium can be adsorbed by particulate matter and transported. Selenites and selenates are the only soluble forms of selenium. In nature, volcanic events, and the weathering of shales, coals, and sulphide ores can produce selenium. The burning of fossil fuels and various manufacturing processes also release selenium into the environment (McNeely *et al.*, 1979). The CPFAL guideline for total selenium has been set at 1 µg/L.

The data from *Peel River above Fort McPherson* only includes the dissolved form of selenium. Dissolved selenium levels ranged from 0.3 to 1.2 µg/L, averaging at 0.6 µg/L (n=142).

The laboratory detection limit for selenium is 1 µg/L, which is exactly at the CPFAL guideline for total selenium. Six out of fifteen sites had total selenium concentrations below the detection limit (and therefore below the CPFAL Guideline), while seven sites were reported exactly at 1 µg/L. The exceptions were *Ogilvie River near Mouth* (A) and *Peel River above the Caribou River* (N) which was substantially higher than other sites (Figure 36). *Peel River above the Hart River* (E) was the only site where dissolved selenium exceeded the detection limit (Figure 36).

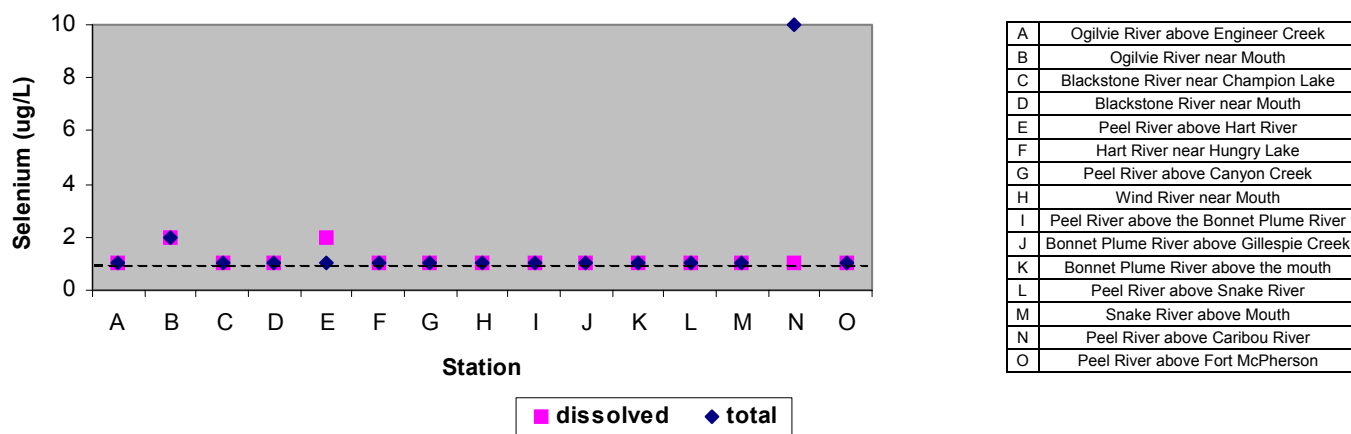


Figure 36. Concentration of total and dissolved selenium at 15 sites in the Peel River drainage basin, March 1999
Broken line indicates CPFAL guideline (1 $\mu\text{g/L}$).

Silver

Silver (Ag), while not abundant, can be found as a pure element or in combination with other ores. Silver compounds are not very soluble, resulting in only trace amounts found in water as most silver is absorbed in the soil. Naturally, silver is weathered from silver sulphide and lead-zinc silver containing ores, as well as from coals, shales, and soils. Silver is toxic to aquatic organisms (McNeely *et al.*, 1979).

The CPFAL guidelines state that the limit for silver is 0.1 $\mu\text{g/L}$. Total silver levels at *Peel River above Fort McPherson* were extremely low with all results being at or below the detection limit of 0.1 $\mu\text{g/L}$ (88% non detects, $n=16$). All total and dissolved silver results for sites within the Peel River basin were at or below the detection limit.

Zinc

Zinc (Zn) is abundant in nature. Zinc chlorides and sulphates are highly soluble in water, however zinc oxides are only slightly soluble. Zinc can be acutely and chronically toxic to aquatic organisms, especially fish. The toxicity of zinc increases with decreasing dissolved oxygen and water hardness. Zinc also becomes more toxic with increasing temperature and greater concentrations of copper and cadmium. Besides naturally occurring zinc, automobiles and industrial processes emit zinc into the environment (McNeely *et al.*, 1979). The CPFAL guideline for zinc is set at 30 $\mu\text{g/L}$.

Total zinc levels at *Peel River above Fort McPherson* ranged from 0.5 $\mu\text{g/L}$ to 212 $\mu\text{g/L}$ and exceeded the CPFAL 19% of the time ($n=139$). The average concentration at baseflow was 8 $\mu\text{g/L}$ ($n=78$). For the March 1999 samples, there were no exceedances of the CPFAL guideline. Total zinc at most sites in the Peel River basin was measured at or below the detection limit of 5 $\mu\text{g/L}$, the exceptions being *Ogilvie River above Engineer Creek* (A), *Hart River near Hungry Lake* (F), and *Peel River above the Caribou River* (Site N, the maximum at 22 $\mu\text{g/L}$). Dissolved zinc showed similar patterns although was lower at Site N (Figure 37).

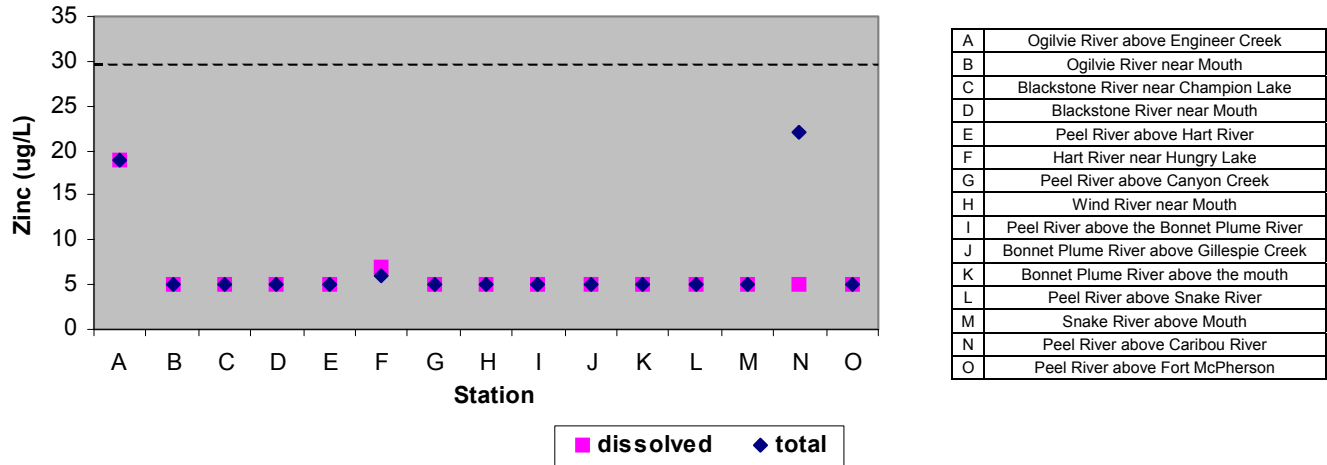


Figure 37. Concentration of total and dissolved zinc at 15 sites in the Peel River drainage basin, March 1999
Broken line indicates CPFAL guideline (30 µg/L).

Table 11. Seasonal variation of metals at *Peel River above Fort McPherson* (median and means by water-year)

Parameter	Units	Freshet	Recession	Baseflow
		median/mean	median/mean	median/mean
Aluminum *	µg/L	5630/7817	1050, 2843	34, 67
(n, sd)		(7, 6266)	(10, 107)	(30, 107)
Arsenic (Dissolved) *	µg/L	0.4/0.7	0.4/0.4	0.2/0.2
(n, sd)		(24, 0.9)	(37, 0.2)	(81, 0.9)
Barium *	µg/L	211/216	138, 138	85/94
(n, sd)		(23, 92)	(36, 56)	(80, 26)
Beryllium *	µg/L	0.40/0.40	0.08, 0.17	0.05, 0.05
(n, sd)		(7, 0.25)	(10, 0.23)	(31, 0)
Cadmium *	µg/L	0.6, 1.01	0.60/0.65	0.10/0.39
(n, sd)		(23, 1.22)	(37, 0.71)	(80, 0.44)
Chromium *	µg/L	10.2, 12.7	1.85, 4.43	0.30/0.47
(n, sd)		(7, 9.6)	(10, 6.39)	(31, 0.45)
Cobalt *	µg/L	5.2, 5.3	2.0/3.0	0.5/1.3
(n, sd)		(24, 3.5)	(37, 3.2)	(80, 1.8)
Copper *	µg/L	14.0/16.5	4.0/7.8	1.0/1.5
(n, sd)		(23, 12.8)	(37, 9.8)	(80, 1.4)
Iron *	mg/L	13.2/20.2	2.2/7.6	0.09/0.18
(n, sd)		(7, 21.7)	(10, 14.2)	(31, 0.27)
Lead *	µg/L	5.5/7.0	2.4/3.4	0.8/1.4
(n, sd)		(23, 5.7)	(37, 3.6)	(80, 1.4)
Lithium *	µg/L	22.8/26.3	13.2/16.1	8.6/8.4
(n, sd)		(7, 14.6)	(10, 11.1)	(31, 1.6)
Manganese *	µg/L	245/228	27/17	11/17
(n, sd)		(7, 128)	(9, 23)	(31, 18)
Mercury	µg/L	No results	0.02/0.03	0.03/0.06
(n, sd)			(3, 0.01)	(4, 0.06)
Molybdenum *	µg/L	1.6/1.7	1.2/1.2	1.0/1.1
(n, sd)		(7, 1.1)	(10, 0.3)	(31, 0.1)

Parameter	Units	Freshet	Recession	Baseflow
		median/mean	median/mean	median/mean
Nickel * (n, sd)	µg/L	16.0, 17.3 (23, 12.0)	5.0/8.9 (37, 8.9)	1.3/1.9 (79, 1.5)
Selenium (Dissolved) * (n, sd)	µg/L	0.500, 0.513 (24, 0.123)	0.600, 0.559 (37, 0.086)	0.700/0.681 (81, 0.128)
Vanadium * (n, sd)	µg/L	13.3/14.9 (23, 13.0)	4.2/8.3 (37, 14.1)	0.5/0.6 (76, 0.7)
Zinc * (n, sd)	µg/L	50.2/63.1 (23, 51.4)	15.0/27.3 (37, 32.0)	4.0/8.0 (78, 16.9)

* Calculated value for the Kruskal-Wallis test statistic is significant (95% confidence interval). Median values do differ significantly between water-years for all metals except mercury.

Conclusions

River discharge and background geology are the most significant natural factors in determining changes in water quality over time and space. River discharge is intimately associated with seasonality. It is greatest during the spring freshet when water levels are high due to snowmelt and runoff. Sediment load is also greatest during freshet because of erosion. High waters create a dilution effect for those variables that are contributed to the system by the dissolution of material in soils and bedrock (Whitfield, 1996). During the summer recession, water flow decreases as surface runoff and snowmelt are reduced. Water levels are lowest during the winter baseflow. Flowing water in winter appears to be derived from groundwater, as there are few lakes in the Peel River basin. The contributing groundwater sources are trapped between the frozen active layer and the regional permafrost, virtually isolated from atmospheric inputs and surface disturbance. In winter, the underlying geology plays the major role in determining the chemical constituents in water. Most dissolved constituents are highest during this time of year, whereas those variables associated with particulate matter tend to be lowest.

The *Peel River above Fort McPherson* is the only long-standing and active water quality site in the Peel River basin. It is an important site due to its proximity to the Yukon/NWT border and therefore its relevancy for transboundary water negotiations between the Yukon and Northwest Territories Governments. The site is located in the upper reach of the Peel River basin and is representative of all the water flowing north through the basin. Sampling at this site is seasonal in an attempt to capture the large water quality variability throughout the year. Any future monitoring should continue this seasonal sampling. Flow measurements, critical for the interpretation of water quality data, are done at the same time as water samples are collected. In general, the historic data at this site indicated that many parameters were present at very low levels or not detectable. Those parameters that exceeded the *Guidelines for the Protection of Aquatic Life* are likely naturally elevated. Given the lack of development, metals that were found are probably from natural sources such as the weathering of rock and should not cause adverse effects to aquatic life.

The most common seasonal trend observed was highest concentrations of water quality parameters during freshet with decreasing concentrations throughout the recession and lowest values during baseflow. The parameters exhibiting this type of trend are those generally associated with suspended material in the water. They include turbidity, total suspended solids, total and particulate nutrients and most metals including aluminum, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, vanadium, and zinc. This trend reflects the effect of erosion input during runoff during the spring freshet (WER Agra, 1993). Spearman's correlations revealed strong positive correlations of total suspended solids with aluminum, chromium, cobalt, copper, iron, lead, lithium and nickel. In each case, the correlation coefficient was greater than 0.8.

Parameters showing highest values in winter and lowest values during freshet and recession are dissolved and include selenium, nitrate+nitrite, reactive silica, alkalinity, calcium, magnesium, strontium, sodium, fluoride, chloride, sulphate, total dissolved solids and conductivity. Dissolved constituents of water that remain in solution are lowest during the freshet due to dilution.

As mentioned, grab samples include both water and sediment. At *Peel River above Fort McPherson* only total metal results have been analysed and discussed. Because of this, the bioavailable metal concentrations are unknown. It would be worthwhile to employ a centrifuge at *Peel River above Fort McPherson*. The centrifuge separates the sediment from the water (the centrifugate). Centrifugate results could be compared with grab sample results to investigate and

quantify the availability of metals and other parameters to aquatic life. Although the effort is great, it would be interesting to have an idea of the dissolved constituents in the river water at this site.

The March 1999 survey of winter water quality in the Peel River basin provided valuable information about the concentration of parameters throughout the basin during baseflow. Water quality at most of the sites studied met the requirements of the CPFAL and the CDWQ guidelines. Exceptions were seen in cases of cadmium, chromium and selenium where the CPFAL was exceeded at least on one occasion. In addition, water samples from *Peel River above Caribou River* (N) exceeded the CPFAL for ammonia, aluminum, and iron and the CDWQ for iron, manganese and turbidity. Copper exceeded its guideline at *Ogilvie River above Engineer Creek*. In the future, methods with lower detection limits should be used for analysis in the case of those metals where dissolved exceeded total, and those parameters where the detection limit was at or above the relevant water quality guideline.

The March 1999 data collected at various sites provides a good basin overview but only a snapshot of water quality. Throughout this report, the March data was compared to long-term water quality data from *Peel River above Fort McPherson*. Differences in water quality between the historic site and all other sites were made evident where some basin variables fell outside of the historic range. The Peel River has site-specific geographical characteristics distinct from its smaller upstream tributaries and as such, hydrology and underlying geology will differ. To better understand the seasonal variability of water quality in the basin, samples should be collected during freshet and recession from some or all of the sites studied in March 1999.

Water quality in the Peel River basin can be considered good as it has been virtually untouched by development. Whitfield *et al.*, (1995, 1996) have studied winter chemistry of rivers in the Yukon Territory including the Peel River basin. It was observed through repeat sampling that winter water chemistry was persistent from year to year. In the absence of major development, this characteristic return to similar chemistry could provide an opportunity to monitor long-term water quality in the Peel Basin. However, factors such as global warming and impending oil and gas exploration warrant a better understanding of this baseline chemistry. It is hoped that this report will contribute to the understanding of water quality in this important northern watershed.

Recommendations for future work:

- Sampling during freshet and recession to better characterize the water-year in the basin;
- Sediment sampling at *Peel River above Fort McPherson* to investigate the effect of sedimentation on water quality and to estimate sediment load;
- Sampling for polycyclic aromatic hydrocarbons (PAHs) organic compounds to qualify and quantify their presence prior to any future oil and gas initiatives and to distinguish natural sources from those present as a result of the development;
- Compilation of the available data from the other long standing, but currently inactive *Peel River at Fort McPherson* site with *Peel River above Fort McPherson* data; and
- Investigate the production of a condensed State of the Aquatic Environment Report, similar in nature to those done for the Slave and Liard rivers by combining previous research by DIAND Yukon and NWT with current work being done by the Department of Fisheries and Oceans.

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Appendix A

QA/QC Data for March 1999 Peel River Basin Sampling Program

Duplicate samples were collected at five of the fifteen sites visited:

*Ogilvie River above Engineer Creek (A);
Ogilvie River near mouth (B);
Hart River near Hungry Lake (F);
Peel River above the Bonnet Plume River (I); and
Bonnet Plume River above Gillespie Creek (M).*

A triplicate sample was collected at *Peel River above Fort McPherson (O)*.

Three field blank bottles were filled with water provided by Taiga Laboratory and carried into the field with the actual samples to replicate field conditions.

Duplicates, triplicate and blank samples were analyzed for physical parameters, major ions, nutrients, and total and dissolved metals. The results are displayed in table X, Y and Z.

The three field blanks were generally similar and report at or below the detection limit for most parameters. The exception among the routine parameters is field blank #3 (990304) that gave a higher conductivity, turbidity and sodium than the other two blanks.

The field blanks were slightly above the detection limit for dissolved barium, total and dissolved chromium, total copper, total and dissolved manganese, total and dissolved titanium, and dissolved strontium.

The field blanks were similar to sample results for ammonia nitrogen, phosphorus, total and dissolved copper, total and dissolved lead, total and dissolved antimony. The sample results for these parameters should be used with caution after a review of the data.

Among the duplicates and triplicates, there was poor accord for sulphate, dissolved titanium, total and dissolved lead, and dissolved antimony.

Appendix A

QA/QC Data Summary for the Peel River Basin Sampling Program, March 1999

Table A1: Total metals QA/QC data

Lab Number	990299	990300	990281	990282	990285	990286	990289	990290	990293	990294	990296	990297	990298	990302	990303	990304
Site Location	A	A	B	B	F	F	I	I	M	M	O	O	O	BLANK	BLANK	BLANK
Description	Ogilvie River above Engineer Creek	Ogilvie River above Engineer Creek	Ogilvie River near mouth	Ogilvie River near mouth	Hart River near Hungry Lake	Hart River near Hungry Lake	Peel River above the Bonnet Plume River	Peel River above the Bonnet Plume River	Bonnet Plume River above Gillespie Creek	Bonnet Plume River above Gillespie Creek	Peel River above Ft. McPherson	Peel River above Ft. McPherson	Peel River above Ft. McPherson	BLANK	BLANK	BLANK
Total metals	Duplicate		Duplicate		Duplicate		Duplicate		Duplicate		TriPLICATE		Field Blanks (3)			
Aluminium (µg/L)	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 12	L 10	L 11	L 10	L 10	L 10
Antimony (µg/L)	1	1.3	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5
Barium (µg/L)	92.1	91.2	103	105	103	102	91.2	91.1	58.3	55.6	83.2	79.8	82	0.1	0.1	0.1
Beryllium (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Bismuth (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Cadmium (µg/L)	0.05	0.05	0	0.04	0.1	0.08	0.02	0.03	0.02	0.01	0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Cesium (µg/L)	0.01	0.01	L 0.01	L 0.01	0.02	0.02	L 0.01	L 0.01	0.01	0.01	L 0.01	0.01	L 0.01	L 0.01	L 0.01	L 0.01
Chromium (µg/L)	0.9	0.8	1.6	2.4	1	0.9	0.9	0.8	1	0.9	0.8	1	0.7	0.3	L 0.1	L 0.1
Cobalt (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Copper (µg/L)	3.2	3.4	0.5	0.4	0.7	0.3	0.2	0.2	0.2	0.3	0.2	0.3	0.2	1.4	11.6	2.6
Iron (mg/L)	0.03	0.02	L 0.02	L 0.02	L 0.02	0.03	L 0.02	L 0.02	0.04	0.05	0.04	0.05	0.05	L 0.02	L 0.02	L 0.02
Lead (µg/L)	0.69	0.67	1.81	0.15	0.35	0.31	0.19	0.15	0.08	0.34	0.2	0.3	0.19	0.13	0.33	0.37
Lithium (µg/L)	22.7	23.3	9.5	8.9	5.4	5.3	4	4	6.6	6.5	4.4	4.2	4.4	L 0.1	L 0.1	L 0.1
Manganese (µg/L)	3.2	3.2	2.4	2.5	0.8	0.7	L 0.1	0.1	15.4	15.5	7.8	7.5	7.5	0.2	0.2	0.3
Molybdenum (µg/L)	3.1	3	1.8	1.6	1.6	1.5	1.1	1.1	0.7	0.7	1.1	1.2	1.2	L 0.1	L 0.1	L 0.1
Nickel (µg/L)	3	3	2.6	2.5	2.7	2.5	1.3	1.3	1.5	1.6	1.6	1.6	1.5	L 0.1	L 0.1	L 0.1
Selenium (µg/L)	L 1	L 1	2	2	1	L 1	1	1	1	1	1	1	1	L 1	L 1	L 1
Silver (µg/L)	L 0.01	0.02	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Thallium (µg/L)	0.05	0.05	0.05	0.06	L 0.05	L 0.05	0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05
Titanium (µg/L)	0.94	1.14	0.82	0.8	0.48	0.43	0.49	0.42	1.64	1.67	0.96	1.05	0.97	0.05	L 0.05	0.06
Uranium (µg/L)	3.25	3.22	1.79	1.82	1.81	1.84	1.38	1.35	0.77	0.77	1.13	1.11	1.13	L 0.05	L 0.05	L 0.05
Vanadium (µg/L)	0.5	0.5	0.6	0.9	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.1	L 0.1	L 0.1
Zinc (µg/L)	19	19	L 5	L 5	6	5	L 5	L 5	L 5	L 5	L 5	0	L 5	L 5	L 5	L 5

Table A2: Dissolved metals QA/QC data

Lab Number	990299	990300	990281	990282	990285	990286	990289	990290	990293	990294	990296	990297	990298	990302	990303	990304		
Site Location Description	A	A	B	B	F	F	I	I	M	M	O	O	O	BLANK	BLANK	BLANK		
	Ogilvie River above Engineer Creek	Ogilvie River above Engineer Creek	Ogilvie River near mouth	Ogilvie River near Hungry Lake	Hart River near Hungry Lake	Peel River near Bonnet Plume River	Peel River above the Bonnet Plume River	Peel River above the Bonnet Plume River	Bonnet Plume River above Gillespie Creek	Bonnet Plume River above Gillespie Creek	Peel River above Ft. McPherson	Peel River above Ft. McPherson	Peel River above Ft. McPherson	BLANK	BLANK	BLANK		
Dissolved metals	Duplicate			Duplicate			Duplicate			Duplicate			TriPLICATE			Field Blanks (3)		
Aluminium (µg/L)	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	
Antimony (µg/L)	0.8	0.8	0.8	1.3	0.7	0.6	0.6	0.8	0.6	0.7	0.6	0.6	0.6	0.8	0.8	0.8	0.9	
Barium (µg/L)	89.3	91.3	103	107	104	93.4	92.1	92.1	56.9	56.9	81.1	79.6	81.6	0.4	0.3	1.3	1.3	
Beryllium (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	
Bismuth (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	
Cadmium (µg/L)	0.06	0.04	0.03	0.01	0.01	0.02	0.02	0.02	0.01	0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	
Cesium (µg/L)	L 0.01	L 0.01	L 0.01	0.02	0.02	L 0.01	0.01	0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	
Chromium (µg/L)	1.3	1	1.1	1.5	1.7	1.1	1.2	1.2	1.4	1	0.9	0.6	0.7	0.5	0.2	0.1	0.1	
Cobalt (µg/L)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
Copper (µg/L)	2.8	2.6	0.9	0.8	0.7	0.6	0.7	0.7	0.6	0.5	0.6	0.5	0.6	0.5	1.6	1.7	1.7	
Iron (mg/L)	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	
Lead (µg/L)	0.38	0.35	0.13	0.34	1.11	0.13	0.19	0.19	0.18	0.16	0.18	0.14	0.15	0.08	0.07	0.34	0.34	
Lithium (µg/L)	25.8	24.9	9.5	6.1	6.2	4.7	4.6	4.6	7.5	7.3	5.4	4.9	4.7	0.1	0.1	0.1	0.1	
Manganese (µg/L)	2.6	2.5	2.5	1.1	1.1	1.1	0.3	0.4	15.6	15.4	7.9	6.9	6.9	0.3	0.3	0.5	0.5	
Molybdenum (µg/L)	3.1	3.1	1.8	1.6	1.7	1.2	1.2	1.2	0.7	0.8	1.2	1.1	1.1	0.1	0.1	0.1	0.1	
Nickel (µg/L)	3.3	3.2	2.9	2.8	2.8	1.5	1.6	1.6	1.7	1.7	2	1.7	1.7	0.1	0.1	0.1	0.1	
Selenium (µg/L)	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Silver (µg/L)	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	
Thallium (µg/L)	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	
Titanium (µg/L)	1.03	0.97	0.67	0.59	0.52	0.54	0.48	0.48	1.56	1.52	0.72	0.71	0.6	0.05	0.05	0.05	0.06	
Uranium (µg/L)	2.76	2.55	1.55	1.69	1.67	1.18	1.31	1.31	0.7	0.72	0.99	1.03	1.07	0.05	0.05	0.05	0.05	
Vanadium (µg/L)	0.6	0.5	0.5	0.6	0.7	0.4	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.1	0.1	0.1	0.1	
Zinc (µg/L)	19	17	L 5	7	6	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	

Table A3: QA/QC data for physical parameters, major ions, and nutrients

Lab Number	990299	990300	990281	990282	990285	990286	990289	990290	990293	990294	990296	990297	990298	990302	990303	990304
Site Location Description	A	A	B	B	F	F	I	I	M	M	O	O	O	BLANK	BLANK	BLANK
	Ogilvie River above Engineer Creek		Ogilvie River near mouth		Hart River near Hungry Lake		Peel River above the Bonnet Plume River		Bonnet Plume River above Gillespie Creek		Peel River above Ft. McPherson		Field Blanks (3)			
Physical parameters	Duplicate		Duplicate		Duplicate		Duplicate		Duplicate		TriPLICATE					
pH	8.28	8.24	7.9	7.93	8.12	8.1	8.06	8.08	8.07	8.14	8.14	8.18	8.21	5.57	5.69	4.43
Colour	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5
Conductivity (uS/cm)	561	559	536	534	406	392	400	400	602	600	440	439	440	1.6	1.5	16.1
Sulphate (mg/L)	98	98	85	85	48	48	98	51	154	160	68	71	69	3	3	3
Tot-Diss-Solids (mg/L)	321	107	302	308	212	215	210	221	370	357	241	243	249	10	10	10
Tot-Suspended-Solids (mg/L)	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Turbidity (NTU)	0.2	0.3	0.2	0.2	0.3	0.2	0.2	0.1	0.5	1	0.7	0.9	1	0.1	0.1	0.2
Major Ions																
Alkalinity (mg/L)	193	192	198	197	160	156	162	162	163	162	158	158	158	L 0.3	L 0.3	L 0.3
Calcium (mg/L)	86.4	83.6	74.8	75.6	54.5	52.4	51.4	51.2	74.6	74.6	56.5	57.5	60.4	0.05	0.05	0.05
Chloride (mg/L)	8.5	8.5	3.5	3.6	2.6	2.6	4	4	0.7	0.7	4.5	4.6	4.5	L 0.2	L 0.2	L 0.2
Fluoride (mg/L)	0.09	0.08	0.11	0.1	0.06	0.06	0.05	0.05	0.06	0.07	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (mg/L)	28.2	28.4	17.3	17.2	15.8	15.2	15.2	15.1	26	26.7	17.8	17.6	20.8	L 0.01	L 0.01	L 0.01
Potassium (mg/L)	0.61	0.6	0.48	0.48	0.37	0.36	0.38	0.38	0.57	0.57	0.53	0.52	0.52	0.02	0.02	0.19
Sodium (mg/L)	11.4	11.7	8.49	8.5	3	2.52	3.71	3.66	5.34	5.3	5.16	5.09	5.09	1.8	1.7	4.5
Strontium Dissolved (mg/L)	261	276	256	257	177	177	158	160	366	373	171	174	169	0.02	0.02	0.19
Strontium Total (mg/L)	280	277	259	258	173	169	157	154	364	366	173	171	170	L 0.1	L 0.1	0.1
Hardness (mg/L CaCO3)	332	326	258	260	201	193	191	190	293	296	214	216	236	L 0.1	L 0.1	0.1
Nutrients																
Ammonia-N (mg/L)	0.004	0.011	L 0.002	0.002	L 0.002	0.002	L 0.002	0.003	L 0.002	L 0.002	0.007	0.003	L 0.002	0.005	L 0.002	L 0.002
Nitrate-N (mg/L)	0.135	0.103	0.194	0.193	0.236	0.231	0.279	0.254	0.139	0.103	0.18	0.189	0.185	L 0.008	0.01	L 0.008
NO3-N+NO2-N (mg/L)	0.135	0.103	0.194	0.193	0.236	0.231	0.279	0.254	0.139	0.103	0.18	0.189	0.185	L 0.008	0.01	L 0.008
T-Phosphorous (mg/L)	0.015	0.014	0.02	0.014	0.013	0.012	0.014	0.014	0.015	0.015	0.015	0.014	0.015	0.013	0.014	0.012

Appendix B

Water Quality Data Summary for Peel River Basin Sampling Program, March 1999

Table B1: Total metals raw data

Lab Number	990299	990281	990301	990283	990284	990285	990287	990288	990289	990291	990305	990292	990293	990295	990296
Site Location	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Ogilvie River above Engineer Creek	Ogilvie River near mouth	Blackstone River near Champion Lake	Blackstone River near mouth	Peel River above Hart River	Hart River near Hungry Lake	Peel River above Canyon Creek	Wind River near mouth	Peel River above the Bonnet Plume River	Bonnet Plume River above Gillespie Creek	Bonnet Plume River above the mouth	Peel River above Snake River	Snake River above mouth	Peel River above Caribou River	Peel River above Ft. McPherson
Aluminium (µg/L)	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	6870	12
Antimony (µg/L)	1	0.7	0.6	0.5	0.7	0.6	0.6	0.5	0.6	0.5	0.6	0.6	0.5	0.7	0.5
Barium (µg/L)	92.1	103	89.9	130	120	103	95.3	111	91.2	71.4	72.5	91.4	58.3	255	83.2
Beryllium (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Bismuth (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Cadmium (µg/L)	0.05	0	0.02	L 0.01	0.02	0.1	0.05	L 0.01	0.02	0.01	L 0.01	0.02	0.02	0.4	L 0.01
Cesium (µg/L)	0.01	L 0.01	L 0.01	L 0.01	L 0.01	0.02	0.01	0.01	L 0.01	0.01	L 0.01	L 0.01	0.01	1	L 0.01
Chromium (µg/L)	0.9	1.6	0.5	1.4	1.3	1	1	0.9	0.9	0.8	0.6	0.6	1	10	0.8
Cobalt (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	2.3	L 0.1
Copper (µg/L)	3.2	0.5	0.2	0.2	0.5	0.7	0.3	0.1	0.2	0.2	0.1	0.2	0.2	2.7	0.2
Iron (mg/L)	0.03	L 0.02	0.05	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	0.05	0.04	5.43	0.04
Lead (µg/L)	0.69	1.81	0.18	0.14	0.22	0.35	1.25	0.13	0.19	0.13	0.35	0.2	0.08	2.3	0.2
Lithium (µg/L)	22.7	9.5	3.9	3.5	7.1	5.4	5.4	2.4	4	4.5	2.4	3.6	6.6	14.8	4.4
Manganese (µg/L)	3.2	2.4	3.4	0.5	1	0.8	0.6	0.4	L 0.1	1.9	0.5	3.3	15.4	453	7.8
Molybdenum (µg/L)	3.1	1.8	1.1	1.1	1.5	1.6	1.5	0.6	1.1	0.6	0.6	1	0.7	1.7	1.1
Nickel (µg/L)	3	2.6	1.7	1	2.4	2.7	2.6	0.8	1.3	1.2	1.2	1.8	1.5	7.2	1.6
Selenium (µg/L)	L 1	2	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	10	1
Silver (µg/L)	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.1	L 0.01
Thallium (µg/L)	0.05	0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	0.05	0.05	L 0.05	L 0.05	L 0.05	L 0.05	0.1	L 0.05
Titanium (µg/L)	0.94	0.82	0.88	0.35	0.69	0.48	0.5	0.22	0.49	1.41	0.71	0.58	1.64	137	0.96
Uranium (µg/L)	3.25	1.79	1.38	1.51	1.65	1.81	1.65	1.04	1.38	1.5	1.52	1.26	0.77	1.7	1.13
Vanadium (µg/L)	0.5	0.6	0.3	0.6	0.5	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.4	30.1	0.4
Zinc (µg/L)	19	L 5	L 5	L 5	L 5	6	L 5	L 5	L 5	L 5	L 5	L 5	L 5	22	L 5

Table B2: Dissolved metals raw data

Lab Number	990299	990281	990301	990283	990284	990285	990287	990288	990289	990291	990305	990292	990293	990295	990296
Site Location	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Ogilvie River above Engineer Creek	Ogilvie River near mouth	Blackstone River near Champion Lake	Blackstone River near mouth	Peel River above Hart River	Hart River near Hungry Lake	Peel River above Canyon Creek	Wind River near mouth	Peel River above the Bonnet Plume River	Bonnet Plume River above Gillespie Creek	Bonnet Plume River above the mouth	Peel River above Snake River	Snake River above mouth	Peel River above Caribou River	Peel River above Ft. McPherson
Aluminium (µg/L)	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10
Antimony (µg/L)	0.8	0.8	0.7	0.6	0.8	1.3	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6
Barium (µg/L)	89.3	103	87.5	131	119	107	95.7	110	93.4	71.6	73.6	89.3	56.9	84.5	81.1
Beryllium (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Bismuth (µg/L)	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1	L 0.1
Cadmium (µg/L)	0.06	0.03	0.02	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	0.02	0.02	L 0.01	0.02	0.01	L 0.01	L 0.01
Cesium (µg/L)	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	0.02	L 0.01	L 0.01	L 0.01	0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Chromium (µg/L)	1.3	1.1	0.9	2	1.5	1.5	1.2	1.3	1.1	1	0.7	0.9	1.4	0.8	0.9
Cobalt (µg/L)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	L 0.1	0.1	0.1	L 0.1	0.1
Copper (µg/L)	2.8	0.9	0.4	0.8	0.9	0.8	0.5	0.5	0.6	0.5	0.3	0.5	0.6	0.6	0.6
Iron (mg/L)	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02	L 0.02
Lead (µg/L)	0.38	0.13	1.17	0.18	0.34	0.34	0.15	0.23	0.13	0.12	0.17	0.17	0.18	0.14	0.18
Lithium (µg/L)	25.8	9.5	4.1	3.9	7.8	6.1	6	2.9	4.7	5.4	2.6	4.2	7.5	4.6	5.4
Manganese (µg/L)	2.6	2.5	3.3	0.8	1.2	1.1	0.8	0.5	0.3	2.2	0.6	3.3	15.6	1.8	7.9
Molybdenum (µg/L)	3.1	1.8	1.2	1.1	1.5	1.6	1.5	0.7	1.2	0.6	0.5	1	0.7	1.1	1.2
Nickel (µg/L)	3.3	2.9	1.8	1.1	2.7	2.8	2.7	1	1.5	1.4	1.3	1.9	1.7	1.8	2
Selenium (µg/L)	1	2	1	1	2	L 1	L 1	L 1	1	1	L 1	1	L 1	1	1
Silver (µg/L)	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01	L 0.01
Strontium (µg/L)	261	256	147	172	243	177	189	81.6	158	199	137	144	366	172	171
Thallium (µg/L)	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05	L 0.05
Titanium (µg/L)	1.03	0.67	0.46	0.48	0.73	0.59	0.41	0.38	0.54	1.31	0.62	0.6	1.56	0.67	0.72
Uranium (µg/L)	2.76	1.55	1.27	1.32	1.52	1.69	1.36	0.92	1.18	1.3	1.35	1.25	0.7	1.08	0.99
Vanadium (µg/L)	0.6	0.5	0.3	0.8	0.6	0.6	0.6	0.5	0.4	0.3	0.4	0.4	0.5	0.4	0.3
Zinc (µg/L)	19	L 5	L 5	L 5	L 5	7	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5

Table B3: Raw data for physical parameters, major ions, and nutrients

Lab Number	990299	990281	990301	990283	990284	990285	990287	990288	990289	990291	990305	990292	990293	990295	990296
Site Location Description	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Ogilvie River above Engineer Creek	Ogilvie River near mouth	Blackstone River near Champion Lake	Blackstone River near mouth	Peel River above Hart River	Hart River near Hungry Lake	Peel River above Canyon Creek	Wind River near mouth	Peel River above the Bonnet Plume River	Bonnet Plume River above Gillespie Creek	Bonnet Plume River above the mouth	Peel River above Snake River	Snake River above mouth	Peel River above Caribou River	Peel River above Ft. McPherson
Physical parameters															
pH	8.28	7.9	8.23	8.05	7.97	8.12	8.07	8.14	8.06	8.19	8.27	8.16	8.07	8.15	8.14
Colour	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5
Conductivity (uS/cm)	561	536	397	409	502	406	410	352	400	528	384	395	602	433	440
Sulphate (mg/L)	98	85	45	35	65	48	49	16	98	133	31	52	154	69	68
Total Dissolved Solids (mg/L)	321	302	210	220	295	212	225	179	210	316	204	210	370	230	241
Total Suspended Solids (mg/L)	5	3	3	3	3	3	3	3	3	3	3	3	3	135	3
Turbidity (NTU)	0.2	0.2	0.5	0.2	0.2	0.3	0.2	0.1	0.2	0.1	0.2	0.3	0.5	127	0.7
Major Ions															
Alkalinity (mg/L)	193	198	150	177	196	160	160	155	162	157	133	150	163	156	158
Calcium (mg/L)	86.4	74.8	50.1	58.2	70.8	54.5	55.4	43.4	51.4	68.4	45.4	48.2	74.6	53.3	56.5
Chloride (mg/L)	8.5	3.5	5.2	1.5	2.8	2.6	2.5	4.2	4	0.5	5.9	5.2	0.7	5	4.5
Fluoride (mg/L)	0.09	0.11	0.07	0.06	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05
Magnesium (mg/L)	28.2	17.3	16	14.8	16.4	15.8	15	15.4	15.2	38.2	17.1	16.1	26	17.4	17.8
Potassium (mg/L)	0.61	0.48	0.47	0.37	0.53	0.37	0.37	0.41	0.38	0.51	0.5	0.47	0.57	0.56	0.53
Sodium (mg/L)	11.4	8.49	4.36	2.27	7.15	3	3.31	3.32	3.71	2.16	4.38	4.28	5.34	4.94	5.16
Strontium Dissolved	261	256	147	172	243	177	189	81.6	158	199	137	144	366	172	171
Strontium Total (µg/L)	280	259	145	171	239	173	187	80.4	157	188	134	140	364	200	173
Hardness (mg/L CaCO3)	332	258	191	206	244	201	200	172	191	328	184	187	293	205	214
Nutrients															
Ammonia-N (mg/L)	0.004	0.002	0.004	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.004	0.002	0.002	0.08	0.007
Nitrate-N (mg/L)	0.135	0.194	0.223	0.265	0.217	0.236	0.288	0.241	0.279	0.151	0.174	0.209	0.139	0.18	0.18
NO3-N+NO2-N (mg/L)	0.135	0.194	0.223	0.265	0.217	0.236	0.288	0.241	0.279	0.151	0.174	0.209	0.139	0.19	0.18
T-Phosphorous (mg/L)	0.015	0.02	0.016	0.012	0.014	0.013	0.014	0.013	0.014	0.015	0.011	0.015	0.015	0.13	0.015