1995/96 ANNUAL REPORT ON

AQUATIC QUALITY MONITORING

NAHANNI NATIONAL PARK RESERVE, NWT

Prepared For

Parks Canada
Canadian Heritage

and

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Executive Summary

The challenge of water resource management in the north is to prevent environmental degradation that has occurred elsewhere due to encroaching development. Nahanni National Park Reserve (NPR) is located in the lower South Nahanni River (SNR) basin, an area which also has considerable future mining potential. The potential of future mining activity in tributaries of the South Nahanni River outside the Park raises concerns about possible degradation of Park waters.

San Andreas Resources Corporation (SARC) have recently carried out advanced stage exploration at their Prairie Creek (Cadillac) zinc-lead-silver-copper property. Geological resources hosted in carbonates and shales as of December 1995 are 10.6 million tonnes, grading 13.1% Zn, 11.3% Pb and 188.4 grams/tonne Ag (Mining North, NWTCM, 1996). The Project may require a comprehensive environmental study and will, at minimum, require screening under the new Canadian Environmental Assessment Act (CEAA). The mothballed Canada Tungsten W-Cu Mine is located in the headwaters of the Flat River, upstream of the Park. Despite these developments, the Park waters are still considered to be in pristine condition.

Information on baseline aquatic quality data conditions in the Park collected during a 3 year study (1988-91) by Canadian Parks Service and Inland Waters Directorate of Environment Canada were used to develop water quality objectives to provide a means to monitor whether and when basin waters exceed limits of natural variability. Since waters have low concentrations of many water quality variables, some objectives lie between or below the lower limits of quantitation and detection of laboratory analysis methods, where data can have uncertainties of +/- 5 to 50%. Such data is said to be "non-robust" (inaccurate, imprecise), as evidenced by situations where the <u>dissolved</u> metal values/objectives exceed <u>total</u> metal values/objectives.

Data collected at seven sites in the Park under the PC/EC monitoring program initiated in 1992 provides information for refining and setting water quality objectives, and evaluating compliance with park water quality objectives. Preservation of Park waters will be enhanced if such water quality objectives are incorporated into the water management plans for the Park and the entire South Nahanni Watershed.

Water quality samples were collected at seven sites on April 10, June 7, and September 11, 1995, representing baseflow, freshet and recession conditions, respectively. (The Flat River Mouth site was also sampled on May 10, November 30, and February 15, 1996). Suspended sediment quality samples were also collected, analyzed and results reported each year, as have fish tissue quality samples (during alternate years, 1992 and 1994).

The water quality in Nahanni NPR is excellent overall, but there are local, naturally high geochemical background levels of water quality variables which exceed Canada-wide (regional) geochemical backgrounds. Therefore, Canadian Water Quality Guidelines (CWQGs) for freshwater aquatic life or drinking water were exceeded under baseflow conditions for total aluminum and cadmium at the Flat River Mouth site, for total selenium at the Rabbitkettle River Mouth site, and for total aluminum and iron at the Nahanni Butte site.

CWQGs for freshwater aquatic life or drinking water were exceeded under freshet conditions for turbidity and total aluminum, copper, iron, manganese, nickel, and zinc at both Flat River sites; turbidity, total aluminum and iron at all sites except the Prairie Creek Mouth site; for non-filterable residue (NFR) at the Flat River Mouth site; true colour, total beryllium, cobalt and lead for the Flat River Park Boundary site; and total beryllium, cobalt, copper, iron, manganese and zinc above Rabbitkettle River. Other freshet CWQG exceedances were noted at Rabbitkettle River Mouth (NFR; total beryllium, copper, manganese, lead and zinc), Virginia Falls (total barium, beryllium, chromium, copper, lead and zinc), Prairie Creek Mouth (field pH), and Nahanni Butte (total copper and zinc. CWQG exceedances occurred under recession conditions for turbidity at all sites except the Prairie Creek Mouth site, and for total iron at all sites except the Prairie Creek Mouth and Flat River Park Boundary sites. Other recession CWQG exceedances occurred at Flat River Mouth (total zinc), Flat River Park Boundary (total aluminum), above Rabbitkettle River (total cobalt and zinc), Rabbitkettle River Mouth (NFR; total cyanide; total aluminum, beryllium, copper, manganese and zinc), Virginia Falls (total aluminum), Prairie Creek Mouth (field pH, total selenium), and Nahanni Butte (total aluminum).

Those CWQG (and objective) exceedances lying within the 95% confidence and prediction limits of the linear regression lines of water quality variables on flow (or field conductivity) can be downplayed; those outside require further examination. Overall, most exceedances are considered to be "natural", reflecting proximity to bedrock with abundant mostly-undeveloped mineral deposits, or geochemical dispersion within overburden overlying that bedrock down-drainage (chemical-hydromorphic) or down-ice (mechanical-glacial) from source rocks. The spatial and temporal (seasonal) variation of the water quality objectives at the seven monitoring sites were evaluated using geological maps, hydrographs, multiple box-and-whisker plots and trend analysis plots. Water quality variable values are clearly <u>spatially</u> controlled by bedrock and surficial geology, and hydrology. Values are <u>temporally</u> controlled by dilution effects, particulate effects (including early flushing of particulates), temperature effects and biological uptake.

Results for analyses of suspended sediment samples from Nahanni NPR in 1995/96) can be compared to interim Canadian Sediment Quality Guidelines (CSQGs) for eight trace metals. Suspended sediment values obtained in 1995 from Nahanni Butte and Virginia Falls exceed the new CSQGs for total arsenic, cadmium, chromium, copper, nickel and zinc. Though no CSQGs exist for total aluminum and iron, both sediment quality sampling sites produced elevated 1995 values, as was the case in 1988-89 and 1992-94.

Continued monitoring of Park water quality is considered appropriate for fiscal year 1996/97 along the guidelines of the 1995/96 EC/PC MOU to complete the five-year follow-up study. The Flat River Mouth site should continue to be sampled opportunistically during under-ice conditions to permit long-term trend analysis and seasonality studies. Results from the five-year study will be compiled and analysed in a final report in 1997/98. The report will revise water quality objectives at five sites, establish water quality objectives at two sites, and establish sediment quality guidelines at one site. The report will also assess future monitoring needs.

Acknowledgements

The Agreement Administrators, Jesse Jasper/ Scott McDonald (Environment Canada) and Rob Prosper (Canadian Parks Service) and the author of this report would like to acknowledge the contributions and cooperation provided by program participants during 1995. Roger Pilling and Gerry Wright of the Water Survey of Canada, and Carl Lafferty an Rob Prosper of Parks Canada in Fort Simpson carried out program field sampling and flow measurements. Pat Wood, Water Survey of Canada supervised field operations and supplied a valuable historic perspective to the program.

Jesse Jasper provided technical input and editing skills. John Kerr provided discharge estimates for the South Nahanni River via flow routings to the Nahanni Butte water quality station. Brian Yurris assisted in the preparation of the 1995 database, drafting of figures and integration of 1995, 1994, 1993, 1992, 1989 and 1988 discharge data from three hydrometric stations.

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1.0 INTRODUCTION

This report describes environmental water and sediment quality monitoring during fiscal 1995/96 at seven sites in Nahanni National Park Reserve (NPR) carried out under a Memorandum of Understanding (MOU) between Canadian Parks and Environment Canada (Appendix III).

Nahanni NPR is one of Canada's premier wild river national parks. The unique deep canyons, falls, white water and meandering reaches of this renowned northern mountain wilderness area resulted in national and international recognition as a Canadian Heritage River and as a UNESCO World Heritage Site, in 1971.

The near pristine quality of Park waters is considered vulnerable to upstream development since the Park is located in the lower reaches of the South Nahanni River (SNR) basin. Past and potential future mining developments on tributaries of the SNR have raised concerns over potential effects of development on the aquatic ecosystem of the Park.

New Canadian Parks Service (CPS) policies and management strategies for national parks led to CPS' interest in comprehensive water quality monitoring to prevent degradation of Nahanni waters from upstream developments. In 1988, CPS signed a MOU with Inland Waters Directorate (IWD) of Environment Canada, covering the collection of baseline water quality data and development of water quality objectives. The December 1991 report entitled "Protecting the Waters of Nahanni National Park Reserve, N.W.T." resulted from the joint 1988-90 CPS/IWD Park water and sediment assessment.

In 1992, a second MOU between IWD and CPS (Appendix III) extended arrangements for collecting and analyzing water and sediment quality samples three times per year, and one set each of suspended sediment and fish tissue samples.

This MOU was extended through 1993, 1994 and 1995. Water, sediment, and fish tissue quality samples were collected at seven, two, and two sites; respectively. Additional water level and flow measurements were also made at three existing stream gauging sites and three special measurement sites. Climate atmospheric information was also obtained from a new EC Virginia Falls weather station. Water quality samples were scheduled for collection on at least three occasions (April, May/June, and September) at each site, with sediment quality samples on one or two occasions during the open water season. Fish tissue quality samples were obtained at SNR below Prairie Creek in September 1992 and 1994 (Flat River Mouth was also sampled in September 1994).

The list of water and sediment analyses carried out in 1995/96 appears in Table 1 in the Appendix.

Water levels, actual flow measurements and computed daily flows were determined for the Flat River and two other water quantity stations on the mainstem South Nahanni River (i.e. above Virginia Falls and near Clausen Creek). The latter site was recently mothballed, due to cuts in funding for unnecesssary monitoring.

This report summarizes activities and water and sediment quality lab analytical results for the 1995/96 and previous field seasons.

2.0 NAHANNI PARK

2.1 The Environment

Nahanni NPR encompasses a spectacular region of waterfalls, canyons, rapids, caves, mountains, valleys, plateaus, karst topography and mineral springs in the lower reaches of the South Nahanni Basin, NWT (Figure 1). The South Nahanni watershed drains 37,000 square kilometres, from icefields near the Yukon-Northwest Territories border 540 kilometres through the Mackenzie Mountains into the Liard and, eventually, Mackenzie Rivers.

Figure 2 shows the Park to be underlain by sedimentary rock formations of marine shales, shallow marine fossiliferous limestones and lesser dolostones, and terrestial sandstones. Granitoid rocks intrude in the western portion. The area is structurally complex due to extensive folding, especially in the west near the intrusions. Extensive development of karst topography, solution channels, caves and sinkholes occurs in the carbonate rocks of the area, due to chemical dissolution and re-precipitation. River erosion and glaciation have also sculpted the present-day landforms (Canadian Parks Service, 1984).

In terms of economic geology, the area's shale, limestone and less common dolostone rock formations host zinc-lead-copper deposits cut by silver-lead-zinc veins, particularly in the Prairie Creek/Cadillac Mine area. Shallow marine carbonates and terrestial sandstones also contain important silver and coal deposits. Further west, in the Howards Pass area near the Yukon-NWT border, shale-hosted zinc-lead-silver-barite deposits occur. Tungsten-copper deposits (e.g. Canada Tungsten Mine) occur in the western Flat River portion of the South Nahanni River basin, along the contacts between granitic and carbonate rocks (Hamilton et al, 1988). Mississippi Valley Type (MVT) lead-zinc, arsenide vein silver, SEDimentary-EXhalative (SEDEX) shale-hosted zinc-lead-silver, sediment-hosted sulphide-barite and tungsten-copper skarn deposits present are well-described in Economic Geology Report 36 (GSC, 1984).

Elevations within the South Nahanni watershed range from 2770 metres above sea level (in the headwaters) to about 180 metres (at the confluence of the Liard and South Nahanni Rivers). Within the Park, the mainstem South Nahanni enters at an elevation of 825 metres and exits at 350 metres, with 90 metres of the vertical drop occuring at Virginia Falls. The rest of the River has an average gradient of 1.2 metres per kilometre.

Hydrographs from Flat River (Figure 3), Virginia Falls (Figure 4) and Clausen Creek (Figure 5) reveal that peak annual flows generally occur from late May to late June each year, due to spring snowmelt and/or early summer rainstorms. The normal annual range of flows is from 55 to 1500 cubic metres per second (Canadian Parks Service, 1984). Flow recession conditions, interspersed with summer rainstorm flood events, prevail from break-up to freeze-up in November. Winter baseflow conditions predominate between November and mid-April, with lowest flows generally occuring in early April. These trends are typical for river basins in the Canadian Cordillera (Whitfield and Whitley, 1986; Koenig, 1995).

Summer mountain rainstorms appear in hydrographs as short-duration "flash floods"; from late April to late August. The "slugs" of water produced by such rainstorms are monitored at three SNR/Flat River stream gauging stations. One such "flash flood" in Dry Canyon Creek, east of Prairie Creek, caused a fatality during summer 1995. The relative contributions of surface water and groundwater to the total flow is not known.

Groundwater in the Park includes formational (connate) waters within karsted carbonate rocks and hydrothermal (magmatic) waters from hot springs. Hot springs occur near fault-controlled upstream reaches of the South Nahanni and Flat Rivers, as well as lower reaches of the Rabbitkettle and Broken Skull Rivers (Hamilton et al, 1991; Gulley, 1993), and may affect water quality at the Rabbitkettle River Mouth, SNR above Rabbitkettle River, and Flat River Mouth sites.

The Rabbitkettle Mouth water quality site is highly influenced by outflows from four hot springs adjacent to travertine mineral deposits, with one hot spring

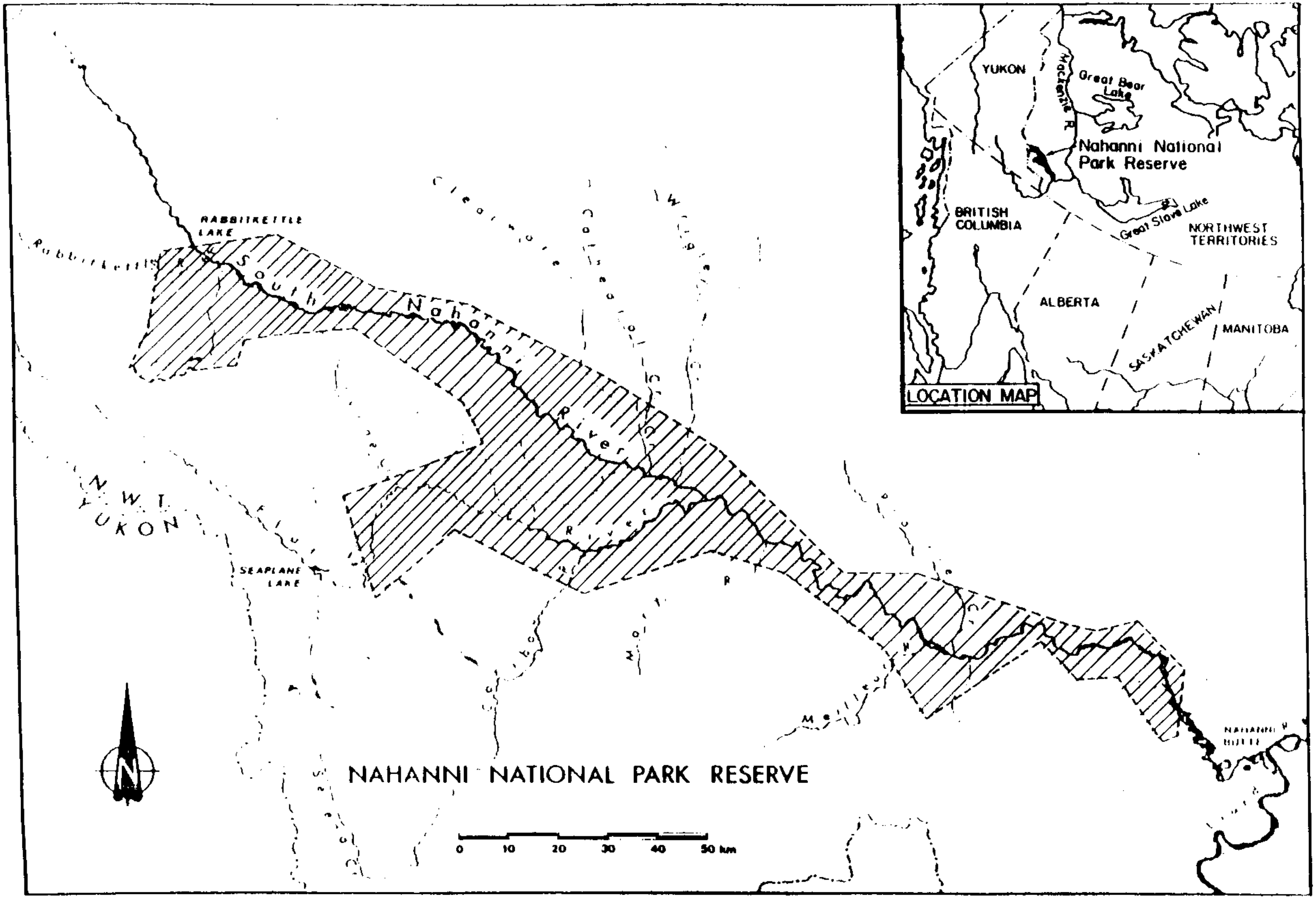
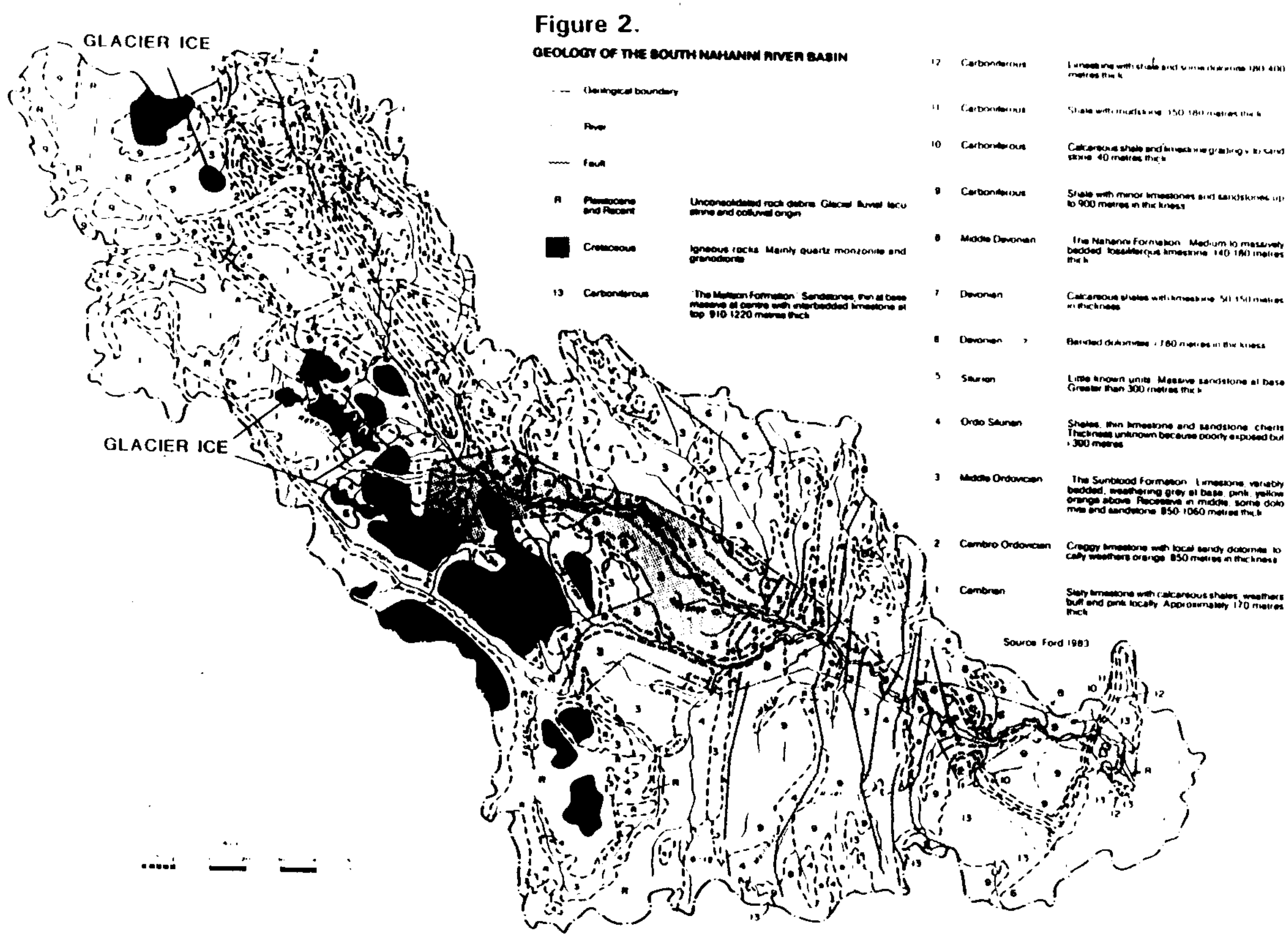


Figure 1. Nahanni National Park Reserve.



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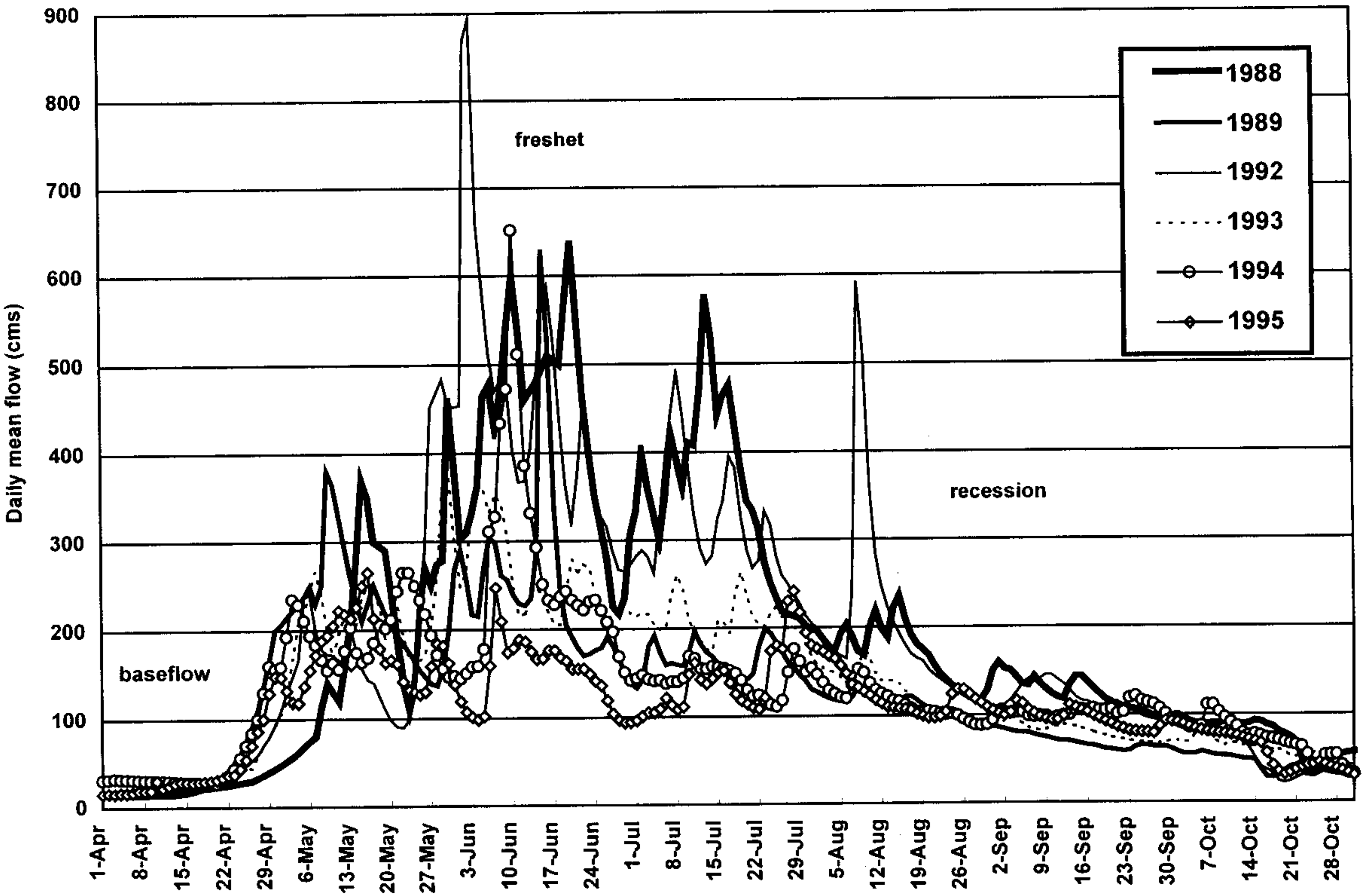


Figure 3 - Flat River near the Mouth (10EA003) - Hydrograph of daily mean flow

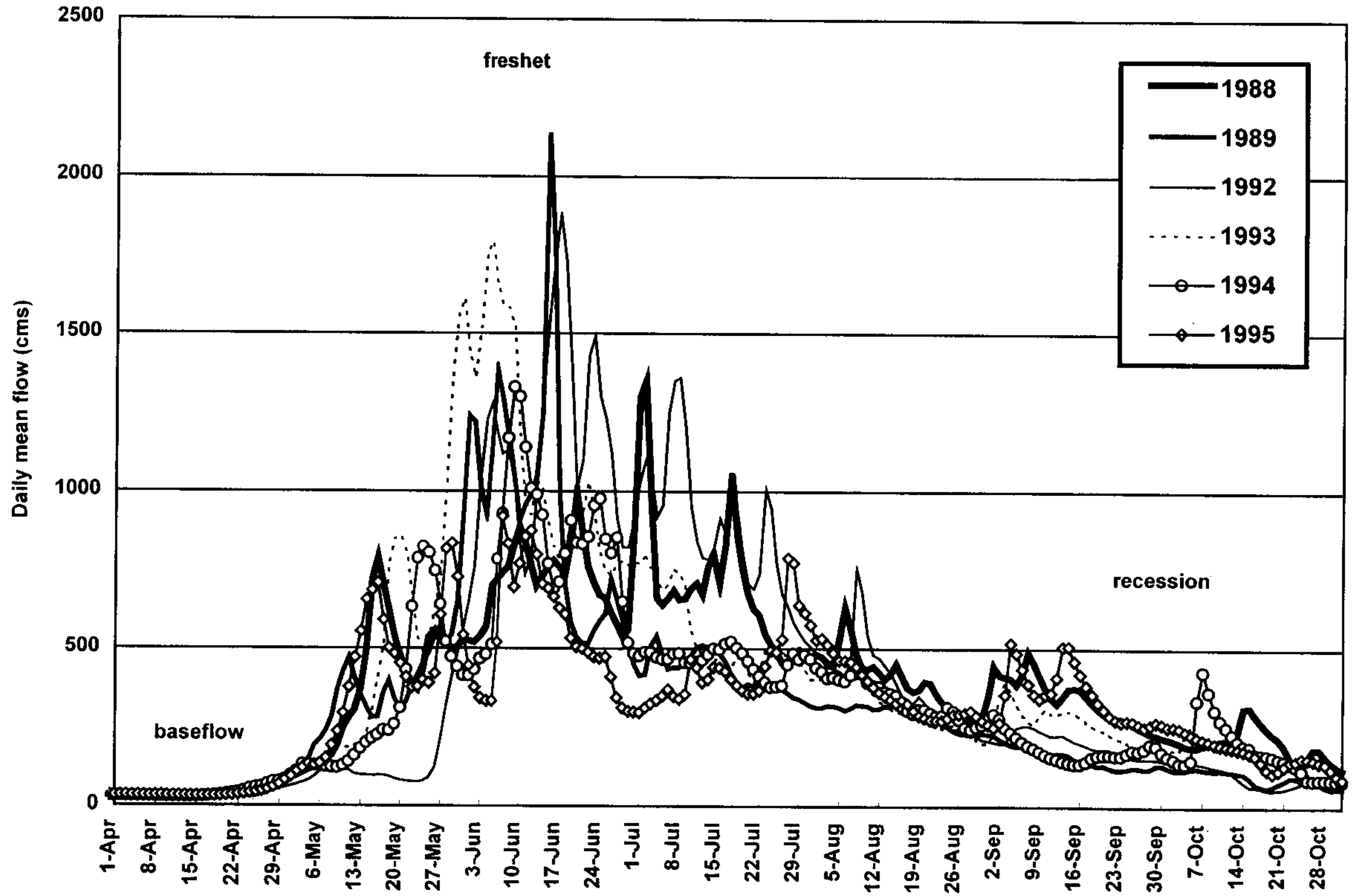


Figure 4 - South Nahanni R above Virginia Falls (10EB001) - Hydrograph of daily mean flow

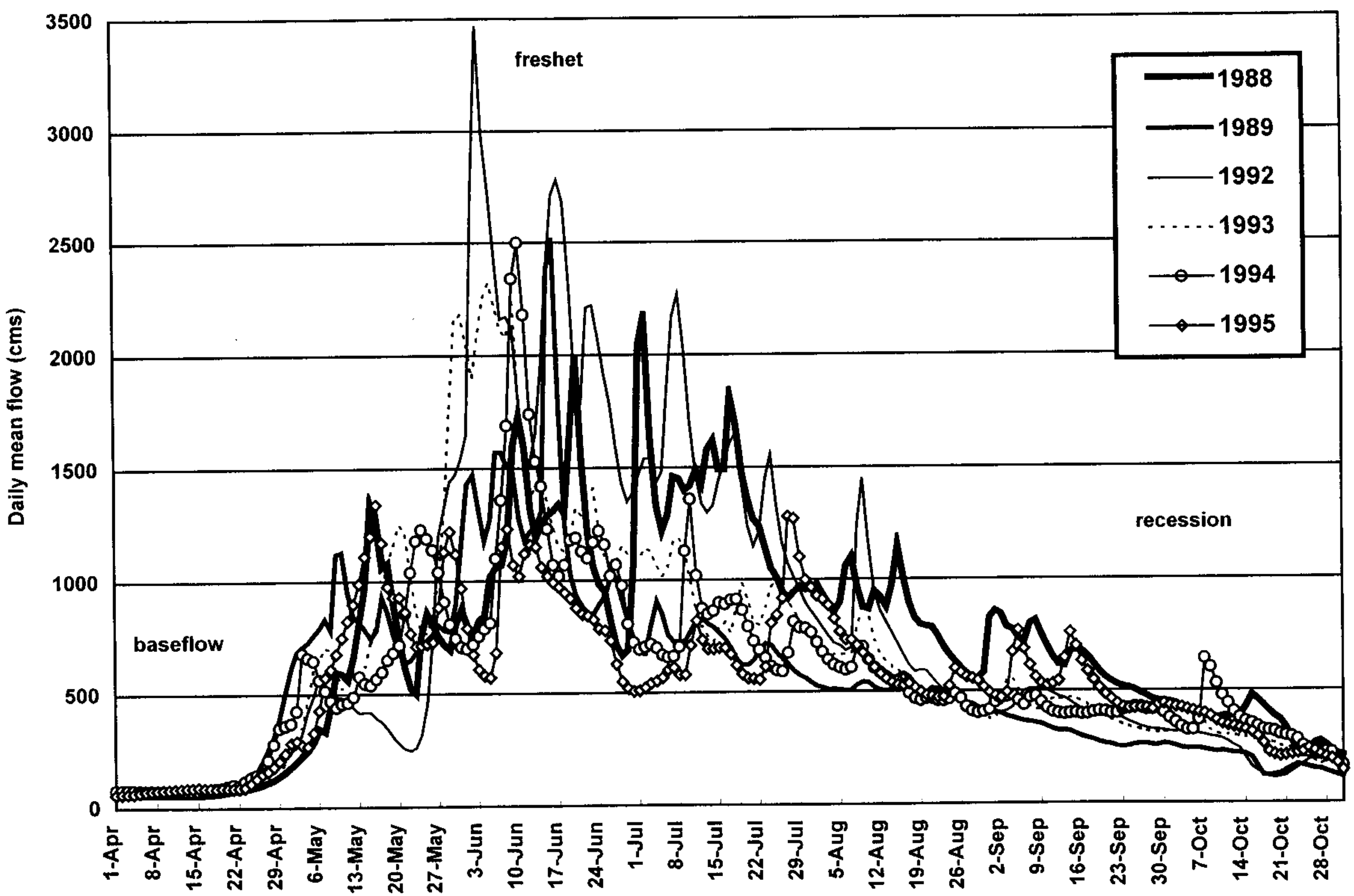
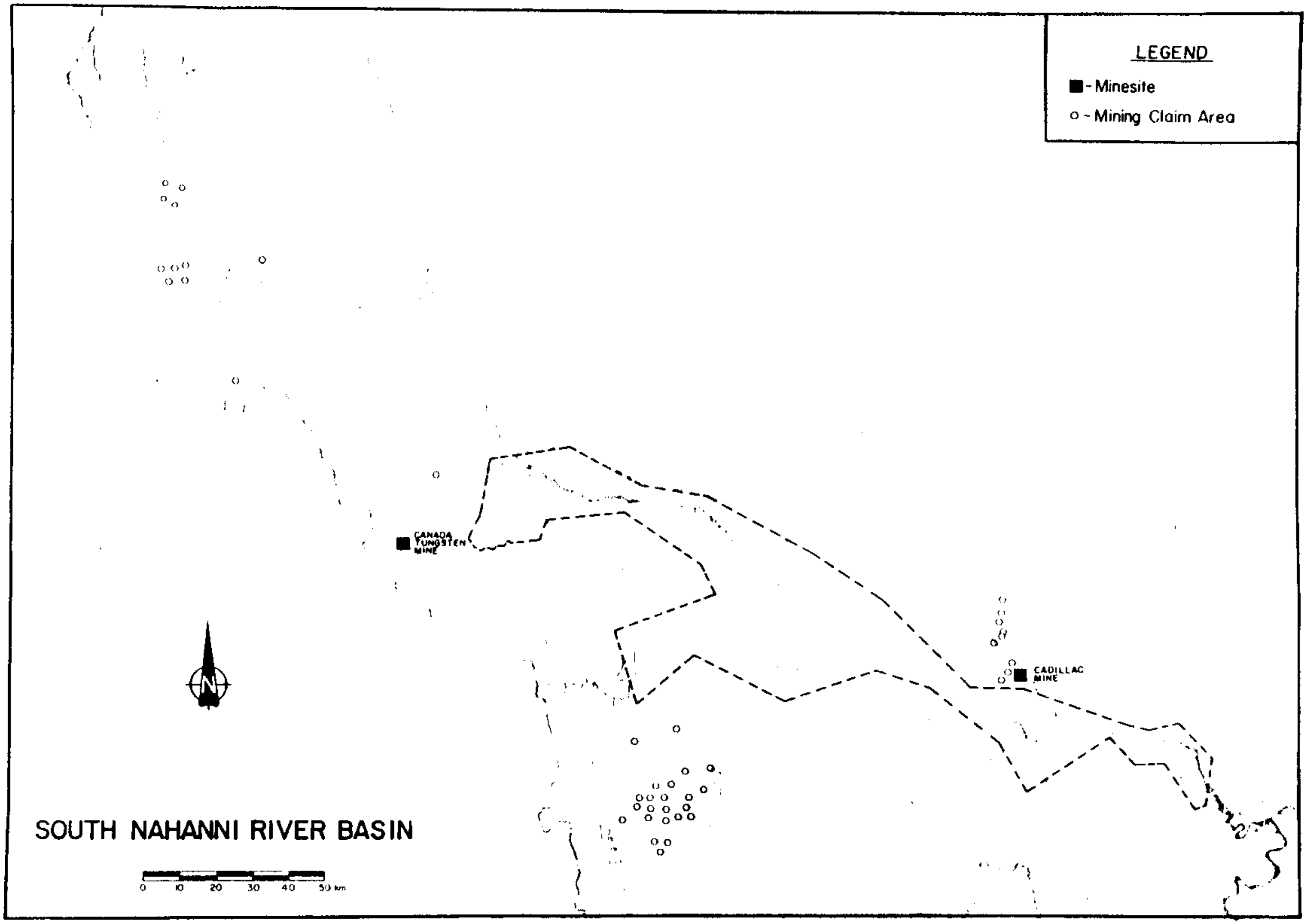


Figure 5 - South Nahanni R above Clausen Creek (10EC001) - Hydrograph of daily mean flow

FIGURE 6. MINING ACTIVITIES IN THE SOUTH NAHANNI RIVER BASIN



AFTER ENVIRONMENT CANADA, 1991

located less than one kilometre from the site. Environmental isotope studies indicate that Rabbitkettle Hotsprings waters are of meteoric origin. Discharge is controlled by artesian pressures, localised by an underlying fault. Carbonate, sulphate, pH and total barium values are higher at the site, due to the partial formational and magmatic origin of these waters, which resided in an open/partially closed karst environment for 10 to 25 years. Spring waters are predominantly meteoric, as chemistry and isotope ratios indicate water temperature never exceeded 100 deg C. (Gulley, 1993).

Park vegetation is characterized by northern boreal forest species in the lowlands, with transition to alpine tundra at higher elevations. Montane and subalpine zones are the most common, with extensive stands of spruce and pine and diverse habitats supporting over 750 plant species, including 40 not found elsewhere in the Mackenzie Mountains (Canadian Parks Service, 1984).

Wildlife found in the Park includes more than 120 bird, 40 mammal and 13 fish species. River flats along the South Nahanni and Flat Rivers provide quality moose and deer habitat, while higher elevation valleys support woodland caribou. Dall sheep live in alpine tundra areas and black and grizzly bear, white tail and mule deer are also present (Canadian Parks Service, 1984).

The climate of the Park is cold continental, with wide annual temperature and precipitation variations. Summer and fall are dominated by westerly air currents from the Pacific Ocean, while arctic air streams predominate in winter and spring. The eastern end of the Park tends to be cooler and wetter, and chinook winds are common throughout the winter. An Environment Canada weather station was installed near the SNR Above Virginia Falls water survey station in 1994 to characterise weather conditions on a data-deficient area and to monitor weather conditions for forest fire management in the Park and nearby areas.

Some 1000 to 2000 visitors come to the Park each year, mainly via chartered float plane from Fort Simpson, NWT or Watson Lake, YT and via the Nahanni Range Road. Chartered float planes and boats are the usual mode of access to the Park itself. The Park offers outstanding river touring (including wild river touring by canoe, kayak or raft), camping, hiking and fishing opportunities. The short visitor season runs from late June to early September, with the best time to travel on the river in July and August (Canadian Parks Service, 1984).

The South Nahanni was designated as a Park Reserve in 1976 by the Canadian Parks Service. In 1978, the Reserve was designated a World Heritage Site by UNESCO. The river was nominated as a Canadian Heritage River in 1987, and was accepted in 1992 (Canadian Parks Service, 1984).

2.2 The Issue

While the Park has not experienced enough development to cause deterioration of water quality, the pristine wilderness reputation of the Park is vulnerable to activities outside the Park within the SNR basin and stresses beyond the SNR watershed, such as LRTAP (Environment Canada, 1991)/ Cold Condensation of contaminants in the Canadian Arctic, ozone depletion/UV-B radiation, and global climatic change/variability. The carbonate rocks buffer the effects of acid deposition.

The Park area is rich in tungsten, lead, zinc, copper and silver mineral deposits with two mothballed mines, the Cadillac (silver-zinc-lead) Mine in the Prairie Creek sub-basin and the Canadian Tungsten (tungsten-copper) Mine on the Flat River (Figure 6). Numerous mineral claims have been staked and recorded in the area surrounding the Park (Environment Canada, 1991).

At Prairie Creek (Cadillac) property, San Andreas Resources Corporation (SARC) has recently carried out advanced stage exploration, including drilling. SARC and Rescan Environmental Services Ltd. have identified a geological resource of

6.213 million metric tonnes grading 12.82% zinc, 12.15% lead, 0.318% copper, and 179.69 grams/tonne silver, hosted in carbonates and shales. A December 4, 1995 News/North newspaper article describes the deposit's tenor as 10.6 million tonnes, grading 13.1% zinc, 11.3% lead, and 188 grams per tonne silver. A 163 kilometre long all-weather access road from the Prairie Creek Mine to the Liard Highway near Lindberg Landing was also proposed (San Andreas Resources and Rescan, 1994). The Project may require comprehensive environmental study and screening under the new Canadian Environmental Assessment Act (CEAA).

Advanced exploration activity has occurred near the Park at several other locations, and additional mines may result should international commodity prices rise. Union Carbide's Lened Creek project had encouraging tungsten exploration results in the early 1980's before being mothballed due to low mineral prices. In the Howards Pass, YT/NWT border area, world-class zinc-lead-silver-barium and barium deposits have not been developed for similar reasons (DIAND, 1995). Substantial base and precious metal mineral potential exists upstream of the Park, in the South Nahanni, Flat and Rabbitkettle river basins (Gordey and Anderson, GSC, 1993; DIAND, 1995).

3.0 ENVIRONMENT CANADA AND INDIAN AND NORTHERN AFFAIRS ACTIVITIES

3.1 1992-1995 Monitoring Program Designs

The 1992-1995 monitoring program evolved from results of the 1988-1991 IWD-CPS study. The objectives of this co-operative study were:

1. characterize variability of water quality variables associated with the mining industry;
2. develop water quality objectives for major streams entering the Park; and
3. design an on-going water quality monitoring program for monitoring compliance with the water quality objectives.

Thirteen sampling sites (Figure 7) were selected to provide representative data for the South Nahanni River and tributaries potentially affected by upstream mining development. Sampling took place in the open water seasons of 1988 and 1989. Spring (May 23- June 11, 1988; May 24-June 11, 1989) and fall (September 9-28, 1988; August 31-September 19, 1989) sampling was selected and conducted to represent extremes in variability of the concentrations of water quality variables occurring largely due to different water flow rates. Historic records for the Flat River Mouth station from 1972 to 1990 suggest that 1988 and 1989 discharge rates were typical for the period of record, with 1988 slightly being above and 1989 slightly below the historic mean discharge (Environment Canada, 1991).

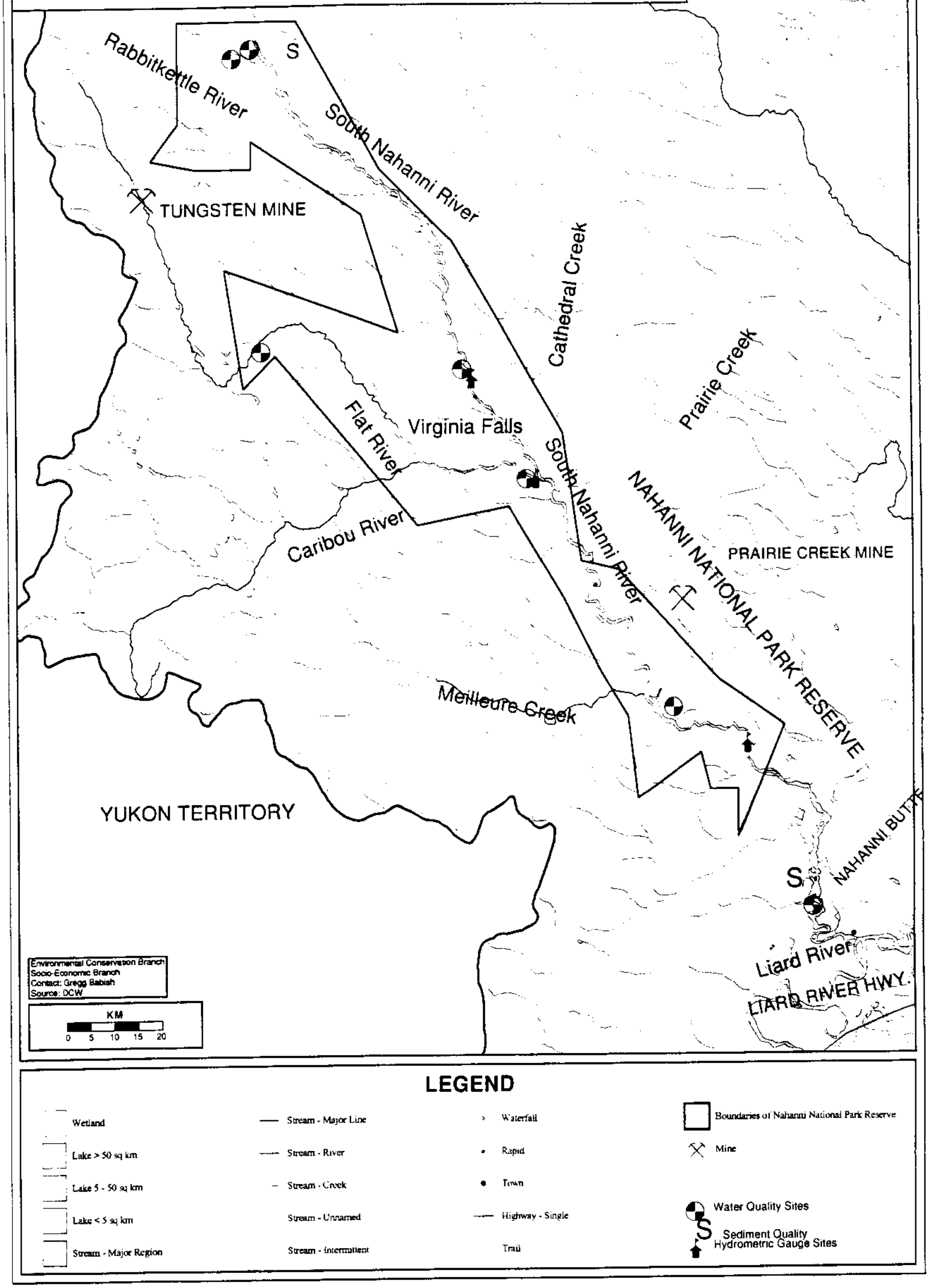
Water quality variables selected for monitoring were those associated with tungsten, silver, lead, zinc and copper mining activities, including a wide range of metals, nitrogen compounds (mine blasting residues), sulphates (possible leaching by acid mine drainage), and various physical and chemical variables. Aluminum is associated with aluminosilicate clay-rich drilling muds used during exploration, development and production. Barium is associated with some drilling muds, but also with zinc-lead-silver-barium and barium mineral deposits known to occur in the Yukon Territory within the upper South Nahanni River basin.

All (unfiltered) water samples were analyzed for "total" (dissolved and particulate) metals; while "dissolved" metals were analysed at some sites to evaluate metals readily available for uptake by aquatic biota, and of concern for the protection of aquatic life. Metals released from mining activities are present in both dissolved and particulate forms.

Figure 7. 1995 Aquatic Quality Sites. Nahanni NPR.

Environment Canada. Atmospheric Environment Branch.

Douglas Halliwell. Regional Aquatic Quality Officer.



Despite the presence of the mothballed Canadian Tungsten W-Cu Mine on the Flat River, total tungsten was not included since no CWQGs exist (CCREM, 1992), the element is immobile in the aquatic environment, levels are expected to be near method detection limits, and tungsten analyses are not currently available at the EC NLET Burlington laboratory. Quality control/quality assurance samples (e.g. triplicates, duplicate blanks) were collected at five sites in both years (Environment Canada, 1991).

Since metals are commonly found bound to particulate matter, suspended stream sediments were therefore collected at five sites (Figure 7) using a continuous-flow (Alpha-Laval) centrifuge, and analyzed for a range of metals. Metals have a greater affinity for smaller particle sizes more likely to be found in suspended, rather than bottom, sediment samples in high-energy environments such as the South Nahanni River and its tributaries (Ongley, 1992; Environment Canada, 1991).

Recommendations from the 1988-89 study included:

- adoption of water quality objectives
- water quality monitoring at five sites by EC
- sampling and analysis of suspended sediment (by EC) and fish (by DFO-CPS)
- expansion of monitoring if exploration and development activities in the South Nahanni River Basin increased
- noting of analytical results of snow samples collected in the vicinity of the watershed
- continuance of the Flat River mouth gauge site
- marketing of the use of water quality objectives to federal and territorial agencies (Environment Canada, 1991).

Evaluation of study results led to the signing of a Memorandum of Understanding by Inland Waters Directorate (IWD) and Canadian Parks Service (CPS) to implement an ongoing water quality program in Nahanni Park on August 20, 1992 (Appendix III).

3.2 IWD/CPS 1992-1995 Water and Sediment Quality Studies

Figure 7 shows the locations of five 1992-1993 water quality, two 1995 suspended sediment quality, and seven 1994-1995 water quality sampling sites. These were sampled during late winter (April) **baseflow**, spring (June) **freshet** high flow, and late summer (August-September) **recession** low flow. Additional samples were collected in May, November and February to allow near-monthly to bimonthly sampling at the Flat River Mouth site to permit long-term trend analysis studies. Additional Prairie Creek Mouth site samples were scheduled, but not collected, due to increasing exploration and proposed mining development.

Suspended sediment samples were also collected by IWD for SNR above Nahanni Butte in September 1992, July and September 1993, July and September 1994, and September 1995; as part of a long-term plan to collect suspended sediment at that site at least every other year. The sampling frequency was doubled in 1992 and 1993 to twice a year as a result of concerns elevated aluminum and metal levels. Additional suspended sediments were collected upstream at SNR Above Clausen Creek (July 1994) and SNR Above Virginia Falls (June 1995).

Table 1 (see Appendix I) summarises the field and lab water quality, lab sediment quality, and NAQUADAT/ENVIRODAT Parameter Codes. The codes describe laboratory analytical methods, instrumentation, lower method detection limits, and units and precision the data is reported in.

The 1995/96 fiscal year water quality results appear in Appendix I, Tables 2-8, inclusive, for Flat River Mouth, Prairie Creek Mouth, SNR Above Nahanni Butte, Rabbitkettle River Mouth, SNR Above Rabbitkettle River, Flat River Park Boundary, and SNR Above Virginia Falls; respectively. Short-term and long-term objectives for the former five water quality stations are shown in Table 9.

The 1992-95 sediment quality results for SNR Above Nahanni Butte and upstream sites appear in Table 10 of Appendix I. Summary statistics for over 31,000 Canadian Cordillera stream sediment and stream water samples (from Energy, Mines and Resources' National Geochemical Reconnaissance (NGR) data set) are shown in Table 11 (Ballantyne, 1991). The draft interim freshwater Canadian Sediment Quality Guidelines appear in Table 12.

Field quality assurance/quality control was carried out in 1995/96. A triplicate river sample and one field blank were collected at Prairie Creek Mouth site and Flat River Park Boundary site in June 1995.

Water quality data for 1992-1995 were interpreted in light of flow/discharge rates for the Flat River Mouth, SNR Above Clausen Creek, and SNR Above Virginia Falls station gauges. Synthetic flow data were produced for Nahanni Butte by "routing" flows at SNR above Clausen Creek 55 kilometres downstream to the SNR above Nahanni Butte water/sediment quality site.

StatGraphics Plus(Version 6.0 for MS-DOS, Version 2.0 for MS Windows) software was used to perform linear regression and correlation analyses, produce time trend analysis plots, calculate Pearson's "r","r-squared" and Spearman's "rho" values (non-parametric equivalent of Pearson's "r"), and produce multiple box-and-whisker plots. The latter shows medians, upper and lower quartiles and outlier non-parametric values for late winter baseflow, spring freshet and summer recession sample values.

Water quality objective and CWQGs exceedance (excursion) values not falling within an 95% confidence envelope of linear regression lines on discharge/flow (at the Flat River Mouth site), synthetic discharge/flow (at the SNR Above Nahanni Butte site), or field conductivity (at the Prairie Creek Mouth, Rabbitkettle River Mouth, and SNR Above Rabbitkettle River sites) were noted as exceedances warranting further investigation. Exceedances of water quality objectives and CWQGs explainable by natural variation (i.e. flow) were downplayed as false positives.

Flow data from Nahanni NPR was measured at the Flat River Mouth and SNR Above Virginia Falls station gauges. Flow data from South Nahanni River at Nahanni Butte was estimated by mathematically "routing" flows from the Clausen Creek gauge to the SNR Above Nahanni Butte water quality station. Miscellaneous flow measurements were also made along transects at the Prairie Creek Mouth, Flat River Park Boundary, and SNR Above Rabbitkettle River sites.

4.0 WATER QUALITY OF THE PARK

The South Nahanni River basin may be subjected to natural resource development in the future. These anthropogenic activities may adversely affect park water quality and disrupt aquatic life. Effective water management plans require knowledge of the basin's water quality dynamics.

The cumulative knowledge of the Park's water quality from the 1988-1989 and 1992-1995 surveys is summarized in this report.

4.1 Spatial Variability

Ground and surface water runoff dissolves minerals and nutrients as it passes through bedrock and surficial material. Differences in water quality characteristics between mainstem and amongst tributaries, reflect spatial variations in geology (Environment Canada, 1991).

Prairie Creek flows through bare upland and steep canyon terrain, and carries sediment concentrations an order of magnitude lower than that carried by the mainstem SNR, where more easily eroded material is available. Since most metals are attached to suspended sediments, concentrations of all **total** metals are therefore also lower than elsewhere in the Park. Levels of **dissolved** metals in Prairie Creek waters are as much as twice as high as in the mainstem, most likely due to effects of mineral springs in heavily karstified carbonate rocks of the area. Prairie Creek flows through areas rich in calcium and calcium-magnesium carbonate-precipitating streams and through Zn-Pb-Cu-Ag mineral deposits spread out along at least a 10 kilometre strike length (DIAND, 1994).

Prairie Creek peak flows in May-June (spring freshet) and July-August (summer storms) are very low (i.e. under 20 cubic metres per second, or cms), and have little influence on South Nahanni water quality (Environment Canada, 1991). Low year-round flow rates of Prairie Creek also limit its natural ability to dilute mining waste discharges or other contaminants.

The Park portion of Prairie Creek watershed is underlain by Devonian banded dolostones and limestone (Canadian Parks Service, 1984) which host the Cadillac Mine/Prairie Creek zinc-lead-copper-silver deposits and zinc-lead-silver veins (DIAND, 1994). Further upstream and outside the Park, Prairie Creek is underlain by shale, calcareous shale and minor sandstone (Canadian Parks Service, 1984). The Prairie Creek Project mineralization lies mostly within Upper Whittaker Formation dolostone (San Andreas Resources and Rescan, 1994).

Flat River shows distinct water quality changes between the Park boundary and its confluence with the South Nahanni River. Suspended sediment concentrations increase dramatically near the confluence of the Flat and Caribou Rivers, reflecting erosion of glacial till and glaciolacustrine clays/silts in the valley (Canadian Parks Service, 1984). Hot springs are also present in the upper reaches of the Flat River (Hamilton et al, 1991; Gulley, 1993). Dissolved solid concentrations increase only slightly however, due largely to increases in calcium. The Flat River flows through areas rich in calcium and calcium-magnesium carbonate-precipitating streams. Comparison of water quality data from the South Nahanni River above and below its confluence with the Flat River suggests the tributary has little affect on the mainstem (Environment Canada, 1991).

Inside the Park, the Flat River cuts through unconsolidated glacial, alluvial, glaciolacustrine and colluvial materials. This material is underlain, in the headwaters, by limestone and lesser dolostone and sandstone, and, further downstream, by shale and lesser limestone, sandstone and chert. Above the Park, the Flat River is underlain by quartz-rich intrusive rocks and dolostones (Canadian Parks Service, 1984). The Canada Tungsten Mine involves tungsten-copper mineralization occurring where metamorphosed limestones and calcareous shales meet quartz-rich intrusive rocks (Geological Survey of Canada, 1984).

Figure 3 shows that the Flat River Mouth station's peak mean daily flow of 247 to 900 cubic metres per second (cms) in 1988-95 (247 cms on June 7, 1995) is lower than that of the South Nahanni River mainstem at Virginia Falls (Figure 4) and Clausen Creek (Figure 5). The mean daily flows on the mainstem for 1988-95 are much higher, SNR Above Virginia Falls peaking at 921 (June 7, 1995) to 2200 cms, and SNR Above Clausen Creek peaking at 1290 (June 8, 1995) to 3500 cms (Water Survey of Canada, 1995). Peak mean daily flows were low during 1993-1995 with the lowest values being measured in 1995, symptomatic of the fact that 1993-1995 were low water years (Water Survey of Canada; 1993, 1994, 1995).

The Caribou River tributary of the Flat River has low sediment loads. with higher concentrations of metals, calcium, sodium carbonates than expected. The Caribou cuts through the same surficial and bedrock geological units as the Flat, with lesser volumes of quartz-rich intrusive rocks. Water quality of the

Caribou River appears to have little effect on the water quality of the Flat River (Environment Canada, 1991).

Rabbitkettle River and the northwest (upstream) portion of the South Nahanni River have very similar water quality, with slightly higher metal concentrations in the Rabbitkettle River. Some metals (e.g. zinc, copper, manganese) are higher in the Rabbitkettle because it drains an area underlain by quartz-rich intrusive rocks and dolostones (Environment Canada, 1991). Other water quality variables (e.g. carbonate, sulphate, pH, total barium) are likely higher at the Rabbitkettle Mouth site because of otflows from four Rabbitkettle area hot springs and adjacent travertine deposits (one hot spring is less than a kilometre from the Rabbitkettle Mouth water quality sampling site), according to Gulley (1993).

Levels and variability of sediment, copper, and sulphate concentrations increase slightly downstream through the SNR basin (Environment Canada, 1991). The SNR Above Nahanni Butte station, just outside the Park, addresses concerns of downstream users about increases in contaminants and temporal variability, as well as being convenient for sampling.

Elevated total iron content of suspended sediments at SNR Above Nahanni Butte may be due to naturally occurring iron in sedimentary rocks (i.e. Sunblood Formation limestones outcropping upstream from all water quality sites except Prairie Creek). Prairie Creek's zinc-lead-copper-silver mineralization might also contain abundant iron sulphides, such as pyrite and marcasite (Geological Survey of Canada, 1984).

Elevated total aluminum content of suspended sediments at the site requires some explanation, since aluminum is so abundant and ubiquitous in the Earth's crust. The possibility of aluminum contamination during cleaning of the centrifuge and sample jar sealing was examined during July and September 1993, but found not to be a problem. The most likely reason is that the centrifuge preferentially concentrates clay minerals (i.e. comprising between 51.35% and 63.53% of suspended sediment samples), aluminosilicate minerals, which are very rich in aluminum.

Aluminum-rich clay particles present in suspended sediment collected at SNR Above Nahanni Butte are likely derived from clayey glaciolacustrine overburden, silty alluvial deposits, and weathering and alteration of feldspar minerals found in many igneous and sedimentary rocks. Aluminum levels in water quality samples at all seven sites routinely exceed the "hard" water CWQG for freshwater aquatic life of 0.005 mg/L in both 1994 and 1995, the only years with analyses for total aluminum, a new element in the 20-element ICP-AES analysis scan.

An alternate hypothesis is that extensive, 12,000 metre per year (DIAND, 1994; NWTCM, 1994) diamond drilling in the Prairie Creek watershed has increased aluminum levels, due to use of aluminum-rich drilling muds for diamond drilling circulation. Prairie Creek Mouth water quality samples are not significantly higher in total aluminum, however, than samples from the other six sites, suggesting that exploration drilling is not the cause.

NWT Health has been advised of these elevated aluminum levels in suspended sediments, and not stream water, near the community of Nahanni Butte. This information resulted in redesign of the water supply for Nahanni Butte. Groundwater, rather than surface water, will be used for the community's water supply (Victor Menkal, Vista Engineering, pers. com.).

4.2 Temporal (Seasonal) Variability

Concentrations of water quality parameters fluctuate over the hydrologic year. The effects of mine development, construction, production and decommissioning are currently undetectable, with natural cycles of substances predominating. The relatively continuous, long-term record of water quality data for Flat River mouth illustrates seasonal and long-term temporal variability.

The available water quality data were entered into Lotus/MS Excel spreadsheet files, respecting the analytical precision available. Non-detects (i.e. values which did not register at the lower limit of detection of lab analysis equipment) were entered as half the method detection limit to eliminate conservative or liberal bias. StatGraphics Plus (Version 6.0 for MS-DOS) and StatGraphics (Version 2.0 for MS Windows 95) software was used for statistical analyses (linear regressions, multiple box-and-whisker plots, correlation matrix analyses, and time trend analyses).

Flat River At Mouth Water Quality Station

Figure 3 illustrates patterns of the annual flow at the Flat River Mouth. Low flows occur from late November to mid-April, followed by rising levels in mid-April from snow melt at lower elevations. June, July and August show the highest flows, but the timing of high summer flows varies with summer rainfall. Historic September to October flows are higher on the Flat River due to greater forest cover and retentive soils (Environment Canada, 1991).

The water quality variable most clearly reflecting flow variations is field conductivity Pearson's "r" = -0.7977 (N=151), "r-squared" = 63.64%; Spearman's "rho" = -0.9020 (N=151), "rho-squared" = 81.36% (see Figure 8). Field conductivity is directly proportional to total dissolved solids (TDS) and inversely proportional to non-filterable residue (NFR). NFR correlates well with discharge ("r" = +0.6968 for N=140; "rho" = 0.8197 for N=140). Dissolved solids or minerals, such as carbonates and sulphates, are contributed from mineral springs via ground and surface water runoff.

At Flat River, an inverse relationship exists between flow and dissolved solids concentration, due to dilution of dissolved solids during all periods of high flow. This occurs because of the contact of water with soluble minerals in the rock or soils, and baseflow through mineral-rich rock are reduced. In 1988-89, field conductivity values ranged from 125 to 500 microsiemens per centimetre (us/cm) (Environment Canada, 1991). Field conductivity values ranged from 130 to 375 uS/cm in 1992 (reflecting higher flow rates), from 100 to 380 us/cm in 1993, from 160 to 320 us/cm in 1994, and from 140 to 350 us/cm in 1995 (see Table 2, Appendix I).

Other water quality variables **positively** correlated with flow/discharge ("r" in brackets) include extractable iron (+0.7996, N=141), total vanadium (+0.7581, N=134), total barium (+0.7489, N=131), total lead (+0.6980, N=134), extractable manganese (+0.6990, N=143), total cobalt (+0.6754, N=134), and dissolved copper (+0.4359, N=65) (see Figure 9). Other water quality variables **negatively** correlated with flow/discharge ("r" in brackets) include field conductivity (-0.7977, N=151), dissolved sulphate (-0.7671, N=145) (See Figure 10), dissolved nickel(-0.5953, N=65), and dissolved zinc (-0.4077, N=65) (See Figure 11).

Total copper, zinc, lead, nickel, vanadium, cobalt, cadmium, and barium values **increase** with increasing flow. Dissolved lead and arsenic also increase with increasing flow, as do extractable iron and manganese, NFR, total ammonia, pH and total cyanide. Dissolved barium, cadmium, cobalt, copper, iron, manganese, nickel, and zinc values **decrease** with increasing flow, as do dissolved sulphate, dissolved nitrate and nitrite, and field conductivity. It appears that barium, cadmium, copper, lead, and zinc are partitioned mostly into particulate forms (chemical species) during the spring freshet and the recession, and dissolved forms during the baseflow. Cobalt, nickel and vanadium are partitioned into particulate forms throughout the water year, while iron and manganese are partitioned into extractable forms throughout the water year (Table 2). Nearly half of the 28 water quality variables with objectives are moderately to strongly flow-controlled (i.e. r >= +0.7 or r <= -0.7). Field pH and field conductivity aren't positively correlated, suggesting that upper Flat River hot springs and ground waters have no effect on the water quality at this site.

Correlation matrices show that high positive "r" correlation coefficients (in excess of +0.65) are common between total metals such as barium, cadmium, cobalt, copper, lead, nickel, vanadium, and zinc; NFR; and extractable metals such as iron and manganese. All are positively correlated with flow. High negative "r" values exist between field conductivity and dissolved sulphate; both are negatively correlated with flow.

Multiple box-and-whisker plots, such as Figure 12 (for total copper), illustrate seasonality of water quality variables during winter baseflow, the spring freshet and summer-fall recession. No early and late winter baseflow samples were collected during 1988 and 1989, the only baseflow samples being collected in April 1992, 1994 and 1995 and late November 1993.

Box-and-whisker plots show 25th and 75th percentiles of the available data as the top and bottom of the "boxes", respectively, and the 50th percentiles or median value at the middle of the "boxes". The 25th percentile to 75th percentile range is known as the quartile range, or "hinge width". "Whiskers" extend above and below boxes to the highest and lowest values lying within 1.5 hinge widths above and below the median, respectively. Significant values not lying within 1.5 hinge widths of the median are considered "outliers" (shown individually).

Box-and-whisker plots and percentiles involve ranked values of variables and non-parametric statistics. Such statistical parameters are therefore universally applicable to all variables whether or not they are Normally (or Lognormally) Distributed.

Some variables (e.g. dissolved zinc) exhibit a negative relationship with flow (Q), due to dilution of concentrations by higher flows of floods; with high baseflow, low freshet, and intermediate recession values. A similar pattern exists for dissolved barium, cadmium, nickel, selenium, sulphate, nitrate-nitrite and field conductivity. Other variables (e.g. dissolved copper) exhibit a positive flow dependence, due to their association with particulates (suspended sediments); with low baseflow values, high freshet values and intermediate recession values. A similar pattern exists for extractable iron, total cyanide, total barium, dissolved arsenic and iron.

Figure 12 (for total copper) illustrates a positive flow dependence relationship and possible negative clockwise hysteresis (i.e. values are systematically higher during rising/freshet flows than falling/recession flow) and early flushing of particulates. Intermediate baseflow values; high freshet values and low recession values are the signature of this. A similar pattern exists for NFR; extractable manganese; dissolved lead; and total cobalt, lead, nickel, vanadium, and zinc. No water quality variables were found to exhibit a negative flow dependence relationship, and possible temperature dependence. The signature of this behaviour is intermediate baseflow values, low freshet values and high recession values.

Some water quality variables exhibit no flow dependence. Field pH, and dissolved cobalt and manganese exhibit positive temperature dependence with no flow dependence, characterised by increasing values from baseflow to freshet to recession. Total ammonia exhibits negative temperature dependence (and/or a positive biological uptake dependence) with no discharge dependence, characterized by decreasing values from baseflow to freshet to recession.

Figure 13 illustrates the seasonal behaviour for all water quality variables at all seven water quality stations.

Figure 8. Flat River Mouth. Field Conductivity VS Flow.

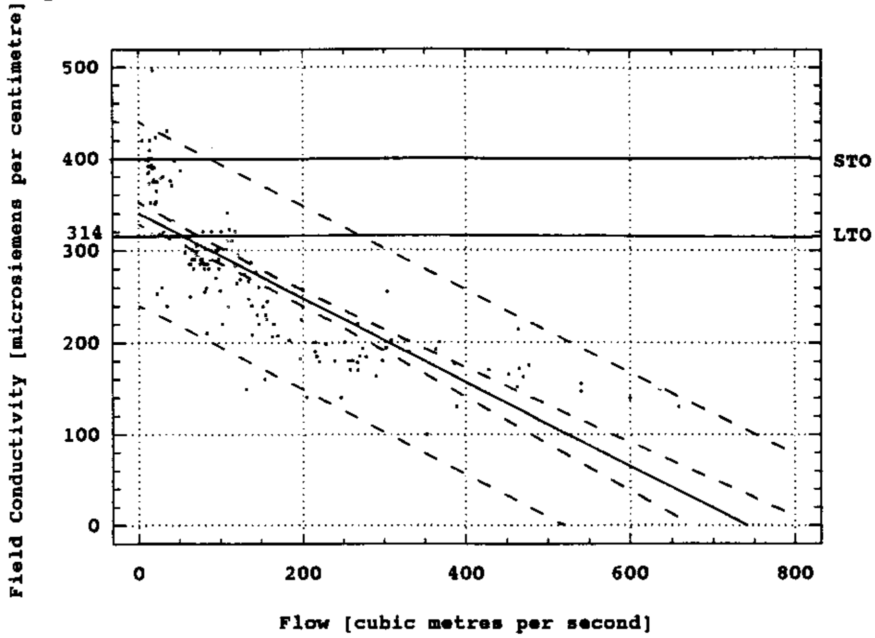
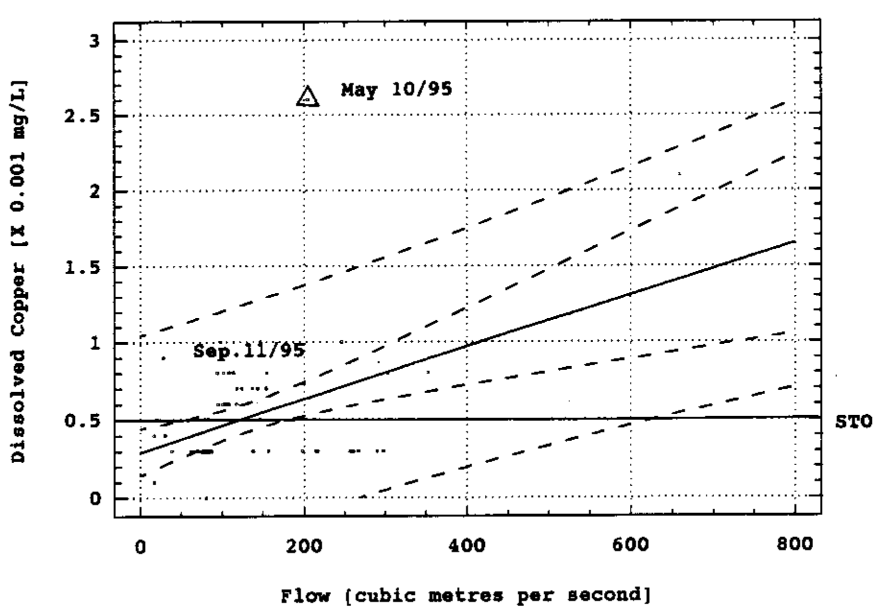
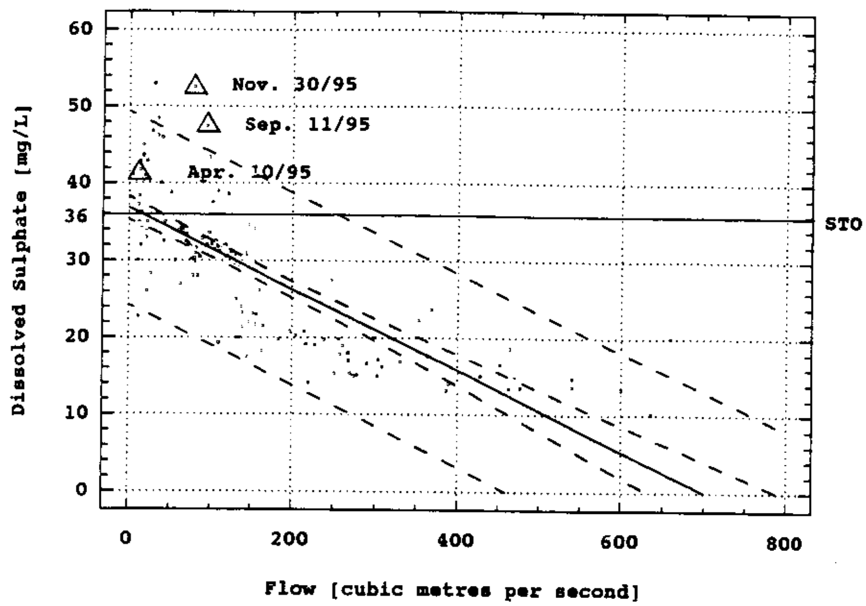


Figure 9. Flat River Mouth. Dissolved Copper VS Flow



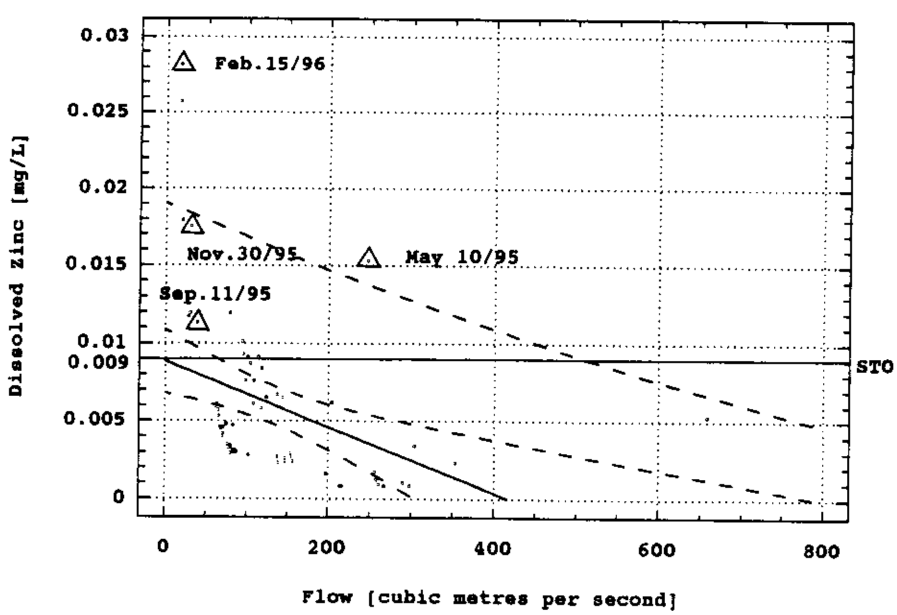
Note: STO Exceedances

Figure 10. Flat River Mouth. Dissolved Sulphate VS Flow



Note: STO Exceedances

Figure 11. Flat River Mouth. Dissolved Zinc VS Flow.



Note: STO Exceedances

Figure 12. Flat River Mouth. Mult.Box&Whisker Plot. Total Cu

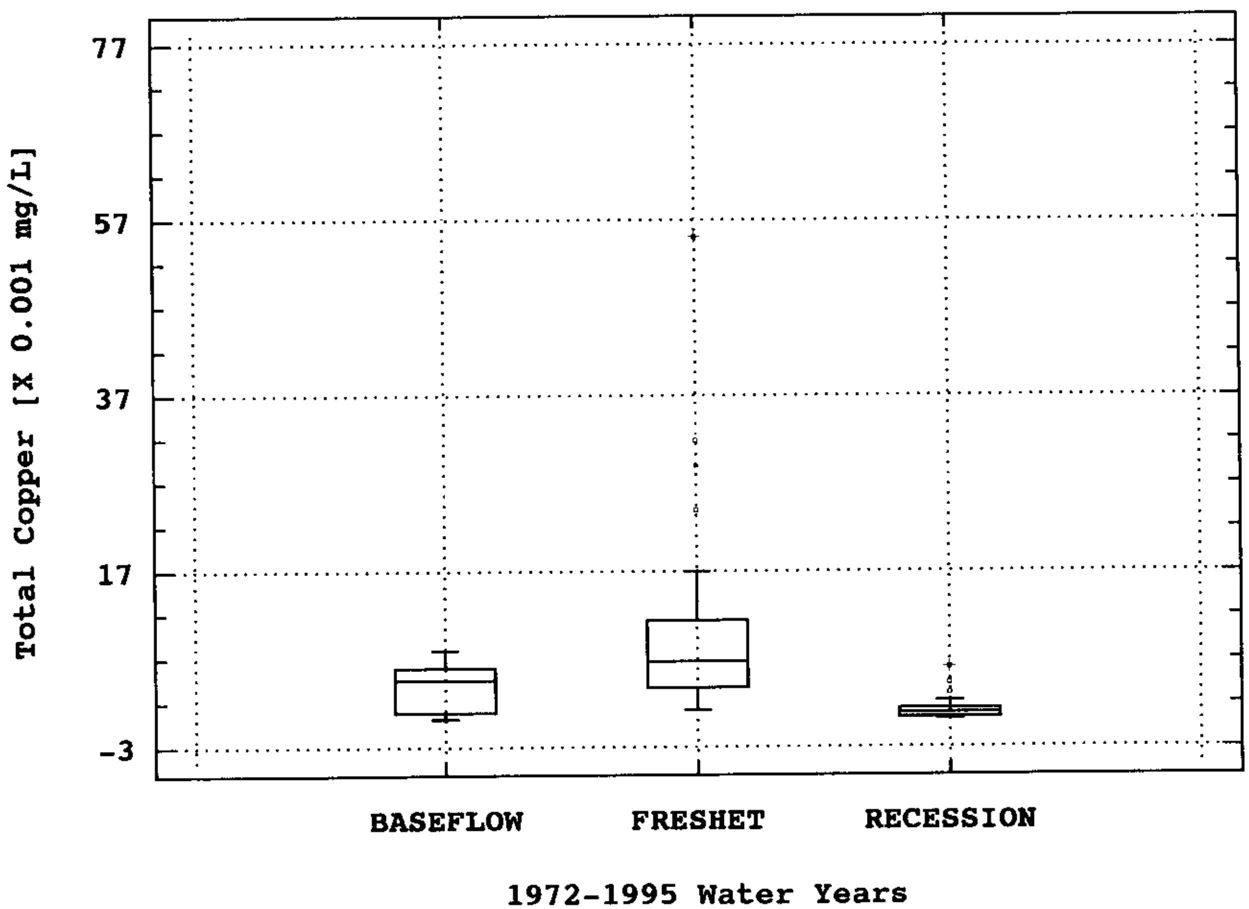


Figure 13. Seasonal Behaviour, Water Quality Variables at Seven Stations Derived From 28X7=196 Multiple Box-and-Whisker Plots.

Seasonal Behaviour	Negative Discharge Dependence, Dilution Effects	Positive Discharge Dependence, Particulate Effects	Positive Discharge Dependence, Early Flushing of Particulates	Negative Discharge Dependence, Temperature Dependence	No Discharge Dependence, Positive Temperature Effects	No Discharge Dependence, Negative Temperature and/or Positive Biological Uptake Dependence
Water Quality Site Name/WQ Values	Baseflow Values> Recession Values> Freshet Values	Freshet Values> Recession Values> Baseflow Values	Freshet Values> Baseflow Values> Recession Values	Recession Values> Baseflow Values> Freshet Values	Recession Values> Freshet Values> Baseflow Values	Baseflow Values> Freshet Values> Recession Values
Flat R.near the Mouth	CONDF,NO3-NO2,SO4D BaD,CdD,NiD,SeD, ZnD	BaT,AsD,CuD,FeD, FeE,CN	NFR,CdT,CoT,CuT, PbT,NiT,VT,ZnT, PbD,MnE		pHF,CoD,MnD	NH3T
Prairie Ck. at Mouth	CONDF,NO3-NO2, SO4D,BaD,CdD,FeD	NFR,BaT,CdT,CoT, CuT,PbT,NiT,AsD, CoD,CuD,PbD,MnD, NiD,FeE,MnE,CN	VT,ZnT	SeD,ZnD	pHF	NH3T,CdD
So.Nahanni R.above Nahanni Bte	CONDF,SO4D,MnD, NiD,SeD	NFR,CdT,CoT,CuT, PbT,NiT,VT,ZnT, AsD,CuD,FeE,MnE,CN	BaT	CdD,CoD,FeD,PbD	pHF,CdD,CoD	NH3T,NO3-NO2,ZnD
Rabbitkettle R. at Mouth	CONDF,SO4D,BaD,CN	pHF,NFR,CoT,CuT, PbT,NiT,VT,ZnT, AsD,CuD,FeD,FeE, MnE	BaT,CdT	CdD,CoD,SeD,ZnD	CdD,CoD,MnD,NiD	NO3-NO2,NH3T,PbD
So.Nahanni R. above RabbitkettleR	CONDF,SO4D,NH3T, NiD	NFR,CoT,CuT,PbT, NiT,VT,ZnT,AsD, FeD,FeE,MnE,CN	BaT,CdT,CuD,FeD	BaD,SeD	pHF,CoD	NO3-NO2,CdD,PbD, MnD,ZnD
Flat River at Park Boundary	CONDF,SO4D,BaT,BaD, PbD,SeD	pHF,NFR,CoT,VT,ZnT, CoD,CuD,FeD,FeE,MnE	NFR,NO3-NO2,CdT, CuT,PbT,FeE	MnD,ZnD	NH3T,NiT,AsD,CoD, NiD,CN	BaT,CdT,PbT,PbD,SeD
So.Nahanni R. above Virginia Falls	CONDF,SO4D,BaT,BaD, CdD,MnD,SeD,ZnD	pHF,NFR,NO3-NO2, CoT,CuT,PbT,NiT,VT, CuD,FeE,MnE	NO3-NO2, CdT,PbT,ZnT,FeD	AsD,CdD,CoD,PbD	NH3T,AsD,CoD,PbD, NiD	-

LEGEND (28 Water Quality Variables): pHF=Field pH; CONDF=Field Conductivity; NFR=Non-Filterable Residue; SO4D=Dissolved Sulphate; NO3-NO2=Dissolved Nitrate+Nitrite, NH3T=Total Ammonia; BaT=Total Barium; CdT=Total Cadmium; CoT=Total Cobalt; CuT=Total Copper; PbT=Total Lead; NiT=Total Nickel; VT=Total Vanadium; ZnT=Total Zinc; AsD=Dissolved Arsenic; BaD=Dissolved Barium; CdD=Dissolved Cadmium; CoD=Dissolved Cobalt; CuD=Dissolved Copper; FeD=Dissolved Iron; PbD=Dissolved Lead; MnD=Dissolved Manganese; NiD=Dissolved Nickel; SeD=Dissolved Selenium; ZnD=Dissolved Zinc; FeE=Extractable Iron; MnE=Extractable Manganese; CN=Total Cyanide.

Prairie Creek at Mouth Water Quality Station

Table 3 in Appendix I shows that the same relationships occur in Prairie Creek. Spring freshet field conductivity is distinctly lower than in the fall, due to dilution during flashy high flow events. Low flows occur over the remainder of the open water season. In 1988-89, field conductivities ranged from 230 to 440 us/cm. Much lower 1992 field conductivity values ranged from 160 to 395 us/cm, reflecting higher flow rates in 1992. Field conductivity values ranged from 200 to 380 us/cm in 1993, from 250 to 300 in 1994, and from 240 to 330 in 1995. Miscellaneous flow measurements were made at this site in 1994 and 1995.

Figure 14 (dissolved copper versus field conductivity) illustrates that some water quality variables are **negatively** correlated with field conductivity (and **positively** correlated with flow). Such variables ("r" in brackets) include total copper (-0.5935, N=92), dissolved copper (-0.5161, N=54) (Figure 14), NFR (-0.5113, N=82), extractable iron (-0.4822, N=92), total nickel (-0.4712, N=92), total vanadium (-0.4694, N=92), extractable manganese (-0.4612, N=92), and total zinc (-0.4013, N=92). Figure 15 (dissolved zinc versus field conductivity) exemplifies water quality variables **positively** correlated with field conductivity (and **negatively** correlated with flow); such variables include dissolved zinc (+0.6798, N=54), dissolved sulphate (+0.6211, N=92) (Figure 16), dissolved selenium (+0.5913, N=52), and dissolved nitrate-nitrite (+0.2727, N=86) (Figure 17). Dissolved arsenic, manganese, and nickel; and total ammonia exhibit no correlation with field conductivity.

Extractable iron and manganese; NFR; total copper, lead, zinc, nickel, cobalt, cadmium and vanadium; and dissolved lead and manganese are directly proportional to flow. Dissolved zinc, selenium, sulphate and nitrate-nitrite are inversely proportional to flow, while pH, total ammonia and dissolved cadmium appear to be unrelated to flow.

Cadmium, copper, lead, nickel and vanadium appear to be associated with particulate (suspended sediment) forms (chemical species) during the freshet and recession, with dissolved forms during the baseflow. Vanadium and cobalt remain as particulate forms throughout the water year, while barium remains as dissolved forms. Iron and manganese remain in extractable forms (coatings) throughout the water year. Dissolved sulphate, selenium and zinc exhibit moderate correlation (i.e. r >= +0.5) with field conductivity while dissolved and total copper, and NFR exhibit a moderate negative correlation (i.e r <= -0.5).

Figure 13 illustrates that dissolved barium, cadmium, iron, sulphate, nitrate-nitrite and field conductivity exhibit a negative flow dependence relationship and dilution effects. Extractable iron and manganese; total cyanide; NFR; dissolved arsenic, cobalt, copper, lead, manganese, and nickel; and total barium, cobalt, cadmium, copper, lead and nickel exhibit a positive flow dependence relationship and particulate effects. Total vanadium and zinc may have lower recession values than baseflow values, suggesting positive flow dependence with early flushing of particulates (i.e. positive counterclockwise hysteresis). Dissolved selenium and zinc exhibit negative flow dependence and positive temperature dependence. pH values increase with freshet to the summer recession, and are independent of flow. Dissolved cadmium and total ammonia decrease with increasing temperature (and/or increasing biological uptake), and are also independent of flow.

South Nahanni River Above Nahanni Butte Water Quality Station

Table 4 in Appendix I shows that regular samples were collected during 1995 in April, June, and September. In 1988-89, field conductivities near Nahanni Butte ranged from 190 to 370 us/cm, 1992 field values from 150 to 450, 1993 values from 140 to 500, 1994 values from 190 to 310, and 1995 values from 210 to 420.

While flow data are not available for the Nahanni Butte water quality station, several methods can be used to compute flow at Nahanni Butte. From at least three available methods, the method described in Appendix II of this report (J.A. Kerr) was used.

This method assumes the same unit runoff (flow per square kilometre) for the drainage area between SNR/Clausen Creek and SNR/Nahanni Butte as between SNR/Virginia Falls-Flat River/Mouth and SNR/Clausen Creek. Relevant flows for days around the days on which flows at SNR/Nahanni Butte were sought were plotted, showing that flows were stable in all cases. This is important because the use of daily flows can introduce errors if flows are not stable. The method involves determining the flow between SNR/Virginia Falls-Flat River/Mouth and SNR/Clausen Creek (i.e. Virginia + Flat - Clausen), multiplying this flow by the 5,100 square kilometre to 7,940 square kilometre drainage area ratio, and adding the result to flows at SNR/Clausen Creek to obtain the flow at SNR/Nahanni Butte (See J.A. Kerr memos, Appendix II).

These calculated synthetic daily flow estimates for 1988-89 and 1992-1995 dates of water quality sampling were used for regressions against water quality variables, in lieu of actual measured flows at Nahanni Butte.

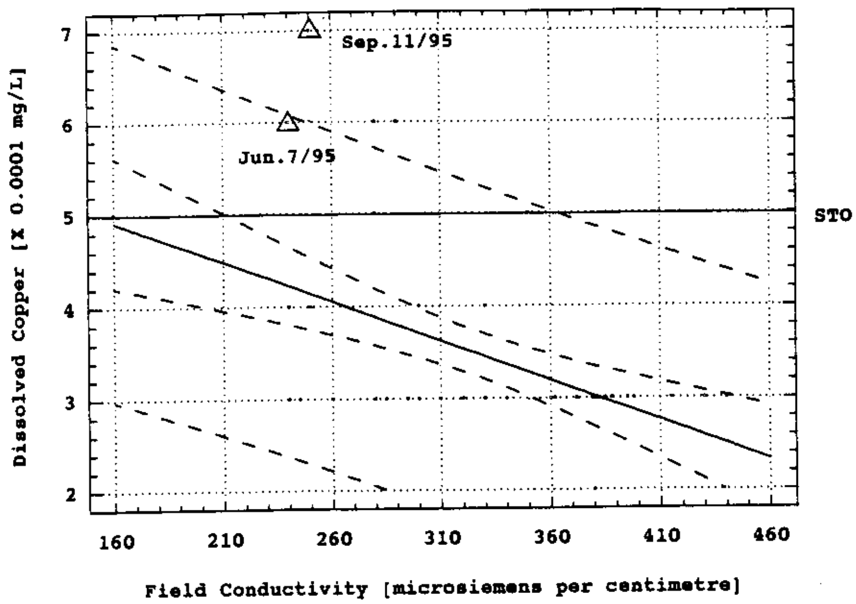
Water quality variables **positively** correlated with flow ("r" in brackets) include total vanadium (+0.7228, N=43), total cadmium (+0.7006, N=43), total copper (+0.6954, N=43) (Figure 18), total nickel (+0.6723, N=43), total zinc (+0.6606, N=43), NFR (+0.6512, N=42), extractable iron (+0.6220, N=43) and total lead (+0.6213, N=43). Water quality variables **negatively** correlated with flow include field conductivity (-0.6499, N=42) and dissolved sulphate (-0.5762, N=42) (Figure 19). Nitrate-nitrite; pH; and dissolved zinc, lead, nickel, cobalt and selenium exhibit no apparent correlation with flow.

Extractable iron and manganese; NFR; total cyanide; total barium, cadmium, cobalt, copper, bismuth, lead, vanadium and zinc; and dissolved arsenic and copper are directly proportional to flow. Field conductivity; and dissolved sulphate, cadmium, cobalt, iron, lead, manganese, nickel and selenium are inversely proportional to flow while pH; total ammonia; and dissolved nitrate-nitrite, cadmium, cobalt and zinc appear to be unrelated to flow.

The elements cadmium, cobalt, copper, lead, nickel and vanadium appear to be associated with particulate (suspended sediment) forms during the open-water season, and dissolved forms during under-ice conditions (Table 4). Zinc is associated with particulate forms year-round, while iron and manganese are associated with extractable forms (coatings) year-round. Total cadmium, copper, nickel, vanadium, and zinc, and NFR exhibit strong to moderate correlation (i.e. r >= +0.65) with flow, while only field conductivity exhibits strong to moderate negative correlation (i.e r <= -0.65).

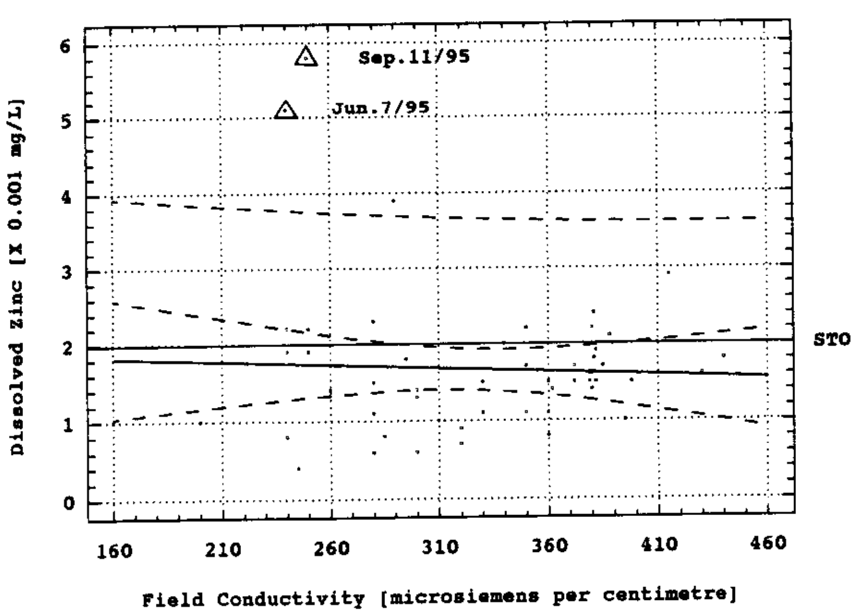
Figure 13 shows that field conductivity and dissolved sulphate, manganese, nickel, and selenium are effected by dilution effects and exhibit a negative flow dependence relationship. NFR; extractable iron and manganese; dissolved arsenic, cobalt and copper; total cyanide; and total cadmium, cobalt, copper, lead, nickel, vanadium and zinc are effected by particulates and exhibit a positive flow dependence relationship. Total barium exhibits a positive flow dependence relationship with possible negative clockwise hysteresis due to thorough flushing of particulates during the freshet, leaving lower recession values than baseflow ones. Dissolved selenium and zinc baseflow, freshet and recession values suggest a negative flow dependence relationship and a positive temperature dependence relationship. Positive temperature dependence, with no flow dependence, is exhibited by field pH. Negative temperature dependence (and/or positive biological uptake dependence) is exhibited by dissolved zinc and nitrate-nitrite, and total ammonia.

Figure 14. Prairie Creek Mouth. Diss.Copper VS FieldConduct.



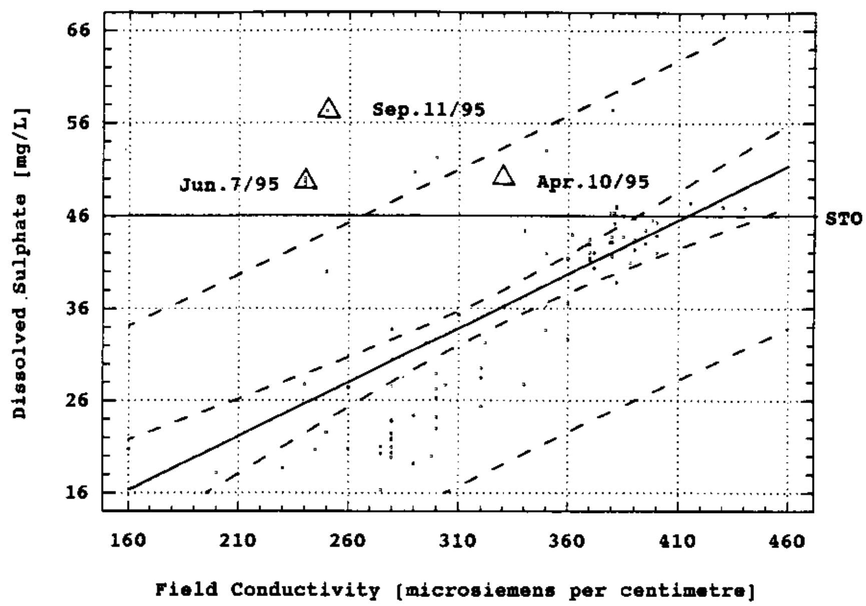
Note: STO Exceedances

Figure 15. Prairie Creek Mouth. Diss.Zinc VS Field Conduct.



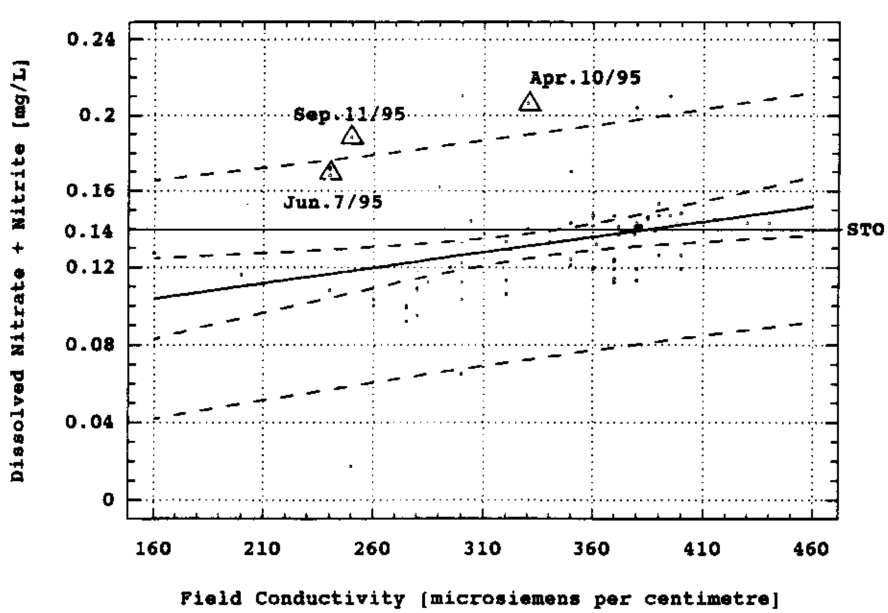
Note: STO Exceedances

Figure 16. Prairie Creek Mouth. Diss.SO4 VS Field Conduct.



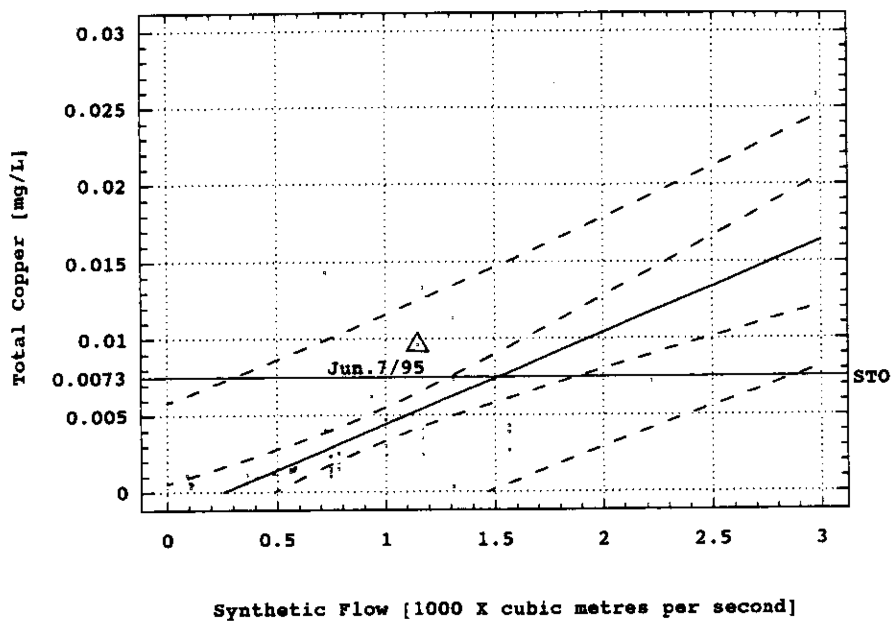
Note: STO Exceedances

Figure 17. Prairie Creek Mouth. Diss.NO3NO2 VS Field Conduct



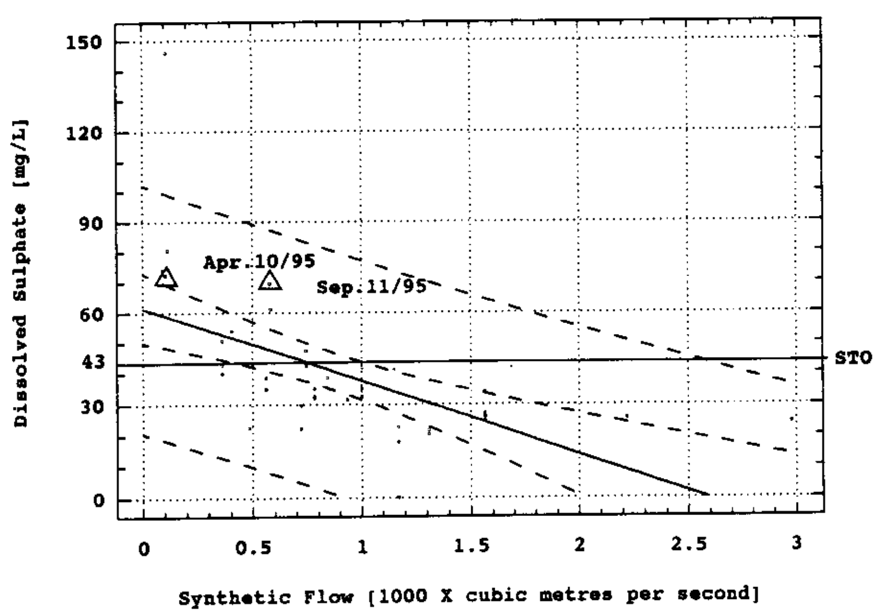
Note: STO Exceedances

Figure 18. SNR Above Nahanni Butte. Tot.Cu VS Synthetic Flow



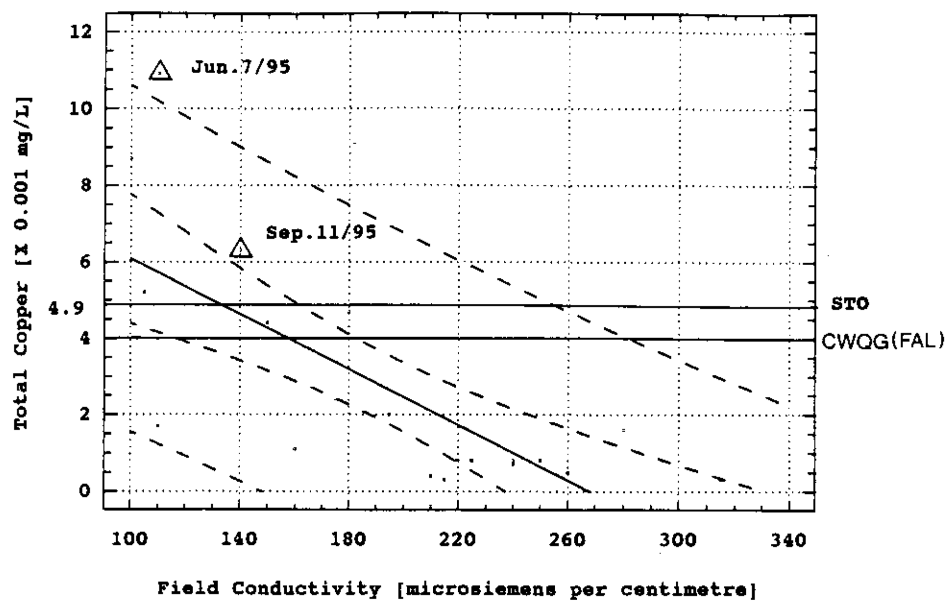
Note: STO Exceedances

Figure 19. SNR Above Nahanni Butte. Diss.SO4 VS Syn.Flow



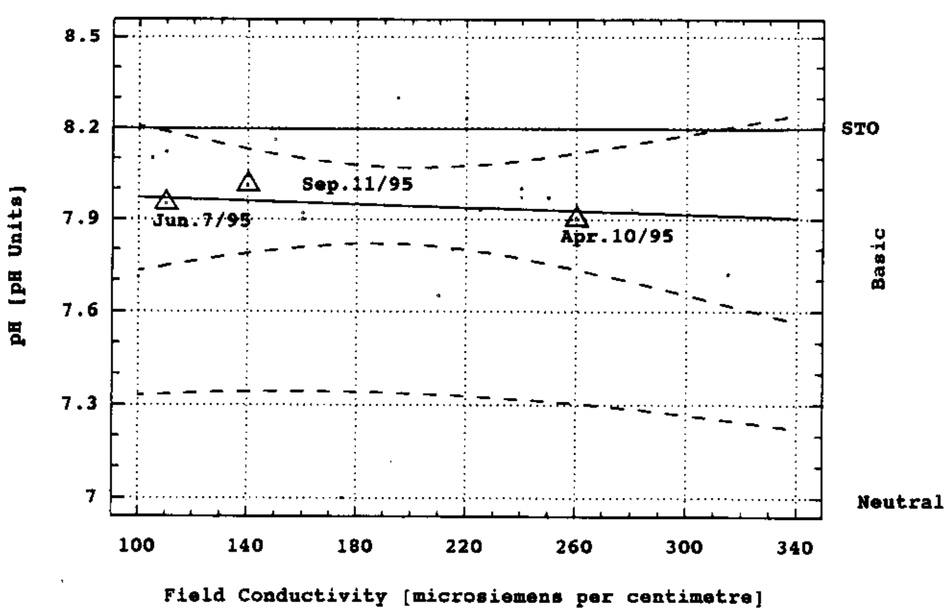
Note: STO Exceedances

Figure 20. Rabbitkettle R.Mouth. Total Copper VS Field Cond.



Note: STO Exceedances

Figure 21. Rabbitkettle R.Mouth. Field pH VS Field Conduct.



Note: STO Exceedances

Rabbitkettle River At Mouth Water Quality Station

Table 5 in Appendix I shows that 1995 field conductivities ranged from 110 to 260 us/cm at Rabbitkettle River mouth while 1994, 1993 and 1992 values ranged from 160 to 280, 100 to 210, and 150 to 315, respectively. 1988-89 values ranged from 105 to 250 us/cm. Like Prairie Creek, flow data is not available for Rabbitkettle River nor can it be reliably estimated. StatGraphics software was used with the Flat River water quality database to produce a correlation matrix.

Discharge is more strongly, albeit negatively, correlated with field conductivity ("r" = -0.7977, N=151 values) than any other water quality variable, as expected. Linear regressions of water quality variables were carried out against field conductivity at the Rabbitkettle River water quality site.

Strong to moderate negative correlations ($r < -0.65$) exist between field conductivity and total copper (Figure 20), zinc, nickel, cadmium, and barium, indicating positive correlation with flow (since field conductivity and flow exhibit strong negative correlations). Field pH exhibits a moderate positive correlation (+0.6017, N=25) with field conductivity (Figure 21), possibly because of the effects of the nearby Rabbitkettle Hotsprings. High pH and conductivity values suggest ground water contributions, especially during April baseflow, when more acidic, less conductive surface water flows are minimal (Environment Canada, 1990; Gulley, 1993). This site is the only one of seven to exhibit this relationship. Dissolved zinc (Figure 22) exhibits a moderately strong negative correlation with flow as indicated by a +0.7653 "r" value against field conductivity for N=12 values. The sample size of water quality samples at this site (e.g. 12 for dissolved metals, 22 for other variables) is not statistically large (i.e. N>30), making some conclusions premature.

NFR; extractable iron and manganese; dissolved arsenic, iron and copper; and total barium, cadmium, cobalt, copper (Figure 20), iron, lead, nickel, vanadium and zinc are directly proportional to flow. Field pH (Figure 21) and conductivity; total cyanide; and dissolved sulphate (Figure 22), barium, cadmium, cobalt, copper, manganese, nickel, selenium, zinc, and sulphate are inversely proportional to flow. Total ammonia; and dissolved cadmium, cobalt, lead, manganese, nickel and nitrate-nitrite appear to be unrelated to flow. Barium, cadmium, lead and nickel appear to be partitioned into particulate forms during the open water season and into dissolved forms during under-ice conditions (Table 5). Cobalt, copper, vanadium and zinc are partitioned into particulate (suspended sediment) forms year-round. Iron and manganese are partitioned into extractable forms (i.e. coatings) year-round. Most of the 28 water quality variables exhibit strong to weak correlation with flow.

Figure 13 shows that a negative flow (Q) dependence relationship (suggesting dilution effects), is exhibited by field conductivity, total cyanide, dissolved barium and dissolved sulphate. A positive flow dependence relationship (suggesting particulate/suspended sediment effects) is exhibited by NFR; pH; extractable iron and manganese; dissolved arsenic, iron and copper; and total cobalt, copper, lead, nickel, vanadium and zinc. Total barium and cadmium have a positive flow dependence relationship with positive counterclockwise hysteresis, suggesting effects of flushing of particulates during spring freshet, leaving. Dissolved cadmium, cobalt, selenium, and zinc exhibit positive temperature dependence, positive clockwise hysteresis and negative flow dependence, values increasing from the winter baseflow to the spring freshet to the summer recession. Dissolved cobalt, cadmium, manganese and nickel exhibit a positive temperature dependence with no flow dependence. Dissolved lead, dissolved nitrate-nitrite and total ammonia exhibit a negative temperature dependence (and/or a positive biological uptake dependence) relationship.

South Nahanni River Above Rabbitkettle River Water Quality Station

The South Nahanni River (SNR) above Rabbitkettle River water quality station lacks flow data. Flow data cannot be as readily "routed" (extrapolated) upstream from the Virginia Falls station gauge. Therefore, linear regression of water quality variables was carried out on field conductivity instead of flow. Table 6 in Appendix I shows that 1995 field conductivities at South Nahanni River above Rabbitkettle River ranged from 130 to 270 us/cm compared to 170 to 280 in 1994, 120 to 300 in 1993, 130 to 370 in 1992, and 140 to 300 in 1988-1989.

Strong to moderate negative correlations (i.e. r <= -0.65) exist between field conductivity and total copper (-0.7832, N=77), extractable manganese (-0.7047, N=77), total zinc (-0.6911, N=77) (Figure 23), total cobalt (-0.6898, N=77), and NFR (-0.6705, N=77); indicating strong positive correlation with flow. Dissolved sulphate (+0.8335, N=77) , field pH (+0.7986, N=77), and dissolved barium (+0.6048, N=16) exhibit strong negative correlations with flow, as indicated by strong to moderate positive correlations with field conductivity. There is no positive correlation between field pH and field conductivity. This suggests that ground water input from hot springs along the fault-controlled reaches of the upper SNR and its Broken Skull River tributary, is having no effect on the water quality at this site. Dissolved nitrate-nitrite[2] (Figure 24) exhibits biological uptake dependence or temperature dependence, and no flow dependence. Total barium exhibits moderate positive flow dependence with early flushing of particulates during the spring freshet, leaving lower levels during recession than during baseflow.

NFR; total cyanide; extractable iron and manganese; dissolved arsenic, iron and copper; and total barium, cadmium, cobalt, copper, lead, nickel, vanadium and zinc are directly proportional to flow. Field conductivity; dissolved barium, nickel, selenium, and sulphate; and total ammonia[3] are inversely proportional to flow while pH and dissolved cadmium, cobalt, lead, manganese, zinc and nitrate-nitrite appear to be unrelated to flow. Barium, cadmium, cobalt, copper, lead, and zinc are partitioned into particulate forms during the open water season and dissolved forms during under-ice conditions. Nickel and vanadium are partitioned into particulate forms year-round, while iron and manganese are partitioned into extractable forms year-round. Most of the 28 water quality variables exhibit some correlation with flow.

A negative discharge (Q) flow relationship suggesting dilution effects is exhibited by field conductivity; total ammonia; and dissolved nickel and sulphate. A positive flow dependence relationship suggesting particulate effects is exhibited by NFR; total cyanide; extractable iron and manganese; dissolved arsenic and iron; and total cobalt, copper, lead, nickel, vanadium and zinc. Dissolved copper and iron, and total barium and cadmium, have a positive flow dependence relationship with negative clockwise hysteresis. Dissolved barium, dissolved selenium, and pH values exhibit a positive temperature dependence, positive clockwise hysteresis, and negative flow dependence. Field pH and dissolved cobalt have a positive temperature dependence and no flow dependence, values increasing from the winter baseflow to the spring freshet to the summer recession. Dissolved cadmium, manganese, lead, zinc, and nitrate-nitrite exhibit a negative temperature dependence relationship (and/or a positive biological uptake dependence relationship).

Flat River at Park Boundary Station

The Flat River at Park Boundary site lacks a flow measurement gauge, so miscellaneous flow measurements were made there in 1994 and 1995. Linear regression of water quality variables was, therefore, carried out on field conductivity instead of flow. Table 7 in Appendix I shows that 1995 field conductivities ranged from 130 to 280 us/cm at the Flat River Park Boundary

Figure 22. Rabbitkettle R.Mouth. Diss.Zinc VS Field Cond.

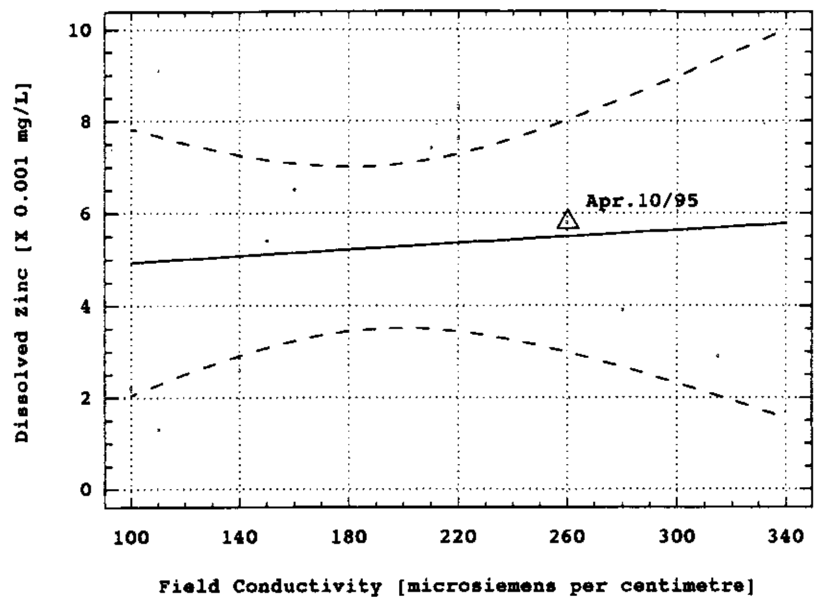
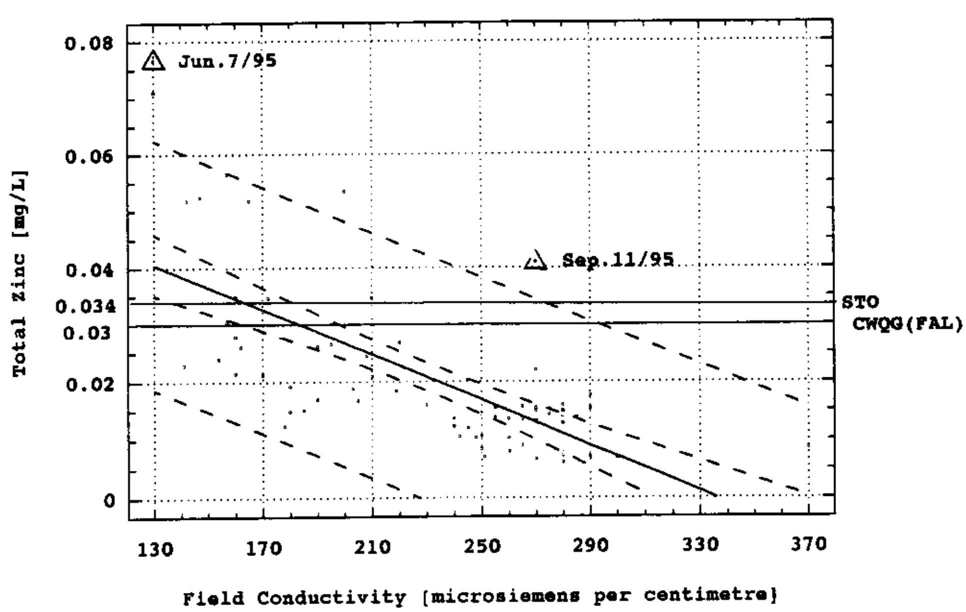


Figure 23. SNR Above Rabbitkettle R. Tot.Zn VS Field Conduct



Note: STO Exceedances

Figure 24. SNR Abv Rabbitkettle R. Diss.NO3NO2 VS Field Cond

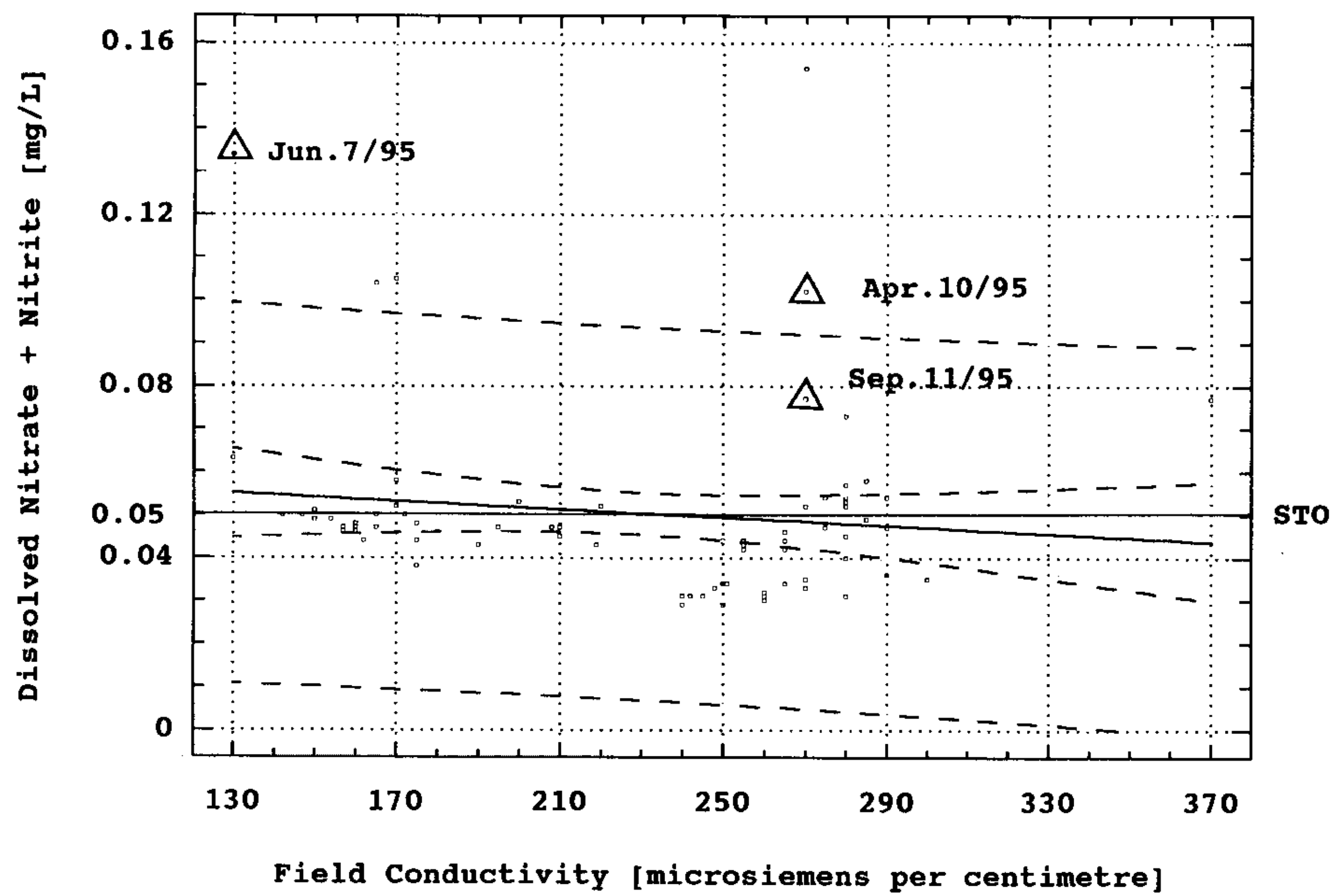


Figure 25. Flat R.Park Boundary. Mult.Box&Whisker. Total Cu

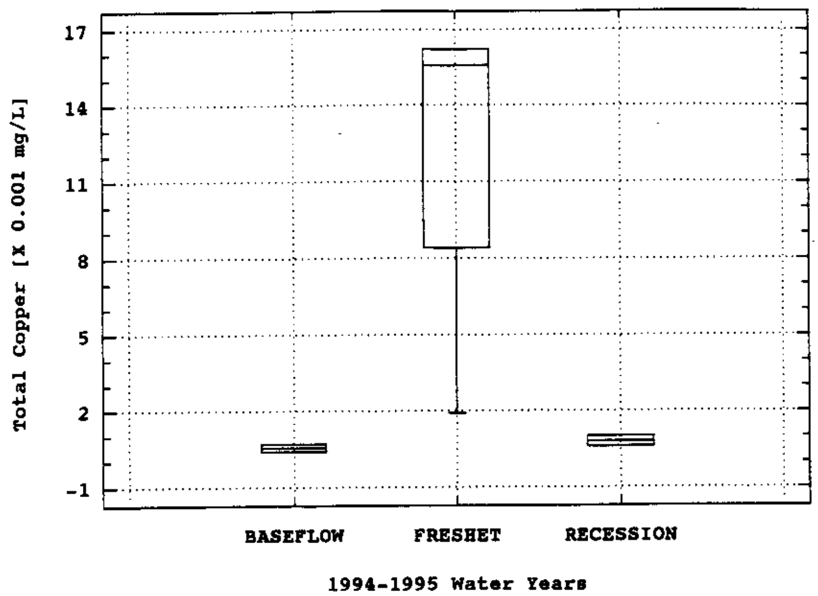


Figure 26. Flat R.Park Boundary. Mult.Box&Whisker. Diss. Ba

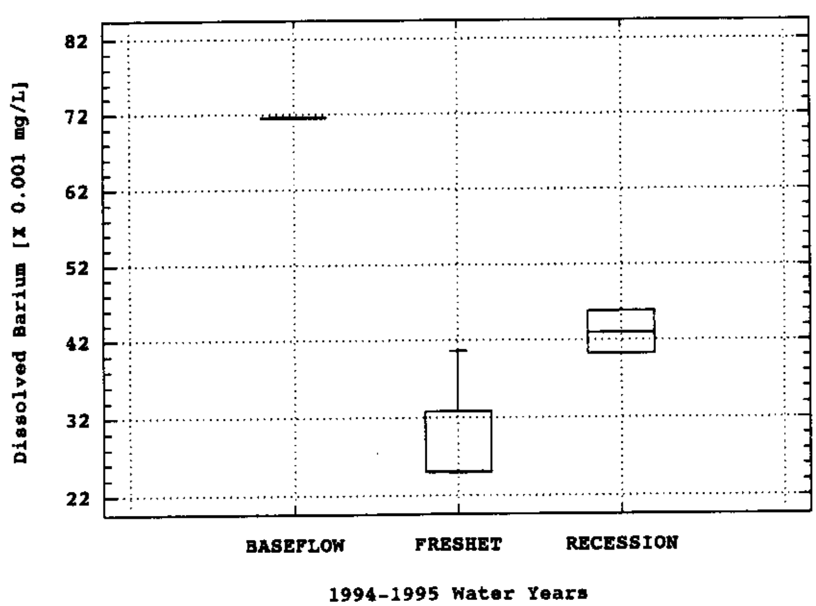


Figure 27. SNR Abv Virginia Falls. Mult.Box&Whisker. Tot. Pb

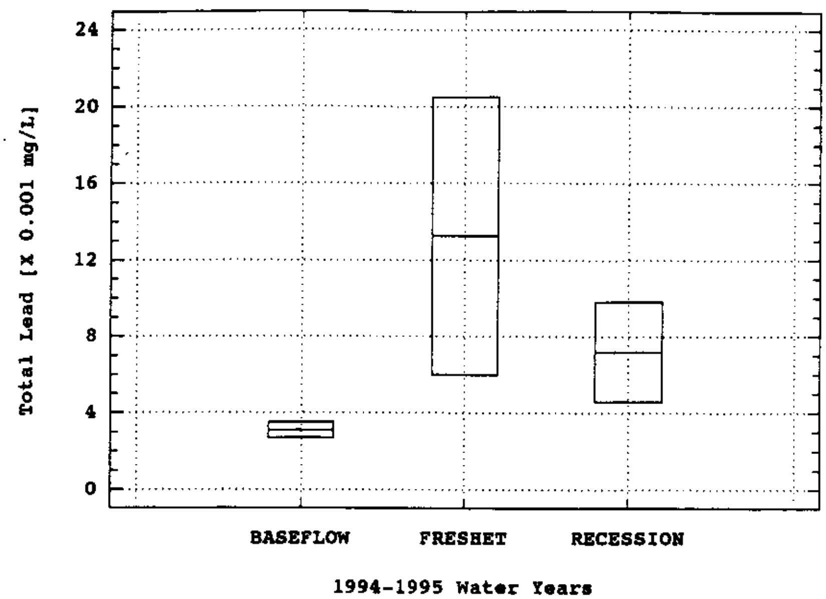
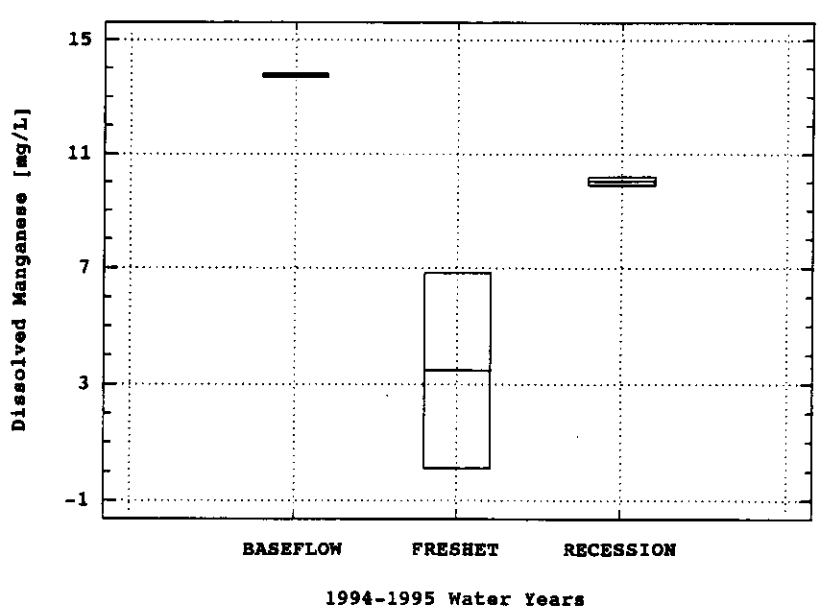


Figure 28. SNR Abv Virginia Falls. Mult.Box&Whisker. Diss.Mn



site while 1994 (first year of water quality sample collection since 1989) values ranged between 200 and 230.

Negative correlations exist between field conductivity and NFR; total barium, cadmium, cobalt, copper (Figure 25), nickel, lead, vanadium and zinc; dissolved arsenic and copper; and extractable iron and manganese. Positive correlations exist between dissolved sulphate, nitrate-nitrite, barium (Figure 26), nickel and selenium. No correlations exist between total ammonia; total barium, cadmium, lead, and nickel; and dissolved arsenic, cobalt, iron, lead, manganese, selenium and zinc. There is no positive correlation between field pH and field conductivity, suggesting that there is little or no impact of hot springs and ground water from the upper reaches of upper Flat River. The sample size is statistically small (i.e. N=8), so there are still uncertainties about the above-mentioned correlations.

South Nahanni River above Virginia Falls Station

The SNR Above Virginia Falls site has a gauge (and meteorologic facility), so linear regression of water quality variables was carried out on flow. Table 8 in Appendix I shows that 1995 field conductivity values ranged from 140 to 320 us/cm at the SNR Virginia Falls site while 1994 field conductivities ranged between 170 and 260. 1995 flows ranged from 31.9 (April) to 921.0 cms (June), while 1994 flows ranged from 32.3 (April) to 442.0 cms (May 30), when water quality samples were collected. 1995 water quality sampling was carried out on the day of peak daily flow (i.e. June 7), while the 1994 peak flow of 1330 cms occurred on June 9, ten days after May 30, 1994 water quality sampling.

Positive correlations exist between (mean daily) flow and field pH; total barium, copper, lead (Figure 27), and zinc; dissolved barium, copper, and iron. Negative correlations exist between flow and field conductivity; and dissolved nitrate-nitrite, sulphate, cadmium, manganese (Figure 28), nickel, selenium, and zinc. No correlations with flow exist for total ammonia and cadmium; extractable iron and manganese; and dissolved arsenic, cobalt, iron, lead, vanadium, and zinc. The sample size is statistically small (i.e. N=6), so that there is much uncertainty about correlation coefficients and the effects of flow on water quality variables.

Non-Filterable Residue (NFR) Values

Non-filterable residue (NFR) is a measure of suspended particles such as silt, clay and organic matter. Large glaciolacustrine deposits of silts and clays occur in valleys of the South Nahanni River Basin. These are easily eroded and supplied to the river as suspended load. NFR is directly proportional to flow and reaches a maximum during the June-July flow peak at Flat River and, to a lesser extent, Prairie Creek. Prairie Creek flows through a resistant canyon and has a smaller supply of erodable material (Environment Canada, 1991).

The positive correlation between NFR and discharge is not as strong as the negative correlation between field conductivity and flow. Banks are frozen at the start of the spring high flows so that slumps are not related to flow. Bank slumps occurring later on in the summer are related to flow. Rainfall events and certain anthropogenic activities (e.g. road construction, exploration drilling) cause localized sediment contibutions. Variable particle sizes remain in suspension for different lengths of time. The turbid matter is largely inorganic and settles out rapidly in quiet waters. The seasonal-temporal variability of NFR results in dramatic NFR peaks corresponding to peak spring water flows (Environment Canada, 1991).

pH Values

pH values are known to be depressed by up to 1.0 pH unit during heavy rainfall events in the Western Cordillera (Whitfield and Dalley, 1987), which includes the South Nahanni River basin. During 1988-94, pH appeared unrelated to flow except at the Rabbitkettle River Mouth, Flat River Park Boundary, and SNR Above Virginia Falls sites, where pH went up during the spring freshet and down during the recession. At the other four stations, the pH exhibited temperature dependence, increasing from late winter (baseflow) to spring (freshet) to summer-fall (recession). The effect of the greater contribution of higher pH, carbonate-rich groundwater during the late winter baseflow period appears to be negligible. The effect of surface waters appears to dominate.

In the relative sense, lower pH values due to increased flow are not apparent in the 1988-89 and 1992-1995 freshet data, except possibly at the Rabbitkettle River Mouth site, where baseflow may include ground water from the Rabbitkettle Hotsprings less than one kilometre away from the sample site. Absolute pH values of the waters of the Park are much higher than those of the eastern Northwest Territories due to the abundance of carbonate rocks, such as limestones and dolostones. (This also increases the calcium and magnesium ion concentrations, and thus the hardness, of the waters- and the appropriate CCME Canadian Water Quality Guidelines to be used). Most of the eastern N.W.T. is underlain by gneisses, meta-intrusives and lesser "greenstones" of the Canadian Shield, and are less capable of buffering acidic rainfall. Canadian Shield rocks are also responsible for "softer" waters, with more stringent CCME Water Quality Guidelines.

Nutrient Values

Nutrients, such as nitrogen, phosphorus and carbon in various chemical forms, exhibit spatial and temporal variabilities. Several of the nitrogen and phosphorus forms are essential for plant growth, and seasonal cycles tend to mirror periods of productivity. Orthophosphate and nitrate-nitrite decline in concentration during summer and fall due to biological uptake and dilution and flushing of the compounds from the system. This is the case in for dissolved nitrate-nitrite and total ammonia at the five 1992-1995 water quality sites, where baseflow values exceed freshet values, and freshet values exceed recession values. Particulate-associated nitrogen and phosphorus are at low levels in the winter and peak in spring (Environment Canada, 1991).

4.3 Significance and Variability of Metals

Metals can pose a threat to the health of aquatic systems, due to their toxicity to organisms, bioconcentration within organisms, biomagnification within the food chain, and resultant human health hazards. Existing levels of metals in the South Nahanni River Basin are very low and likely from natural sources. Increased mining activity could increase metal concentrations in the water, adversely affecting resident biota that have adapted to natural levels (Environment Canada, 1991).

The impact of metals, including aluminum, is determined by their availability to aquatic life. Toxicity is influenced by physico-chemical characteristics of metals in dissolved and particulate states and chemical properties of the water. Dissolved metals are more readily available for biological uptake than particulate or extractable metals.

Sediment-related metals can be directly ingested. Sediments are of biological importance as regulators of elements in the dissolved state when physical and chemical interchanges occur between the solute and particulate phases (Environment Canada, 1991). Anthropogenic chemicals from point or non-point (diffuse) sources can be scavenged (adsorbed) by fine sediment particles at any point along pathways from source to sink (Thomas and Meybeck, 1990).

Heavy metals often concentrate in the sediment loads of the first flush of storm runoff. Annual heavy metal loadings from small catchments require accurate sediment load determination on a storm by storm basis. Long-term metal loads of major river systems are usually dominated by particulate sources during flood flows or by particulate scavenging any time a sediment concentration increases (Bobba and Ongley, 1987).

Despite the physiological need of aquatic organisms for many metals, bioaccumulation may produce concentrations toxic to organisms. Effects include impaired reproductive capacities, retarded growth and maturation of juveniles, shorter lifespans, decreased viability of populations and reduced species diversity (Environment Canada, 1991).

Biomagnification of metal in aquatic food chains is a major concern. Metals are accumulated in fauna and flora; the upper trophic levels (including humans) may receive highly elevated concentrations of metals naturally present in aqueous form at low or undetectable concentrations. Human exposure to high metal levels (e.g. lead, mercury, aluminum) may cause neurological and physiological impairment (Environment Canada, 1991).

Metals exhibit temporal and spatial variability for both total amounts and amounts present in various phases. Under natural conditions, metals can be found dissolved in water or attached to solid matter. The chemistry of the metal and ambient physical and chemical conditions (e.g. pH, Eh or oxidation potential, temperature, atmospheric pressure, dissolved oxygen content, salinity) play important roles. Most of the metals, particularly iron and manganese, are transported almost entirely in association with suspended sediments (Environment Canada, 1991). Copper, mercury, chromium, and lead also occur largely in the particulate phase with particles finer than 0.45 micrometers (Bobba and Ongley, 1987). Arsenic and selenium exist predominantly in the dissolved state. Metals in the dissolved phase shift in equilibrium towards the solid phase, this occurring along the course of a river under regular flow conditions. Exchange of metals between the dissolved and solid-associated phases results from changes in pH, Eh, salinity and other factors (Environment Canada, 1991).

The seasonal temporal pattern of metal concentrations depends on whether metals occur in the dissolved or extractable phase. Changes in total concentration and in the proportion of metals in the dissolved or solid-associated state occur over the year, reflecting changes in metal sources, flow and sediment regimes, and biological uptake. Metals introduced from point sources, such as mines or municipalities, are diluted during high flow conditions. Metals from natural sources, such as bank erosion, may be increased or diluted as metals are mobilized from the drainage basin in solution and associated with mineral and organic solids (Environment Canada, 1991).

Dissolved metal concentrations peak during periods of low flow and low sediment concentration. Copper, manganese and other metals essential for biological activity may decline in the dissolved phase as the available fraction is assimilated by organisms for growth and reproduction (Environment Canada, 1991).

Solid-associated metals increase in the spring freshet along with the flow and sediment levels, with concentrations remaining low during the rest of the year. They may also respond to short-term fluxes in the summer and fall sediment regimes. The seasonal pattern is evident from 1988-89, 1992, 1993, and 1994 SNR Above Nahanni Butte data, where the sum of metals throughout the basin is accumulated, and in the same years of Prairie Creek data, where metal concentrations are extremely low. In both cases, the metals concentration is highest and most variable during the spring freshet (Environment Canada, 1991). This is readily shown in multiple box-and-whisker plots (Figures 12, 24-27).

Metal concentrations in the basin did not appear to be of concern in the 1988-89 study and 1992-1995 monitoring program, as levels were almost always below water quality guidelines for the protection of aquatic life (Appendix I). More exceedances were noted during the 1992 study than during the 1988-1989 and 1993-1995, due to higher flows (Figures 3-5) and collection of samples during peak 1992 spring freshet flows (e.g. June 4 at Flat River). Existing concentrations are not a threat to the health of the aquatic ecosystem.

Metal concentrations in fish tissue from the Flat River in 1988-89 were not significantly above background levels (Environment Canada, 1991).

Following the September 1992 survey at two sites close to SNR Below Prairie Creek, DFO Yellowknife noted that arsenic and lead were not detected in 17 arctic grayling, longnose sucker, and burbot collected. Mercury and nickel were present in trace amounts. Copper and zinc were found in concentrations similar to those recorded for fish living in an environment modified by mining activities. Cadmium concentrations reported were unusual for an undisturbed system, however, and further monitoring was therefore recommended at two year intervals. Sampling was carried out at the SNR Below Prairie Creek (near Dry Canyon Creek) and Flat River near MacLeod Creek (near the Park Boundary) sites in September 1994, with a minimum of 10 specimens of each fish collected to assess levels of heavy metals in fish tissue. Analyses of these fish tissue samples has recently been completed and the report is imminent in early 1997.

Effective July 1995, interpretation of metal levels in suspended sediments is possible due to the drafting of interim freshwater Canadian Sediment Quality Guidelines (CSQGs) by CCME (Smith et al, 1995). With the drafting of interim freshwater CSQGs, suspended sediment sampling at SNR Above Nahanni Butte provides a baseline, with increased importance (Environment Canada, 1991). High (per cent) values were noted for total iron and aluminum.

High total iron values are believed to be due to exposures of "Sunblood Formation" limestone and lesser dolostone and sandstone in all sub-basins, except for Prairie Creek. Prairie Creek is a minor contributor to the water and sediments downstream at Nahanni Butte, and iron sulphide (i.e pyrite, marcasite) gangue minerals may be associated with zinc-lead-copper-silver mineralization near the Cadillac Mine.

The high aluminum values are not likely due to contamination from techniques employed for handling suspended sediment samples before analysis, such as using aluminum foil to help seal sediment jars (a situation corrected in 1993). The high aluminum values are likely due to the abundance of aluminosilicate clays derived from erosion of clay-rich tills and glaciolacustrine deposits, as well as the weathering and alteration of feldspar minerals present in various types of intrusive and sedimentary bedrock. Aluminum has only been measured in Nahanni NPR stream waters since April 1993 and entered into the database since April 1994.

No water quality objectives were established for total aluminum in Nahanni NPR during 1988-89. The few measurements made at all seven sites typically exceed the 0.005-0.1 mg/L CWQG for freshwater aquatic life. The fact that total aluminum levels in stream waters from the Prairie Creek Mouth site is not elevated suggests that aluminosilicate-rich drilling muds from the 12,000 metres per year of diamond drilling by SARC (DIAND, 1994) are not responsible for the high aluminum levels. Diamond drilling muds have been shown to have elevated aluminum levels in waters affected by BHP-Diamet's diamond exploration (BHP-EIS, 1995). NWT Health and consultants involved with the design of the Nahanni Butte townsite water supply are currently aware of this environmental concern.

5.0 WATER QUALITY OBJECTIVE COMPLIANCE MONITORING

5.1 Background

Section 5 is a near-verbatum duplicate of the Nahanni Park 1995 Water and Sediment Quality Objectives Exceedance Report. This section is inserted in this annual report for completeness, and to render this report a "stand-alone" report.

Water quality objectives have been set for the waters of Nahanni National Park Reserve, based on a joint 1988-90 EC/CPS study of Park water quality, and subsequent monitoring program work.

A water quality objective is a numerical concentration or narrative statement designed to support and maintain designated water uses. Canadian Water Quality Guidelines (CWQGs) provide the basic scientific information used to establish site-specific water quality objectives to support and protect designated uses of water within specified locations (CCREM, 1995).

Water quality objectives are a common tool for managing discharges to waterbodies to ensure that water quality is not degraded and is of suitable quality for present and future uses. The CWQGs have been developed using a variety of methods, based on needs, issues, parameters and variables of concern, available data, and other factors. By setting objectives to meet needs of the most sensitive water use (often freshwater aquatic life), all other uses are also protected. The approach used can be tailored for the water body concerned and objectives of water management agencies (Blachford, 1988).

While Canada-wide definitions of **water quality guidelines, water quality objectives, water quality standards** and **criteria** are quoted in the CWQGs (CCREM, 1995), exact definitions vary between jurisdictions. Additional terminology is also used in water quality objectives development methodologies. Additional concepts are covered by terms like **maximum allowable concentration, water quality indicator, long-term and short-term indicators (objectives), alert level, procedural objective, safe level,** and **swimmers level** (Blachford, 1988).

The water quality objectives approach requires collection of data on ambient water quality conditions, development of water quality objectives, and on-going water quality monitoring. If objectives are exceeded, the cause, extent and severity of the exceedance should be investigated to determine whether the exceedance is due to natural or anthropogenic (human) causes, and whether action is needed (Environment Canada, 1991).

As research on environmental and human health impacts of many compounds is incomplete, water quality objectives must be regularly reviewed, and new scientific information incorporated into them. On-going evaluation is required to ensure that the objectives are protecting the resource or water use of concern.

Water quality objectives developed for five sites (Flat River Mouth, Nahanni Butte, Prairie Creek Mouth, Rabbitkettle River Mouth, Above Rabbitkettle River) within Nahanni Park in 1991 (Figure 7) represent the first application of objectives in Canada's north. Nahanni Park objectives were derived in a manner similar to those for protection of recreational and fish consumption end uses at Prince Albert National Park (Blachford, 1988) and Waterton Lakes National Park (Blachford, 1990). Caution is required in extending use of objectives for flat, temperate Boreal Plain and Boreal Shield Ecozones to the rugged, subarctic Tundra/Taiga Cordillera Ecozone, as knowledge of the latter is less complete. Assumptions regarding safe levels of contaminants in the subarctic are less well founded, although the scientific knowledge base is substantial (Environment Canada, 1991).

In Canada, draft/interim Canadian Sediment Quality Guidelines (CSQGs) for freshwater sediments are currently being established for mercury, cadmium and other sediment quality variables. A July 1995 report by Environment Canada and MacDonald Environmental Sciences Ltd. tables draft/interim Canadian Sediment Quality Guidelines (CSQGs) for freshwater and marine sediments. CSQGs exist for eight trace metals, as well as six polycyclic aromatic hydrocarbons, eight pesticides and total polychlorinated biphenyls. Site-specific Nahanni Park sediment quality objectives have not been established so far.

5.2 The Approach

The Canadian Parks Service policy on environmental conservation and Nahanni Park Management Plan state that natural resources will be managed with minimal interference to natural processes, and that park waters will be protected to ensure no unnatural changes in water quality. The setting of Park water quality objectives recognised that existing and future mining activities outside of the Park could alter natural water quality conditions, impacting on park aquatic life.

A two-level approach, involving short- and long-term indicators, was used by the Prairie Provinces Water Board (PPWB). Water quality indicators describe the chemical concentration, or biological or physical effect, to be investigated if exceeded in water crossing inter-provincial boundaries. Water quality variables are monitored in conjunction with river discharge (flows), and statistical summaries used to formulate indicators. Water quality variables are tested for seasonality to establish whether separate ice-cover and open water indicators are needed, or a single annual indicator is adequate. Maximum acceptable long-term concentrations are derived from literature on the effects of various elements on biota (Blachford, 1988).

Short-term indicators or objectives (STOs) are intended to protect Park waters and aquatic biota from major deviations in water quality conditions. Aquatic organisms can be stressed by short duration fluctuations in water quality outside the natural range, or near extremes in that range for periods of time greater than regular seasonal cycles. STOs also address possible impacts from accidental or planned releases from mines and related activities. Values are usually not seasonally differentiated, and concerns related to acute toxicity are addressed through maximum acceptable concentration (Blachford, 1988).

Long-term indicators or objectives (LTOs) are required to characterise existing, or unspoiled, water quality conditions. Deviations from LTOs warn that water quality is changing. Long-term monitoring is, therefore, required to show trends over long periods of time, and for comparison with annual and seasonal means of historic data (Blachford, 1988).

Nahanni Park lies within the remote Tundra and Taiga Cordillera Ecozones (tundra and taiga, for areas above and below tree-line, respectively). The Park's South Nahanni River (SNR) and its tributaries are "flashy" mountain streams, characterised by spring snow melt, summer rainstorms and winter low flow periods similar to rivers in British Columbia and the Yukon, rather than prairie rivers in Prince Albert and Waterton National Parks.

Nahanni Park STOs were derived as the 90th percentile value from the 1988-91 study period dataset. As non-parametric statistics, they are not not sensitive to population distribution type and assume neither Normality nor Lognormality.

The percentile methodology initially used for setting Nahanni Park STOs is of limited value however, since it does not allow for seasonality and the wide range of flow conditions experienced in the area. Many values exceeding STOs are due to natural conditions, such as high flow rates coincident with low field conductivities. The South Nahanni River basin 1992 spring freshet peak flows within the Park significantly exceeded those of 1988-1989 and 1993-1995. Water quality samples were also collected at the peak of the 1992 spring freshet, resulting in a large number of STO exceedances. The exceedances were related to lack of data for high flow conditions rather than any change in natural basin conditions.

SNR basin **1995** spring freshet flows were more similar to 1988-1989 and 1993-1994 flows for the SNR gauge sites above Virginia Falls and above Clausen Creek than the higher 1992 flows. The peak flow value at Virginia Falls (921 cms on June 7) was less than the 1300 cms plus peak discharges observed in 1989, and 1992- 1994. The peak flow value at Clausen Creek (1290 cms on June 8, 1995) was similar to values observed in 1988-1989 and 1993-1994, but less than the 3500 cms peak discharge value observed in 1992. This gauge was recently shut down. Station analyses for 1995 reveal that good records were collected at both sites during the 1995 open water season. Good and fair records were collected during winter under ice conditions at Virginia Falls and Clausen Creek sites, respectively.

The **1995** freshet peak flows for the Flat River Mouth site were more similar to 1988-1989 peak flows (without the Mid-June 1989 summer storm) than the high 1992 and low (flat) 1993 peak flows. Flat River Mouth flow peaked at 247 cms on June 7, far below the 400 to 900 cms peak flows of the other five years when water quality samples were collected in Nahanni NPR. Station analyses for 1995 reveal that fair records were collected for the open water season and during ice conditions, with the channel having apparently shifted again.

5.3 Water Quality Objectives

The short- and long-term water quality objectives for five water quality stations in Nahanni NPR are presented in Table 9.

Data from stations upstream of the South Nahanni River- Rabbitkettle River confluence define water quality for the Park. Both have mineral occurrences and claims in their headwaters. Data from the SNR Virginia Falls station defines water quality/quantity (along with 1995 sediment quality and 1994 onwards meteorology) for the central portion of Nahanni NPR, and the Park as a whole. The Flat River Mouth station is located downstream from the mothballed Canada Tungsten's Mine and Caribou River, while the new Flat River Park Boundary station is located upstream from the Caribou River and downstream from the Mine. Other mineral occurrences and claims are also abundant near the Flat River and its major tributary, the Caribou River (Gordey and Anderson, 1993). The Prairie Creek Mouth station is located downstream from the mothballed Cadillac Mine and recent base/precious metal exploration activity. The Nahanni Butte station represents water leaving the Park.

At other Prairie and Northern Region national parks, short-term indicators were calculated as the means of mean annual and maximum allowable concentrations as recommended in current water quality literature. Values are not seasonally differentiated. The consideration of maximum acceptable concentration by short-term indicators addresses acute toxicity concerns (Blachford, 1988).

At other Region national parks, long-term indicators were calculated as the range of values within two standard deviations of seasonal (open water and ice cover) or annual (for variables not exhibiting seasonality) mean concentrations. They show trends which may occur over a period of time, and compare annual or seasonal means of historical and future datasets (Blachford, 1988).

Nahanni Park short-term objectives (STOs) are similar to short-term indicators, and were set at the ninetieth percentile value for the period of record. These values include almost all values on record, except for extreme outliers (Environment Canada, 1991). STOs have not yet been changed to include 1992-1995 data since LTO values would still be weighted in favour of the more abundant 1988 and 1989 data. STOs will be reset for the five original sites (and initially set for two other sites) to include more recent data to the end of the 1996/97 fiscal year, following five years of additional monitoring (fiscal years 1992/93 through 1996/97, inclusive).

Long-term Park objectives (LTOs) are similar to long-term indicators, having been developed as average values of water quality variables over the period of record (1972-1990 for Flat River, 1988-1989 for the other four sites). Use of non-parametric statistics (i.e. percentiles) avoids the need for assumptions concerning the Normality or Lognormality of distributions. Original LTO values were accepted because flow conditions during 1988 and 1989 appeared to be typical (slightly above and below historic means, respectively) and water quality values are strongly governed by flow. Study and historic data also suggested that study period water quality was typical of conditions at Flat River during 1972-1990 (Environment Canada, 1991). LTOs have not yet been changed to include 1992-1995 data, these LTO values are still based on the more abundant 1988-1989 data. LTOs will be reset at the end of the 1992-1997 monitoring program to include more recent, non-redundant data.

Sediment quality objectives have not yet been set for Nahanni NPR, since these can only be derived once Canadian Sediment Quality Guidelines exist. Measured arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc values can be compared to draft/interim Canadian Sediment Quality Guidelines (CSQGs) for freshwater sediments, recommended by Environment Canada (EC) in a recent EC-MacDonald Environmental report (Smith, MacDonald, Keenleyside and Gaudet, 1995).

Comparison of Table 9 with CCME Canadian Water Quality Guidelines shows that the LTOs and STOs are well (generally several orders of magnitude) below CWQGs (CCREM, 1995) for freshwater aquatic life. Over half of all 1988-1989 and more recent water quality values for Park monitoring sites are at or below laboratory method lower detection limits (LDLs).

It is important to understand limitations of laboratory analyses and results at such low concentrations. For example, total and dissolved metal values near LDLs for atomic adsorption (AA) and induced coupling argon plasma (ICAP) instruments lack precision (repeatability) and accuracy. This explains why the STO for **dissolved** zinc at the South Nahanni River above Rabbitkettle River is 0.499 mg/L while the corresponding value for **total** zinc is only 0.034 mg/L. Lab technology improvements (e.g. increased automation and cost-effectiveness, lower LDLs) resulted in ICAP-atomic emission spectroscopy (AES) becoming the standard method used by Environment Canada's National Laboratory for Environmental Testing (NLET) midway through 1992. Laboratory values at or below the lower limits of detection and quantitation for laboratory instruments tend not to yield "robust" water quality values, and tend to be less accurate and less precise than higher values.

During **1992**, laboratory accuracy/precision difficulties near the LDLs resulted in dissolved metal concentration measurements exceeding total metal concentration measurements for nickel at Flat River and Nahanni Butte, lead at the two upstream water quality sites, copper above Rabbitkettle River, and cobalt at the mouth of Rabbitkettle River. Similar **1993** problems resulted in dissolved metal concentration measurements exceeding total metal concentration measurements for copper in September at Prairie Creek, nickel in November at Prairie Creek, and cadmium in November at Flat River. Similar **1994** difficulties near ICAP-AES LDLs resulted in dissolved metal concentration measurements exceeding total metal concentration measurements at Flat River Mouth (molybdenum, sodium, strontium), Nahanni Butte (molybdenum), Prairie Creek (copper, molybdenum, sodium, nickel, strontium), Rabbitkettle (calcium, potassium, magnesium, molybdenum, sodium, nickel, strontium), Upper South Nahanni (calcium, chromium, potassium, molybdenum, sodium, strontium), and Flat

River Park Boundary (barium, calcium, copper, potassium, molybdenum, sodium, lead, strontium, zinc).

In 1995, dissolved metal lab values exceeded total metals at Flat River Mouth (barium, chromium, copper, lithium, magnesium, sodium, potassium, strontium), Flat River Park Boundary (calcium, cadmium, lithium, molybdenum, potassium, strontium), SNR above Rabbitkettle (calcium, iron, lithium, magnesium, nickel, potassium, strontium), Rabbitkettle River Mouth (chromium, lead, potassium), Virginia Falls (barium, copper, lithium, manganese, molybdenum, potassium, sodium, strontium, zinc), Prairie Creek Mouth (calcium, cadmium, chromium, cobalt, copper, lithium, nickel, potassium, zinc), and Nahanni Butte (calcium, lithium, molybdenum, nickel, potassium). This occurred in 89 cases out of 588 (about 15% of the time); and was most common for lithium and potassium (8 cases each); magnesium (6 cases); calcium, copper, and zinc (5 cases each); and strontium (4 cases). NLET Burlington lab recognises that this problem occurs most frequently for the major cations potassium, sodium, calcium and magnesium, and offers a new analytical technique designed to reduce the problem. Budget limitations precluded its use, however.

Most of the values are so low as to be below the lower limit of quntitation (LLOQ) and just above the lower limit of detection (LLOD), and the data is **non-robust.** This phenomenon is common and was discussed in June 28, 1995 with staff from NLET Burlington Lab. The NLET trace metal lab stated in a June 30, 1995 letter that dissolved and total trace metal results have uncertainties of +/- 5%, +/- 10%, or even +/- 50%, with uncertainty increasing upon approaching the LLOD.

5.4 Interpretation of Objectives

Monitoring site water quality data needs to be regularly compared with water quality objectives, to assess whether values are in natural variability ranges.

STOs apply to single water quality grab samples, which can be directly compared to STOs. The same values are then averaged and compared to LTOs. Exceedance of STOs may be a cause for concern, although as major rainfall events (common events in the Cordillera in summer) often result in extreme erosion and naturally elevated concentrations of sediment-related metals. Natural occurrences do not require a management response. However, any exceedance not explainable by natural factors alone should be investigated to determine the appropriate action.

Data collected for each water quality variable must be averaged over time and compared to LTOs. Values from all seasons can be combined; at the minimum, data should represent spring freshet and fall recession conditions (as done in Nahanni Park in 1988-1989 and 1992-1995; winter baseflow conditions were also documented in 1992-1995). Exceedances can be significant, however. Comparison is somewhat subjective because objectives are based upon a limited dataset, and may not be representative of long-term natural variability. LTOs constitute the best information available at the time, however, and should be used until more comprehensive information becomes available.

Manugistics' StatGraphics Version 2.0 (for Windows) and StatGraphics Plus Version 6.0 (for DOS) software were used to perform statistics and prepare graphics. Linear regressions of water quality variables on flows for EC's Flat River Mouth and SNR Virginia Falls gauging stations, calculated. Or "synthetic" flows for SNR Nahanni Butte (calculated by routing flows from Clausen Creek downstream to the Butte), or miscellaneous flow measurements and field conductivity measurements at stations where gauged flow data is unavailable. Field conductivity was used in lieu of discharge for these sites because of its' well-known strong negative correlation with flow. Analysis of the historic (1972-1995) Flat River mouth dataset confirms this pattern for the

Nahanni Park area (e.g. "r" of -0.7977, r^2 of 63.64%, Spearman's rho non-parametric rank correlation of -0.9020).

For data through 1994, "natural factors" was interpreted to apply for all values "within the 95% confidence and prediction limit 'envelope' about the appropriate flow/ water quality variable linear regression line". Values exceeding STOs, but within regression line 95% confidence and prediction limits were considered natural, and not cause for concern. Values exceeding both STOs and 95% confidence and prediction limits of the linear regression lines were identified for further analysis. Action should be taken if an anthropogenic cause can be determined for these exceedances.

5.5 Application of the Objectives

Water quality objectives provide in-stream environmental targets or alert values, warning of detrimental environmental conditions. The objectives alert future developers to requirements for maintenance of ambient water quality conditions. South Nahanni watershed data collected by Environment Canada (EC), Indian and Northern Affairs Canada (INAC) and others are a baseline for developers. Developers are expected to incorporate mitigative measures to ensure operations maintain these environmental targets.

Exploration and development activities in the NWT are screened by the Regional Environmental Review Committee (RERC) and regulated by the NWT Water Board. The Canadian Parks Service (CPS) staff will participate in these screenings.

The water quality monitoring strategy for Nahanni Park involves production of information on the state of the aquatic environment, for comparison to LTOs and STOs. Environment Canada, CPS, and INAC also need to participate in establishing effluent quality standards for exploration and development sites in the South Nahanni watershed during the water licencing process, to reflect LTOs and STOs developed for the Park.

Ongoing monitoring of water quality is recommended below such mines to verify compliance with LTOs and STOs after temporary or permanent closures of these facilities. Proper decommissioning is important to ensure that Park waters aren't degraded after mining activities are completed.

5.6 LTO and STO Exceedances Observed in 1995/96 Data

Refer to Table 7, Figures 8-11, and Figures 14-24.

Water quality variables are plotted against discharge/flow (Flat River Mouth), synthetic flow (SNR above Nahanni Butte) or field conductivity (all other stations), with STO, LTO, and CWQG exceedances superposed. Field conductivity serves as a proxy for discharge, since the two very typically exhibit a strong negative correlations ("r" and "rho" of -0.8 to -0.9). This is illustrated at Flat River Mouth (Figure 8).

Long-Term Objective (LTO) Exceedances

Averages of Flat River Mouth station water quality values for April 10, May 10, June 7, September 11, November 30, 1995 and February 15, 1996 samples in fiscal year 1995/96 resulted in LTO exceedances for total ammonia, dissolved nitrate-nitrite, total cyanide; dissolved cadmium, copper, nickel, and zinc; extractable iron and manganese, and total barium, cadmium, copper, lead, nickel, vanadium and zinc. LTO exceedances were also noted in the period 1992-95 for dissolved nitrate-nitrite, total cyanide; total barium, cadmium, copper, lead, nickel and zinc; extractable iron and manganese; and dissolved copper. LTO exceedances not attributable to flow **may** suggest a recent deterioration trend in water quality relative to 1988 and 1989, but results to date are inconclusive. Further monitoring is needed to determine whether a long-term change is occurring in water quality, and whether this is due to natural or anthropogenic causes. Hotsprings occur near the fault-controlled upstream reaches of the Flat River (Hamilton et al, 1991; Gulley, 1993), and may affect the water quality at this site.

At the Prairie Creek Mouth station, LTO exceedances were noted in 1995/96 for field pH, total ammonia, dissolved sulphate and nitrate-nitrite, dissolved iron, selenium and zinc. LTO exceedances were also noted through the 1992-95 period for dissolved nitrate-nitrite, zinc and selenium. Further monitoring is required to discern if water quality changes (e.g. dissolved selenium, zinc, nitrate-nitrite) are due to natural or anthropogenic long-term causes. Results will have to be interpreted in light of the probability of undiscovered zinc-lead-copper-silver-iron mineral deposits in the Prairie Creek catchment, potential effects of past and future mining at or near Cadillac Mine, and high extractable metal (e.g. iron, manganese) contents present.

At SNR Nahanni Butte, LTO exceedances were observed in 1995/96 for field conductivity; total NH_3; total cyanide; dissolved SO_4; total Ba, Cd, Cu and Zn; and dissolved cadmium, copper, nickel, selenium and zinc. LTO exceedances have been noted throughout 1992-1995 for sulphate, total barium, cadmium and zinc; and dissolved cadmium and copper. Since the Nahanni Butte site integrates similar results at upstream locations, these results are expected. Further monitoring of long-term trends is warranted, until upstream causes can be identified.

At Rabbitkettle River Mouth, LTO occurrences were also observed in 1995/96 for field pH, NFR, total ammonia, dissolved sulphate and nitrate-nitrite, extractable iron and manganese, and total barium, cadmium, copper, nickel, vanadium, and zinc. No recurrent LTO occurrences were noted throughout 1992-1995, suggesting no apparent change in the water quality. Future monitoring of this station to discern long-term changes in water quality is recommended.

This site is highly influenced by hot spring activity from four springs and adjacent travertine deposits, one less than one kilometre from the water quality sample site. The Rabbitkettle Hotsprings waters are of meteoric origin, according to environmental isotope studies. Discharge is controlled by artesian pressures, localised by an underlying fault (Gulley, 1993). Carbonate, sulphate, pH and total barium values are likely to be higher at this site, due to the partial connate (formational) and magmatic origin of these waters. The waters resided in an open/partially closed karst environment for 10 to 25 years, according to environmental isotope studies, but the waters are predominantly meteoric in terms of chemistry and isotope ratios since the water temperature never exceeded 100oC (Gulley, 1993).

For SNR above Rabbitkettle River, LTO exceedances were observed in 1995 for field conductivity, total ammonia, dissolved sulphate and nitrate-nitrite, total cyanide, total cadmium, cobalt, copper, nickel, lead, vanadium and zinc, extractable iron and manganese; and dissolved cadmium, iron, manganese, nickel and selenium. LTO exceedances have been noted throughout 1992-1995 for total cobalt, copper, lead, vanadium, and zinc, and dissolved sulphate, nickel and selenium. As water quality for waters entering the Park may be undergoing some change, and considerable mineral development potential exists upstream (Gordey and Anderson, 1993), future monitoring appears warranted at this site. A series of hotsprings upstream of the site along the fault-controlled reaches of the upper South Nahanni River and its tributary, the Broken Skull River (Gulley, 1993), may have minor effects on water quality at this site.

For the newly reinstated Flat River Park Boundary and South Nahanni River above Virginia Falls sites, no LTOs currently exist. A larger database is required prior to calculation of such water quality objectives. Future monitoring is required to define these LTOs.

Short-Term Objective (STO) and CWQGs Exceedances

STO exceedances outside water quality variable/flow (or field conductivity) regression line confidence limits were observed at all five sites, during 1995 late winter baseflow, spring freshet, and summer-fall recession.

At Flat River Mouth, STO exceedances not readily explainable by flow occurred during the April 1995 late winter baseflow for dissolved sulphate$_4$ (Figure 10), total ammonia, and dissolved copper (Figure 9), iron, manganese, nickel, and zinc (Figure 11). Similar STO exceedances occurred under May-June 1995 freshet conditions for total ammonia, dissolved iron, nickel and zinc (Figure 11), and total barium, cadmium, cobalt, lead, vanadium and zinc. Similar STO exceedances occurred during the July-October 1995 recession for dissolved sulphate, (Figure 10); total ammonia, and dissolved iron, manganese, nickel and zinc (Figure 11). The high total copper values **may** be associated with past mining at Canada Tungsten (W-Cu) Mine. Samples, therefore, were collected on the Flat River near the Park boundary since April 1994, to discern whether water quality is affected by the Caribou River (tributary of the Flat River) or the upper Flat River downstream of the mothballed mine.

Canadian Water Quality Guidelines (CWQGs) for freshwater aquatic life or drinking water were exceeded for true colour; turbidity; and total aluminum and iron.

At Prairie Creek Mouth, an STO exceedance not readily explainable by flow or field conductivity occurred during the April 1995 baseflow for dissolved sulphate (Figure 16), dissolved nitrate-nitrite (Figure 17), and total cyanide. Similar STO exceedances occurred during the May-June 1995 freshet for dissolved sulphate (Figure 16), copper (Figure 14) and zinc (Figure 15). September 1995 summer recession exceedances were observed for dissolved sulphate (Figure 16) and nitrate-nitrite (Figure 17), total ammonia, dissolved copper (Figure 14) and zinc (Figure 15).

Due to exploration upstream of this station near Cadillac Mine, additional opportunistic sampling by Parks Canada was recommended for July and August 1995, however these samples were not collected. These samples should help determine whether the exceedances are one-time incidents or due to anthropogenic activity (or undiscovered zinc-lead-copper-silver-iron deposits).

At SNR Nahanni Butte, STO exceedances unrelated to discharge occurred during April 1995 baseflow for dissolved sulphate (Figure 19). No STO exceedances occurred during the May-June 1995 freshet. Similar STO exceedances occurred during September 1995 recession for dissolved sulphate (Figure 19) and zinc. Total copper values peaked in 1995 with the June 7 sample (0.0096 mg/L), below the CWQG (freshwater aquatic life) and LTO, but above the STO (Figure 10). There were CWQG exceedances at Nahanni Butte for true colour, turbidity, total aluminum and total iron.

At Rabbitkettle River Mouth, STO exceedances not readily explainable by flow or field conductivity occurred during the April 1995 baseflow for dissolved sulphate. Similar STO exceedances occurred during the May-June 1995 freshet for NFR; dissolved sulphate and nitrate-nitrite, and total cobalt, copper (Figure 20) and nickel. Similar STO exceedances occurred during the September 1995 recession for total cyanide, dissolved sulphate, and dissolved nitrate-nitrite. STO exceedances, and abundant mineral deposits present upstream (Gordey and Anderson, 1993), are two reasons why careful monitoring is needed here in the future. CWQG exceedances also occurred for turbidity and total iron.

At SNR above Rabbitkettle River, STO exceedances not readily explainable by flow or field conductivity occurred during April 1995 baseflow for dissolved sulphate and nitrate-nitrite (Figure 24). STO exceedances also occurred in the May-June 1995 freshet for dissolved nitrate-nitrite (Figure 24) and cobalt, extractable iron, and total barium, cadmium, cobalt, vanadium and zinc (Figure 23). Similar STO exceedances occurred during the September 1995 recession for total ammonia, dissolved sulphate, dissolved nitrate-nitrite (Figure 24), dissolved cobalt, dissolved nickel, total nickel, and total zinc (Figure 23). The CWQGs for freshwater aquatic life were also exceeded for turbidity, total aluminum, and toatl zinc. STO and CWQG exceedances, and the abundant mineral deposits upstream (Gordey and Anderson, 1993), are good reasons for careful monitoring here in the future.

At all water quality stations, simple linear regression plots against flow or field conductivity, with superposed LTO, STO and CWQG thresholds, illustrate that exceedances of STOs not explainable by high flows or low field conductivities are fairly common during the 1988-1989 and 1992-1994 spring freshets as well.

The higher flows during the 1992 spring freshet resulted in more frequent exceedances and higher values. Some exceedances were observed under recession and baseflow conditions during 1993-1995. Late summer to fall recession exceedances were rare during 1988, 1989 and 1992; but were more common in 1994-1995. No late winter exceedances were observed in 1988-1989 because no baseflow water quality samples were collected during those years.

6.0 INTERIM SEDIMENT QUALITY GUIDELINE COMPLIANCE MONITORING

Suspended sediments were sampled using a stainless steel Alfa-Laval flow-through centrifuge modified and thoroughly cleaned to avoid contamination. Samples were collected on September 1, 1992; July 21, 1993; September 9, 1993; July 19, 1994; September 12, 1994 and September 13, 1995. Conductivity, pH and temperature were noted in the field. The suspended sediments were sent to EC's National Laboratory for Environmental Testing (NLET) in Burlington for analysis of total mercury, arsenic, selenium, copper, molybdenum, manganese, iron, zinc, chromium, aluminum, cadmium, lead, vanadium, cobalt and nickel (Table 1). DOE's National Water Research Institute (NWRI)'s sedimentology laboratory also performed particle-size distribution analysis (Table 10).

The sediment quality values obtained appear in Table 10. The high total iron values of 27,800 to 374,500 mg/kg (ppm, or 2.78% to 3.75% by weight) is likely real, given the high iron content of sedimentary rocks (e.g. Sunblood Formation limestone) upstream. The unusually high total aluminum values of 56,100 to 84,200 mg/kg (ppm, or 5.61% to 8.42% by weight) were originally thought to be due to contamination during sample preparation before shipping and the data was temporarily censored. During 1992 and 1993, aluminum foil was used to cap and seal sediment jars and aluminum brushes were used for cleaning. These practices were curtailed and the author assisted with the September 1993 suspended sediment (and water) sampling. The 1992 high aluminum values were reproduced both times in 1993, and both times in 1994, with the highest aluminum value (84,200 mg/kg Al) occurring in September 1994!

Particle-size distribution analyses in 1992-1995 show that most of the suspended sediment samples were the 6.0 to 10.0 microns size class in September 1992, 1.0 to 8.0 in July 1993, 0.5-6.0 in September 1993, and 0.5-15.6 in September 1995. All samples were in the minus 177 micron size class. 1995 suspended sediments were composed of 44.88% clay, 31.83% silt, 23.29% sand and 0% gravel while previous suspended sediments were composed of 57.64%-63.53% clay, 32.35%-37.48% silt, 4.12%-4.88% sand, and 0% gravel. In 1993-1994 when two samples were collected each year, the high flow July samples contained more sand and less clay than the low flow September samples. Metal values are expected to be higher in the finer September sample, and this was the case.

Relatively few suspended sediments have been collected and analysed in Canada, so it is difficult to compare results with other areas. Table 11 gives statistics on over 31,200 analyses of bed load samples in the <177 µ size class. These bed load (bottom) stream sediments were collected in active stream channels in the Canadian Cordillera reported in the pre-1984 National Geochemical Reconnaissance (NGR) dataset (Ballantyne, GSC 1981).

The Selwyn Basin just west of Nahanni Park has been the focus of intensive stream geochemical surveys carried out by Geochemistry Subdivision, Geological Survey of Canada. The Selwyn Basin also has a high geochemical background for zinc and copper (Bonham-Carter and Goodfellow, 1984; Goodfellow and Aronoff, 1988).

The September 1992-1995 and July 1993-1994 suspended sediment data from Nahanni Butte are compared to 31,200 samples in the NGR Canadian Cordillera dataset in Table 11. All values are total metal values.

Suspended sediment samples collected in 1992-1995 at SNR Above Nahanni Butte are anomalously elevated for zinc, cobalt, nickel, arsenic, lead and iron contents. Unfortunately, neither cadmium nor chromium percentile information appears in Table 11.

The September 1995 values from the SNR above Nahanni Butte site of 390 ppm (mg/kg dry weight) zinc lies at the 97^{th} percentile of the larger GSC dataset, 84 ppm nickel at the 94^{th} percentile, 19.2 ppm cobalt at the 92^{nd} percentile, 19.6 ppm arsenic at the 85^{th} percentile, 1700 ppm barium at the 85^{th} percentile, 13 ppm lead at the 76^{th} percentile, and 36 ppm copper at the 75^{th} percentile. The sediments also contain 6.50% aluminum and 2.79% iron (73^{rd} percentile). The July and September 1994 values from SNR Above Nahanni Butte of 19.6-23.7 ppm (mg/kg) arsenic lie in the 85^{th} to 92^{nd} percentile range, while 1995 barium values of 957-1310 ppm lie in the 64^{th} to 78^{th}, 1995 lead values (both 12.6 ppm) at the 76^{th}, cobalt values of 12.0-17.4 ppm in the 70^{th} to 85^{th}, copper values of 23.8-30.5 ppm in the 51^{st} to 68^{th}, iron values of 2.58%-3.75% in the 65th-90^{th}, mercury values of 0.053-0.084 ppm in the 57^{th} to 77^{th}, nickel values of 54.2-85.8 ppm in the 88th-94^{th}, and zinc values of 224-331 ppm in the 92^{nd} to 97^{th} percentile range. All total metal values from SNR Above Nahanni Butte site suspended sediment samples increased or stayed the same from July 1994 to September 1994, with the exception of total arsenic, manganese, and vanadium despite a decrease in total organic (and inorganic) carbon.

As the NGR dataset bedload samples were typically collected in third, fourth and fifth order streams by hand (plastic scoops), they contain higher percentages of sand (and lower percentages of clay) than suspended sediments collected by Alpha-Laval centrifuge. It is therefore not surprising that the finer suspended Nahanni NPR sediments are higher in total metals contents.

The elevated total zinc values were the most anomalous of all metals, throughout 1992-1995. The elevated zinc may be related to high total and dissolved zinc values observed in stream waters at all five stations the above-mentioned years.

Prior to the July 1995 drafting of (interim) freshwater Canadian Sediment Quality Guidelines (CSQGs) (Table 12), it was difficult to assess the relevance of these numbers. In Canada, Interim Sediment Quality Guidelines (ISQGs) were established for mercury and cadmium in December 1994. Draft reports by CCME and Environment Canada recommended ISQGs of 0.17 mg/kg (dry weight) for total mercury, and 0.6 mg/kg (dry weight) for total cadmium (Pers. Comm. Sherri Smith, 1995). A draft manuscript prepared in July (Smith et al, 1995, Environment Canada and MacDonald Environmental Sciences Ltd.) entitled "The Development and Implementation of Canadian Sediment Quality Guidelines" containing a table (Table 12) listing draft interim freshwater CSQGs for arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc, five PAHs, eight pesticides, and total PCBs.

Total mercury values from 1992-1995 suspended sediments collected at SNR Above Nahanni Butte have ranged from 0.048 to 0.087 mg/kg (dry weight) from samples collected in July 1993-1994 and September 1992-1995. The maximum value of 0.084 mg/kg (dw) mercury, obtained from suspended sediment on September 12, 1994, is approximately half the (0.174 mg/kg (dw) mercury) interim CSQG for freshwater aquatic life. The lowest total mercury value (0.048 mg/kg dw) was obtained from the September 1995 sample. The SNR above Virginia Falls suspended sediment collected June 20, 1995 contained 0.050 mg/kg (dw) mercury. The SNR Above Clausen Creek site suspended sediment sample collected July 19, 1994 contained 0.052 mg/kg (dw) mercury. No exceedances of the CSQG for mercury and for freshwater aquatic life were observed any of the sites.

Total cadmium values from 1992-1995 suspended sediments collected at SNR Above Nahanni Butte have ranged from 1.11 kg/kg (dw) to 2.3 mg/kg (dw) from samples collected in July 1993-1994 and September 1992-1995. The maximum value of 2.3 mg/kg (dw) cadmium, obtained from suspended sediment on September 1, 1992, is more than double the (0.6 mg/kg (dw) interim CSQG for freshwater aquatic life. The September 1995 value also exceeded the CSQG for total cadmium. The June 1995 SNR Above Virginia Falls site suspended sediment sample contained 1.8 mg/kg (dw) cadmium while the July 1994 SNR above Clausen Creek site suspended sediment sample contained 1.76 mg/kg (dw) mercury. All values from the three sites exceed the interim CSQG for cadmium and freshwater aquatic life. The high local cadmium background along the NWT-YT border in the stream sediments area of the South Nahanni and Flat Rivers was referred to by CCME in their draft ISQG report. Elevated cadmium levels along this portion of the NWT-YT border are reported in stream waters and sediments (Goodfellow and Aronoff, 1988; Bonham-Carter and Goodfellow, 1984), fush tissue and caribou (Pers. Comm. Lyle Lockhart, DFO, 1994).

Total zinc values from 1992-1995 suspended sediment samples collected at SNR Above Nahanni Butte (and the June 1995 and July 1994 suspended sediment samples collected at SNR Above Virginia Falls and SNR Above Clausen Creek, respectively) all exceed (and double) the interim CSQG of 123 mg/kg for freshwater (freshwater aquatic life). Similarly, all values measured at the above-mentioned sites and periods exceed the interim freshwater aquatic life CSQGs for arsenic (5.9 mg/kg), chromium (37.3 mg/kg) and nickel (18.0 mg/kg).

At present, no interim CSQGs have been established for total aluminum or iron. Samples also routinely contain very high levels of total aluminum (5,61-8.42%) and iron (2.58-3.75%) and would surely exceed draft/interim CSQGs for these elements if they existed.

It will be several years before sufficient data has been collected to enable establishment of area-specific Nahanni NPR sediment quality objectives for the SNR Above Nahanni Butte site, or other Nahanni NPR sites.

Nahanni NPR has a natural local geochemical background that is different (higher for most metals) than the regional geochemical background for Canada.

7.0 SUMMARY AND RECOMMENDATIONS

The large number of LTO, STO and CWQG exceedances encountered in the 1992 data, and to a lesser extent the 1988-1989 and 1993-1995 data, is to be expected, given the limited dataset available and the variability of flows in the area. This suggests that it would be useful to maintain all seven water quality sites and one suspended sediment site for some time, to more thoroughly define the range of water and sediment conditions.

Water quantity (flow), field conductivity and other water quality data from

1992 and other years confirm that high spring freshet flows are responsible for most elevated total and dissolved trace metals levels.

Individual values frequently exceeded STOs and total trace metal values on June 4, 1992 exceeded CWQGs for freshwater aquatic life (copper, lead at Flat River Mouth; copper, zinc at Prairie Creek Mouth; lead at SNR Above Nahanni Butte; zinc at Rabbitkettle River Mouth; and copper at SNR Above Rabbitkettle River). On June 7, 1993, CWQGs for freshwater aquatic life were also exceeded for total copper at Flat River Mouth, SNR Above Nahanni Butte, Rabbitkettle River Mouth and SNR Above Rabbitkettle River; total zinc at Rabbitkettle River Mouth and SNR Above Above Rabbitkettle River; and total cadmium at Rabbitkettle River Mouth. On May 30, 1994, CWQGs for freshwater aquatic life were exceeded for total iron at Flat River (Mouth, Park Boundary sites) and South Nahanni River (Nahanni Butte, Virginia Falls, Rabbitkettle River sites).

On June 7, 1995, CWQGs for freshwater aquatic life were exceeded for total aluminum, copper, iron, manganese, nickel and zinc were exceeded at both Flat River water quality sites. All sites, with the exception of the Prairie Creek Mouth site, reported June 7, 1995 exceedances for turbidity, total aluminum, and total iron. Other June 7, 1995 exceedances occurred at Flat River Mouth (non-filterable residue), Flat River Park Boundary (true colour; total cobalt, lead), SNR above Rabbitkettle River (total cobalt, copper, iron, manganese, zinc), Rabbitkettle River Mouth (NFR; total copper, lead, manganese, zinc), Virginia Falls (total barium, chromium, copper, lead, zinc), Prairie Creek Mouth (field pH), and Nahanni Butte (total copper, zinc). CWQG exceedances were common throughout the Park (except the Prairie Creek Mouth site) on September 11, 1995 for turbidity and total iron. There also a few April 10, 1995 CWQG exceedances for total aluminum and cadmium (Flat River Mouth), total selenium (Rabbitkettle River Mouth), and total aluminum and iron (SNR above Nahanni Butte).

Furthermore, the suspended sediment values from Nahanni Butte in July 1993-1994 and September 1992-1995 are elevated for zinc, cobalt, nickel, arsenic, lead, and iron and exceed the 80th percentiles from the NGR dataset population. The total zinc content fell between the 94th and 99th percentiles. All values measured from suspended sediment samples from the SNR Above Nahanni Butte site during 1992-1995, and SNR Above Virginia Falls site in June 1995, and SNR above Clausen Creek site in July 1994, exceeded the interim freshwater aquatic life Canadian Sediment Quality Guidelines (CSQGs) for arsenic, cadmium, chromium, nickel and zinc, probably due to natural sources/causes. Aluminum and iron are very high (% levels, by weight), but freshwater CSQGs do not currently exist for these trace metals.

With little data from a highly variable environment, a reasonable assumption is that variations outside the 95% confidence and prediction limits of simple linear regression of water quality variables on flow, synthetic flow, or field conductivity (near-perfect negative correlatiuon with flow) are likely natural in origin, unless they are so persistent as to be due to anthropogenic origin. The only drilling to occur is at Prairie Creek, and likely of minimal significance to water and sediment quality. The only other significant activities include Tungsten Mine (abandoned since 1982) and Union Carbide (inactive since 1984).

Suspended sediments are excellent media for integrating of water quality of the four upstream sites in the Nahanni NPR portion of the SNR basin. Elevated levels of the six above-mentioned metals plus total aluminum, repeatable results during 1992-1995 suggest that continued suspended sediment sampling is warranted at the SNR above Nahanni Butte site. The elevated values from the seven metals (especially, total aluminum) was seen as one-time investigations further upstream at the SNR above Virginia Falls and SNR above Clausen Creek sites, where all metal values proved to be higher.

Relationships between water quality variables and water quantity (flow) appear to be stronger in the rugged terrain of Nahanni Park and the Taiga Cordillera Ecozone than in the tundra and taiga ecozones of the Canadian Shield. Therefore, miscellaneous flow measurements were made during 1994-1995 at the ungauged Prairie Creek Mouth, Flat River Park Boundary and SNR above Rabbitkettle River water quality sites whenever water quality samples are collected (and when logistics permit). After sufficient data is collected (more than three points from one year), water quality variable/flow ratings curves can be constructed as they were constructed at the Flat River Mouth site.

Correlation coefficient analysis matrices confirmed strong relationships between water quality variables in three distinct groupings, variables directly proportional to flow, variables inversely proportional, and variables unrelated to flow. Water quality variables exhibited some correlation (Pearson's "r" >0.5 or <-0.5) with flow/ field conductivity most of the time at the Rabbitkettle River Mouth, SNR above Rabbitkettle River, Flat River Mouth, and SNR above Nahanni Butte sites, and only rarely at Prairie Creek Mouth site. The cause for the lower flow/ field conductivity control over water quality variable values on Prairie Creek is unknown.

Barium, cadmium, copper, lead, nickel and zinc are largely found in particulate forms (chemical species) during the open-water season and sometimes (zinc at SNR above Nahanni Butte and Rabbitkettle River Mouth, copper at Rabbitkettle River Mouth) during under-ice conditions. These trace metals are mainly found in dissolved forms during under-ice conditions at most or all water quality sites. Cobalt, nickel, and vanadium are found mostly as particulate forms all year round. Iron and manganese are found mostly in extractable forms all year round.

Figure 13 collates data from 196 multiple box-and-whisker plots (28 water quality variables times seven stations) and summarizes seasonal behaviour (seasonality).

Field conductivity, dissolved sulphate, and sometimes dissolved nitrate-nitrite and barium exhibit a negative flow (Q) dependence with dilution effects; the multiple box-and-whisker plot "signature" of this is high baseflow, low freshet and intermediate recession water quality values. Extractable iron and manganese; NFR; total cyanide; total cobalt, copper, lead, nickel (sometimes cadmium, vanadium and zinc); and dissolved arsenic, copper and iron exhibit a positive flow dependence with particulate effects; the multiple box-and-whisker plot "signature" has high freshet values, intermediate recession values and low baseflow values.

A positive flow relationship with flows due to early flushing of particulates is exhibited by total barium, cadmium, vanadium and zinc; the box-and-whisker plot is marked by high spring freshet water quality values, low (depleted) recession values and intermediate recession values. Negative flow dependence and positive temperature dependence is exhibited by dissolved selenium. Water quality variables with little or no flow dependence may either have positive temperature dependence marked by increasing values from baseflow to freshet to recession (field pH, dissolved cobalt), or negative temperature dependence (and/or a positive biological uptake dependence), marked by decreasing values (total ammonia, dissolved nitrate-nitrite).

The water and suspended sediment quality of Nahanni Park is essentially pristine, however 1992-1995 LTO exceedance data suggest that 1988-1991 water quality work failed to describe the large natural variability of water quality in the Park. STO and CWQG exceedances (for zinc, copper, cadmium, lead, etc.) at all five sites confirm that future water quality and other media monitoring is warranted. It is too early to interpret the meaning of CWQG exceedances at the two sample sites established or re-established in 1994 (e.g. Flat River

Park Boundary, SNR above Virginia Falls), and no LTOs or STOs have been established for these two sites.

The Flat River and SNR above Rabbitkettle River sites are apparently not affected by hot springs in the upper reaches of the SNR and Flat River and their upstream tributaries. The positive field pH/field conductivity correlation at the Rabbitkettle River Mouth site and the close proximity (one kilometre) to the Rabbitkettle Hotsprings suggests some connate (karst, formational) and magmatic water influences at this site. The water is believed to have stayed underground 10-25 years, never boiled, and retained its meteoric water isotopic signature (Gulley, 1993).

Recommendations

1. The 1995/96 program involving water and suspended sediment sampling at seven water quality sites and one sediment quality site should be continued into 1996/97, for the final year of a five-year extended monitoring program.

2. Quality assurance/quality control protocols should continue for waters, including collection of field triplicates and blanks. Duplicate suspended sediment samples should continue to be archived.

3. More baseflow water quality data is needed to more closely examine variations in the Park waters.

4. Two additional water quality samples should be collected in 1996 at the Prairie Creek Mouth (and possibly the Flat River Park Boundary) sites, one in July and one in August-September, to better assess any current effects of past base metal mining activity. Delineation exploration drilling activity, proposed development activity, and current (1994-1996) INAC-EC environmental impact assessments of the San Andreas Resources Corporation's Prairie Creek zinc-lead-copper-silver Mining Property make additional Prairie Creek samples a high priority.

5. Opportunistic winter water quality sampling at the Flat River site should continue at least one more year for time trend analysis purposes, and to define separate water quality objectives at Flat River Mouth site for the ice-covered portion of the water year.

6. High metal (zinc, cadmium, arsenic, chromium, nickel, aluminum, iron) values for from the 1992-1995 suspended sediment samples at SNR above Nahanni Butte, above Clausen Creek, and above Virginia Falls suggest a need for suspended sediment samples during 1996 at the SNR above Rabbitkettle River site.

7. The report on the two-site (SNR/ Dry Canyon Creek, Flat River Park Boundary) September 1994 fish tissue sampling should be prepared as soon as possible.

8. Miscellaneous flow measurements should be made when water quality samples are collected at the Prairie Creek Mouth, SNR above Rabbitkettle River, and Flat River Park Boundary sites.

9. Continued collection of meteorologic and hydrologic (water quality/quantity) data at the SNR Above Virginia Falls gauge site would be useful to support interpretation of water quality data and help characterize the Taiga Cordillera Ecozone. Air quality, precipitation chemistry and biota (fish tissue, etc.) sampling/analysis would also be useful in establishing a better baseline of biota exposure, dose, and response to future anthropogenic activities.

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Appendix I

Tables

Table 1. NAQUADAT/ENVIRODAT Field and Lab Parameter Codes for Waters and Suspended Sediments Sampled in 1993.
NAL=INAC Yellowknife **N**orthern **A**nalytical **L**ab,
NLET=EC Burlington **N**ational **L**ab for **E**nvironmental **T**esting.

Sample Media	Water Quality Variable	NAQUADAT/ENVIRODAT Parameter Code	Lab
Water	Temperature (Field)	02061F	-
Water	pH (Field)	10301F	-
Water	Conductivity (Field)	02041F	-
Water	Turbidity	02081L	NAL
Water	Non-Filterable Residue	10401L	NAL
Water	Nitrate-Nitrite	07260L	NLET
Water	Dissolved Sulphate	16306L	NLET
Water	Dissolved Arsenic	33108L	NLET
Water	Dissolved Barium	56109L	NLET
Water	Dissolved Cadmium	48109P	NLET
Water	Dissolved Cobalt	27109P	NLET
Water	Dissolved Copper	29109P	NLET
Water	Dissolved Iron	26109P	NLET
Water	Dissolved Lead	82109P	NLET
Water	Dissolved Manganese	25109P	NLET
Water	Dissolved Nickel	28109P	NLET
Water	Dissolved Selenium	34108L	NLET
Water	Dissolved Vanadium	23109P	NLET
Water	Dissolved Zinc	30109P	NLET
Water	Extractable Iron	02741P	NLET
Water	Extractable Manganese	02743P	NLET
Water	Total Barium	56009P	NLET
Water	Total Cadmium	48009P	NLET
Water	Total Cobalt	27009P	NLET
Water	Total Copper	29009P	NLET
Water	Total Lead	82009P	NLET
Water	Total Nickel	28009P	NLET
Water	Total Vanadium	23009P	NLET
Water	Total Zinc	30009P	NLET
Water	Total Cyanide	06610P	NAL
Sediment	Temperature (Field)	02061F	-
Sediment	pH (Field)	10301F	-
Sediment	Conductivity (Field)	02041F	-
Sediment	Total Aluminum	13053L	NLET
Sediment	Total Arsenic	33052L	NLET
Sediment	Total Cadmium	48053L	NLET
Sediment	Total Chromium	24053L	NLET
Sediment	Total Cobalt	27053L	NLET
Sediment	Total Copper	29053L	NLET
Sediment	Total Iron	26053L	NLET
Sediment	Total Manganese	25053L	NLET
Sediment	Total Mercury	80050L	NLET
Sediment	Total Molybdenum	42053L	NLET
Sediment	Total Nickel	28053L	NLET
Sediment	Total Selenium	34052L	NLET
Sediment	Total Vanadium	23053L	NLET
Sediment	Total Zinc	30050L	NLET

Table 2

Water Quality Results. Flat River Mouth, 1995/96

Station NW10EA0004 Nahanni National Park Reserve, NWT

Date	Time	Project	Sample	Discharge	Origin	CondF	TempF	pHF	ColourL	CondL	FR	NFR	pHL	TurbL	CN
				cms		us/cm	oC.	pH Units	TCU	us/cm	mg/L	mg/L	pH Units	mg/L	mg/L
7-Feb-95		796	957333	17.4	BASEFLOW	390	0.0	8.27	5	419.0		3.0	7.83	2.1	0.002
10-Apr-95		796	957362	20.4	BASEFLOW	350	0.0	7.93	L5	437.0		4.0	7.75	4.3	0.004
10-May-95		796	957389	205.0	FRESHET	140	7.0	8.13	75	198.0		3.0	7.61	0.1	0.001
7-Jun-95		796	957409	247.0	FRESHET	140	10.0	8.19	10	213.0		311.0	7.55	93.2	0.002
11-Sep-95		796	957535	94.3	RECESSION	270	11.5	8.42	10	311.0		13.0	8.25	12.0	L0.001
30-Nov-95		796	957595	30.3	RECESSION	320	0.0	8.50	L5	395.0		1.5	8.08	0.9	0.002
15-Feb-96		796	960124	17.0	BASEFLOW	320	0.0	8.22	L5	405.0		3.0	8.10	2.7	L0.001

Table 2

Date	Cl	SO4	SiO2	NO3NO2	NH3T	AlD	BaD	BeD	CaD	CdD	CoD	CrD	CuD	FeD	KD	LiD
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
7-Feb-95	0.65	43.7	6.71	0.128	L0.005	0.017	0.0681	L0.05	62.6	0.0003	0.0002	L0.0002	L0.0002	0.0033	1.14	0.0102
10-Apr-95	0.61	41.0	6.31	0.104	0.001	0.021	0.0649	L0.05	52.2	0.0001	0.0001	0.0001	0.0005	0.0067	0.73	0.0077
10-May-95	1.02	20.2	4.26	0.046	L0.005	0.071	0.0359	L0.05	28.8	0.0002	0.0004	0.0002	0.0026	0.1330	0.69	0.0042
7-Jun-95	0.51	27.4	4.09	0.063	0.130	0.084	0.0268	L0.05	28.7	0.0005	0.0001	0.0001	0.0010	0.0229	0.51	0.0050
11-Sep-95	0.37	47.5	5.63	0.068	0.010	0.065	0.0498	L0.05	50.9	0.0001	0.0002	0.0001	0.0008	0.0148	0.75	0.0091
30-Nov-95	0.49	52.9	7.12	0.174	0.007	0.010	0.0671	L0.05	61.4	0.0001	0.0001	0.0029	0.0004	0.0221	0.93	0.0108
15-Feb-96	NA	NA	NA	0.172	0.024	0.017	0.0705	L0.05	65.2	0.0003	0.0003	L0.0002	0.0004	0.0082	0.84	0.0083

Table 2

Date	MgD	MnD	MoD	NaD	NiD	PbD	SrD	VD	ZnD	AsD	SeD	AlE	BE	BaE	BeE	CaE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
7-Feb-95	12.70	0.0030	0.0024	1.50	0.0055	L0.0002	0.2040	0.0001	0.0282	0.0002	0.0008	L0.05	L0.01	0.069	L0.001	66.1
10-Apr-95	13.70	0.0027	0.0026	1.26	0.0053	L0.0002	0.1980	0.0001	0.0179	0.0003	0.0007	0.086	0.01	0.069	L0.001	63.7
10-May-95	4.76	0.0114	0.0013	0.51	0.0049	L0.0002	0.0813	0.0004	0.0062	0.0006	0.0004	2.110	L0.01	0.238	L0.001	46.5
7-Jun-95	4.54	0.0040	0.0013	0.50	0.0011	L0.0002	0.0856	0.0003	0.0153	0.0005	0.0003	2.400	L0.01	0.141	L0.001	49.6
11-Sep-95	8.78	0.0025	0.0019	1.13	0.0040	L0.0002	0.1530	0.0002	0.0101	0.0005	0.0004	0.200	L0.01	0.062	L0.001	51.3
30-Nov-95	12.10	0.0040	0.0024	1.49	0.0053	L0.0002	0.2010	0.0001	0.0175	0.0002	0.0009	L0.05	0.01	0.066	L0.001	61.8
15-Feb-96	12.90	0.0037	0.0025	1.53	0.0062	L0.0002	0.2080	L0.0001	0.0251	0.0002	0.0006	0.060	0.03	0.069	L0.001	62.9

Table 2

Date	CdE	CoE	CrE	CuE	FeE	KE	LiE	MgE	MnE	MoE	NaE	NiE	PbE	SrE	VE	ZnE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
7-Feb-95	L0.005	L0.005	L0.005	L0.005	0.107	L2	0.0060	13.4	L0.002	L0.005	L2	L0.005	L0.02	0.207	L0.005	0.029
10-Apr-95	L0.005	L0.005	L0.005	L0.005	0.214	L2	0.0070	12.5	0.006	L0.005	L2	0.005	L0.02	0.207	L0.005	0.026
10-May-95	L0.005	L0.005	0.005	0.008	5.000	L2	0.0100	7.3	0.158	L0.005	L2	0.026	L0.02	0.125	0.010	0.121
7-Jun-95	L0.005	L0.005	L0.005	0.006	4.720	L2	0.0090	6.7	0.195	L0.005	L2	0.023	L0.02	0.141	0.007	0.086
11-Sep-95	L0.005	L0.005	L0.005	L0.005	0.322	L2	0.0130	9.5	0.010	L0.005	L2	0.005	L0.02	0.170	L0.005	0.016
30-Nov-95	L0.005	L0.005	L0.005	L0.005	0.044	L2	0.0090	11.8	0.004	L0.005	L2	0.005	L0.02	0.197	L0.005	0.023
15-Feb-96	L0.005	0.007	0.005	L0.005	0.133	L2	0.0100	12.8	0.006	L0.005	L2	0.014	L0.02	0.199	0.009	0.034

Table 2

Date	AlT	BaT	BeT	CaT	CdT	CoT	CrT	CuT	FeT	KT	LiT	MgT	MnT	MoT	NaT	NiT
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
7-Feb-95	0.069	0.0724	L0.05	59.80	0.0004	0.0002	L0.0002	0.0002	0.1410	1.12	0.0107	12.50	0.0047	0.0025	1.5300	0.0060
10-Apr-95	0.114	0.0690	L0.05	64.40	0.0004	0.0003	0.0003	0.0007	0.2400	0.92	0.0099	12.40	0.0061	0.0026	1.3700	0.0057
10-May-95	5.670	0.2900	0.31	41.40	0.0022	0.0056	0.0078	0.0135	12.6000	1.10	0.0206	7.89	0.1650	0.0032	0.5800	0.0260
7-Jun-95	5.050	0.1670	0.39	45.30	0.0014	0.0058	0.0056	0.0169	10.3000	1.18	0.0228	7.16	0.1990	0.0019	0.6400	0.0193
11-Sep-95	0.268	0.0565	L0.05	50.90	0.0001	0.0004	0.0003	0.0010	0.3590	0.71	0.0083	9.11	0.0089	0.0016	1.2200	0.0053
30-Nov-95	0.030	0.0665	L0.05	69.60	0.0002	0.0002	L0.0002	0.0004	0.0512	0.77	0.0093	10.50	0.0033	0.0025	0.8700	0.0056
15-Feb-96	0.067	0.0728	L0.05	67.20	0.0004	0.0004	L0.0002	0.0003	0.1530	0.90	0.0086	12.90	0.0054	0.0025	1.4900	0.0064

Table 2

Date	PbT	SrT	VT	ZnT
	mg/L	mg/L	mg/L	mg/L
7-Feb-95	L0.0002	0.210	0.0003	0.0305
10-Apr-95	L0.0002	0.212	0.0004	0.0277
10-May-95	0.0069	0.128	0.0167	0.1330
7-Jun-95	0.0078	0.146	0.0121	0.0913
11-Sep-95	L0.0002	0.154	0.0006	0.0145
30-Nov-95	L0.0002	0.193	0.0002	0.0204
15-Feb-96	L0.0002	0.208	0.0002	0.0317

Table 3

Water Quality Results. Prairie Creek Mouth, 1995/96

Station 10EC0014 **Nahanni National Park Reserve, NWT**

Date	Time	Project	Sample	Discharge	Origin	CondF	TempF	pHF	ColourL	CondL	FR	NFR	pHL	TurbL	CN
				cms		us/cm	oC	pH Units	TCU	us/cm	mg/L	mg/L	pH Units	mg/L	mg/L
10-Apr-95		796	957363	1.56	BASEFLOW	330	0.5	8.28	2.5	407.0		3.0	8.05	0.40	0.004
7-Jun-95		796	957410	8.32	FRESHET	240	11.0	8.54	2.5	383.0		1.5	8.06	0.40	0.002
7-Jun-95		796	957411	8.32	FRESHET	240	11.0	8.54	2.5	383.0		1.5	8.10	0.60	0.002
7-Jun-95		796	957412	8.32	FRESHET	240	11.0	8.54	2.5	385.0		1.5	8.12	0.60	0.002
11-Sep-95		796	957535	13.20	RECESSION	250	10.0	8.58	2.5	394.0		6.0	8.47	1.10	0.002

Table 3

Date	Cl	SO4	SiO2	NO3NO2	NH3T	AlD	BaD	BeD	CaD	CdD	CoD	CrD	CuD	FeD	KD	LiD
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.69	50.1	3.22	0.2060	0.003	0.005	0.0751	L0.05	47.2	L0.0001	0.0001	0.0002	0.0004	0.0007	0.29	0.0022
7-Jun-95	0.60	50.0	3.33	0.1720	0.013	0.012	0.0637	L0.05	46.7	L0.0001	0.0001	0.0001	0.0006	0.0104	0.31	0.0027
7-Jun-95	0.56	49.3	3.36	0.1710	0.009	0.006	0.0639	L0.05	47.2	L0.0001	L0.0001	0.0001	0.0003	0.0020	0.33	0.0027
7-Jun-95	0.57	49.7	3.35	0.1680	0.008	0.023	0.0644	L0.05	47.3	L0.0001	0.0001	0.0001	0.0004	0.0072	0.32	0.0027
11-Sep-95	0.48	57.2	3.49	0.1880	0.029	0.010	0.0687	L0.05	55.3	L0.0001	0.0001	0.0001	0.0007	0.0037	0.36	0.0033

Table 3

Date	MgD	MnD	MoD	NaD	NiD	PbD	SrD	VD	ZnD	AsD	SeD	AlE	BE	BaE	BeE	CaE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	18.4	0.0001	0.0020	0.75	0.0002	0.0001	0.339	0.0002	0.0015	L0.0001	0.0006	L0.05	0.01	0.078	L0.001	47.8
7-Jun-95	17.1	0.0002	0.0023	1.00	0.0004	0.0001	0.231	0.0002	0.0019	0.0001	0.0006	L0.05	L0.01	0.065	L0.001	45.1
7-Jun-95	17.3	0.0001	0.0024	1.02	0.0003	0.0001	0.234	0.0002	0.0051	0.0002	0.0006	L0.05	L0.01	0.065	L0.001	45.5
7-Jun-95	17.3	0.0002	0.0022	1.02	0.0003	0.0001	0.234	0.0002	0.0022	0.0001	0.0006	L0.05	L0.01	0.064	L0.001	44.9
11-Sep-95	19.5	0.0002	0.0024	1.08	0.0005	0.0001	0.255	0.0002	0.0058	0.0002	0.0011	L0.05	L0.01	0.076	L0.001	55.0

Table 3

Date	CdE	CoE	CrE	CuE	FeE	KE	LiE	MgE	MnE	MoE	NaE	NiE	PbE	SrE	VE	ZnE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	L0.005	L0.0005	0.0025	0.001	L0.005	1	L0.005	18.4	0.001	L0.005	1	0.005	0.010	0.350	L0.005	L0.005
7-Jun-95	L0.005	L0.0005	0.0025	0.001	L0.005	1	L0.005	16.1	0.001	L0.005	1	0.005	0.010	0.239	L0.005	L0.005
7-Jun-95	L0.005	L0.0005	0.0025	0.001	L0.005	1	L0.005	16.3	0.001	L0.005	1	0.005	0.010	0.239	L0.005	L0.005
7-Jun-95	L0.005	L0.0005	0.0025	0.001	L0.005	1	L0.005	16.0	0.001	L0.005	1	0.005	0.010	0.230	L0.005	L0.005
11-Sep-95	L0.005	L0.0005	0.0025	0.001	L0.005	1	0.007	20.3	0.001	L0.005	1	0.005	0.027	0.274	L0.005	L0.005

Table 3

Date	AlT	BaT	BeT	CaT	CdT	CoT	CrT	CuT	FeT	KT	LiT	MgT	MnT	MoT	NaT	NiT
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.008	0.0762	L0.05	46.3	L0.0001	0.0001	0.0001	0.0002	0.0113	0.28	0.0022	18.6	0.0002	0.0020	0.80	0.0002
7-Jun-95	0.035	0.0645	L0.05	47.1	L0.0001	L0.0001	0.0001	0.0006	0.0436	0.41	0.0027	17.2	0.0004	0.0230	1.13	0.0003
7-Jun-95	0.019	0.0649	L0.05	47.2	L0.0001	0.0001	0.0001	0.0003	0.0209	0.39	0.0027	17.4	0.0004	0.0230	1.15	0.0003
7-Jun-95	0.020	0.0658	L0.05	47.6	L0.0001	0.0001	0.0001	0.0004	0.0254	0.42	0.0028	17.5	0.0003	0.0230	1.18	0.0003
11-Sep-95	0.025	0.0715	L0.05	55.0	L0.0001	L0.0001	0.0001	0.0003	0.0333	0.32	0.0028	20.2	0.0001	0.0025	1.22	0.0006

Table 3

Date	PbT	SrT	VT	ZnT
	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.0001	0.359	0.0002	0.0014
7-Jun-95	0.0002	0.237	0.0003	0.0020
7-Jun-95	0.0001	0.239	0.0002	0.0013
7-Jun-95	0.0001	0.242	0.0002	0.0016
11-Sep-95	0.0001	0.256	0.0003	0.0027

Table 4

Water Quality Results. SNR Above Nahanni Butte, 1995/96

Station NW10EC0017 — Nahanni National Park Reserve, NWT

Date	Time	Project	Sample	Discharge	Origin	CondF	TempF	pHF	ColourL	CondL	FR	NFR	pHL	TurbL	CN
				cms		us/cm	oC	pH Units	TCU	us/cm	mg/L	mg/L	pH Units	mg/L	mg/L
10-Apr-95		796	957363	91.4	BASEFLOW	420	0.0	7.82	2.5	506.0		1.5	7.72	3.7	0.002
7-Jun-95		796	957424	1150.0	FRESHET	220	12.5	7.57	10.0	273.0		382.0	7.80	66.8	0.002
11-Sep-95		796	957537	579.6	RECESSION	210	11.0	8.40	10.0	342.0		21.0	8.16	14.6	0.002

Table 4

Date	Cl	SO4	SiO2	NO3NO2	NH3T	AlD	BaD	BeD	CaD	CdD	CoD	CrD	CuD	FeD	KD	LiD
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	8.28	73.8	5.64	0.136	0.016	0.039	0.0711	L0.05	64.9	L0.0001	0.0001	0.0001	0.0007	0.0401	0.97	0.0163
7-Jun-95	0.88	40.8	4.11	0.080	0.004	0.086	0.0405	L0.05	35.0	L0.0001	0.0001	0.0002	0.0007	0.0103	0.48	0.0056
11-Sep-95	1.62	69.5	4.99	0.099	0.006	0.102	0.0504	L0.05	50.4	L0.0001	0.0002	0.0001	0.0007	0.0057	0.61	0.0093

Table 4

Date	MgD	MnD	MoD	NaD	NiD	PbD	SrD	VD	ZnD	AsD	SeD	AlE	BE	BaE	BeE	CaE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	16.30	0.0133	0.0023	5.60	0.0031	0.0001	0.281	0.0001	0.0088	0.0002	0.0009	0.075	0.01	0.076	L0.001	64.8
7-Jun-95	8.48	0.0019	0.0014	0.78	0.0013	0.0001	0.151	0.0006	0.0009	0.0004	0.0006	1.660	L0.01	0.142	L0.001	81.6
11-Sep-95	12.40	0.0136	0.0019	1.71	0.0036	0.0001	0.209	0.0003	0.0055	0.0005	0.0006	0.420	0.01	0.069	L0.001	53.6

Table 4

Date	CdE	CoE	CrE	CuE	FeE	KE	LiE	MgE	MnE	MoE	NaE	NiE	PbE	SrE	VE	ZnE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	L0.005	L0.005	L0.005	L0.005	0.264	1	0.012	16.7	0.028	L0.005	6.5	0.005	0.01	0.294	L0.005	0.014
7-Jun-95	L0.005	L0.005	L0.005	L0.005	3.280	1	0.010	19.4	0.149	L0.005	1.0	0.012	0.01	0.241	0.006	0.071
11-Sep-95	L0.005	L0.005	L0.005	L0.005	0.603	1	0.011	13.8	0.021	L0.005	2.4	0.018	0.01	0.237	L0.005	0.016

Table 4

Date	AlT	BaT	BeT	CaT	CdT	CoT	CrT	CuT	FeT	KT	LiT	MgT	MnT	MoT	NaT	NiT
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.130	0.0755	L0.05	64.2	0.0001	0.0002	0.0003	0.0011	0.301	1.06	0.0162	16.80	0.0300	0.0027	5.80	0.0036
7-Jun-95	3.100	0.1650	0.23	76.2	0.0011	0.0038	0.0038	0.0096	6.470	0.95	0.0163	18.90	0.1500	0.0016	0.94	0.0153
11-Sep-95	0.499	0.0615	0.05	51.4	L0.0001	0.0006	0.0005	0.0014	0.615	0.60	0.0089	13.10	0.0178	0.0015	1.93	0.0006

Table 4

Date	PbT	SrT	VT	ZnT
	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.0001	0.296	0.0005	0.0141
7-Jun-95	0.0046	0.246	0.0100	0.0718
11-Sep-95	0.0001	0.213	0.0010	0.0137

Table 5 Water Quality Results. Rabbitkettle River Mouth, 1995/96

Station NW10EB0013 Nahanni National Park Reserve, NWT

Date	Time	Project	Sample	Discharge	Origin	CondF	TempF	pHF	ColourT	CondL	FR	NFR	pHL	TurbL
				cms		us/cm	oC	pH Units	TCU	us/cm	mg/L	mg/L	pH Units	NTU
10-Apr-95		796	957365		BASEFLOW	260	0.0	7.90	2.5	386.0		1.8	7.79	1.8
7-Jun-95		796	957422		FRESHET	110	4.0	7.95	10.0	190.0		464.0	7.68	123.2
11-Sep-95		796	957532		RECESSION	140	7.0	8.01	5.0	182.0		306.0	8.05	121.0

Table 5

Date	CN	Cl	SO4	SiO2	NO3NO2	NH3T	AlD	BaD	BeD	CaD	CdD	CoD	CrD	CuD	FeD	KD
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.002	0.63	52.3	6.19	0.178	0.005	0.015	0.0678	0.025	54.9	0.0001	0.0001	0.0002	0.0005	0.0030	1.19
7-Jun-95	0.003	0.33	22.9	3.22	0.133	0.001	0.084	0.0317	0.050	26.5	L0.0001	0.0001	0.0001	0.0005	0.0060	0.55
11-Sep-95	0.010	0.26	32.5	3.48	0.146	0.052	0.096	0.0277	0.025	27.9	0.0001	0.0004	0.0001	0.0003	0.0051	0.59

Table 5

Date	LiD	MgD	MnD	MoD	NaD	NiD	PbD	SrD	VD	ZnD	AsD	SeD	AlE	BE	BaE	BeE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.0073	9.62	0.0037	0.0035	1.26	0.0014	0.0004	0.1870	0.0008	0.0058	0.0012	0.0012	0.025	0.010	0.073	L0.001
7-Jun-95	0.0029	3.51	0.0037	0.0017	0.27	0.0011	0.0001	0.0711	0.0005	0.0013	0.0005	0.0005	3.580	0.005	0.216	L0.001
11-Sep-95	0.0038	4.04	0.0086	0.0021	0.41	0.0030	0.0001	0.0793	0.0005	0.0026	0.0006	0.0006	3.800	0.005	0.155	L0.001

Table 5

Date	CaE	CdE	CoE	CrE	CuE	FeE	KE	LiE	MgE	MnE	MoE	NaE	NiE	PbE	SrE	VE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	55.4	L0.005	L0.005	L0.005	L0.005	0.056	1	0.0070	9.9	0.006	L0.005	1	0.005	0.010	0.195	L0.005
7-Jun-95	74.9	L0.005	0.011	0.015	0.010	5.060	1	0.0170	9.0	0.199	L0.005	1	0.031	0.047	0.161	0.023
11-Sep-95	65.8	L0.005	L0.005	L0.005	0.006	4.670	1	0.0250	11.6	0.150	L0.005	1	0.031	0.010	0.137	0.015

Table 5

Date	ZnE	AlT	BaT	BeT	CaT	CdT	CoT	CrT	CuT	FeT	KT	LiT	MgT	MnT	MoT	NaT
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.006	0.061	0.0716	L0.05	54.2	0.0001	0.0001	0.0001	0.0005	0.0631	1.17	0.0073	9.95	0.0066	0.0037	1.34
7-Jun-95	0.102	5.940	0.2510	0.43	72.3	0.0016	0.0125	0.0157	0.0109	9.3900	1.93	0.0288	9.64	0.2050	0.0022	0.48
11-Sep-95	0.114	4.150	0.1410	0.32	56.1	0.0010	0.0038	0.0033	0.0063	5.0500	1.48	0.0271	10.20	0.1200	0.0012	0.62

Table 5

Date	NiT	PbT	SrT	VT	ZnT
	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.0014	0.0001	0.199	0.0009	0.0060
7-Jun-95	0.0337	0.0071	0.162	0.0244	0.0990
11-Sep-95	0.0153	0.0041	0.114	0.0122	0.0932

Table 6 — Water Quality Results. SNR Above Rabbitkettle River, 1995/96

Station NW10EB0012 — Nahanni National Park Reserve, NWT

Date	Time	Project	Sample	Discharge cms	Origin	CondF us/cm	TempF oC	pHF pH Units	ColourL TCU	CondL us/cm	FR mg/L	NFR mg/L	pHL pH Units	TurbL mg/L	CN mg/L	Cl mg/L
10-Apr-95		796	950201	25.6	BASEFLOW	270	0.0	7.80	2.5	400		4.0	7.69	0.6	0.003	0.58
7-Jun-95		796	950424	830.0	FRESHET	130	7.5	7.86	10.0	200		166.0	7.71	56.7	0.002	0.31
11-Sep-95		796	951007	322.0	RECESSION	270	9.5	8.07	5.0	281		20.0	7.99	11.4	0.003	0.34

Table 6

Date	SO4 mg/L	SiO2 mg/L	NO3NO2 mg/L	NH3T mg/L	AlD mg/L	BaD mg/L	BeD mg/L	CaD mg/L	CdD mg/L	CoD mg/L	CrD mg/L	CuD mg/L	FeD mg/L	KD mg/L	LiD mg/L	MgD mg/L
10-Apr-95	64.9	5.38	0.102	0.031	0.042	0.0435	0.025	51.8	0.0001	0.0002	0.0002	0.0008	0.0866	0.70	0.0086	13.90
7-Jun-95	23.1	3.27	0.134	0.005	0.133	0.0249	0.025	24.4	0.0001	0.0004	0.0001	0.0007	0.0106	0.33	0.0038	5.56
11-Sep-95	66.6	4.78	0.077	0.005	0.111	0.0373	L0.005	40.0	0.0002	0.0019	0.0001	0.0009	0.0493	0.48	0.0080	9.93

Table 6

Date	MnD mg/L	MoD mg/L	NaD mg/L	NiD mg/L	PbD mg/L	SrD mg/L	VD mg/L	ZnD mg/L	AsD mg/L	SeD mg/L	AlE mg/L	BE mg/L	BaE mg/L	BeE mg/L	CaE mg/L	CdE mg/L
10-Apr-95	0.0065	0.0014	1.12	0.0045	0.0001	0.192	0.0002	0.0115	0.0003	0.0007	0.025	0.010	0.060	0.0005	51.5	0.0025
7-Jun-95	0.0073	0.0007	0.29	0.0035	0.0002	0.090	0.0002	0.0052	0.0004	0.0004	1.280	0.005	0.069	0.0005	40.9	0.0025
11-Sep-95	0.0284	0.0009	0.64	0.0137	0.0001	0.151	0.0002	0.0137	0.0004	0.0005	0.580	0.005	0.047	0.0005	42.2	0.0025

Table 6

Date	CoE mg/L	CrE mg/L	CuE mg/L	FeE mg/L	KE mg/L	LiE mg/L	MgE mg/L	MnE mg/L	MoE mg/L	NaE mg/L	NiE mg/L	PbE mg/L	SrE mg/L	VE mg/L	ZnE mg/L	AlT mg/L
10-Apr-95	0.0025	0.0025	0.0025	0.045	1	0.0060	14.0	0.008	0.0025	1	0.005	0.01	0.198	0.0025	0.014	0.052
7-Jun-95	0.0025	0.0025	0.0025	1.750	1	0.0060	10.1	0.096	0.0025	1	0.017	0.01	0.125	0.0025	0.068	2.630
11-Sep-95	0.0025	0.0025	0.0025	0.452	1	0.0110	11.0	0.047	0.0025	1	0.030	0.01	0.168	0.0025	0.049	0.629

Table 6

Date	BaT mg/L	BeT mg/L	CaT mg/L	CdT mg/L	CoT mg/L	CrT mg/L	CuT mg/L	FeT mg/L	KT mg/L	LiT mg/L	MgT mg/L	MnT mg/L	MoT mg/L	NaT mg/L	NiT mg/L	PbT mg/L
10-Apr-95	0.0679	0.025	49.8	0.0001	0.0002	0.0001	0.0006	0.046	0.69	0.0080	13.70	0.0084	0.0015	1.14	0.0044	0.0001
7-Jun-95	0.0837	0.180	39.8	0.0008	0.0041	0.0031	0.0073	4.800	0.69	0.0114	10.50	0.0964	0.0011	0.37	0.0161	0.0042
11-Sep-95	0.0419	0.060	39.3	0.0002	0.0026	0.0005	0.0020	0.462	0.45	0.0079	10.10	0.0392	0.0009	0.71	0.0160	0.0004

Table 6

Date	SrT mg/L	VT mg/L	ZnT mg/L
10-Apr-95	0.198	0.0002	0.0149
7-Jun-95	0.129	0.0055	0.0712
11-Sep-95	0.147	0.0007	0.0409

Table 7 Water Quality Results. Flat River Park Boundary. 1995/96.

Station NW10EA0008 Nahanni National Park Reserve, NWT

Date	Project	Sample	Discharge	Origin	CondF	TempF	pHF	ColourL	CondL	FR	NFR	pHL	TurbL	CN	Cl	SO4
			cms		us/cm	oC	pH Units	TCU	us/cm	mg/L	mg/L	pH Units	mg/L	mg/L	mg/L	mg/L
10-Apr-95	796	957207	5.16	BASEFLOW	280	0.2	7.80	2.5	394		1.5	7.70	1.5	0.003	0.62	33.6
07-Jun-95	796	957417	173.00	FRESHET	130	7.5	7.94	10	203		250.0	7.64	68.6	0.002	0.35	29.6
07-Jun-95	796	957418	173.00	FRESHET	130	7.5	7.94	30	199		252.0	7.61	62.9	-0.002	0.38	30.2
07-Jun-95	796	957419	173.00	FRESHET	130	7.5	7.94	10	199		257.0	7.48	74.6	0.002	0.35	29.3
11-Sep-95	796	957533	44.40	RECESSION	240	9.5	NA	5	277		7.0	8.11	5.6	L0.001	0.27	56.5

Table 7

Date	SiO2	NO3NO2	NH3T	AlD	BaD	BeD	CaD	CdD	CoD	CrD	CuD	FeD	KD	LiD	MgD	MnD
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	7.41	0.126	0.009	0.012	0.0716	0.025	58.7	0.0001	0.0002	0.0001	0.0004	0.0089	1.02	0.0157	9.08	0.0080
07-Jun-95	3.30	L0.005	0.005	0.077	0.0250	0.025	26.2	L0.0001	0.0002	0.0001	0.0007	0.0112	0.45	0.0049	3.96	0.0074
07-Jun-95	3.81	0.078	0.006	0.077	0.0249	0.025	26.5	L0.0001	0.0002	0.0001	0.0009	0.0099	0.48	0.0050	4.02	0.0101
07-Jun-95	3.80	0.094	0.007	0.076	0.0251	0.025	25.7	L0.0001	0.0001	0.0001	0.0006	0.0098	0.45	0.0049	3.89	0.0072
11-Sep-95	5.76	0.084	0.010	0.065	0.0402	0.025	43.8	0.0001	0.0004	0.0001	0.0007	0.0137	0.76	0.0111	7.43	0.0093

Table 7

Date	MoD	NaD	NiD	PbD	SrD	VD	ZnD	AsD	SeD	AlE	BE	BaE	BeE	CaE	CdE	CoE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.0016	1.77	0.0025	0.0001	0.1850	L0.0001	0.0065	0.0003	0.0005	0.025	0.010	0.075	0.0005	58.0	L0.005	L0.005
07-Jun-95	0.0008	0.42	0.0012	0.0002	0.0797	0.0002	0.0056	0.0007	0.0003	2.210	0.005	0.097	0.0005	39.4	L0.005	L0.005
07-Jun-95	0.0009	0.44	0.0011	0.0002	0.0810	0.0002	0.0013	0.0008	0.0003	2.200	0.005	0.096	0.0005	39.1	L0.005	L0.005
07-Jun-95	0.0009	0.42	0.0012	0.0001	0.0792	0.0002	0.0018	0.0008	0.0002	2.280	0.005	0.101	0.0005	39.7	L0.005	L0.005
11-Sep-95	0.0014	1.13	0.0045	0.0001	0.1360	0.0002	0.0039	0.0006	0.0003	0.260	0.005	0.047	0.0005	43.6	L0.005	L0.005

Table 7																
Date	CrE	CuE	FeE	KE	LiE	MgE	MnE	MoE	NaE	NiE	PbE	SrE	VE	ZnE	AlT	BaT
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	L0.005	L0.005	0.151	1	0.012	9.3	0.011	L0.005	2.4	0.005	0.010	0.192	L0.005	0.009	0.032	0.0745
07-Jun-95	L0.005	0.006	3.840	1	0.009	5.2	0.169	L0.005	1	0.018	0.010	0.122	0.006	0.066	4.000	0.0973
07-Jun-95	L0.005	0.007	3.780	1	0.008	5.1	0.166	L0.005	1	0.014	0.010	0.121	0.007	0.068	3.920	0.0969
07-Jun-95	L0.005	0.007	3.970	1	0.009	5.3	0.171	L0.005	1	0.019	0.010	0.123	0.006	0.070	4.390	0.1120
11-Sep-95	L0.005	L0.005	0.267	1	0.011	8.0	0.017	L0.005	1	0.015	0.021	0.148	L0.005	0.012	0.282	0.0424

Table 7																
Date	BeT	CaT	CdT	CoT	CrT	CuT	FeT	KT	LiT	MgT	MnT	MoT	NaT	NiT	PbT	SrT
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	L0.05	57.2	L0.0001	0.0002	0.0001	0.0004	0.146	1.11	0.0157	9.39	0.0115	0.0017	1.92	0.0026	0.0001	0.195
07-Jun-95	0.35	34.3	0.0010	0.0052	0.0041	0.0149	8.280	1.03	0.0155	5.33	0.1710	0.0014	0.52	0.0182	0.0070	0.126
07-Jun-95	0.35	35	0.0010	0.0054	0.0041	0.0162	8.150	0.98	0.0171	5.46	0.1720	0.0014	0.51	0.0155	0.0067	0.127
07-Jun-95	0.38	36.9	0.0011	0.0057	0.0048	0.0162	8.690	1.12	0.0193	5.98	0.1730	0.0015	0.54	0.0194	0.0077	0.123
11-Sep-95	0.05	42.5	L0.0001	0.0006	0.0002	0.0010	0.257	0.68	0.0099	7.57	0.0144	0.0011	1.25	0.0056	0.0001	0.135

Table 7		
Date	VT	ZnT
	mg/L	mg/L
10-Apr-95	0.0002	0.0098
07-Jun-95	0.0088	0.0700
07-Jun-95	0.0087	0.0697
07-Jun-95	0.0102	0.0756
11-Sep-95	0.0005	0.0112

Table 8 Water Quality Results. SNR Above Virginia Falls, 1995/96

Station NW10EB1111 — Nahanni National Park Reserve, NWT

Date	Time	Project	Sample	Discharge	Origin	CondF	TempF	pHF	ColorL	CondL	FR	NFR	pHL	TurbL	CN
				cms		us/cm	oC	pH Units	TCU	us/cm	mg/L	mg/L	pH Units	mg/L	mg/L
10-Apr-95		796	957361	31.9	BASEFLOW	320	0	7.89	2.5	405.0		4.00	7.65	0.9	0.003
07-Jun-95		796	957415	921.0	FRESHET	140	9	8.23	10.0	225.3		323.00	7.65	81.6	0.004
11-Sep-95		796	957534	359.0	RECESSION	260	11	7.96	5.0	291.0		11.00	8.10	10.1	L0.001

Table 8

Date	Cl	SO4	SiO2	NO3NO2	NH3T	AlD	BaD	BeD	CaD	CdD	CoD	CrD	CuD	FeD	KD	LiD
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.65	56.3	5.59	0.104	0.001	0.022	0.0625	L0.05	52.2	0.0001	0.0001	0.0001	0.0005	0.0067	0.73	0.0077
07-Jun-95	0.44	30.5	3.48	0.072	0.011	0.098	0.0315	L0.05	27.1	0.0005	0.0001	0.0001	0.0008	0.0100	0.36	L0.0001
11-Sep-95	0.34	61.8	4.84	0.187	0.013	0.100	0.0421	L0.05	42.0	0.0001	0.0005	0.0015	0.0012	0.0151	0.53	0.0077

Table 8

Date	MgD	MnD	MoD	NaD	NiD	PbD	SrD	VD	ZnD	AsD	SeD	AlE	BE	BaE	BeE	CaE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	13.70	0.0038	0.0017	1.03	0.0031	0.0001	0.1820	0.0001	0.0074	0.0005	0.0007	0.025	0.010	0.010	0.069	53.2
07-Jun-95	0.11	0.0004	L0.0001	0.01	0.0001	0.0001	0.0937	0.0003	0.0044	0.0005	0.0004	1.670	0.005	0.005	0.113	68.3
11-Sep-95	10.20	0.0068	0.0012	0.68	0.0084	0.0001	0.1510	0.0003	0.0101	0.0005	0.0006	0.420	0.005	0.005	0.052	43.9

Table 8

Date	CdE	CoE	CrE	CuE	FeE	KE	LiE	MgE	MnE	MoE	NaE	NiE	PbE	SrE	VE	ZnE
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	L0.005	L0.005	L0.005	L0.005	0.045	1	0.006	14.2	0.005	L0.005	1	0.005	0.01	0.194	0.025	0.004
07-Jun-95	L0.005	L0.005	L0.005	L0.005	2.630	1	0.009	14.7	0.123	L0.005	1	0.019	0.01	0.159	0.005	0.080
11-Sep-95	L0.005	L0.005	L0.005	L0.005	0.351	1	0.008	11.1	0.020	L0.005	1	0.025	0.01	0.166	L0.005	0.024

Table 8

Date	AlT	BaT	BeT	CaT	CdT	CoT	CrT	CuT	FeT	KT	LiT	MgT	MnT	MoT	NaT	NiT
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.038	0.0682	0.025	53.1	0.0001	0.0001	0.0001	0.0005	0.0487	0.74	0.0080	14.40	0.0044	0.0017	1.16	0.0035
07-Jun-95	3.47	0.1410	0.250	65.5	0.0012	0.0041	0.0043	0.0087	6.4700	1.03	0.0162	14.80	0.1270	0.0017	0.44	0.0205
11-Sep-95	0.474	0.0470	0.050	42.6	0.0001	0.0010	0.0002	0.0014	0.3310	0.47	0.0073	10.60	0.0165	0.0011	0.71	0.0098

Table 8

Date	PbT	SrT	VT	ZnT
	mg/L	mg/L	mg/L	mg/L
10-Apr-95	0.0001	0.195	0.0002	0.0077
07-Jun-95	0.0049	0.166	0.0111	0.0861
11-Sep-95	0.0001	0.149	0.0008	0.0226

TABLE 9. Water Quality Objectives for Nahanni National Park Preserve

LTO Long Term Objectives — STO Short Term Objectives

Parameter			South Nahanni River above Rabbitkettle River		Rabbitkettle River at mouth		Flat River at mouth		Prairie Creek at mouth		South Nahanni River above Nahanni Butte	
			LTO	STO	LTO	STO	LTO	STO	LTO	STO	LTO	STO
Conductance		usie/cm	222	280	198	245	314	400	337	395	256	325
Non-filterable Residue			70	230	87	227	68	204	14	23	166	335
Nitrite/Nitrate		mg/l	0.04	0.05	0.08	0.10	0.07	0.13	0.12	0.14	0.11	1.77
Total Ammonia		mg/l	0.005	0.005	0.005	0.005	0.005	0.014	0.005	0.005	0.005	0.045
pH			8.1	8.4	7.9	8.2	8.0	8.2	8.4	8.8	8.0	8.3
Sulphate		mg/l	29	41	21	31	27	36	34	46	32	43
Arsenic	Dissolved	ug/l	0.50	0.50	1.74	1.95	0.50	0.8	0.50	0.5	0.50	0.7
Barium	Dissolved	mg/l	0.04	0.04	—	—	0.08	0.04	0.08	0.08	—	—
	Total	mg/l	0.08	0.08	0.08	0.14	0.08	0.19	0.08	0.10	0.08	0.19
Cadmium	Dissolved	ug/l	0.1	0.1	—	—	0.1	0.2	0.1	0.1	0.01	0.3
	Total	ug/l	0.17	0.4	0.29	0.60	0.45	0.80	0.10	0.10	0.30	0.60
Cobalt	Dissolved	ug/l	0.5	0.5	—	—	0.5	1.4	0.5	0.5	0.5	0.5
	Total	ug/l	1.0	2.3	1.0	2.2	1.2	3.0	0.5	0.7	1.6	3.3
Copper	Dissolved	ug/l	2.1	0.9	—	—	0.5	0.7	0.5	0.5	0.5	0.9
	Total	ug/l	1.8	3.9	2.1	4.9	3.1	7.0	0.8	1.8	3.7	7.3
Cyanide		ug/l	1.0	1.0	1.0	1.2	1.0	1.0	1.0	1.0	1.0	1.0
Iron	Dissolved	mg/l	0.04	0.14	—	—	0.03	0.04	0.004	0.007	—	—
	Extractable	mg/l	0.53	1.32	1.04	2.64	0.98	2.96	0.19	0.36	1.60	2.69
Lead	Dissolved	ug/l	1.0	2.0	—	—	0.7	1.3	0.7	1.9	0.7	0.9
	Total	ug/l	1.0	2.7	1.05	2.5	1.64	3.8	0.70	1.1	2.37	5.7
Manganese	Dissolved	mg/l	0.007	0.024	—	—	0.005	0.007	0.002	0.004	—	—
	Extractable	mg/l	0.028	0.058	0.037	0.087	0.036	0.100	0.008	0.019	0.067	0.106
Nickel	Dissolved	ug/l	2.90	3.9	—	—	3.17	4.5	0.46	1.0	1.11	2.4
	Total	ug/l	6.80	9.8	5.37	8.4	6.81	11.7	1.57	3.0	7.60	15.2
Selenium	Dissolved	ug/l	0.50	0.95	1.21	1.75	0.59	0.80	0.50	1.0	0.68	1.2
Vanadium	Total	ug/l	1.1	3.2	4.6	11.3	2.2	6.1	0.5	1.4	3.9	6.7
Zinc	Dissolved	mg/l	0.016	0.499	—	—	0.005	0.009	0.001	0.002	0.002	0.007
	Total	mg/l	0.019	0.034	0.024	0.048	0.024	0.047	0.005	0.010	0.027	0.059

Sheet1

Table 10 — Suspended Sediments Results for Nahanni Butte, 1992-1995

Station NW10EC0017 Nahanni National Park Reserve, NWT

Station NW10EC1111=SNR Above Clausen Creek

Station	Date	Project	Sample	SampleType	pHF	CondF	TempF	PARTICLE SIZE DISTRIBUTION				Shepard	Org.Carbon	Inorg.Carbon	Total Org.N	AsT
					pH Units	us/cm	oC	%Gravel	%Sand	%Silt	%Clay	Label	%	%	%	mg/kg dw
10EC0017	13-Sep-95	796	957703	Centrifuge	NA	NA	NA	0.00	23.29	31.83	44.88	Sand-Silt-Clay	2.74	1.41	0.12	19.60
10EB1111	20-Jun-95	796	957702	Centrifuge	7.60	150	13.5	0.00	2.13	50.08	47.80	Clayey Silt	2.41	1.80	0.09	28.84
10EC0017	12-Sep-94	796	947901	Centrifuge	NA	NA	NA	NA	NA	NA	NA	Silty Clay?	2.04	1.09	0.16	19.60
10EC0017	19-Jul-94	796	944857	Centrifuge	7.98	230	14	NA	NA	NA	NA	Silty Clay?	4.26	1.55	0.20	23.70
10EA1111	19-Jul-94	796	947078	Centrifuge	7.97	260	11	NA	NA	NA	NA	Silty Clay?	3.86	1.01	0.18	26.20
10EC0017	08-Sep-93	796	937098	Centrifuge	7.95	300	NA	0.00	4.12	32.35	63.53	Silty Clay	1.68	NA	0.10	34.00
10EC0017	21-Jul-93	796	937078	Centrifuge	8.07	260	16	0.00	4.88	37.48	57.64	Silty Clay	2.31	2.81	0.13	17.90
10EC0017	01-Sep-92	796	921189	Centrifuge	6.50	370	10	0.00	7.81	40.84	51.35	Silty Clay	NA	NA	NA	21.00

Sheet1

SeT	AlT	BaT	CdT	CoT	CrT	CuT	FeT	MnT	MoT	NiT	PbT	VT	ZnT	Hg
mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw
1.00	65000	1700	2.00	19.2	56.0	36.0	27900	462	L10	84.0	13.0	193	390	0.048
0.70	61900	1400	1.80	22.0	61.0	40.0	35000	540	L10	92.0	15.0	122	439	0.050
1.70	84200	1310	2.06	17.4	82.6	30.5	37500	417	L10	85.8	12.6	221	331	0.084
0.90	54800	957	1.11	12.0	52.3	23.8	25800	419	L10	54.2	12.6	148	224	0.053
1.00	61400	1400	1.76	15.4	57.5	25.8	28600	430	L10	71.3	17.8	167	313	0.052
1.33	67500	1450	2.01	17.8	59.1	31.9	34700	476	L10	78.7	25.4	197	347	0.060
1.19	56100	2040	1.61	14.7	60.4	24.5	27800	366	L10	60.5	13.9	198	262	0.060
NA	56400	NA	2.30	16.0	69.7	30.8	31300	412	L10	73.9	16.5	218	324	0.060

NWRI SEDIMENTOLOGY LABORATORY

SAMPLE INFORMATION

South Nahanni River above Virginia Falls

Sample ID: **95wynz7702**
Analysis Type: Sieve, Sedigraph
Date: 01-16-1996 Time: 14:18:20
Sample Weight (G): 3.9957

PARTICLE-SIZE DISTRIBUTION

Phi	Microns	Class Freq.(%)	Cum.(%) Coarser	Histogram (*) and Cumulative Frequency Curve (+)
1.00	500.00	0.02	0.02	+
1.50	353.55	0.02	0.04	+
2.00	250.00	0.04	0.07	+
2.50	176.78	0.07	0.14	+
3.00	125.00	0.13	0.27	+
3.50	88.39	0.41	0.68	+
4.00	62.50	1.44	2.13	* +
4.50	44.19	0.74	2.87	* +
5.00	31.25	2.71	5.59	*** +
5.50	22.10	5.06	10.64	***** +
6.00	15.63	6.26	16.91	****** +
6.50	11.05	7.56	24.46	******** +
7.00	7.81	8.47	32.93	******** +
7.50	5.52	9.17	42.10	********* +
8.00	3.91	10.11	52.20	********** +
8.50	2.76	9.80	62.00	********** +
9.00	1.95	7.90	69.90	******** +
9.50	1.38	6.47	76.37	****** +
10.00	0.98	5.49	81.86	***** +
10.50	0.69	4.92	86.78	***** +
11.00	0.49	4.32	91.10	**** +
11.50	0.35	2.77	93.87	*** +
12.00	0.24	1.63	95.50	** +

% Gravel = 0.00 % Sand = 2.13 % Silt = 50.08 % Clay = 47.80

Gravel+Sand= 2.13 Silt/(Silt+Clay)= 0.51 Grav+Sand/Silt+Clay= 0.02

Folk: -GMS -SCS MUD Shepard CLAYEY SILT

SUMMARY STATISTICS

	Percentiles						
	5	16	25	50	75	84	95
Phi	4.89	5.93	6.53	7.89	9.39	10.22	11.85
Microns	33.68	16.43	10.81	4.21	1.49	0.84	0.27

	Mean Phi	Mean Microns	Std. Dev. Phi	Skewness	Kurtosis
Moment	7.81	4.46	1.87	-0.01	-0.44
Folk(Inclusive)	8.01	3.87	2.13	0.11	1.00

Folk Interpretation - VERY POORLY SORTED, FINE-SKEWED MESOKURTIC.

NWRI SEDIMENTOLOGY LABORATORY

SAMPLE INFORMATION

South Nahanni River above Nahanni Butte

Sample ID: **95wnyz7703**
Analysis Type: Sieve, Sedigraph
Date: 01-16-1996 Time: 14:18:21
Sample Weight (G): 3.9984

PARTICLE-SIZE DISTRIBUTION

Phi	Microns	Class Freq.(%)	Cum.(%) Coarser	Histogram (*) and Cumulative Frequency Curve (+)
1.50	353.55	0.40	0.40	+
2.00	250.00	2.87	3.27	***+
2.50	176.78	6.06	9.33	****** +
3.00	125.00	7.10	16.43	******* +
3.50	88.39	4.13	20.56	**** +
4.00	62.50	2.73	23.29	*** +
4.50	44.19	0.78	24.08	* +
5.00	31.25	2.41	26.49	** +
5.50	22.10	3.49	29.98	*** +
6.00	15.63	3.77	33.75	**** +
6.50	11.05	4.22	37.97	**** +
7.00	7.81	4.90	42.87	***** +
7.50	5.52	5.71	48.57	****** +
8.00	3.91	6.55	55.12	******* +
8.50	2.76	6.46	61.58	****** +
9.00	1.95	5.77	67.35	****** +
9.50	1.38	5.01	72.36	***** +
10.00	0.98	4.33	76.69	**** +
10.50	0.69	4.09	80.78	**** +
11.00	0.49	4.07	84.84	**** +
11.50	0.35	3.47	88.31	*** +
12.00	0.24	3.03	91.34	*** +

% Gravel = 0.00 % Sand = 23.29 % Silt = 31.83 % Clay = 44.88
Gravel+Sand= 23.29 Silt/(Silt+Clay)= 0.41 Grav+Sand/Silt+Clay= 0.30
Folk: -GMS -SCS SANDY MUD Shepard SAND-SILT-CLAY

SUMMARY STATISTICS

	Percentiles						
	5	16	25	50	75	84	95
Phi	2.14	2.97	4.69	7.61	9.80	10.90	*****
Microns	226.43	127.65	38.71	5.12	1.12	0.52	*****

	Mean Phi	Mean Microns	Std. Dev. Phi	Skewness	Kurtosis
Moment	6.80	8.96	2.96	-0.10	-1.12
Folk(Graphic)	7.16	7.00	3.96	-0.17	*****

Folk Interpretation - VERY POORLY SORTED, COARSE-SKEWED

Table 11. Summary Statistics (31212 Samples) for Canadian Cordillera Minus 177 Micron Stream Sediments and Stream Waters From National Geochemical Reconnaissance data Set Compiled For data released to December 1984.

VARIABLE NAME	UNITS	N	MINIMUM	MAXIMUM	MEDIAN	GEOM MEAN	ARITH MEAN	PERCENTILES				
								1st	2nd	5th	10th	20th
Zn	ppm	31211	2.	12000.	68.	72.3	109.2	15.	18.	24.	31.	40.
Cu	ppm	31212	1.	2850.	22.	21.8	30.1	3.	4.	6.	8.	12.
Pb	ppm	31208	1.	4500.	6.	5.7	12.4	1.	1.	1.	1.	2.
Ni	ppm	31212	1.	2050.	20.	18.7	31.2	1.	2.	4.	6.	9.
Co	ppm	31212	1.	550.	9.	8.8	11.1	1.	1.	3.	4.	5.
Mn	ppm	31212	5.	75000.	420.	432.8	639.1	70.	90.	130.	170.	235.
Fe	pct	31212	.05	32.25	2.10	2.008	2.305	.35	.50	.80	1.05	1.35
Used	ppm	31081	.1	430.0	3.2	3.59	5.97	.5	1.0	1.0	1.4	2.0
Mo	ppm	31213	1.	475.	1.	1.6	2.3	1.	1.	1.	1.	1.
Hg	ppb	20009	5.	99999.	40.	42.6	73.3	5.	5.	10.	10.	20.
Ag	ppm	31206	.1	39.0	.1	.12	.16	.1	.1	.1	.1	.1
As	ppm	12885	.2	1000.0	3.0	3.56	10.29	.5	.5	.5	.5	1.0
Sb	ppm	7152	.1	54.5	.4	.41	.96	.1	.1	.1	.1	.1
W	ppm	27806	1.	1200.	2.	1.9	2.9	1.	1.	1.	1.	1.
Sn	ppm	5192	.5	520.0	1.0	1.72	3.46	.5	.5	.5	1.0	1.0
Ba	ppm	10144	20.	17000.	800.	865.0	1657.4	140.	200.	280.	370.	490.
UWAT	ppb	30345	.01	89.80	.10	.105	.405	.01	.01	.02	.02	.02
FWAT	ppb	30363	5.	9600.	40.	40.4	69.0	10.	10.	10.	10.	20.
pH	pH	30605	2.3	9.1	7.6	7.49	7.52	5.4	6.0	6.5	6.8	7.0

VARIABLE NAME	PERCENTILES											
	25th	30th	40th	50th	60th	70th	75th	80th	90th	95th	98th	99th
Zn	45.	50.	58.	68.	80.	95.	105.	118.	174.	265.	500.	865.
Cu	14.	15.	18.	22.	26.	32.	36.	42.	56.	75.	105.	137.
Pb	2.	3.	5.	6.	8.	11.	12.	15.	24.	36.	60.	96.
Ni	11.	13.	16.	20.	24.	29.	32.	37.	57.	86.	148.	235.
Co	6.	7.	8.	9.	11.	12.	14.	15.	19.	24.	34.	43.
Mn	260.	290.	350.	420.	501.	615.	690.	780.	1100.	1600.	2600.	3800.
Fe	1.50	1.60	1.85	2.10	2.40	2.70	2.90	3.10	3.75	4.30	5.10	5.85
Used	2.0	2.3	2.8	3.2	3.9	4.7	5.5	6.5	14.2	18.2	33.7	51.0
Mo	1.	1.	1.	1.	1.	2.	2.	3.	4.	7.	12.	18.
Hg	20.	30.	40.	40.	60.	70.	80.	90.	130.	180.	290.	410.
Ag	.1	.1	.1	.1	.1	.1	.1	.1	.2	.4	.8	1.1
As	1.0	1.5	2.0	3.0	5.0	7.5	9.0	12.0	22.8	37.2	70.0	105.0
Sb	.2	.2	.2	.4	.4	.6	.8	1.0	2.0	4.0	7.4	10.2
W	1.	2.	2.	2.	2.	2.	2.	2.	4.	6.	14.	25.
Sn	1.0	1.0	1.0	1.0	1.0	2.0	3.0	5.0	8.0	11.0	19.0	32.0
Ba	540.	590.	680.	800.	920.	1100.	1200.	1400.	2250.	3750.	7000.	9999.
UWAT	.02	.05	.05	.10	.14	.24	.30	.42	.84	1.60	3.00	4.60
FWAT	22.	26.	32.	40.	50.	62.	72.	86.	140.	210.	360.	500.
pH	7.2	7.3	7.4	7.6	7.8	7.9	8.0	8.1	8.2	8.3	8.5	8.5

after Ballantyne, EMR 1991

Table **12** Draft interim freshwater sediment quality guidelines (TELs), probable effect levels (PELs), and incidence (%) of adverse biological effects in concentration ranges defined by these values.[‡]

CHEMICAL	TEL	PEL	% ≤ TEL	TEL < % < PEL	% ≥ PEL
METALS (mg • kg⁻¹)					
Arsenic	5.90	17.0	5	25	12
Cadmium	0.596	3.53	11	12	47
Chromium	37.3	90.0	2	19	49
Copper	35.7	197	4	38	44
Lead	35.0	91.3	5	23	42
Mercury	0.174	0.486	8	34	36
Nickel	18.0	35.9	4	18	44
Zinc	123	315	5	32	36
POLYCYCLIC AROMATIC HYDROCARBONS (μg • kg⁻¹)					
Phenanthrene	41.9	515	4	17	44
Benz(a)anthracene	31.7	385	13	6	38
Benzo(a)pyrene	31.9	782	11	16	30
Chrysene	57.1	862	8	14	25
Fluoranthene	111	2355	8	23	49
Pyrene	53.0	875	7	16	32
PESTICIDES (μg • kg⁻¹)					
Chlordane	4.50	8.9	2	17	70
p,p'-DDD	3.54	8.51	3	30	85
p,p'-DDE	1.42	6.75	6	20	47
DDT, total	6.98	4450	20	54	82
Dieldrin	2.85	6.67	1	10	60
Endrin	2.67	62.4	1	64	59
Heptachlor epoxide	0.60	2.74	3	12	67
Lindane	0.94	1.38	0	50	49
MISCELLANEOUS ORGANICS (μg • kg⁻¹)					
PCBs, total	34.1	277	4	40	50

[‡] Draft TELs and PELs presented here have been calculated based on the information compiled in BEDS as of January 1994.

After Smith et al, 1995

Appendix II

Calculation/ Synthesis of Discharge at South Nahanni River above Nahanni Butte Water/ Sediment Quality Station

(J.A. Kerr)

SOUTH NAHANNI PROJECT

FLOWS AT NAHANNI BUTTE

MEMO SN94-2

J. A. Kerr, July 22/94, 22:00

Copies to DH, JJ & RM

References:

1. ***Memo SN94-1, JK, July 21/94 (1 page) (attached)***
2. ***RM's followup memo dated July 22/94 (1 page & 2 graphs) (attached)***
3. ***RM's backup table to latter (4 pages) (attached)***
4. ***SNFPR1, JK, July 18/93 (copies with JK, RM & DH)***

DH has requested approximate flows for the S Nahanni R at Nahanni Butte on Jun 7, Sep 7 and Nov 29/93. As per (3) above, the flows at Clausen were

2110 cms on Jun 7/93 and 434 cms on Sep 7/93,

and computed flows at Butte are

2220 cms on Jun 7/93 and 485 cms on Sep 7/93.

The ratios Butte/Clausen were thus 2220/2110=1.05 on Jun 7/93, and 485/434=1.12 on Sep 7/93.

As per (1), the computed flows at Butte were obtained by multiplying the incremental flow between Virg/Flat and Clausen by a ratio of drainage areas (5100/7940) and adding this amount to the flow at Clausen. It was felt that this would give a better approximation of the flow at Butte than multiplying the flow at Clausen by the ratio of the drainage areas above Butte and Clausen. From (4) above, the latter ratio is 36200/31100=1.164. The presumibly less accurate flows at Butte would have been

2110x1.164= 2460 cms on Jun 7/93 and 434x1.164= 505 cms on Sep 7/93.

This suggests that on these two dates the unit flow (flow per square kilometer) was higher in the higher part of the basin than in the lower part (particularly in Jun/93), that is, that the unit flows for rivers such as the Cathedral, Clearwater, Mary, Meilleur, Prairie.and Wrigley were lower than the unit flows in mountainous areas. This justifies the procedures used.

Item (4) above presents graphical and tabular comparisons of monthly mean flows from approximately 1970 to 1991 for the above three gaging stations, the above two incremental flow areas, and Butte. For instance, in Jun/91 the above ratio was 1370/1270=1.08, in Sep/91 it was 657/575=1.14, and in Nov/91 it was 145/134=1.08.

Turning to RM's informative curves, flows are stable in the vicinity of Jun 7/93 so that no adjustments to the procedures are required. An example of the need to curves would be if the discharge at Butte had been requested for Sep 2/93. Here Nahanni/Virg have suddenly risen. but because of the time lag the S Nahanni/C. not, causing the incremental flows to compute as negative when they are physica

As regards Nov 29/93, flows should be stable at that time of the year, and it is su glance at the flows at the three streamflow measurement stations on and in the v date to ensure that in the flows are in fact are stable. There is no real need for a one is prepared, it need only be for say Nov 25-31/93, and it can be done manua faster than adding it to the spreadsheet table.

SOUTH NAHANNI PROJECT

FLOWS AT NAHANNI BUTTE

MEMO SN94-1

J. A. Kerr, July 21/94, 00:01 am

Copies to DR, JJ, & DH

DH requires flows for the South Nahanni River at Nahanni Butte for three days in 1993. He will provide the dates. In order to concentrate on Mack mainstem recalibration tools during the next few hours myself, I am asking RM to work with DH on this - basically it it is a question of of explaining and checking - although if we can get 1993 daily data from the YK VAX for 1993 for three stations we can plot seven curves on one graph as well (see below).

The SIMMAC Model is operational for the South Nahanni River between Virg./Flat and Clausen, but it is not the intention to apply it to the Clausen-Butte reach.

Attached is SNFPR1 (South Nahanni Flows Progress Report 1, J. A. Kerr, July 18/93. The first page of the text in this report indicates that the drainage area between Clausen and Butte is 7,940 sk, and tht the drainage area between Clausen and Butte is 5,100 sk (not 4,100 sk).

The method proposed in 1993 was to assume the same unit runoff (runoff per square kilometer) for the two areas, and hence to:

- *Determine the flow between Virg./Flat and Clausen (Virg. + Flat - Clausen)*
- *Multiply that flow by 5,100/7,940*
- *Add the result to the flow at Clausen to obtain the flow at Butte*

It was assumed that this would be more accurate than assuming that the unit flows were the same above Clausen and Butte.

The difficulty arises in obtaining the flow between Virg./Flat and Clausen for one specific day when flow conditions are not steady. Monthly mean flows were computed to improve the accuracy, and are presented in graphical and tabular form for the period from 1960 to 1991 in SNFPR1), because the long-term flows at SN/Butte were being sought.

As the present request is for flows for only three days in 1993, whether flows at Virg./Flat/Clausen were steady for the days prior to those days can best be determined by getting these flows (from hardcopy or YK VAX) and plotting them (by hand or sprecadsheet). The observed flows at the three stations, the above two incremental flows, and the flows at Butte can be plotted on the same EXCEL 5.0 graph. If the flow was steady before the date considered, there is no need to go further for that day. If the flow was not steady, then the incremental flow between Virg./Flat and Clausen can be derivedby extrapolating its curve from when it was steady, causing it to rise if the flows at Virg./Flat/Clausen were rising.If the data is readily available from the YK VAX, it usually arrives as all data for one year (1993). The above seven curves would then be plotted for the entire year. If the data are plotted manually, the plotting only needs to be done for the part of the year including the three days and some days before the first day, or a few days before each of the three days considered.. It might be faster to get the data from hardcopy and enter it by console or plot it manually, but we have a long-term interest in the South Nahanni River and in being able to get our own data from across the room electronically more easily.

Government of Canada | Gouvernement du Canada

MEMORANDUM

NOTE DE SERVICE

TO/A: John Kerr
Studies Engineer

FILE/REFERENCE:

FROM/DE: Russell Miyagawa
Co-op Engineering Student

DATE: 22 July 1994

SUBJECT/OBJET: **South Nahanni River at Nahanni Butte Discharges**

I spoke with Doug today with regards to the "South Nahanni Project". He explained, briefly, requires and what he is going to do with this data. The dates on which he requires discharg Nahanni Butte are June 7, September 7, and November 29, 1993.

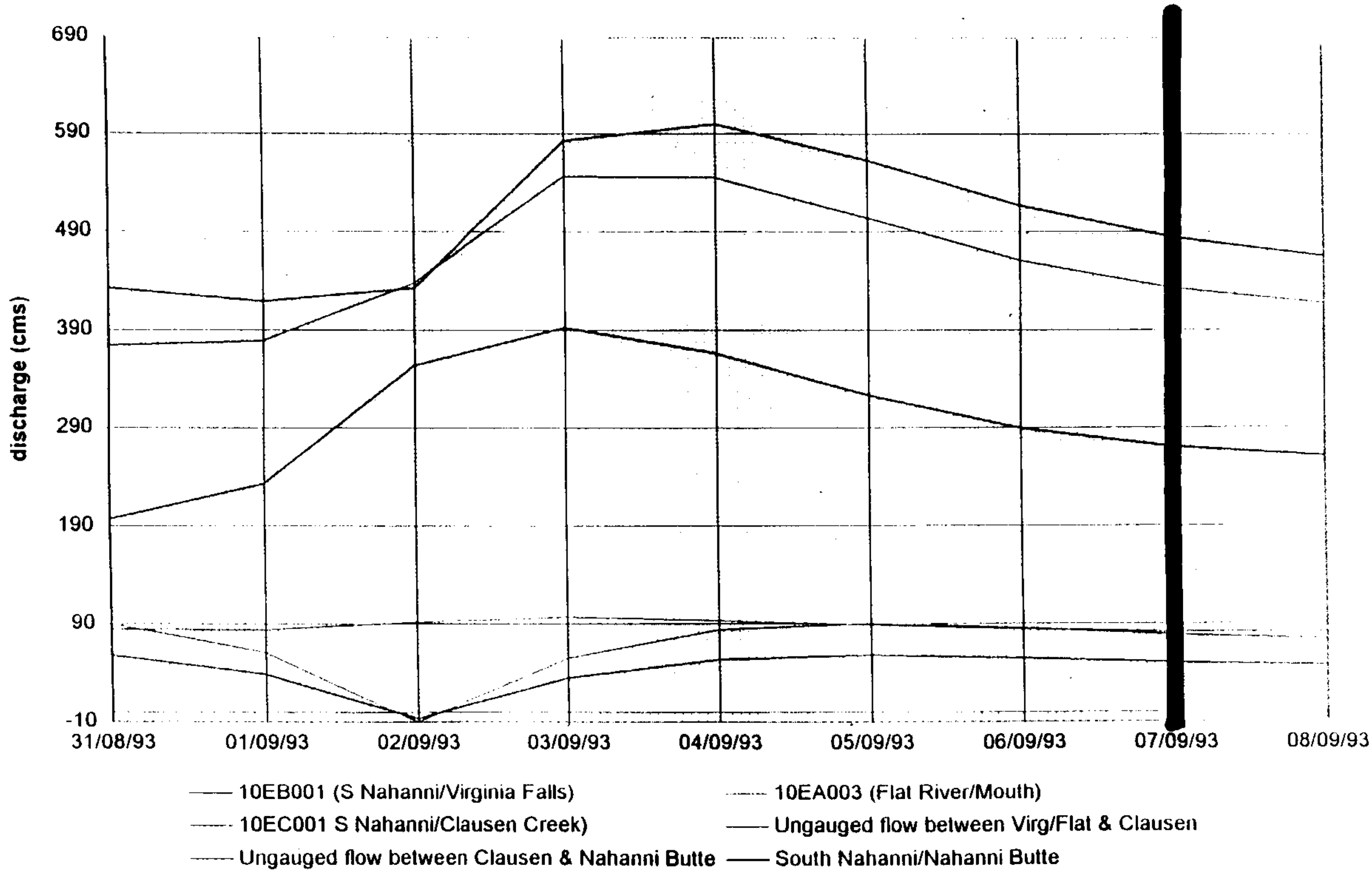
Paul had prepared hydrographs for the South Nahanni at Virginia Falls and Clausen Creek. River at the Mouth. This gave me hope that the 1993 data would be available readily in an e medium, and even better, in a spreadsheet format. After some searching with Paul, we disc relevant files in Quattro Pro for DOS format. Unfortunately, Paul had only entered six montl each station (April to September).

I translated Paul's Quattro Pro files into Excel and extracted the relevant data. These data an Excel worksheet, \SNAHANNI.WQ\DSCHARGE.DAT\SNAHANNI.XLS. Using this data, I appropriate formulae to determine the incremental flows and then generated the attached pl June 7 and September 7 appear to fall while the river is in recession, and the ungauged flo the desired dates appear relatively steady (especially September 7). Please check the curve me your professional opinion on whether any further work is needed for these two dates.

In order to analyze the discharge for November 29, 1993, I will have to obtain the hard copy at the three hydrometric stations and enter them into my spreadsheet. This task should not t particularly long, and I would have completed it today, but I have found that keypunching ar afternoons do not mix well. I will get back to this on Monday morning.

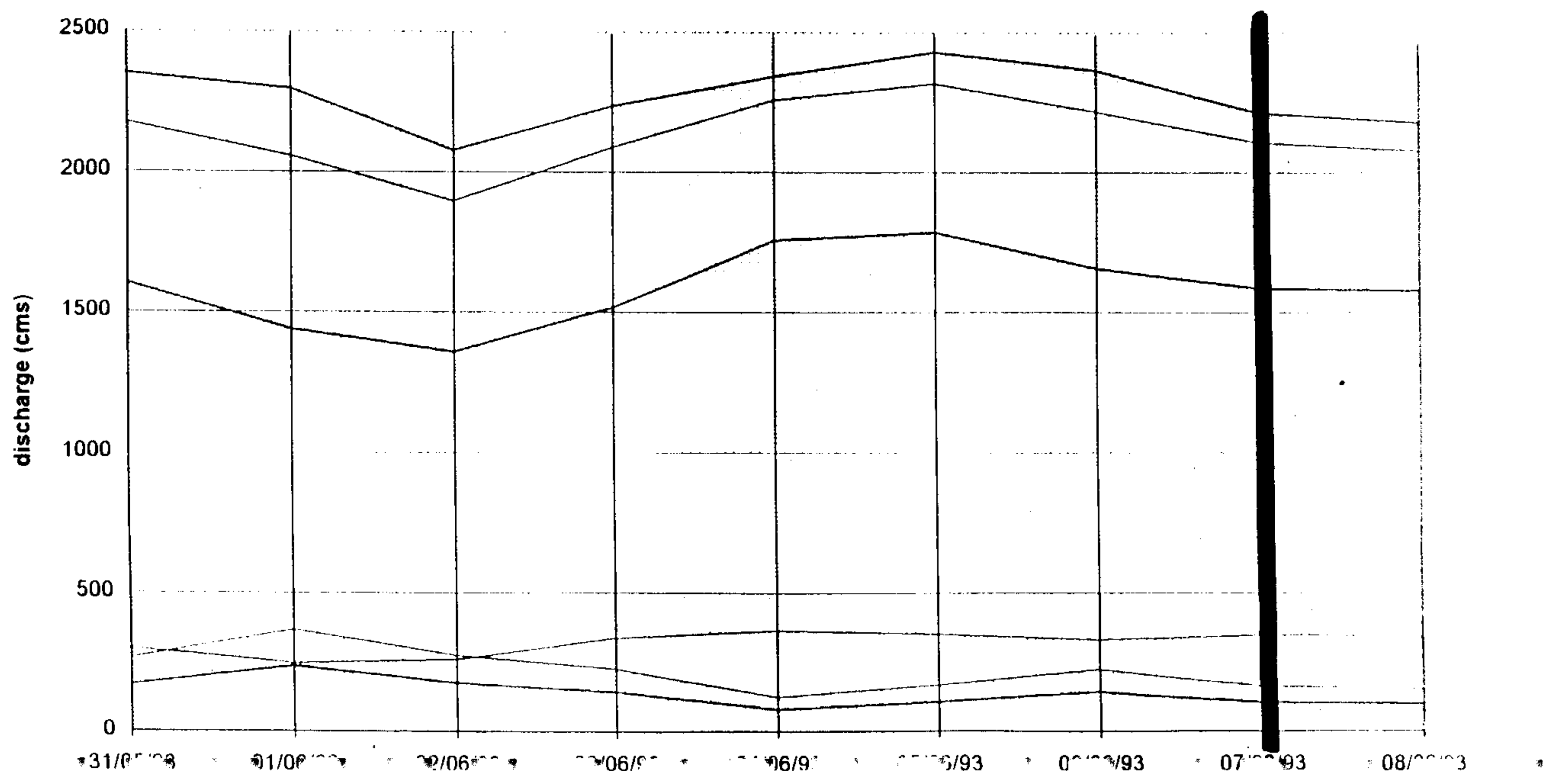
RKM

South Nahanni River at Nahanni Butte
Discharge analysis for September 7, 1993



June 7

South Nahanni River at Nahanni Butte
Discharge analysis for June 7, 1993



DATE	10EB001 (1) (cms)	10EA003 (2) (cms)	10EC001 (3) (cms)	(3)-[(1)+(2)] (4) (cms)	(4)*5100/7940 (5) (cms)	(5)+(3) (6) (cms)
01/04/93	29.4	18.5	60.8	12.9	8.29	69.09
02/04/93	29.4	18.3	59.1	11.4	7.32	66.42
03/04/93	30	18.1	58.9	10.8	6.94	65.84
04/04/93	30.3	18.1	58.8	10.4	6.68	65.48
05/04/93	30.6	18	57.2	8.6	5.52	62.72
06/04/93	31.6	18	58.2	8.6	5.52	63.72
07/04/93	31.8	18	58.5	8.7	5.59	64.09
08/04/93	31	17.9	59	10.1	6.49	65.49
09/04/93	30.8	17.8	59.5	10.9	7.00	66.50
10/04/93	30.7	18	59.8	11.1	7.13	66.93
11/04/93	31.1	18.5	60	10.4	6.68	66.68
12/04/93	31.7	18.7	60.5	10.1	6.49	66.99
13/04/93	31.5	19.2	61.5	10.8	6.94	68.44
14/04/93	31.4	19.5	62.5	11.6	7.45	69.95
15/04/93	31.4	20	63	11.6	7.45	70.45
16/04/93	31.9	20.5	64	11.6	7.45	71.45
17/04/93	32.6	22	65	10.4	6.68	71.68
18/04/93	33.1	23.5	67	10.4	6.68	73.68
19/04/93	33.4	25	70	11.6	7.45	77.45
20/04/93	34.8	26.5	74.3	13	8.35	82.65
21/04/93	36.4	28	78.7	14.3	9.19	87.89
22/04/93	39.4	40	97.2	17.8	11.43	108.63
23/04/93	40.5	50	116	25.5	16.38	132.38
24/04/93	39	49	118	30	19.27	137.27
25/04/93	37.1	46	112	28.9	18.56	130.56
26/04/93	36.8	44	102	21.2	13.62	115.62
27/04/93	40.3	58	104	5.7	3.66	107.66
28/04/93	44.9	69	117	3.1	1.99	118.99
29/04/93	51.9	82	140	6.1	3.92	143.92
30/04/93	62.5	94	200	43.5	27.94	227.94
01/05/93	80.9	106	257	70.1	45.03	302.03
02/05/93	91.5	120	309	97.5	62.63	371.63
03/05/93	116	168	350	66	42.39	392.39
04/05/93	124	206	480	150	96.35	576.35
05/05/93	137	220	604	247	158.65	762.65
06/05/93	143	244	653	266	170.86	823.86
07/05/93	159	266	705	280	179.85	884.85
08/05/93	189	240	696	267	171.50	867.50
09/05/93	193	198	594	203	130.39	724.39
10/05/93	185	169	526	172	110.48	636.48
11/05/93	184	196	533	153	98.27	631.27
12/05/93	191	215	606	200	128.46	734.46
13/05/93	200	199	586	187	120.11	706.11
14/05/93	229	207	623	187	120.11	743.11
15/05/93	299	236	728	193	123.97	851.97
16/05/93	405	251	829	173	111.12	940.12

DATE	10EB001 (1) (cms)	10EA003 (2) (cms)	10EC001 (3) (cms)	(3)-[(1)+(2)] (4) (cms)	(4)*5100/7940 (5) (cms)	(5
17/05/93	510	252	946	184	118.19	
18/05/93	777	225	1070	68	43.68	
19/05/93	848	190	1160	122	78.36	
20/05/93	860	205	1250	185	118.83	
21/05/93	808	229	1210	173	111.12	
22/05/93	677	193	1020	150	96.35	
23/05/93	534	168	861	159	102.13	
24/05/93	493	163	773	117	75.15	
25/05/93	527	166	768	75	48.17	
26/05/93	633	173	847	41	26.34	
27/05/93	732	205	1020	83	53.31	
28/05/93	997	258	1300	45	28.90	
29/05/93	1360	361	1750	29	18.63	
30/05/93	1560	384	2160	216	138.74	
31/05/93	1610	302	2180	268	172.14	
01/06/93	1440	249	2060	371	238.30	
02/06/93	1360	263	1900	277	177.92	
03/06/93	1520	341	2090	229	147.09	
04/06/93	1760	370	2260	130	83.50	
05/06/93	1790	357	2320	173	111.12	
06/06/93	1660	333	2220	227	145.81	
07/06/93	1590	353	2110	167	107.27	
08/06/93	1580	342	2080	158	101.49	
09/06/93	1520	307	2240	413	265.28	
10/06/93	1180	247	1820	393	252.43	
11/06/93	963	215	1460	282	181.13	
12/06/93	928	218	1350	204	131.03	
13/06/93	1030	244	1430	156	100.20	
14/06/93	1010	247	1470	213	136.81	
15/06/93	901	237	1350	212	136.17	
16/06/93	826	219	1230	185	118.83	
17/06/93	783	206	1150	161	103.41	
18/06/93	790	205	1130	135	86.71	
19/06/93	848	240	1180	92	59.09	
20/06/93	921	279	1320	120	77.08	
21/06/93	933	265	1290	92	59.09	
22/06/93	1030	274	1390	86	55.24	
23/06/93	935	269	1410	206	132.32	
24/06/93	806	238	1230	186	119.47	
25/06/93	750	219	1110	141	90.57	
26/06/93	732	210	1070	128	82.22	
27/06/93	768	220	1090	102	65.52	
28/06/93	780	227	1150	143	91.85	
29/06/93	767	220	1120	133	85.43	
30/06/93	774	218	1100	108	69.37	
01/07/93	772	214	1100	114	73.22	

DATE	10EB001 (1) (cms)	10EA003 (2) (cms)	10EC001 (3) (cms)	(3)-[(1)+(2)] (4) (cms)	(4)*5100/7940 (5) (cms)	(5)+(3) (6) (cms)
02/07/93	792	218	1140	130	83.50	1223.50
03/07/93	759	216	1130	155	99.56	1229.56
04/07/93	712	205	1060	143	91.85	1151.85
05/07/93	688	199	1020	133	85.43	1105.43
06/07/93	704	201	1060	155	99.56	1159.56
07/07/93	754	239	1170	177	113.69	1283.69
08/07/93	740	260	1180	180	115.62	1295.62
09/07/93	699	243	1130	188	120.76	1250.76
10/07/93	560	210	987	217	139.38	1126.38
11/07/93	507	192	858	159	102.13	960.13
12/07/93	482	185	791	124	79.65	870.65
13/07/93	462	177	752	113	72.58	824.58
14/07/93	459	174	728	95	61.02	789.02
15/07/93	482	208	790	100	64.23	854.23
16/07/93	459	205	812	148	95.06	907.06
17/07/93	440	195	764	129	82.86	846.86
18/07/93	473	240	883	170	109.19	992.19
19/07/93	466	263	983	254	163.15	1146.15
20/07/93	422	235	909	252	161.86	1070.86
21/07/93	390	212	808	206	132.32	940.32
22/07/93	430	204	799	165	105.98	904.98
23/07/93	488	202	877	187	120.11	997.11
24/07/93	513	215	969	241	154.80	1123.80
25/07/93	517	223	1010	270	173.43	1183.43
26/07/93	493	212	968	263	168.93	1136.93
27/07/93	470	198	905	237	152.23	1057.23
28/07/93	457	200	854	197	126.54	980.54
29/07/93	452	198	818	168	107.91	925.91
30/07/93	431	181	773	161	103.41	876.41
31/07/93	404	168	731	159	102.13	833.13
01/08/93	401	158	693	134	86.07	779.07
02/08/93	404	154	674	116	74.51	748.51
03/08/93	407	151	664	106	68.09	732.09
04/08/93	420	149	665	96	61.66	726.66
05/08/93	413	144	663	106	68.09	731.09
06/08/93	405	138	667	124	79.65	746.65
07/08/93	401	136	671	134	86.07	757.07
08/08/93	407	149	788	232	149.02	937.02
09/08/93	445	180	888	263	168.93	1056.93
10/08/93	403	164	835	268	172.14	1007.14
11/08/93	356	148	726	222	142.59	868.59
12/08/93	334	140	664	190	122.04	786.04
13/08/93	323	139	633	171	109.84	742.84
14/08/93	312	140	609	157	100.84	709.84
15/08/93	301	135	590	154	98.92	688.92
16/08/93	297	128	565	140	89.92	654.92

DATE	10EB001 (1) (cms)	10EA003 (2) (cms)	10EC001 (3) (cms)	(3)-[(1)+(2)] (4) (cms)	(4)*5100/7940 (5) (cms)	(5
17/08/93	292	123	544	129	82.86	
18/08/93	287	117	529	125	80.29	
19/08/93	283	112	512	117	75.15	
20/08/93	277	110	503	116	74.51	
21/08/93	261	107	486	118	75.79	
22/08/93	252	103	465	110	70.65	
23/08/93	247	101	455	107	68.73	
24/08/93	254	101	458	103	66.16	
25/08/93	259	98.5	457	99.5	63.91	
26/08/93	250	96.7	453	106.3	68.28	
27/08/93	236	94.4	439	108.6	69.76	
28/08/93	223	91.6	421	106.4	68.34	
29/08/93	211	89.1	403	102.9	66.09	
30/08/93	201	87.2	387	98.8	63.46	
31/08/93	198	85.7	375	91.3	58.64	
01/09/93	233	85.2	380	61.8	39.70	
02/09/93	355	92.7	439	-8.7	-5.59	
03/09/93	393	98	547	56	35.97	
04/09/93	367	94.3	546	84.7	54.40	
05/09/93	324	89.7	505	91.3	58.64	
06/09/93	290	85.6	462	86.4	55.50	
07/09/93	271	83.1	434	79.9	51.32	
08/09/93	261	82.2	418	74.8	48.05	
09/09/93	289	83.6	411	38.4	24.66	
10/09/93	309	86.5	452	56.5	36.29	
11/09/93	296	87	462	79	50.74	
12/09/93	294	88.8	461	78.2	50.23	
13/09/93	300	87.7	463	75.3	48.37	
14/09/93	304	86.5	467	76.5	49.14	
15/09/93	298	84.8	462	79.2	50.87	
16/09/93	286	82.8	449	80.2	51.51	
17/09/93	271	80.3	434	82.7	53.12	
18/09/93	258	78.2	413	76.8	49.33	
19/09/93	247	76.5	398	74.5	47.85	
20/09/93	241	74.5	382	66.5	42.71	
21/09/93	231	73.1	370	65.9	42.33	
22/09/93	220	71.7	358	66.3	42.59	
23/09/93	213	70.5	346	62.5	40.14	
24/09/93	205	70	338	63	40.47	
25/09/93	196	69.1	331	65.9	42.33	
26/09/93	187	68.3	323	67.7	43.48	
27/09/93	182	67.9	317	67.1	43.10	
28/09/93	182	68.1	311	60.9	39.12	
29/09/93	182	68.6	312	61.4	39.44	
30/09/93	182	70.4	313	60.6	38.92	

Appendix III

Memorandum of Understanding

Nahanni National Park

Environmental Water Quality Monitoring

and Assessment Program

NAHANNI NATIONAL PARK RESERVE
NORTHWEST TERRITORIES

ENVIRONMENTAL WATER QUALITY MONITORING AND ASSESSMENT PROGRAM

MEMORANDUM OF UNDERSTANDING

BETWEEN

CANADIAN PARKS SERVICE
PRAIRIE & NORTHERN REGION
ENVIRONMENT CANADA

AND

CONSERVATION & PROTECTION SERVICE
WESTERN & NORTHERN REGION
ENVIRONMENT CANADA

FOR

WORK AND COST SHARED

ENVIRONMENTAL MONITORING AND ASSESSMENT SERVICES

August 20, 1992

Memorandum of Understanding (MOU)
between
Canadian Parks Service, Prairie & Northern Region
(herein referred to as CPS)
and
Conservation & Protection, Western & Northern Region
(herein referred to as C&P)

1. PURPOSE

This Memorandum of Understanding (MOU), outlines the procedures by Inland Waters Directorate (IWD) of Conservation & Protection ar National Park Reserve of Canadian Parks Service (CPS) (herein refer Parties) with respect to the implementation and management of the Water Quality Monitoring and Assessment Program (herein referred Program) for the Nahanni National Park Reserve in the Northwest T annual program will be designed to meet the recommendations mad of the December 1991 report entitled "Protecting the Waters of Na Park Reserve, N.W.T." However, other services can be negotiated required basis.

The parties are committed to promoting shared utilization of resour the overall performance and effectiveness of the program under Car Plan.

2. ADMINISTRATION

2.1 The Administrators of this MOU will be the Chief, NWT Progra the Superintendent, Nahanni National Park Reserve for CPS.

2.2 The Administrators will be fully responsible for the planning, im monitoring and reporting of the Program; and

2.3 The Administrators will meet at least once per year. Other Me held at such times as required for the effective planning and delive Program.

3. <u>ENVIRONMENTAL WATER QUALITY MONITORING AND ASSESSMENT PROGRAM</u>

3.1 The Program will be initiated in 1992-93 and will be continued annually, contingent on the availability of appropriate financial and human resources to carry out joint cost-shared and/or work-shared activities;

3.2 The Administrators will meet prior to February 28 of each year, to review the previous years activities, approve the format of the Annual Report and finalize and sign off the next years operating schedules. Schedules to be appended to this MOU will include:

Schedule 'A' - A summary of the Annual Financial Contributions to be made by each party;

Schedule 'B' - The Annual Work Plan of activities to be undertaken by each party; and

Schedule 'C' - Details of additional Environmental Services to be provided by each party on an as required basis.

3.3 The parties will ensure that; all sampling is carried out to establish standards; a quality assurance/quality control program is implemented; and samples are processed, handled and shipped for analysis without undue delay;

3.4 IWD will ensure that; all laboratory analyses are carried out; laboratory results are obtained on the priority basis; results are verified on receipt, and CPS advised immediately should any significant deviations in environmental quality be observed;

3.5 The Parties agree that significant deviations will be analyzed promptly and that immediate joint action will be taken as appropriate;

3.6 IWD will produce for inclusion in the Annual Report a tabulation of all verified data, by May 31 of the following year;

3.7 The Parties will jointly produce for inclusion in the Annual Report an assessment of compliance with the Water Quality Objectives established in the December 1991 Report "Protecting the Waters of Nahanni National Park Reserve, N.W.T. and including any other work carried out by July 31 of the following year; and

3.8 The Annual Report will be produced and released by August 15
following year; and

3.8 All verified data produced under this MOU are public data, equa
by both parties.

4. **FINANCIAL CONSIDERATIONS**

4.1 The Annual Work Plan will be carried out on a cost-shared basis
funding provided in Schedule 'A' and the arrangements defined in S

4.2 Each Party will be responsible for the delivery of those activities
subsequent payment of those expenditures associated with their de
responsibilities under Schedule 'B';

4.3 Up-to-date information on the implementation of the Annual W
associated costs will be shared between the parties on a regular ba

4.4 The parties will prepare an annual Financial Report, to be part o
Report, which identifies the actual costs associated with the deliver
including, but not limited to, capital, operating and maintenance and
expenditures.

NOTICE OF CHANGE

Notices of change in financial and/or for working practices and procedur
Party, will be provided immediately in writing to the other party for rev
endorsement by the Administrators.

Approved by:

Conservation & Protection
Western & Northern Region
Environment Canada

B.M. Burns
Director General
August 20, 1992

Canadian Parks Service
Prairie & Northern Region
Environment Canada

for W.D. Harper
Director General

SCHEDULE 'A'
1996-97 Annual Financial Contributions (Non-Salary)

NAHANNI NATIONAL PARK RESERVE
"ENVIRONMENTAL QUALITY MONITORING AND ASSESSMENT PROGRAM"

MEMORANDUM OF UNDERSTANDING
between
Canadian Parks Service
Canadian Heritage
and
Prairie & Northern Region
Environment Canada
for
1996-97 Program Implementation

This schedule provides a summary of the annual (non-salary) financial contributions, made by Canadian Parks Service, Canadian Heritage and Environment Canada, for implementation of the 1996-97 Nahanni Environmental Monitoring and Assessment Program.

Canadian Parks Service, Canadian Heritage	$20,000
Environment Canada	$10,000
TOTAL	$30,000
	=======

The expenditure of these funds will be in accordance with procedures defined in the Memorandum of Understanding.

Approved by Administrators:

For Atmospheric Environment Branch,
Environment Canada

Jesse N. Jasper
Head, Arctic Section
Atmospheric & Hydrologic Sciences Division

R. Scott McDonald
Chief, NWT Monitoring & Operations Division

For Canadian Parks Service
Canadian Heritage

Rob Prosper
Departmental Operations Manager
Deh Cho

February 28, 1996

SCHEDULE 'B'
1996-97 Annual Work Plan

NAHANNI NATIONAL PARK RESERVE

"ENVIRONMENTAL QUALITY MONITORING AND ASSESSMENT PROGRAM"

MEMORANDUM OF UNDERSTANDING
between
Canadian Parks Service
Canadian Heritage
and
Environment Canada
Prairie & Northern Region
for
1996-97 Program Implementation

1.0 Sampling Stations

1.1 Water Quality:

ENV#NW10EC0017 South Nahanni River above Nahanni Butte*
ENV#NW10EC0014 Prairie Creek at Mouth
ENV#NW10EA0004 Flat River near Mouth
ENV#NW10EB0013 Rabbitkettle River at Mouth
ENV#NW10EB0012 South Nahanni River above Rabbitkettle River*
ENV#NW10EA0008 Flat River at Park Boundary
ENV#NW10EB1111 South Nahanni River above Virginia Falls

*Water Quality/ Suspended Sediment Quality Sampling Station

1.2 Water Quantity

HYD#10EA003 Flat River near the Mouth*
HYD#10EB001 South Nahanni River above Virginia Falls*
South Nahanni River above Nahanni Butte**
HYD#10EA222 Flat River at Park Boundary+
HYD#10EC111 Prairie Creek at Mouth+
HYD#10EB111 South Nahanni River above Rabbitkettle River+

* Hydrometric Gauging Stations
\+ Miscellaneous Discharge Measurement Sites
** Synthetic Discharge Measurement Site

1.3 Atmospheric

HYD#10EB001 South Nahanni River above Virginia Falls

1.4 Fish Sampling

No fish tissue quality monitoring during the 1996/97 fiscal year.

2.0 Sampling Variables

2.1 Water Quality Grab Samples:

The following parameters will be measured in each sample:

In the Field:
Temperature (Air & Water), pH and Conductivity

In the Laboratory:

- Physicals: pH, Specific Conductance, Turbidity, Temperature, True Colour, Non-Filterable Residue;
- Total Cyanide;
- Dissolved Metals: Arsenic, Barium, Cadmium, Cobalt, Copper, Iron, Lead, Manganese, Nickel, Selenium, Zinc, Other Dissolved Metals in ICAP-AES Package;
- Total Metals: Aluminum, Barium, Cadmium, Cobalt, Copper, Iron, Lead, Manganese, Nickel, Vanadium and Zinc, Other Total Metals in ICAP-AES Package;
- Extractable Metals: Iron, Manganese, Other Extractable Metals in ICAP-AES Package;
- Dissolved Nitrogen Forms: Nitrate/Nitrite, Total Ammonia;
- Sulphate

Quality Assurance/Quality Control Samples will be collected and shipped and analyzed according to Environment Canada standard practices and procedures.

2.2 Suspended Sediment Samples

Samples will be collected by centrifuge for analysis of the following:

- Total Metals: Aluminum, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Molybdenum, Mercury, Nickel, Selenium, Vanadium and Zinc; Other Total Metals in ICAP-AES Package;
- Organic Carbon and Nitrogen Content;

2.3 Fish Samples

No fish tissue sampling in 1996/97.

2.4 Water Quantity Measurements

Stage and discharge measurements and published daily flows for hydrometric gauging stations specified in Section 1.2, plus miscellaneous discharge measurements at other sites specified in Section 1.2.

3.0 Sampling Frequency and Schedule

3.1 Water Quality Grab Samples:

- Routine samples to be collected at each of the seven (7) stations (listed under 1.0 Sampling Stations) during Early April/ Mid April 1996, Late May/ Early June 1996, and Late August/ Early September 1996.
- Quality assurance/ quality control samples to be collected from Rabbitkettle River at the Mouth in May/June 1996 and South Nahanni River above Virginia Falls during April 1996, and Flat River near the Mouth in August/September 1996.

3.2 Suspended Sediment Samples:

- Collected at South Nahanni River above Rabbitkettle River in Early to Mid June 1996.
- Collected at South Nahanni River above Nahanni Butte in Early September 1996.

3.3 Fish Samples:

- No fish tissue samples will be collected in 1996/97 FY.

3.4 Water Quantity Measurements:

- Continuous measurements at hydrometric gauging stations.
- Miscellaneous discharge measurements in Early April/ Mid April 1996, Late May/ Early June 1996, and Late August/ Early September 1996.

4.0 Responsibilities

All field activities will be implemented under the joint planning and management of the Departmental Operations Manager, Nahanni National Park Reserve for **Canadian Parks Service** and the Officer-in-Charge, Water Survey of Canada, NWT Monitoring & Operations Division, **Atmospheric Environment Branch**, Fort Simpson Office for Environment Canada. These officers will ensure that all required staff and staff training is provided for each aspect of the Program, and that samples are collected and shipped to Indian and Northern Affairs Canada's Northern Analytical Laboratory in Yellowknife, NWT and Environment Canada's Canada Centre for Inland Waters laboratories in Burlington, Ontario for analysis according to standard procedures.

The Regional Aquatic Quality Officer, Arctic Section, Atmospheric & Hydrologic Sciences Division, **Atmospheric Environment Branch** in Yellowknife, NWT will be responsible for overall project design and management; and the verification, evaluation, and distribution of data to CPS Fort Simpson.

5.0 Financial Administration

Canadian Parks Service of Canadian Heritage will be responsible for costs associated with:

- Aircraft rental, fuel purchasing and caching, and helipad construction;
- Lakejohn or other flat-bottomed boat and motor purchasing, positioning and de-positioning;
- Fish sampling and analysis, and
- Salary for CPS staff.

Environment Canada will be responsible for the costs associated with:

- Operation and maintenance of Water Quantity Stations at Flat River near the Mouth, South Nahanni River above Virginia Falls, and other miscellaneous sites;
- Discharge measurements at Prairie Creek near the mouth, Flat River at the Park boundary, and South Nahanni River above Rabbitkettle River;
- Sample shipping and laboratory analysis associated with water quality routine grab samples, quality assurance/ quality control and suspended sediment samples; and
- Aircraft fuel used from Environment Canada fuel caches.
- Salary for DOE Staff.

In the event of cost-underruns, either party may use the unspent portion of the budget to purchase and cache drums of helicopter turbo fuel, or purchase and position fixed assets (e.g. Lakejohn boats, etc.) required for future delivery of the program.

6.0 Survey Products

All original survey products will be made available to Canadian Parks Service for review with Environment Canada retaining ownership and archival rights. Copies of all survey products will be made available to Canadian Parks Service on request.

Approved by Administrators:

For Atmospheric Environment Branch,
Environment Canada

Jesse N. Jasper
Head, Arctic Section
Atmospheric & Hydrologic Sciences Division

R. Scott McDonald
Chief, NWT Monitoring & Operations Division

For Canadian Parks Service
Canadian Heritage

Rob Prospero
Departmental Operations Manager
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February 28, 1996