Protecting the Aquatic Quality of Nahanni National Park Reserve, N.W.T.

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Protecting The Aquatic Quality of Nahanni National Park Reserve, N.W.T.

by

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EXECUTIVE SUMMARY

The challenge of water resource protection 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 South Nahanni River (SNR) basin, an area which also has considerable mining potential. This potential mining activity in tributaries of the South Nahanni River outside the Park raises concerns about possible degradation of Park waters.

Baseline water, sediment and fish tissue quality data were collected throughout the Park during an intensive 1988-91 study and a follow-up 1992-97 monitoring program. The two programs describe the natural and anthropogenic variability of aquatic quality in space and time in order to help evaluate the health of this sub-arctic ecosystem. Observed values of variables were compared to the appropriate Canadian Council of Ministers of the Environment Water and Sediment Quality Guidelines for protection of freshwater aquatic life and drinking water. Site-specific short and long term water and sediment quality objectives developed in 1991 were refined in 1997 to provide water managers with improved tools to better assess any fluctuations in aquatic quality beyond the limits of natural variability. Such natural variability is due to flows, seasons, extreme events, and other factors. The 1992-97 monitoring program provides the aquatic quality data necessary for evaluating compliance with objectives.

The Park water and suspended sediment is of high quality, and pristine to near-pristine, overall. Park waters can be characterized as naturally conductive, weakly alkaline, highly coloured, turbid, hard, and rich in suspended and dissolved solids. Certain metal levels are naturally elevated in Nahanni NPR waters, suspended sediments, and fish tissue (e.g. livers and gills) due to high local geochemical and biochemical backgrounds. Zinc, cadmium, copper, and iron in particular appear to be naturally elevated above national guidelines. While the aquatic ecosystem of the South Nahanni River basin appears to have largely adapted to these natural stressors, the already-stressed ecosystem may be vulnerable to future anthropogenic stress from mining and other human activities.

Incorporation of water and sediment quality objectives into the ecological management plans of the Park and the entire South Nahanni watershed is imperative to preservation of the Park's aquatic ecosystem. Aquatic quality monitoring activities should continue at present levels, and be increased if new development occurs in the South Nahanni River basin, such as start-up of a metal mine on Prairie Creek, re-opening of the Tungsten Mine, or development of mineral deposits upstream of the Park. Natural catastrophic events (e.g. floods, debris torrents, earthquakes, landslides, avalanches) are known to cause spatio-temporal variability in water quality, and warrant additional post-event monitoring.

RÉSUMÉ

La protection des eaux dans le Nord Canadien vise à empêcher la dégradation environnementale qui s'est produite ailleurs en raison développements envahissants. La Réserve de Parc National Nahanni est située dans le bassin de la Rivière Nahanni Sud, région qui compte d'énormes possibilités d'exploitation minière. Toute activité minière dans les affluents de la Rivière Nahanni Sud suscite des inquiétudes quant à la dégradation éventuelle des eaux du Parc.

Des données de base sur la qualité de l'eau, des sédiments et du tissu des poissons ont été recueillies à la grandeur du Parc dans le cadre d'une étude exhaustive menées de 1988 à 1991 et d'un programme de surveillance mis en ouevre entre 1992 et 1997. L'étude aussi bien que le programme décrivent les variations naturelles et anthropiques de la qualité de l'eau dans le temps et dans l'espace en vue d'évaluer la santé de l'écosystème de cette région sub-arctique. Les résultats des observations ont étés comparés aux lignes directrices sur la qualité de l'eau et des sédiments élaborées par le Conseil Canadien des Ministres de l'Environnement (CCME) en vue de protéger la vie aquatique en eau douce et l'eau potable. Les objectifs de la qualité de l'eau et des sédiments à court et à long termes élaborés pour chaque site en 1991 ont étés modifiés en 1997 afin de procurer aux directeurs de programmes de meilleurs outils pour évaluer les variations de la qualité de l'eau au-delà des variations naturelles. L'écoulement des eaux, les saisons, les conditions extrêmes et d'autres facteurs comptent au nombre de ces variations naturelles. Le programme de surveillance mené entre 1992 et 1997 fournit des données sur la qualité de l'eau, données qui sont nécessaires à l'évaluation de l'atteinte objectifs fixés.

Le Parc regorge d'eau et de sédiments en suspension de très grande qualité, en général dans un état pur ou presque pur. L'eau de Parc se caractérise comme étant naturellement conductrice, faiblement alcaline, très colorée, dure, troubles et riche en solides suspendus et dissous. Certaines concentrations de métaux sont naturellement élevées dans les eaux, les sédiments en suspension et le tissu des poissons (par exemple, le foie et les branchies) de la Réserve de Parc National Nahanni, et ce en raison des fonds géochimique et biochimique élevées de l'endroit. Les concentrations de zinc, de cadmium, de cuivre, et de fer semblent être naturellement plus élevées que les concentrations nationales. Même si l'êcosystème aquatique déjà perturbé du bassin de la Rivière Nahanni Sud semble en grande partie s'être adapté aux agents naturels d'agression, il n'en reste pas moins vulnérable à de futures agressions anthropiques résultant d'activités minières et d'autres activités humaines.

Incorporer les objectifs portant sur la qualité de l'eau et des sédiments aux projets de gestion écologique du Parc et de tout le bassin de drainage de la Rivière Nahanni Sud est impératif à la conservation de l'écosystème aquatique du Parc. Il faudra augmenter les activités de surveillance de la qualité des eaux si une mine s'installe le long des rives de Prairie Creek, si la mine à Tungsten reprend ses activités ou si on entreprend l'exploitation des dépôts miniers en amont du Parc. On sait que des catastrophes naturelles, comme des inondations, des éboulis de débris, des tremblements de terre, des glissements de terrain et des avalanches, peuvent à la longue nuire à la qualité de l'eau. C'est pourquoi, il faudra offrir davantage de programmes de surveillance si ce genre de catastrophe ou d'activité se produit.

ACKNOWLEDGEMENTS

The authors relied heavily on information from the 1991 report entitled "Protecting the Waters of Nahanni National Park Reserve, NWT". Monitoring Program Agreement Administrators, Jesse Jasper, Scott McDonald, and Dale Ross of Environment Canada, and Rob Prosper of Canadian Heritage, and the authors of this report would like to acknowledge the contributions and co-operation provided by program participants. Roger Pilling and Gerry Wright of the Water Surveys Section, Environment Canada, Anne Wilson of Environment Canada (formerly of Fisheries and Oceans Canada), and Rob Prosper and Carl Lafferty of Parks Canada, Canadian Heritage in Fort Simpson, NWT carried out program field sampling and flow measurements. Pat Wood of the Water Survey of Canada in Fort Simpson supervised field operations and supplied a valuable historic perspective to the program.

Jesse Jasper, Head, Arctic Section, Atmospheric & Hydrologic Sciences Division provided technical input and editorial suggestions. John Kerr, Studies Engineer, Arctic Section, provided discharge estimates for the South Nahanni river via flow routings to the Nahanni Butte water quality station. Chris Spence, Regional Hydrologist, Arctic Section assisted with preparation of some GIS maps, technical input and field support. Technical input was also provided by Mark Dahl, Aquatic Quality Officer, Arctic Section in Yellowknife, and Roger Pilling and Gerry Wright of the Water Surveys Section in Fort Simpson. Dr. Charlie Jefferson of the Geological Survey of Canada in Ottawa assisted with writing of the geology and economic geology sections, as well as supplying an electronic bedrock geology map. The following individuals assisted with the preparation of 1972-91 and 1992-97 databases for the area, and preparation of figures and tables: Mark Dahl, Chris Clarke, Brian Yurris, Scott Wytrychowski, Sonja Vandervaart, Marnie Fyten, and Paul Squires. Erik Val of Environment Canada assisted me with the French translation of the Executive Summary.

Cover Photograph: The Confluence of the South Nahanni and Rabbitkettle Rivers
Photograph by: Doug Halliwell, Arctic Section, **Environment Canada**

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1.0 INTRODUCTION

Nahanni National Park Reserve (NNPR) is Canada's premier wild river national park. Towering waterfalls, dramatic river canyons, challenging white water, hot springs, and unique myths and legends all contribute to make Nahanni a mecca for wilderness river enthusiasts. Formally established as a national park reserve in 1976 by the efforts of many (including Prime Minister Pierre Elliott Trudeau), Nahanni was also designated as one of the first seven UNESCO World Heritage Sites (in 1978) and a Canadian Heritage River.

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 Parks Canada policies and management strategies for national parks led to their interest in comprehensive water quality monitoring to prevent degradation of Nahanni waters from upstream developments. In 1988, Parks Canada signed a Memorandum of Understanding (MOU) with Inland Waters Directorate (IWD) of Environment Canada, covering the collection of baseline water and sediment 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 a joint 1988-90 Parks Canada/Environment Canada Park water and sediment program.

In 1992, a second MOU was signed between Environment Canada and Parks Canada, extending arrangements for the collection and analysis of water quality samples three times per year, with additional suspended sediment and fish tissue sampling. This MOU was extended through 1993 to 1997. 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 the three existing stream gauging sites and three special measurement sites. Climate atmospheric information was also obtained from a new Environment Canada weather station at Virginia Falls. Water quality samples were scheduled for collection on at least three occasions (April, May/June, and August/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).

This report summarises field activities and laboratory analytical results collected over a decade of water, sediment and fish tissue quality monitoring in Nahanni NPR, under various agreements between Parks Canada and Environment Canada.

The complete set of water, sediment, and fish tissue analyses carried out since 1988, and since 1972 at the Flat River Mouth site, is available as spreadsheet files on diskette. Files include information on sampling locations, readily exportable into various geographical information systems (GIS).

LAND

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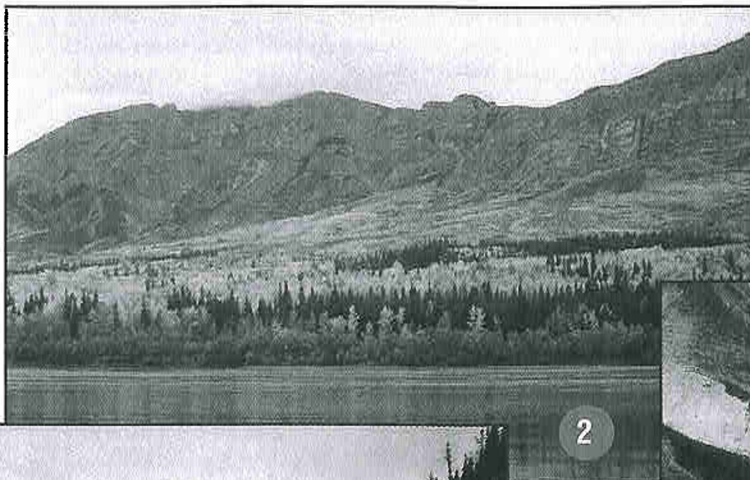
Photo by: D. Halliwell, Environment Canada



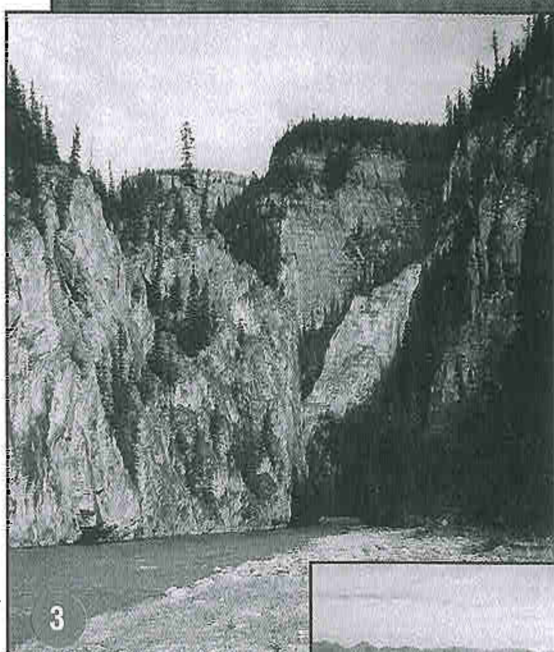


Photo by: D. Halliwell, Environment Canada

Photo by: D. Halliwell, Environment Canada

Photo by: D. Halliwell, Environment Canada

Photo by: D. Halliwell, Environment Canada

1. *Prairie Creek Delta was built by sediment carried down stream during catastrophic flood and debris torrent events*

2. *Nahanni Butte area near confluence of South Nahanni and Liard Rivers*

3. *Gorge at head of Prairie Creek Delta*

4. *Avalanche-caused natural dam formation at confluence of Clearwater and Cathedral Creeks. May have been triggered by earthquake*

5. *Rabbit Hot Springs area, Tufa Mounds*

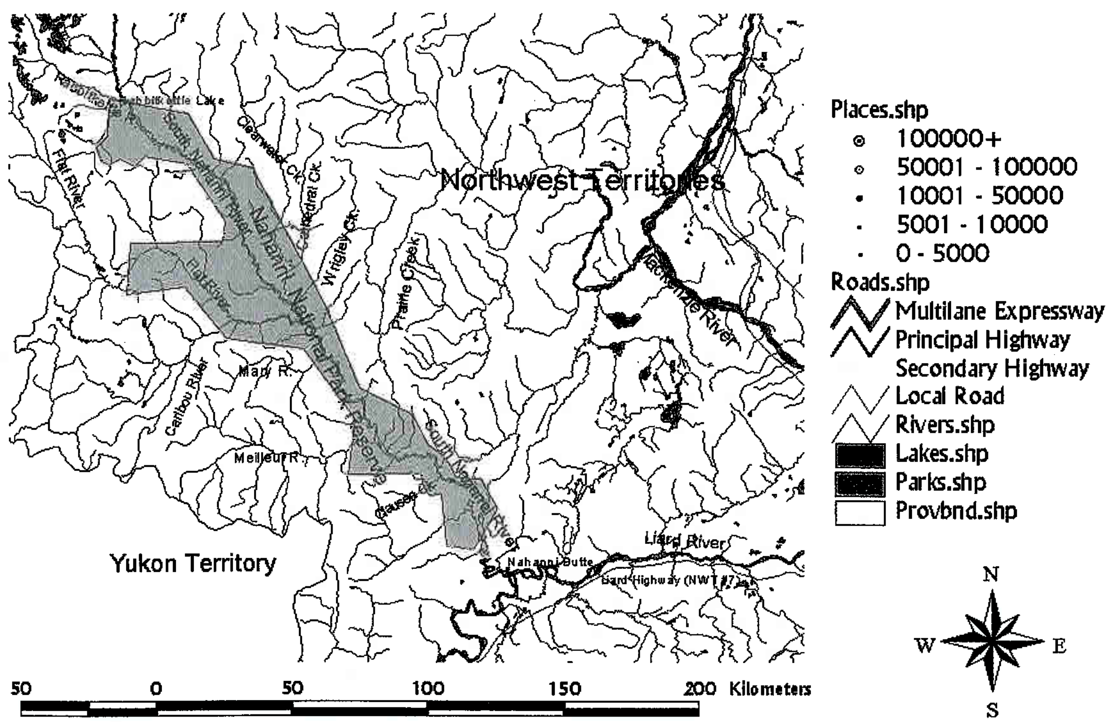
6. *Ragged Range, northwest of Nahanni National Park Reserve*

2.0 NAHANNI NATIONAL PARK RESERVE

2.1 The Land

Nahanni NPR is located at 61 to 62 degrees North Latitude and 128 to 132 degrees West Longitude. Nahanni NPR covers 4,766 square kilometres. The Park 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. Figure 1 shows that the South Nahanni watershed drains 37,000 square kilometres, from the icefields near the Yukon-Northwest Territories border 540 kilometres through the Mackenzie Mountains into the Liard and, eventually, the Mackenzie Rivers.

Figure 1. Nahanni National Park Reserve



After Environmental Systems Research Institute (ESRI) Inc. ArcCanada for ArcView GIS, Schools & Libraries Edition Version 1.0, 1997. Portions of this data were contributed by Natural Resources Canada, Environment Canada, Statistics Canada, Generation 5, Agriculture and Agri-Food Canada.

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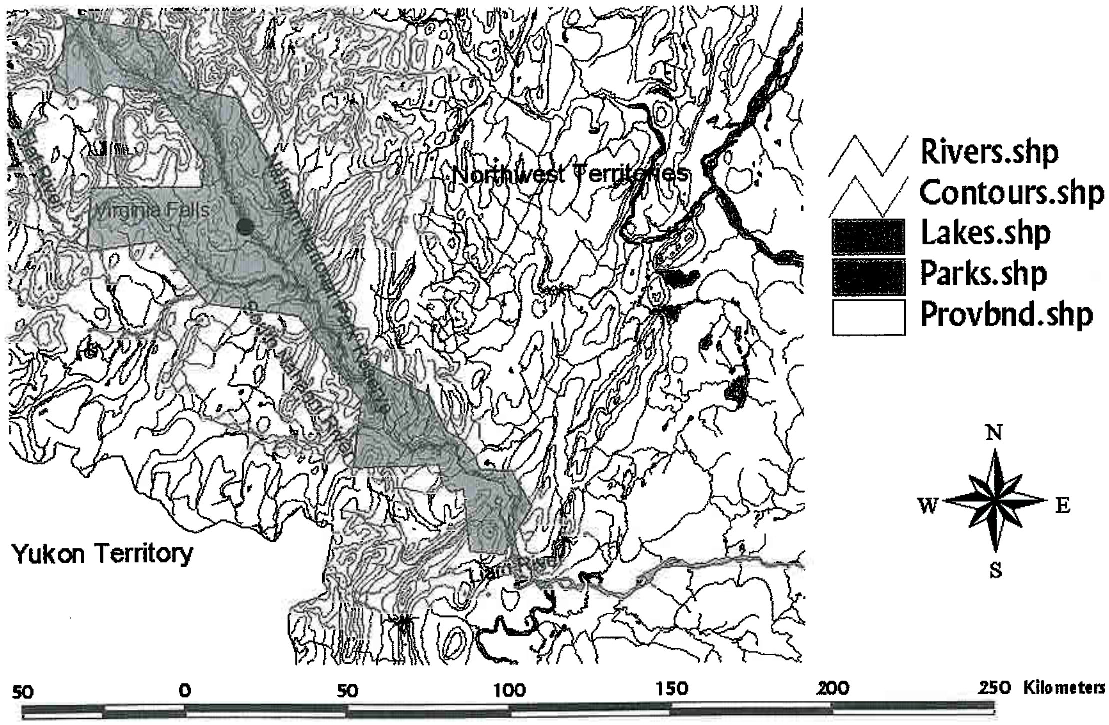
Figure 2 shows that elevations within the South Nahanni watershed range from 2770 metres above sea level (in the headwaters) to about 180 metres (at the confluence of the Liard and South Nahanni Rivers). Within the Park, the mainstem South Nahanni enters at an elevation of 825 metres and exits at 350 metres. Much (i.e. 96 metres) of the vertical drop occurs at Virginia Falls, this nearly twice the 59 metre vertical drop of Niagara Falls. The rest of the River has an average gradient of 1.2 metres per kilometre.

Figure 2. Nahanni NPR Topography.



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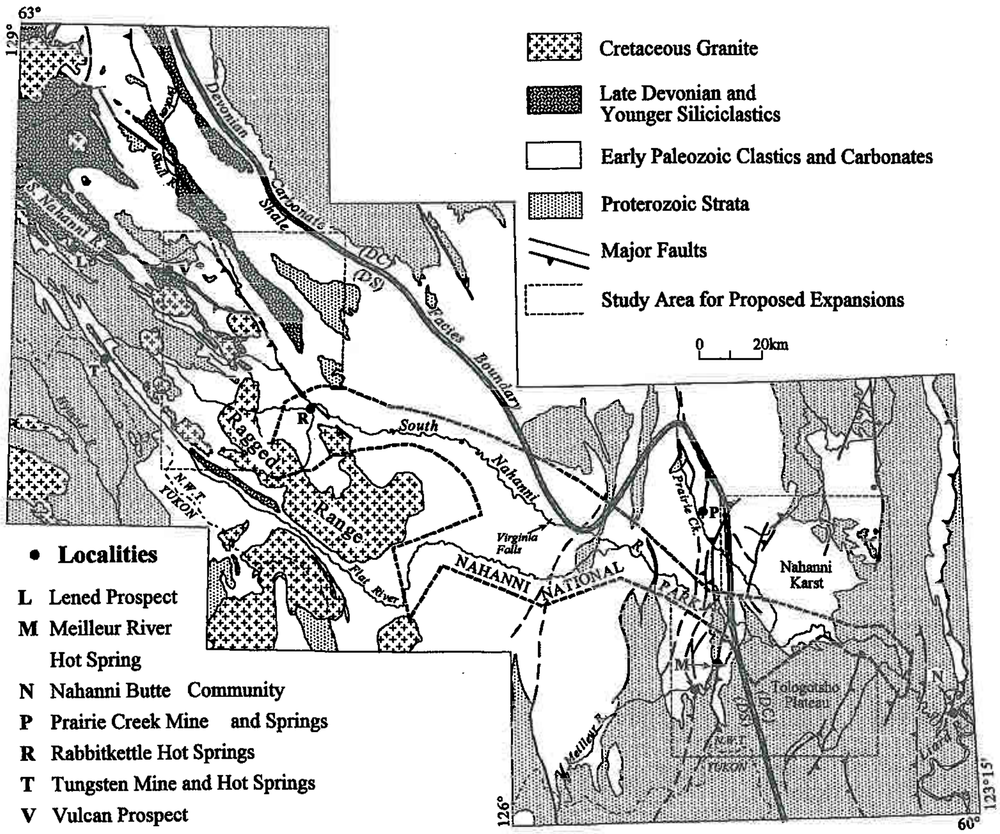
The Nahanni NPR area transects the southern Mackenzie Mountains fold and thrust belt, which is most structurally complex due to extensive folding and thrust faulting in the Ragged Ranges (Hamilton et al, 1988). Figure 3 shows the simplified distribution of underlying sedimentary and granitoid rock packages. The complex bedrock geology has been simplified by Hamilton et al (1988) into four main packages, ordered here by decreasing age. (1) The oldest package is late Proterozoic glaciomarine conglomerates, iron-formation, argillites, shales, and some carbonates (limestones and dolostones). (2) The early Palaeozoic package comprises platformal carbonate strata to the north and east, and Selwyn Basin shales to shaly carbonates on the southwest side of the Devonian carbonate/Devonian shale (DC/DS) facies boundary. (3) The Late Devonian to Jurassic package includes basinal shales, porcellanites, and turbiditic sandstones to conglomerates of the Earn Group (in the Ragged Ranges area) and fine to coarse, continental to marine, coal-bearing clastics (in the Tologotsho Plateau). (4) The youngest, Cretaceous granitoid package extensively intrudes the Ragged Ranges area, forming most of the glacially-sculpted peaks (Hamilton et al, 1988).

In terms of economic geology, the oldest package is generally deeply buried and has limited mineral potential within the area of the Park. To the north, it hosts the significant Redstone Copper Belt and the Gayna River lead-zinc deposits. The early Palaeozoic package hosts silver-lead-zinc veins, particularly in the Prairie Creek area. There is high potential in the second and third rock packages for carbonate-hosted Mississippi Valley Type (MVT) lead-zinc, SEDimentary-EXhalative (SEDEX) shale-hosted zinc-lead-silver deposits, and arsenide vein silver deposits. MVT lead-zinc deposits occur elsewhere in the NWT at Pine Point, Polaris and Nanisivik. SEDEX deposits occur in the Howards Pass area near the Yukon-NWT border, and in the Anvil Range near Faro, Yukon. The remoteness of this area requires economic silver-lead-zinc deposits to be very large, and of higher grade than those currently known in the region.

Shallow marine to terrestrial carbonates and sandstones of the third package also contain coal measures. Tungsten-copper and base metal skarn deposits (e.g. Canada Tungsten Mine) and many gold showings are located in the Ragged Ranges, along granite-carbonate contacts (Hamilton et al, 1988). Placer gold been identified in the Ragged Ranges and in the northern Liard Range- southern Ram Plateau area, by Spinto et al (1988), and Jefferson and Pare (1991). All of the above-mentioned mineral deposit types are described in Geology of Canada No. 8 (Eckstrand et al, 1995).

Figure 3. Bedrock Geology of Nahanni NPR



After Hamilton, Michel & Jefferson, 1988

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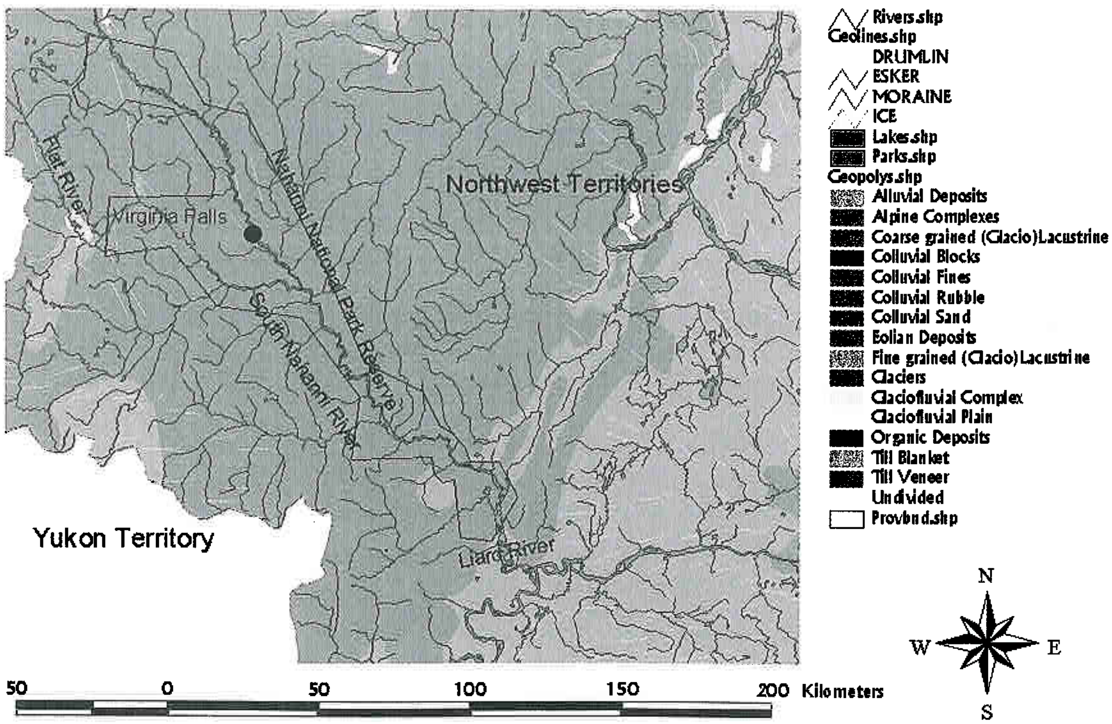
Extensive karst topography, solution channels, caves and sinkholes occurs in the carbonate rocks of the region, particularly in the Nahanni Karst (Ram Plateau) area, due to chemical dissolution and re-precipitation of the naturally soluble carbonates by rainwater and snow-melt (Hamilton et al, 1988). River erosion and glaciation have also sculpted the present-day landforms (Parks Canada, 1984).

Surficial deposits of the NNPR area (Figure 4) are dominated by colluvial fine rubble, with a till blanket in the south west, alluvial deposits in the northwest, and a glaciofluvial plain in the vicinity of the Liard River-South Nahanni River confluence. Drumlin fields occur in the east and west. Drumlin fields occur in the east and west. Drumlins are oriented northwest-southeast in the northern half of the area and east-west in the southern half of the area. The ice margin forms a U-shape closing to the north in Figure 4, delineating the area not receiving continental glaciation.

Figure 4. Nahanni NPR Surficial Deposits



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2.2 The Climate

The climate of the Park is classified as cold continental, with long, cold winters and 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, possibly the result of systems from the Pacific Ocean and Beaufort Sea described in Burns (1973, 1974), and chinook winds are common throughout the winter. Environment Canada installed a weather station near the SNR Above Virginia Falls water survey station in 1994 to characterise weather conditions of a data-deficient area and to monitor weather conditions for forest fire management in the Park and nearby areas. In 1995, Parks Canada established a weather station at Rabbitkettle Lake.

2.3 The Water (Flows and Levels)

Water levels, actual flow measurements and computed daily flows are 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), as part of a long-term monitoring program by Environment Canada and Parks Canada. The latter site was mothballed in 1995, due to a reductions in funding unnecessary monitoring.

Hydrographs from Virginia Falls (Figure 5), Flat River (Figure 6) and Clausen Creek (Figure 7) reveal that peak annual flows (discharges) generally occur from late May to late June each year, due to spring snowmelt

WATER

Photo by: C. Spence, Environment Canada

Photo by: R. Pilling, WSC, Environment Canada

Photo by: C. Spence, Environment Canada

Photo by: C. Spence, Environment Canada

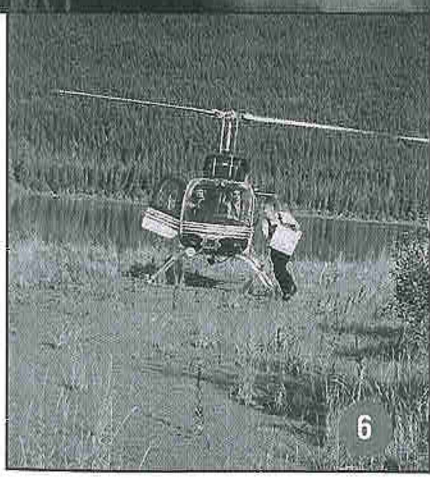


Photo by: C. Spence, Environment Canada

Photo by: G. Wright, WSC, Environment Canada

1. *WSC's Gerry Wright making a flow measurement on Prairie Creek*
2. *WSC staff collect suspended sediment sample on South Nahanni River above Nahanni Butte after centrifuging*
3. *Virginia Falls on South Nahanni River, nearly twice the vertical drop of Niagara Falls*
4. *Doug Halliwell of Environment Canada collecting water quality sample at the Prairie Creek Mouth site*
5. *WSC's Roger Pilling collecting a water quality sample near Nahanni Butte*
6. *Helicopters were used to collect water quality samples*

and/or early summer rainstorms. The normal annual range of flows is from 55 to 1500 cubic metres per second at the Virginia Falls site.

Figure 5. South Nahanni River above Virginia Falls Hydrograph.

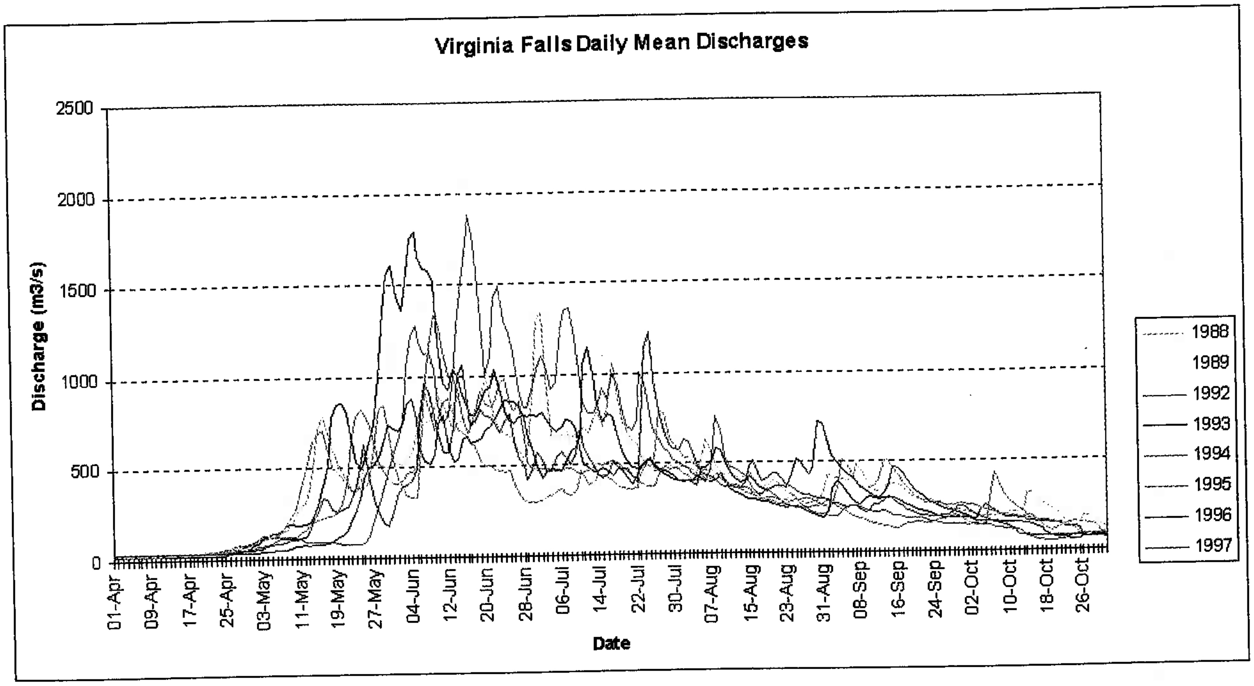


Figure 6. Flat River near the Mouth Hydrograph.

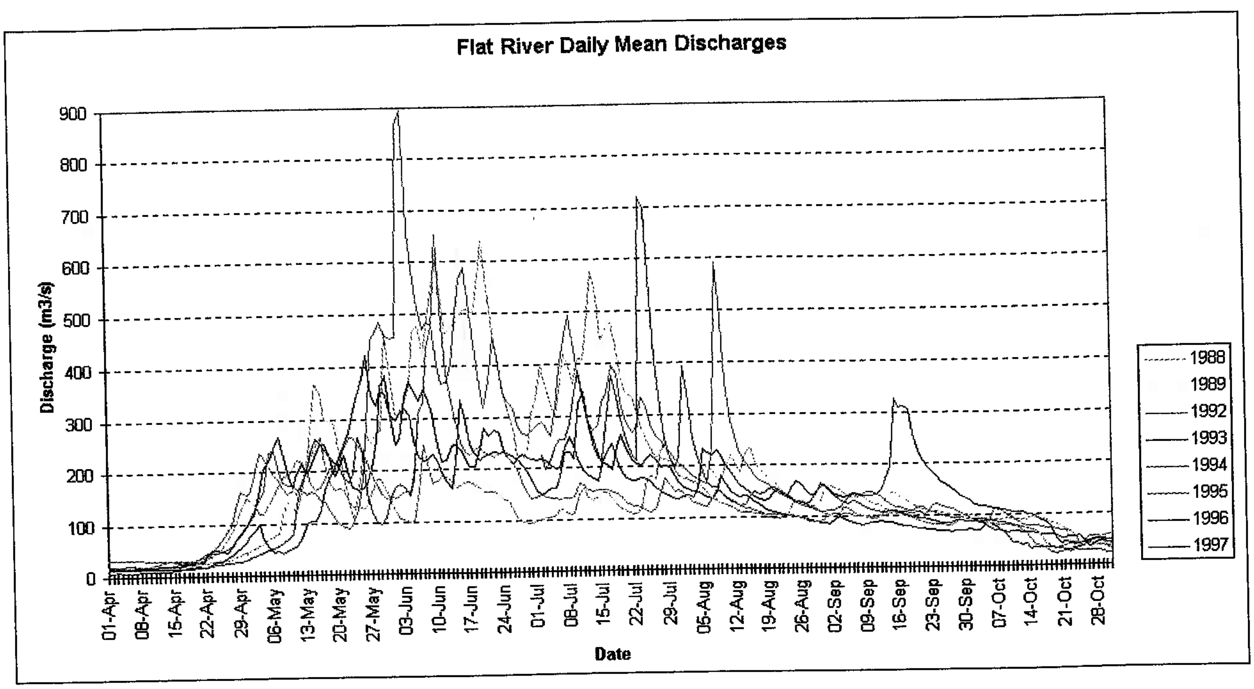
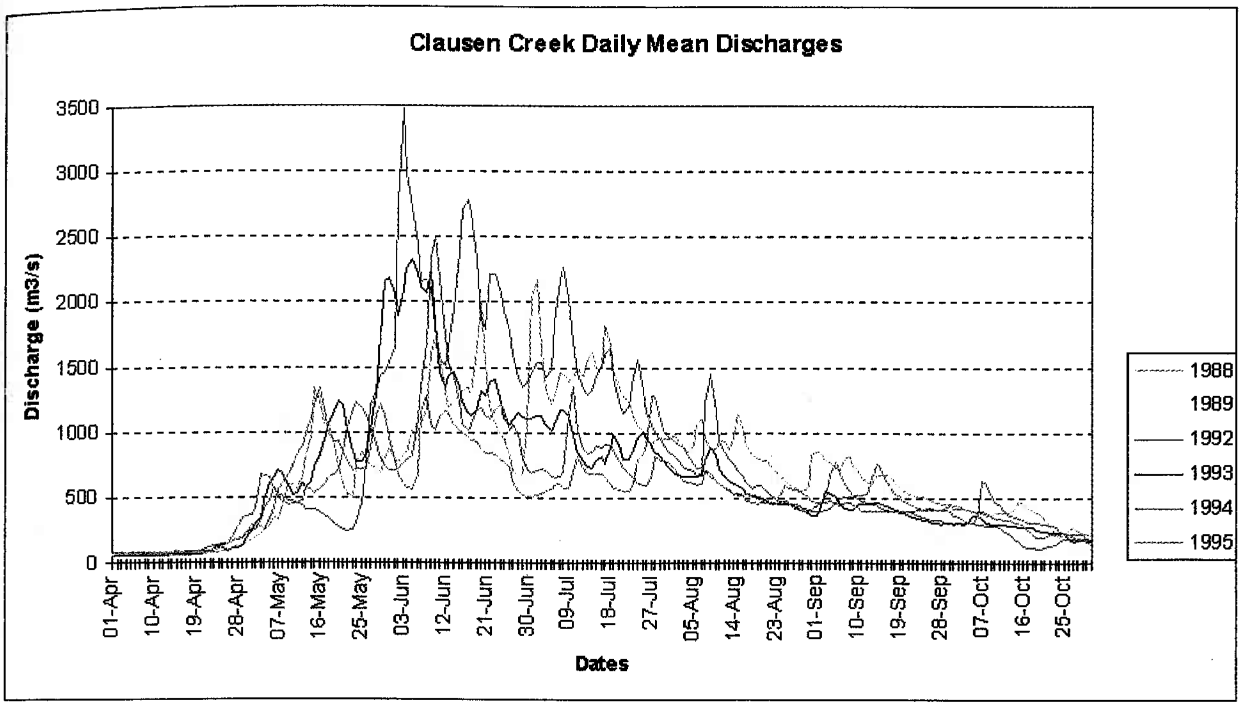


Figure 7. South Nahanni River above Clausen Creek Hydrograph.



Flow recession conditions, interspersed with summer rainstorm flood events, prevail from break-up to freeze-up in November. Winter base flow conditions predominate between November and mid-April, with lowest flows generally occurring 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 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 River Mouth water quality site is highly influenced by outflows from four hot springs adjacent to travertine mineral deposits, one hot spring being located less than one kilometre from the site. Environmental isotope studies indicate that Rabbitkettle Hotsprings waters are predominantly of meteoric (surficial) origin. Flow 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 degrees Celsius. (Gulley, 1993).

Plants and Animals

Photo by: Parks Canada

Photo by: Parks Canada

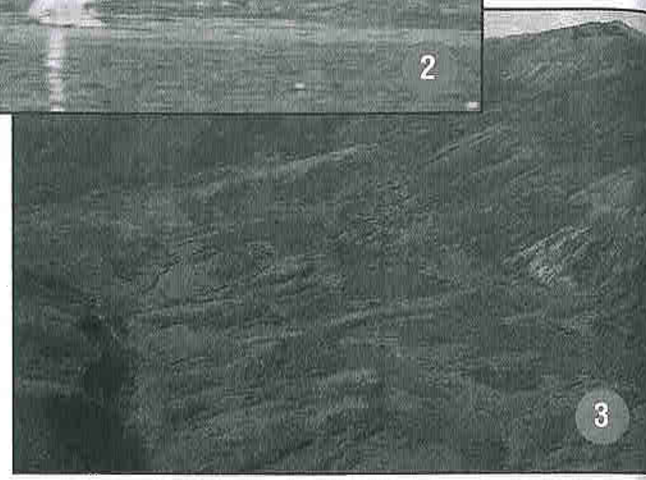


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Photo by: M. Coubis Nahanni National Park and Parks Canada

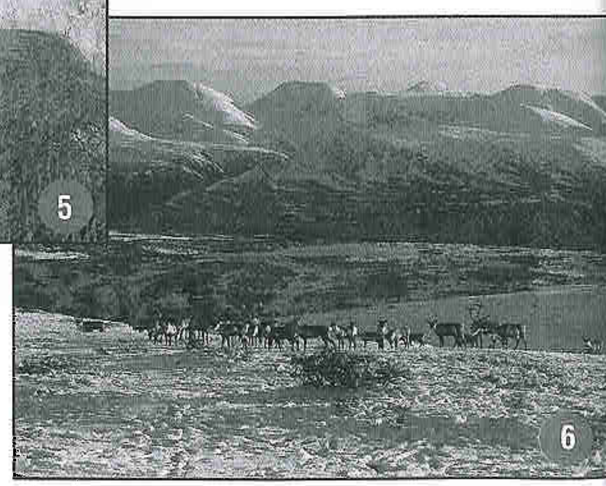


Photo by: Parks Canada

1. *Cow Moose*
2. *Trumpeter Swans*
3. *Burn Deadman Valley*
4. *Dall Sheep*
5. *Fire effect first canyon*
6. *Woodland Caribou*

2.4 Vegetation, Plants & Animals

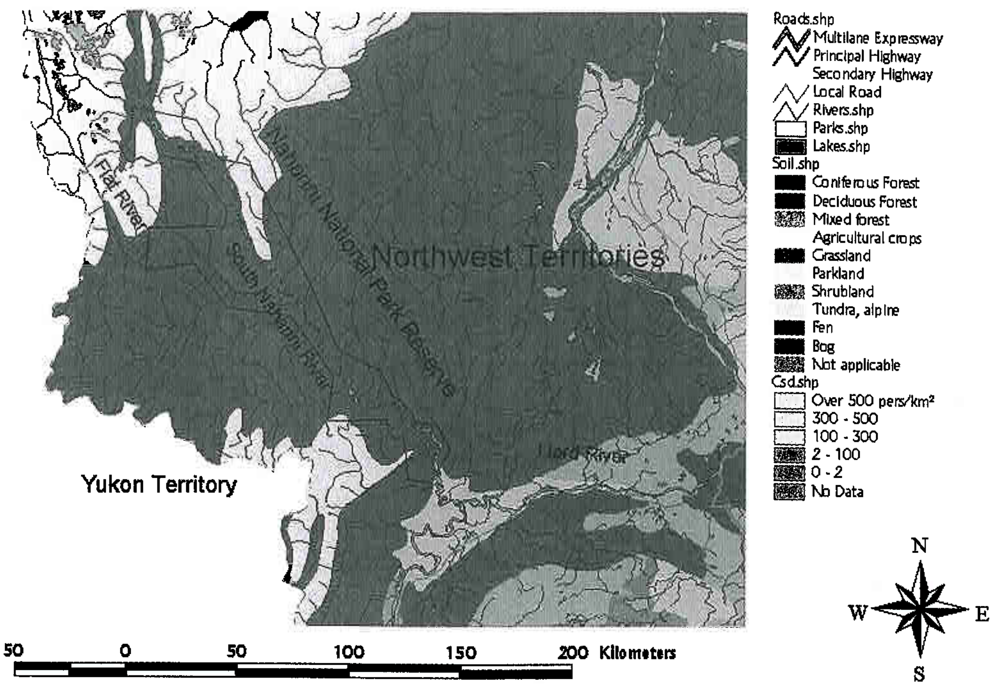
Vegetation in Nahanni National Park Reserve (NNPR) is primarily characterized by northern Boreal forest species along river corridors, with transition to Cordilleran species in the sub-alpine and alpine zones of the Park. Approximately 89% of the area of NNPR is vegetated, while the remaining 11% is a mixture of alluvial deposits, steep talus slopes, water, permanent snow, and ice. Montane and Sub-alpine vegetation communities are most common. Diverse habitats throughout the Park support 590 species of vascular flora, 352 species of bryophytes, and in excess of 336 species of lichen. The flora of NNPR is far richer than any other area of comparable size in the continental Northwest Territories, including future Nunavut Territory (Parks Canada, 1984).

There are various complex reasons for the widely varied and abundant flora in Nahanni NPR. The presence of highly specialized habitats, such as wet calcareous substrates, mist zones of waterfalls, hot and cold mineral springs, and unglaciated terrain are important (Cody et al, 1979). The presence of discontinuous permafrost and periglacial habitats is also of importance in determining the abundance and distribution of various vegetation communities.

Fire is a normal, integral, cyclic component of the Boreal forest (Rowe and Scotter, 1973). Lightning induced fires are relatively frequent in the thick stands of spruce, pine, and mixed forest that predominate along the South Nahanni River valley. NNPR policy allows wildfire to burn without interference unless life or property are at risk. Fire is an important influence in the forest cover of NNPR, as evidenced by the strong representation of fire-adapted tree species in the forest coverand the small mean fire interval. Many fires in this rugged terrain burn rapidly and intensively across vast areas (Parks Canada, 1984). Erosion of these intensely burned areas, due to slope failure or rainfall, results in the movement of copious amounts of mineral soil and other material into the South Nahanni and Flat Rivers.

Figure 8 shows that the vegetation is dominated by coniferous forest, deciduous forest occurring at lower elevation on the Liard River upstream from its confluence with the South Nahanni River. Alpine tundra dominates at higher elevations in the northwest and southwest, while shrubland and bog occur at lowest elevations near the Liard River and its confluence with the South Nahanni River.

Figure 8. Nahanni NPR Vegetation



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Wildlife species in Nahanni NPR have never been widely studied, and much of what is known is a result of short-term studies, which limits how representative or accurate such data is (Parks Canada, 1984).

A total of 16 species of fish have been located in the South Nahanni River drainage basin. The barrier of Virginia Falls, on the South Nahanni River, has been a fundamental factor in limiting upstream post-glacial dispersal. Available habitat and habitat selection preferred by various species are the main other factors determining present fish distribution (Parks Canada, 1984).

More than 170 bird species, are known to inhabit the Park, at least seasonally. Many of the wetlands and small ponds provide seasonal nesting habitat for a variety of waterfowl, including the rare Trumpeter Swan. Large predatory birds, such as bald and golden eagles, as well as peregrine falcons, are known to nest along the South Nahanni River corridor.

Fifty-one (51) mammalian species, are known to inhabit the Park, at least seasonally. The South Nahanni River valley immediately upstream of Virginia Falls is important wintering habitat for the South Nahanni herd of woodland caribou. The ponds and wetlands adjacent to the upper South Nahanni and Flat Rivers provide important habitat for significant populations of moose. The river valleys are principal travel corridors for large predators such as grizzly and black bears, as well as wolves.

HUMAN ACTIVITY

Photo by: M. Conly, Environment Canada

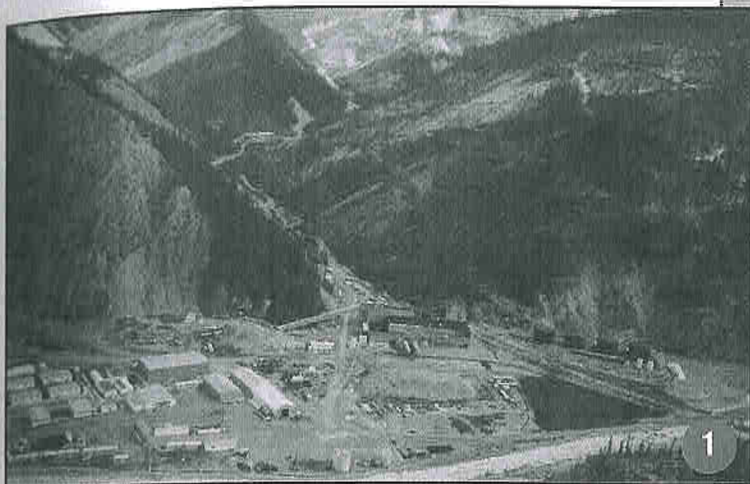


Photo by: P. Wood, Environment Canada

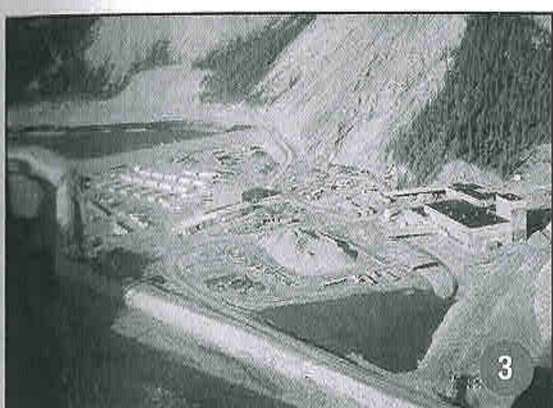


Photo by: M. Conly, Environment Canada

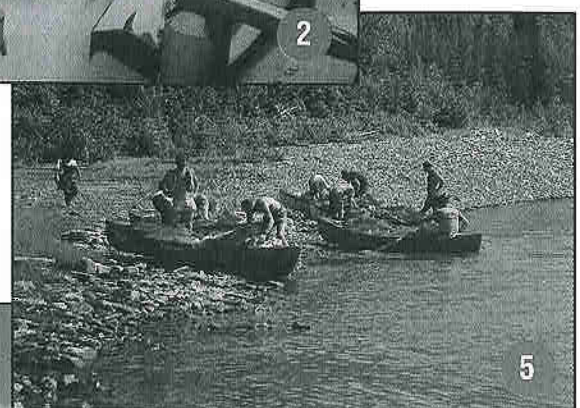


Photo by: Parks Canada

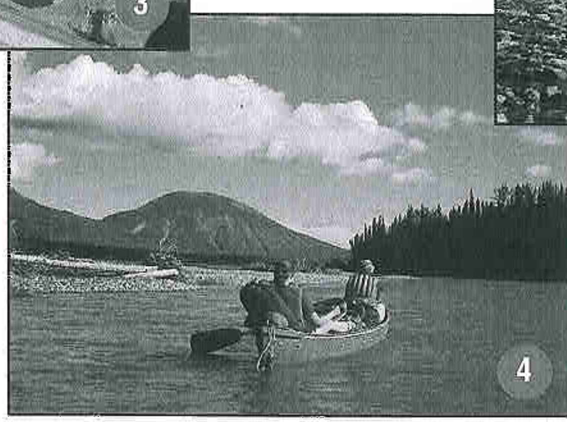


Photo by: Parks Canada

1. *The Cadillac (silver-lead-zinc) Mine on Prairie Creek, upstream of Nahanni National Park Reserve*
2. *The Tungsten (tungsten-copper) Mine on the Upper Flat River, upstream of Nahanni National Park Reserve in winter*
3. *The Cadillac (silver-lead-zinc) Mine on Prairie Creek, upstream of Nahanni National Park Reserve in summer*
4. *Canoeists on South Nahanni River*
5. *Canoeists at Figure Eight Rapids, South Nahanni River*

2.5 Human Activity

The human history of Nahanni NPR is poorly documented. Despite that fact that two years of preliminary archaeological assessment have been carried out in NNPR (Amsden, 1978, 1979), the prehistory of the South Nahanni River (SNR) watershed remains a mystery. Similarly, the early historic era of the area is poorly understood and documented. Oral histories assembled by Parks Canada in 1987 have helped to improve the knowledge of the human history of the area (Gimbarzevsky et al, 1979).

Although there is no archaeological record of permanent communities or habitations within the area of Nahanni NPR, and little evidence of prehistoric aboriginal habitation, there is considerable evidence of short-term or seasonal habitations from an historic era. These sites can be linked to aboriginal and non-aboriginal trappers, prospectors, and traders. The closest Hudson's Bay Company posts were established at Fort Simpson (1804) and Fort Liard (1805). Groups of Dene families lived near Bluefish Creek, on the SNR, which is only a few kilometres upstream of the confluence of the Liard and South Nahanni Rivers. A similar community developed at Netla, which is located on the Liard River a few kilometres upstream of the mouth of the SNR. Eventually, the residents of these two communities moved to the settlement of Nahanni Butte, which is the only permanent community within the SNR watershed (Gimbarzevsky et al, 1979).

During the early part of the 20th Century, the Nahanni region took on a near-mythical allure for many people, including prospectors. Stories of tropical valleys, lost treasure, and headless corpses all helped to promote the region and draw in adventure seekers. *Dangerous River*, *Nahanni*, and *Wings of the North* were books written by R.M. Patterson and Dick Turner which helped increase the area's renown. A National Film Board production about Albert Faille's lifelong search for gold did much to promote the region (Gimbarzevsky et al, 1979).

Mineral exploration within the SNR watershed resulted in the staking of numerous claims throughout the region. In addition, the 1960s saw considerable activity involving consideration of a potential hydropower development at Virginia Falls.

In February 1972, Prime Minister Pierre Elliott Trudeau (after canoeing the South Nahanni River) was instrumental in setting the area aside as a proposed national park. In 1976, a portion of the South Nahanni and Flat Rivers were formally established as a national park reserve. Prior to the establishment of Nahanni NPR, the only permanent residents within the Park were Gus and Mary Kraus and their family. They had built a homestead upstream of Klausen Creek at a permanent hot springs, which has become known as Kraus Hot Springs. Following the lands being set aside as a proposed national park, the Kraus family moved from their homestead and established a new home at Little Doctor lake, northeast of the Park (Gimbarzevsky et al, 1979).

Since the creation of Nahanni National Park Reserve (NNPR), the Park has been designated as the first-ever UNESCO World Heritage Site (1978), and that portion of the SNR within NNPR was designated a Canadian Heritage River in 1987. Annual levels of visitation vary from year to year, but normally 900 to 1200 people travel to the Park. Visitation takes one of two forms; (a) multi-day back-country trips down the river by non-motorized water craft, or (b) brief scenic day trips to Virginia Falls by float plane. Nahanni NPR offers exceptional white water river touring opportunities for people travelling by canoe, kayak, or raft. The Park consistently receives the highest levels of visitation of any national park in the Northwest Territories, including Nunavut, and is world-renowned as a wilderness river destination. Access to the Park is by chartered aircraft from Fort Simpson, Watson Lake (Yukon), or Lindberg Landing to one of two designated landing sites, or by non-motorized water craft. The brief visitor season runs from early June until late September, with the majority of visitation in July and August.

While the Park has not experienced enough development to cause deterioration of aquatic 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.

It is likely that the most serious threat to aquatic quality within the Park comes from mining interest/potential in the area. The Park area is rich in tungsten, lead, zinc, copper and silver mineral deposits.. Numerous mineral claims have been staked and recorded in the area surrounding the Park (Environment Canada, 1991). The Canada Tungsten Company developed a tungsten-copper mine near the headwaters of the Flat River, which is the largest tributary of the South Nahanni River. This mine was fully operational from 1974 until 1986, when it was shut down due to low commodity prices. It is estimated that there are still two years worth of mining reserves that may be extracted at some future point.

A silver-lead-zinc mine known as the Cadillac Mine was developed adjacent to Prairie Creek, approximately 17 kilometres upstream from the South Nahanni River in the 1980s. This mine was mothballed just prior to going into production. The property was acquired by San Andreas Resources Corporation (SARC) in the early 1990s, and 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) and/or the newer Mackenzie Valley Resource Management Act (MVRMA).

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, high quality 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, 1997).

3.0 MONITORING AND STUDIES ACTIVITIES TO DATE

3.1 1988-1991 Program

The 1992-1997 monitoring program evolved from results of the 1988-1991 Environment Canada-Parks Canada study. The objectives of the 1988-1991 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 were selected to provide representative data for the South Nahanni River and tributaries potentially affected by upstream mining development. Sampling was continued at six of these sites during the 1992-1997 follow-up monitoring program and appear on Figure 9 in Section 3.2. Additional sites in the 1988-91 program were located below the South Nahanni-Rabbitkettle River confluence, above the Flat River-Caribou River confluence (two sites), on the South Nahanni River above the Flat River, above the South Nahanni River-Meilleur River confluence (two sites) , and on the South Nahanni River above Clausen Creek (Figure 9, Section 3.2).

Sampling took place during the open water seasons of 1988 and 1989 during spring (i.e. late May to early June) and fall (i.e. September), on consecutive days. Sampling was 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 flow (Environment Canada, 1991).

Water quality variables selected for monitoring were those associated with silver, lead, zinc, copper and tungsten 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 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 and 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. Despite the presence of the mothballed Canadian Tungsten (tungsten-copper) Mine on the Flat River, total tungsten was not included since no Canadian Water Quality Guidelines (CWQGs) exist (CCREM, 1992), the element is immobile in the aquatic environment, levels are expected to at or below method detection limits, and tungsten analyses are not currently available at Environment Canada's National Laboratory for Environmental Testing (NLET) Burlington laboratory. Quality control/quality assurance samples (e.g. triplicates, duplicate blanks) were collected at five sites in both years (Environment Canada, 1991).

Metals are commonly found bound to particulate matter, in stream and lake sediments. Metals have a greater affinity for smaller particle sizes found in the suspended sediments commonly found in high-energy environments such as the South Nahanni River (SNR) and its tributaries. Suspended sediments can be collected using a continuous-flow centrifuges, such as the Alpha-Laval Sedi-Samp centrifuge (Ongley, 1992;

Environment Canada, 1991). Therefore, this centrifuge was used to collect suspended stream sediment samples at four sites along the South Nahanni River (Figure 9), the sites being the SNR above Nahanni Butte, Clausen Creek, Virginia Falls and Rabbitkettle River. The samples were analyzed for a range of metals and nutrients, and particle size distribution analyses were carried out.

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 and 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).

3.2 1992-97 Water, Sediment, & Biota Quality Monitoring Program

Evaluation of the above-mentioned study results led to the signing of a Memorandum of Understanding by Environment Canada and Parks Canada to implement an ongoing water quality program in Nahanni Park on August 20, 1992, appearing in the Appendix.

Separate agreements were made between the departments of Canadian Heritage, Fisheries & Oceans Canada, and Environment Canada for the 1992 and 1994 fish tissue sampling programs.

The objectives of the 1992-1997 follow-up aquatic quality monitoring program were to:

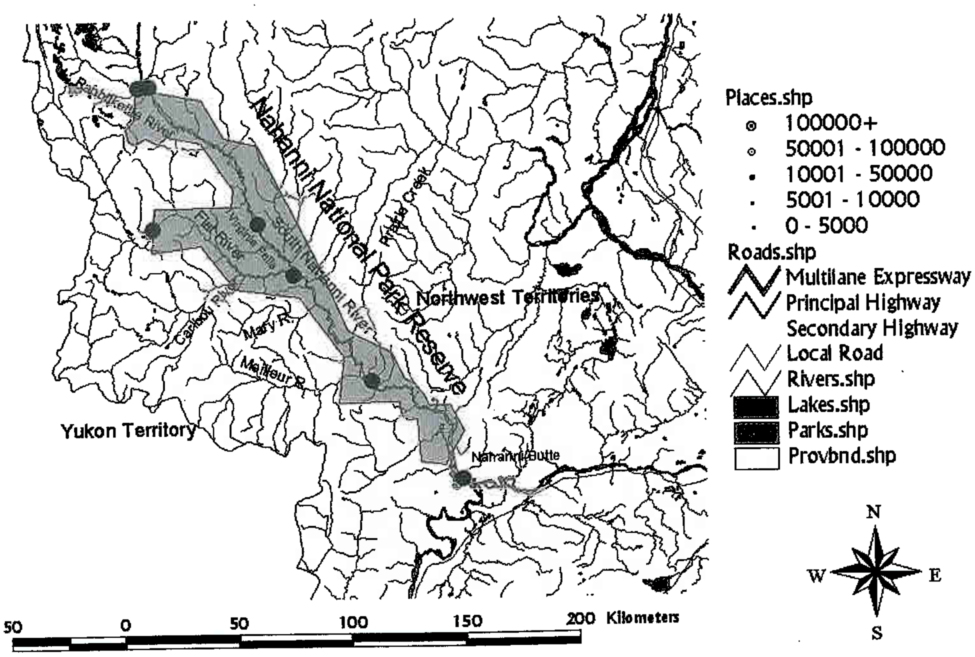
- characterize natural & anthropogenic variability of water, sediment, and fish tissue quality variables (including metal & other contaminants) in space and time within Nahanni NPR, associated with ecosystem health of Taiga Cordillera & Taiga Plains Ecozones & mineral exploration/development activities upstream of Nahanni NPR.
- develop and define site-specific water and sediment quality objectives for streams within Nahanni NPR for the widest possible range of flows.
- monitor compliance with CCME water and sediment quality guidelines, and site-specific, flow-weighted water & sediment quality objectives.
- ry to discern whether spatial & temporal variabilities are due to natural or anthropogenic causes.
- supply development proponents & environment impact assessment (EIA) responsible agencies with baseline information to assist them in the design of multi-year baseline aquatic quality monitoring programs & water licences throughout the entire life of a mine or other development.

Follow-up 1992-1997 aquatic quality monitoring was required after the 1988-1991 study because:

- 1988-1990 values did not represent the true range of natural variability in flows and water quality values, such as 1992 & 1997 high flows and 1993-1995 low flows.
- 1988-1989 water quality samples were only collected during high spring flows and medium summer-fall flows, not during late winter low flows, where the highest dissolved, bioavailable trace metals values were expected.
- mineral exploration and development companies were still active in the area during 1992-1997 near Cadillac Mine/Prairie Creek, Tungsten Mine/Flat River, and at least 31 mineral occurrences upstream of Nahanni NPR have been inventoried by the Geological Survey of Canada (Gordey and Anderson, 1993).

Figure 9 shows the locations of seven water quality sites, with sediment quality sampling also being performed at the four sites along the South Nahanni River (SNR).

Figure 9. 1992-1997 Water & Sediment Sample Sites



After ESRI ArcCanada for ArcView GIS, Schools & Libraries Edition, Version 1.0, 1997.
Natural Resources Canada / Ressources naturelles Canada

Water quality samples were collected during the three major portions of the water year, the late winter (April) **baseflow**, spring (June) **freshet** high flow, and late summer (August-September) **recession**, as clearly seen on hydrographs (Figures 5, 6, and 7). The data indicates three distinct seasonal ranges of flows and water quality values. 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 opportunistic Prairie Creek Mouth site samples were collected by Parks Canada staff on a few occasions during the open water season, due to varying concerns with the level of mineral exploration and development activities in that catchment basin.

Suspended sediment samples were collected by Environment Canada for SNR above Nahanni Butte in September 1992, July and September 1993, July and September 1994, September 1995; and September 1996 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 about elevated metals levels, and to investigate any seasonality in suspended stream sediment quality values at the SNR above Nahanni Butte site. Additional suspended sediments were collected upstream at SNR above Clausen Creek (July 1994), SNR above Virginia Falls (June 1995), and SNR above Rabbitkettle River (June 1996) to investigate spatial variability in stream sediment quality.

The 1992-1997 field and lab water quality, lab sediment quality, and NAquaDat/EnviroDat Parameter Codes are summarized in Table 1 of the Appendix. The codes describe laboratory analytical methods, instrumentation, lower method detection limits, and units and precision the data is reported in.

The historic water quality results from 1988 (back to 1972, at the Flat River Mouth site) to 1997 for the seven water quality sampling sites of SNR above Rabbitkettle River, Rabbitkettle River Mouth, SNR above Virginia Falls, Flat River Park Boundary, Flat River Mouth, Prairie Creek Mouth, and SNR above Nahanni Butte are available on diskette. Table 2 in the Appendix shows short-term and long-term objectives for the seven water quality sites and one sediment quality site.

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 3 (Ballantyne, 1991). Fish tissue quality results from 1994 fieldwork at the South Nahanni River below Dry Canyon Creek site are available on diskette. Fish tissue quality results from 1996 fieldwork at the South Nahanni River below Dry Canyon Creek and Flat River near the Mouth sites are also available on diskette.

Water quality field quality assurance/quality control (QA/QC) sampling was carried out throughout the 1992-1997 follow-up study. QA/QC sampling consisted of a field triplicate samples and one field blank collected once every year at key sites and once every two to three years at other sites. The field triplicates and field blank samples results are examined to determine the field precision (spread of measured values) and field accuracy (closeness of the measured values to actual values), respectively.

Water quality data from 1988 (from 1972, at the Flat River Mouth site) to 1997 were interpreted in light of stream flow at the SNR above Virginia Falls and Flat River Mouth station gauges. For the SNR above Clausen Creek site (decommissioned in 1995), flows were "routed" 55 kilometres downstream to the SNR above Nahanni Butte water/sediment quality site to create "synthetic" flow data. At all other sites, field conductivity was used as an indicator of flow (i.e. low conductivity implies high flow while high conductivity implies low flow). At some sites, manual flow measurements were made at the same time samples were collected.

StatGraphics Plus software was used to perform various statistical calculations on the data, and display correlation between water quality variables and trends in the data over time. These took the forms of linear regression and correlation analyses, time trend analysis plots, calculated Pearson's "r" correlation coefficients, "r-squared" and Spearman's "rho" values (non-parametric equivalent of Pearson's "r"), multiple box-and-whisker plots. Multiple box-and-whisker plots use data "ranked" from highest to lowest values and show median values (i.e. "middle" values at the 50th percentile), upper (75th to 100th percentile) and lower (0th to 25th percentile) quartiles and outlier values for water quality values during late winter baseflow, spring freshet and summer recession periods of the water year (and hydrograph). The practice of ranking data values from highest to lowest and using percentiles is referred to as non-parametric statistics. This practice is superior to using traditional parametric statistics, which assumes that values follow Normal, bell-shaped curve distributions (an incorrect assumption for most water and sediment quality data).

Measured water quality values exceeding Canadian Water Quality Guidelines, or site-specific water quality objectives, values raise concerns. These concerns are more well-founded if the values do not fall close to (i.e. within an 95% confidence envelope of) linear regression lines relating water quality values to flow (at the SNR above Virginia Falls and Flat River Mouth sites), synthetic flow (at the SNR above Nahanni Butte site), or field conductivity (at the SNR above Rabbitkettle River, Rabbitkettle River Mouth, Flat River Park Boundary and Prairie Creek Mouth sites). These exceedances warrant further investigation. Exceedances of water quality objectives and CWQGs explainable by natural variation in stream flow (i.e. plotting close to linear regression lines) 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 above 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, Rabbitkettle River Mouth, and SNR above Rabbitkettle River sites.

4.0 WATER QUALITY OF THE PARK

The South Nahanni River basin may experience 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 and sediment quality from the 1972 to 1997 studies and monitoring is summarized in this report. Knowledge of the Park's fish tissue quality gained from 1992 and 1994 sampling programs at the SNR below Dry Canyon Creek (the first north side tributary downstream from Prairie Creek) and Flat River Near the Mouth sites is also summarized.

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 along the SNR mainstem and amongst tributaries, reflect spatial variations in bedrock geology (i.e. rock types and structures) and surficial geology (i.e. glacial, alluvial and organic deposits), which, in turn, affect downward percolation of precipitation through soil and bedrock to below the water table, thus affecting groundwater flow. Carbonate-rich sedimentary rocks are more readily dissolved by even weakly acidic precipitation than other rocks, creating networks of sinkholes and caves, and permitting maximum groundwater flow. In the Nahanni NPR region and elsewhere around the world, heat sources within the ground, such as volcanoes and buried magma chambers, cause groundwater to be heated (i.e. hydrothermal, or "hot water", activity), sometimes to boiling temperature. Such waters may come to the surface in vents, such as hot springs, typically located along fractures in bedrock and overburden. Hot springs are known to occur along Rabbitkettle River, Flat River, and upstream of Nahanni NPR (e.g. Broken Skull River). Proximity to mineral deposits (more often formed by hydrothermal processes than magmatic ones) can also affect water and sediment quality.

Flows, sediment transport, water quality, and sediment quality are affected by the amount of precipitation runoff. The amount and type of vegetation cover affects the amount of soil moisture retained in root systems, and the amount of transpiration. The runoff ratio (i.e. the ratio of surface runoff to precipitation) depends upon vegetation cover and type. Runoff ratios can vary from 30%, in boreal coniferous forest, to 70%, in treeless tundra (Environment Canada, 1991). Evaporation and sublimation rates also affect the amount of runoff.

Other changes in the land and water of Nahanni NPR which can cause spatial variability in flow, sediment transport and aquatic quality include changes in stream slopes, changes in stream sub-basin sizes, rainfall events and catastrophic events. Known catastrophic events in Nahanni NPR related to climatic and geologic changes (acting separately or together) include rainstorms, earthquakes/tremors, landslides, avalanches, and debris flows/torrents. These often affect only limited areas or select catchment basins, causing considerable spatial variability in aquatic quality.

Rainfall events in the Canadian Cordillera can lower pH by up to 1.0 pH unit within a few hours because natural precipitation is slightly acidic (i.e. pH 5.7) and human activity-induced acid precipitation can be even more acidic (Whitfield & Dalley, 1987). Such rainfall events create "slugs" of water which are detected at different gauge or water measurement locations and at different times (due to lag times). Extreme rainfall events and/or temperature changes in the mountains can cause avalanches, landslides, and debris flows/torrents (consisting of water, soil, trees, and rocks) rapidly flowing down streams within narrow channels and valleys. These are known, in other areas, to change aquatic quality by increasing levels of total dissolved solids, total suspended solids, turbidity, true colour, and total (mostly particulate) trace metals. Such events can even cause human (tourist) fatalities in Nahanni NPR, as was the case in Dry Canyon Creek during the summer of 1995.

South Nahanni River/ Rabbitkettle River Confluence Area

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 flows 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).

Flat River-Caribou River Area

Flat River shows distinct water quality changes between the Park boundary and its confluence with the South Nahanni River (SNR). 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 mainstem water quality (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 6 shows that the Flat River Mouth station's maximum 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 above Virginia Falls (Figure 5) and Clausen Creek (Figure 7). The maximum 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 high sediment loads. with higher concentrations of metals, calcium, and 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).

Prairie Creek Area

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) compared to the SNR mainstem, and have little influence on SNR 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 mineral deposits lie mostly within Upper Whittaker Formation dolostone (San Andreas Resources and Rescan, 1994).

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 dissolved (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).

SNR Near Nahanni Butte Area

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.

Elevated total iron content of suspended sediments at the SNR above Nahanni Butte site is not surprising 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).

While aluminum is very abundant and ubiquitous in the Earth's crust, elevated total aluminum content of suspended sediments at the site requires investigation. 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), alumino-silicate 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. Total aluminum analyses of water quality samples were only been carried out since 1994, as part of a new 17 metal analyses scan.

Alternatively, extensive, 12,000 metre per year (DIAND, 1994; NWTCM, 1994) diamond drilling in the Prairie Creek watershed may have increased aluminum levels, due to use of aluminum-rich drilling muds for diamond drilling circulation. As Prairie Creek Mouth water quality samples are not significantly higher in total aluminum than samples from the other six sites, exploration drilling is not likely the cause of elevated aluminum levels.

NWT Health has been advised of these elevated aluminum levels in suspended sediments, but 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, was used for the community's water supply (Victor Menkal, Vista Engineering, pers. com.).

4.2 Temporal Variability

Water and sediment quality is variable over time because of changes in water flows and levels during each water year (i.e. seasonality), and between water years. Long-term changes in Nahanni NPR water quantity and quality may be occurring, especially if the Mackenzie River basin (which includes Nahanni NPR) is one of three climate change/variability global warming "hotspots" (Final Report of the Mackenzie Basin Impact Study, Environment Canada, 1997).

Concentrations of water quality variables (and to a lesser extent, sediment quality variables) fluctuate over the water year. The effects of Tungsten Mine and Cadillac 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 the Flat River Mouth site illustrates seasonal and long-term temporal variability.

Changes in the land and water over time, including catastrophic/extreme events, such as rainstorms and earthquakes, can cause temporal variability in water and sediment quantity (and quality). In Winter 1997, failure along a weak bedding plane in the bedrock, possibly triggered by an earthquake, caused an avalanche above the Cathedral Creek-Clearwater Creek confluence just northeast of Nahanni NPR. This caused natural damming, and the formation of a 15 kilometre lake upstream of the landslide. This was followed, in Summer 1997, by natural breaching of the newly-created dam and flooding in the lower SNR. Several canoeists were flooded out of their campsites and forced to sleep in their canoes!

Study and monitoring program water quality data were entered into MS Excel spreadsheet files, respecting the analytical precision available and significant figures. 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 software was used for statistical analyses (linear regressions, multiple box-and-whisker plots, correlation matrix analyses, and time trend analyses). Figure 10 illustrates the seasonal behaviour for all water quality variables at the seven water quality stations.

Figure 10. Seasonal Behaviour, Water Quality Variables, Based on Multiple Box-and-Whisker Plots.

Seasonal Behaviour	Negative Flow Dependence, Dilution Effects	Positive Flow Dependence, Particulate Effects	Positive Flow Dependence, Early Flushing of Particulates	Negative Flow Dependence, Temperature Dependence	No Flow Dependence, Positive Temperature Effects	No Flow 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 Rabbitkettle R	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.

Box-and-whisker plots show numerical values ranked from highest to lowest and percentiles (values below which certain percentages of ranked numerical data fall). These plots show 25th and 75th percentiles (i.e. values below which 25% and 75% of the numerical data fall, respectively) of the available data as the top and bottom of the "boxes", respectively, and the 50th percentiles or median (middle) 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).

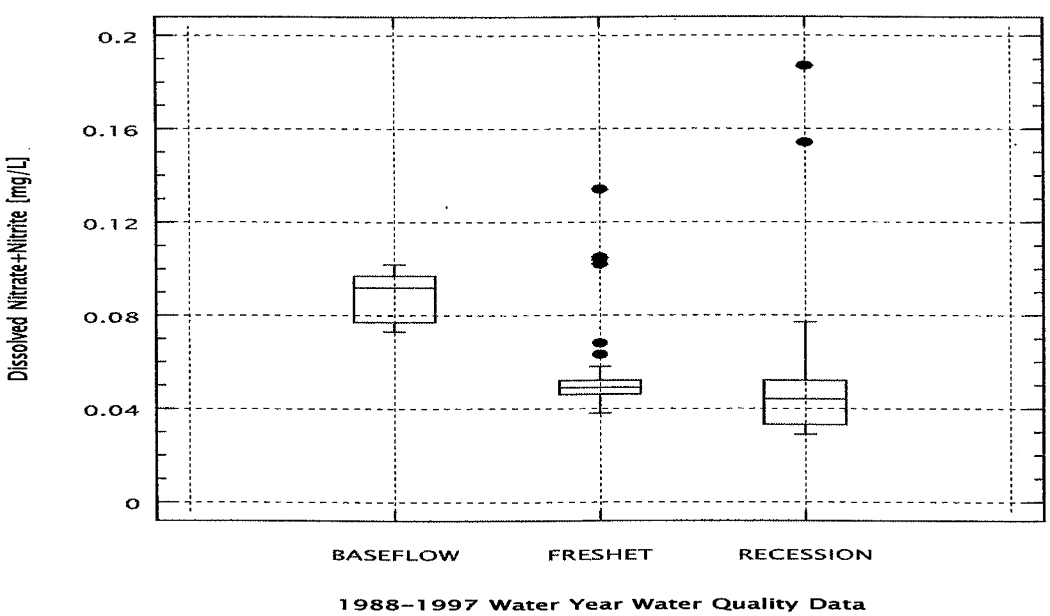
Multiple Box-and-Whisker Plot Legend:

Individually-Plotted Points	=	Extreme Values
Top of Upper "Whisker"	=	Maximum Value, Excluding Extreme Value
Top Horizontal Line of "Box"	=	Upper Quartile (75th Percentile) Value
Middle Horizontal Line of "Box"	=	Median (50th Percentile) Value
Bottom Horizontal Line of "Box"	=	Lower Quartile (25th Percentile) Value
Bottom of Lower "Whisker"	=	Minimum Value

Box-and-whisker plots and percentiles involve ranked values of variables and non-parametric statistics. Such statistical parameters don't assume that any particular statistical distribution of values exists and are, therefore, universally applicable to all variables whether or not they are Normally (or Lognormally) Distributed. The multiple box-and-whisker plot for dissolved nitrate-nitrite at the SNR above Rabbitkettle River (Figure 11) exemplifies the case where the water quality values have no flow dependence, but decrease throughout the open water season with increasing temperature and/or biological uptake, such that values are highest during late winter baseflow and lowest during fall recession.

EXAMPLE OF BIOLOGICAL UPTAKE EFFECTS

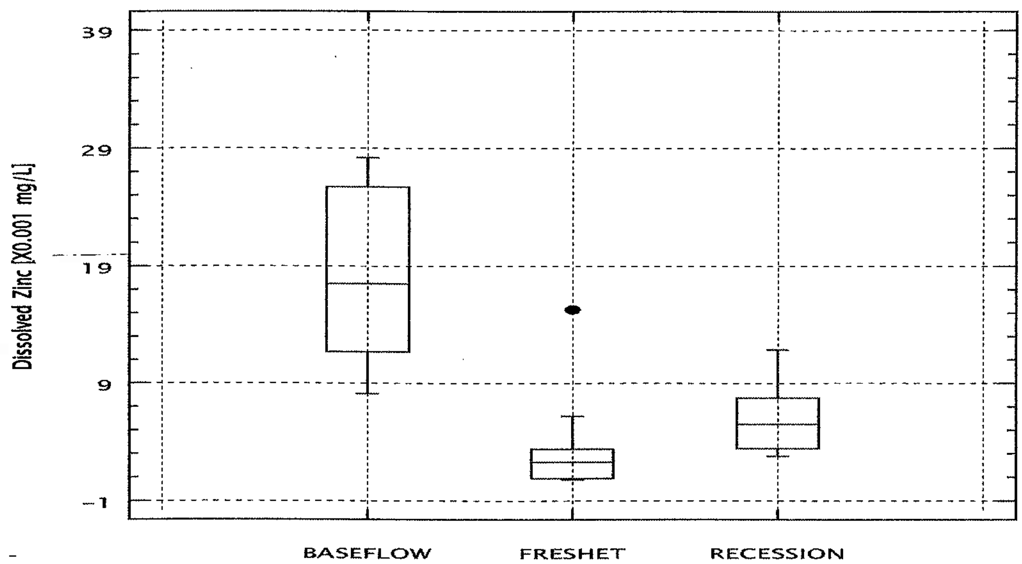
Figure 11. Mult.Box&Whisker Plot, Diss.NO3NO2,SNR/Rabbitktle



Negative flow dependence is shown in the multiple box-and-whisker plot for dissolved zinc at Flat River near the Mouth (Figure 12), where water quality values are highest during the baseflow and lowest during the freshet due to dilution effects.

EXAMPLE OF DILUTION EFFECTS

Figure 12. Mult.Box&Whisker Plot, Diss.Zinc at Flat R.Mouth

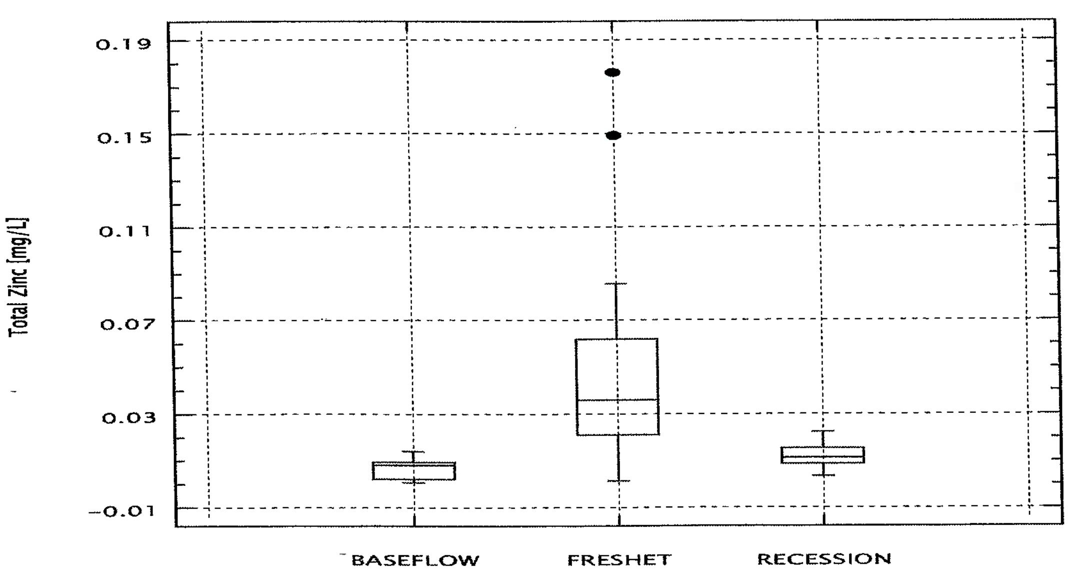


1988-1997 Water Year Water Quality Data

Positive flow dependence is shown in the multiple box-and-whisker plot for total zinc at SNR above Nahanni Butte (Figure 13), where values are highest during the freshet (due to particulate effects) and lowest during baseflow.

EXAMPLE OF PARTICULATE EFFECTS

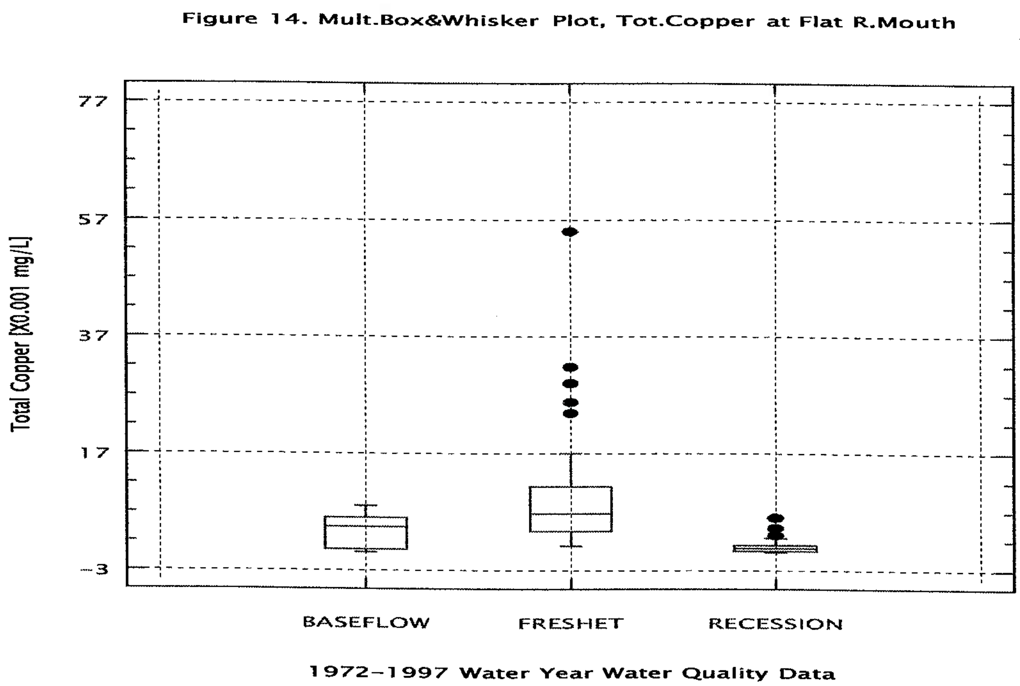
Figure 13. Mult.Box&Whisker Plot. Tot.Zinc at SNR/NahanniBte



1988-1997 Water Year Water Quality Data

Positive flow dependence with early flushing of particulates is exemplified by the multiple box-and-whisker plot for total copper at the Flat River Mouth site (Figure 14), where values are highest during the spring freshet and lower during the fall recession than the late winter baseflow. Flushing of particulate metals during the freshet is so complete that it leaves the system more depleted of metals during the summer-fall recession than during late winter baseflow.

EXAMPLE OF PARTICULATE EFFECTS WITH FLUSHING OF METALS DURING FRESHET



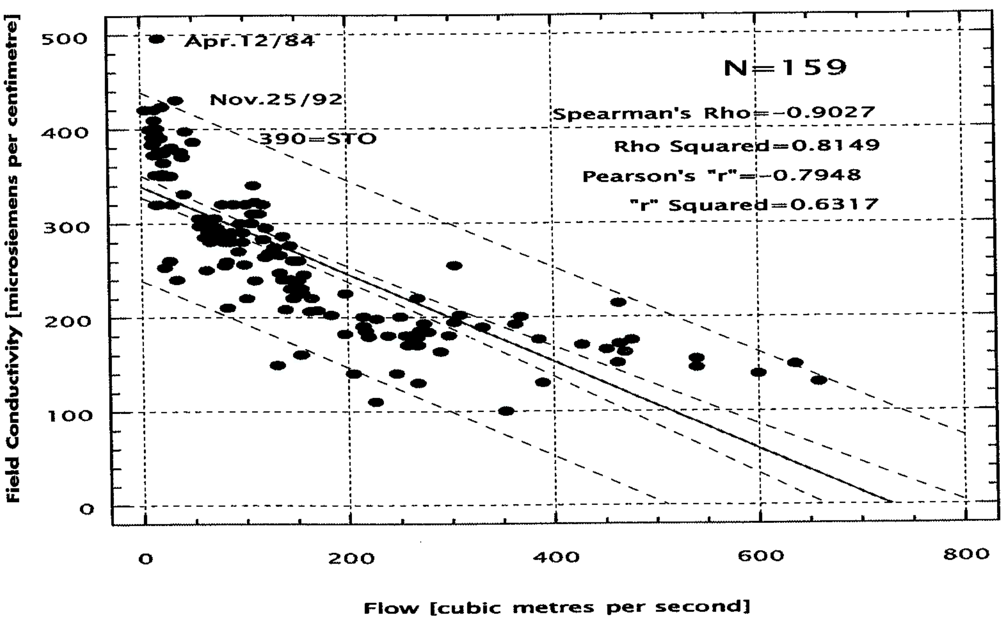
Multiple box-and-whisker plots, such as Figures 11-14, illustrate seasonality of water quality variables during winter baseflow, the spring freshet and summer-fall recession. These plots include more freshet and recession data than baseflow data because baseflow samples were not collected during 1988-89 study program, only during 1992-97 monitoring program.

South Nahanni River above Rabbitkettle River Water Quality Station

The South Nahanni River (SNR) above Rabbitkettle River water quality site lacks flow data. Flow data cannot be as readily "routed" (extrapolated) upstream from the Virginia Falls station gauge. Therefore, some miscellaneous flow measurements were made at the same time and place of water quality sampling. In most cases, flows were not available at the time of water or sediment quality sampling. Therefore, linear regression of water quality variables was carried out on field conductivity instead of flow.

Field conductivity is considered to be the best substitute, or proxy, water quality variable to use in place of flow, if flow measurements are not made at the same time and place of water quality sampling. This is because field conductivity is the water quality variable most clearly reflecting flow variation at world-wide water quality sites (Sanders et al, Colorado State Univ., 1983) and has a strong negative relationship with flow, as illustrated in Figure 15.

Figure 15. Flat R./Mouth, Field Conductivity vs Flow



In Nahanni NPR, this strong negative correlation between field conductivity and flow (discharge) is best illustrated in the 25 year (1972-1997) record of flow and field conductivity measurements at the Flat River Mouth site (Figure 15). Assuming Normal Distribution of flow and field conductivity values, the Pearson's "r" parametric correlation coefficient is -0.7948 for statistically large (N=159) sample populations of field conductivity and flow values. The "r-squared" value suggests that field conductivity explains 63.17% of the natural variability in flow. Actually, flow and field conductivity are not distributed in Normal "bell curves" at this site. Thus, it is more appropriate to rank both sets of values from highest to lowest and calculate a non-parametric correlation coefficient (Spearman's "rho") of -0.9027 for the same statistically large sample populations. The more appropriate "rho-squared" value shows that field conductivity variability "explains" 81.49% of the natural variability in flow, an even stronger negative correlation (Figure 15).

Water quality variables, such as field conductivity, are not really linearly related to flow. They actually exhibit **non-linear relationships**, as follows:

WQ = A + (B x Q) + (C x Q x Q),

where WQ = water quality value, Q = flow value, A = y-intercept of curve, B, C = constant values

In this report, **linear relationships** between water quality and flow values are assumed as an approximation, for simplicity sake. Water quality and flow are related, as follows:

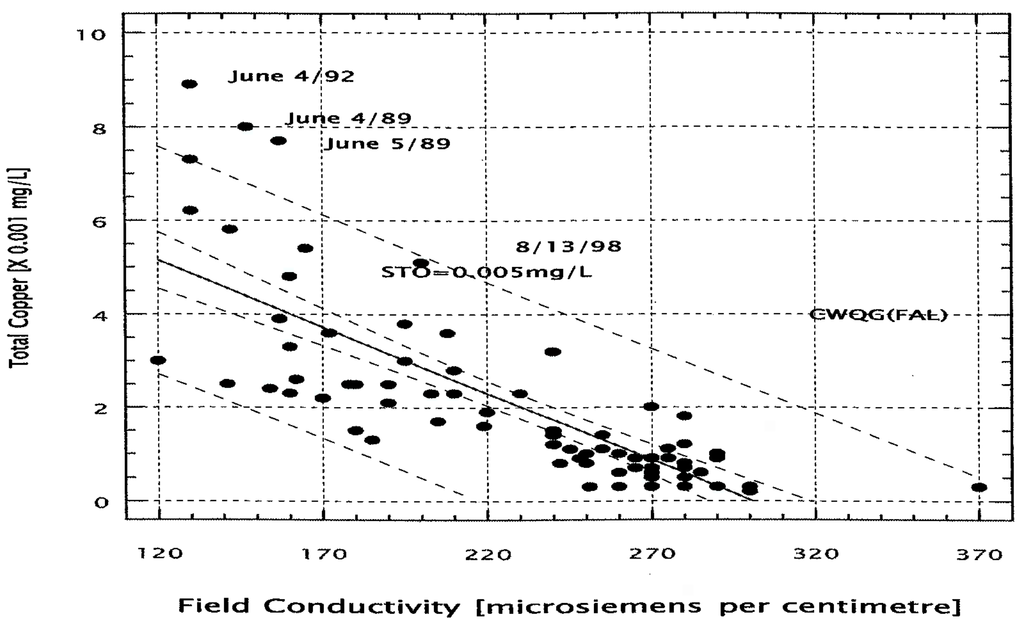
WQ = A + (B x Q)

where WQ = water quality value, Q = flow, A = y-intercept of line, B = slope

Field conductivities measured at South Nahanni River above Rabbitkettle River between 1988 and 1997 ranged from 120 to 370 microsiemens per centimetre (μs/cm), corresponding to flows ranging from 830.0 to 24.1 cubic metres per second (cms), respectively. The flows may have a larger range since manual measurements were only taken during the 1994-1997 period.

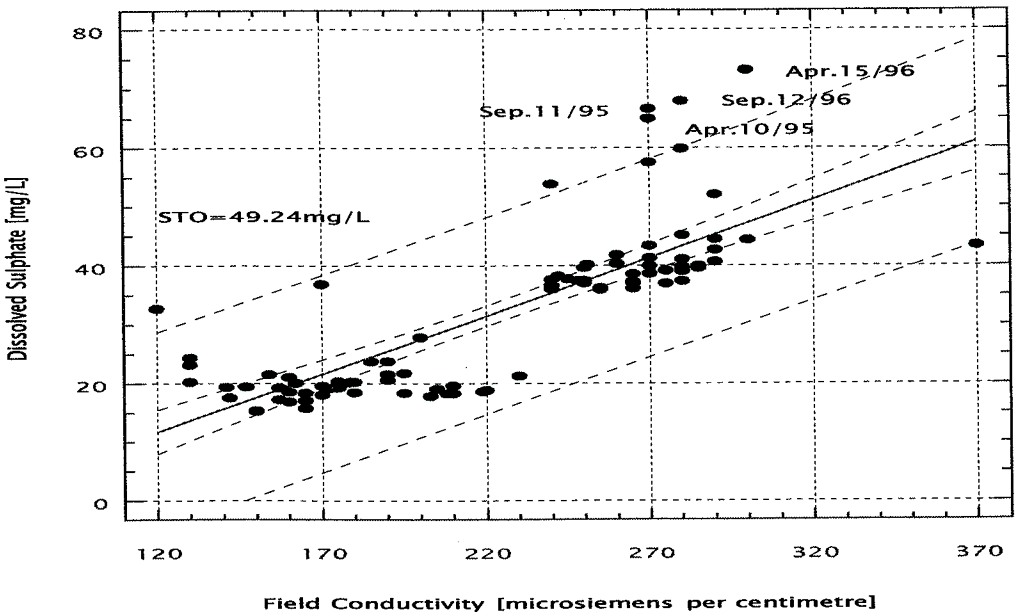
Strong positive flow correlation between water quality and flow values is indicated by the large, negative Spearman "rho" (non-parametric) correlation coefficients (i.e. rho <= -0.65) existing between field conductivity and non-filterable residue, or NFR (-0.9033, N=82), extractable manganese (-0.9005, N=82), extractable iron (-0.8622, N=82), total copper (-0.8481, N=82, Figure 16), total vanadium (-0.7942, N=82), total cobalt (-0.7201, N=82), and total lead (-0.6819, N=82). Other such correlations exist but sample populations are statistically small (i.e. N<30).

Figure 16. SNR/Rabbitkettle R., Tot. Copper vs Field Cond.



Dissolved sulphate (rho=+0.8252, N=82) exhibits strong negative correlation with flow, as indicated by strong to moderate positive correlation with field conductivity (Figure 17), as does dissolved selenium (rho=+0.7571, N=54).

Figure 17. SNR/Rabbitkettle R., Diss.SO4 vs Field Cond.



Similar negative correlation with flow is exhibited by dissolved barium, molybdenum, and selenium. 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.

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 ammonia3 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. Dissolved nitrate-nitrite 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. Most of the 28 water quality variables exhibit some correlation with flow. These relationships are shown in Figure 10.

Rabbitkettle River at Mouth Water Quality Station

Field conductivities measured at the site between 1988 and 1997 ranged from 105 to 315 microsiemens per centimetre (μs/cm) at Rabbitkettle River Mouth. Like Prairie Creek, flow data is not available for Rabbitkettle River nor can it be reliably estimated. Flow is strongly, albeit negatively, correlated with field conductivity, as expected. Linear regressions of water quality variables were carried out against field conductivity at the Rabbitkettle River/Mouth water quality site.

Strong to moderate negative correlations (rho < -0.65) exist between field conductivity and extractable manganese (rho=-0.7810, N=32), extractable iron (rho=-0.7171, N=32), total cobalt (rho=-0.7164, N=32), total copper (rho=-0.6946, N=32, Figure 18), total zinc (rho=-0.6616, N=32, Figure 19), and total nickel (rho=-0.6528, N=32).

Figure 18. Rabbitkettle R.Mouth, Total Copper vs Field Cond.

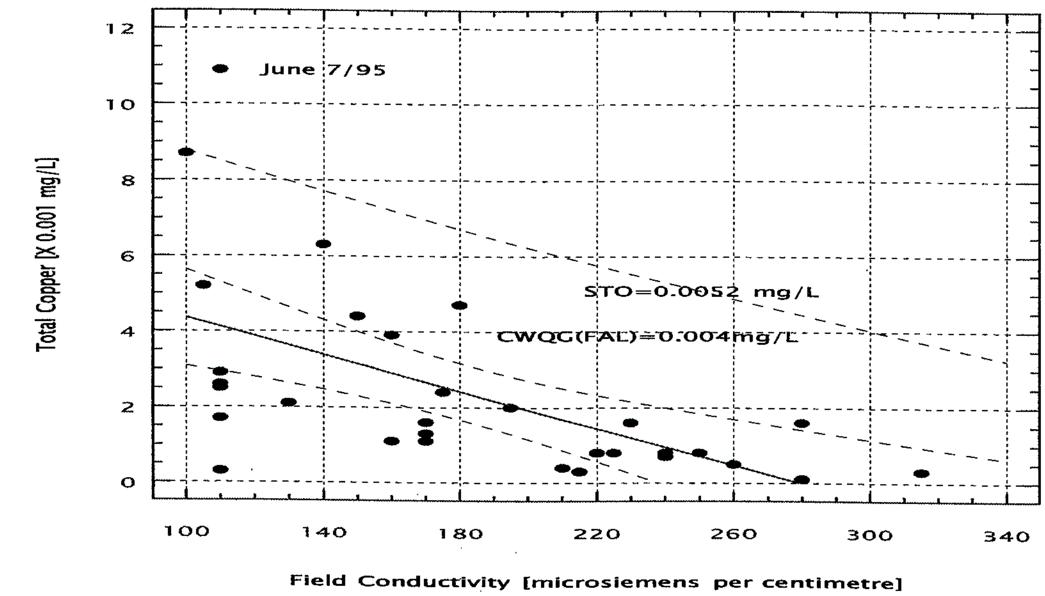
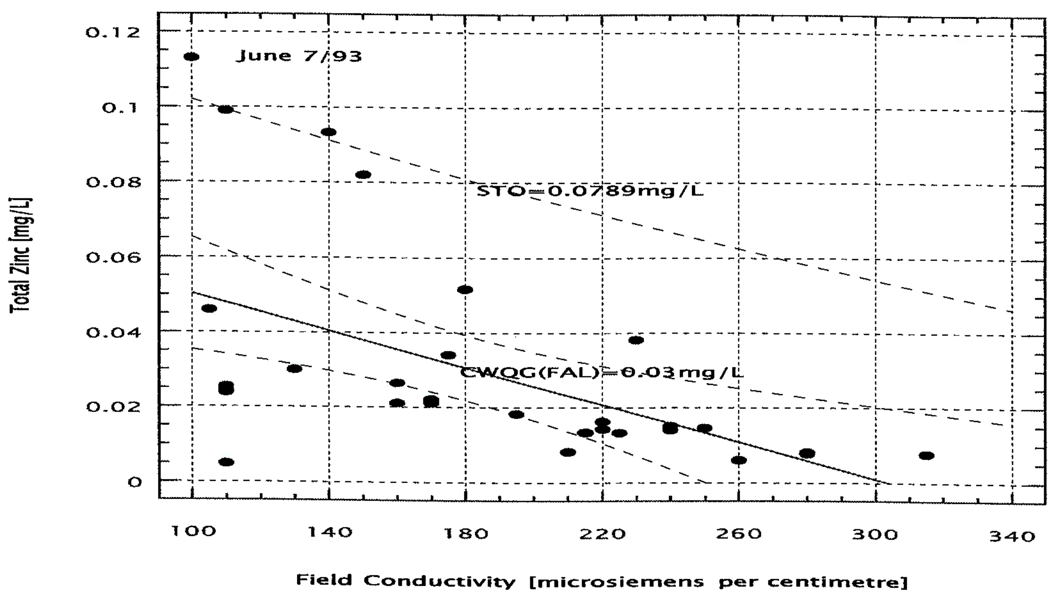


Figure 19. Rabbitkettle R.Mouth, Total Zinc vs Field Cond.



Field pH exhibits a moderate positive correlation with field conductivity, possibly because of the contributions of the nearby Rabbitkettle Hot Springs and ground water to overall water quality. 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 to exhibit this relationship.

Dissolved selenium exhibits a moderately strong negative correlation with flow as indicated by a +0.7012 Spearman's "rho" value against field conductivity for N=32 values.

The sample size of water quality samples at this site (e.g. N=16 for other variables) is not statistically large (i.e. N<30), making any other conclusions premature.

Non-filterable residue; extractable iron and manganese; dissolved arsenic, iron and copper; and total barium, cadmium, cobalt, copper, iron, lead, nickel, vanadium and zinc concentrations are directly proportional to flow. Field pH and conductivity; total cyanide; and dissolved sulphate, barium, cadmium, cobalt, copper, manganese, nickel, selenium, zinc, and sulphate concentrations are inversely proportional to flow, due to dilution effects. 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. 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 are correlated with flow to some extent.

South Nahanni River above Virginia Falls Station

The SNR above Virginia Falls site has a gauge (and meteorologic station), which allowed linear regression of water quality variables to be carried out on flow. 1994-1997 field conductivity values ranged from 140 to 320 µs/cm at the SNR Virginia Falls site while 1994-1997 flows ranged from 30.5 (April 1996) to 850 cms (June 1997), on days when water quality samples were collected.

It appears that moderate to strong positive correlations exist between (mean daily) flow and field pH, NFR, and turbidity; total ammonia, aluminum, barium, beryllium, cadmium, chromium, cobalt, copper, iron, nickel, lead, vanadium and zinc; extractable iron and manganese; and dissolved copper. This is exemplified by NFR (Figure 20), total copper (Figure 21) and extractable iron (Figure 22). The sample size (N) of 16 to 17 is statistically small (i.e. N<30), so conclusions may be premature.

Figure 20. SNR/Virginia Falls, NFR vs Flow

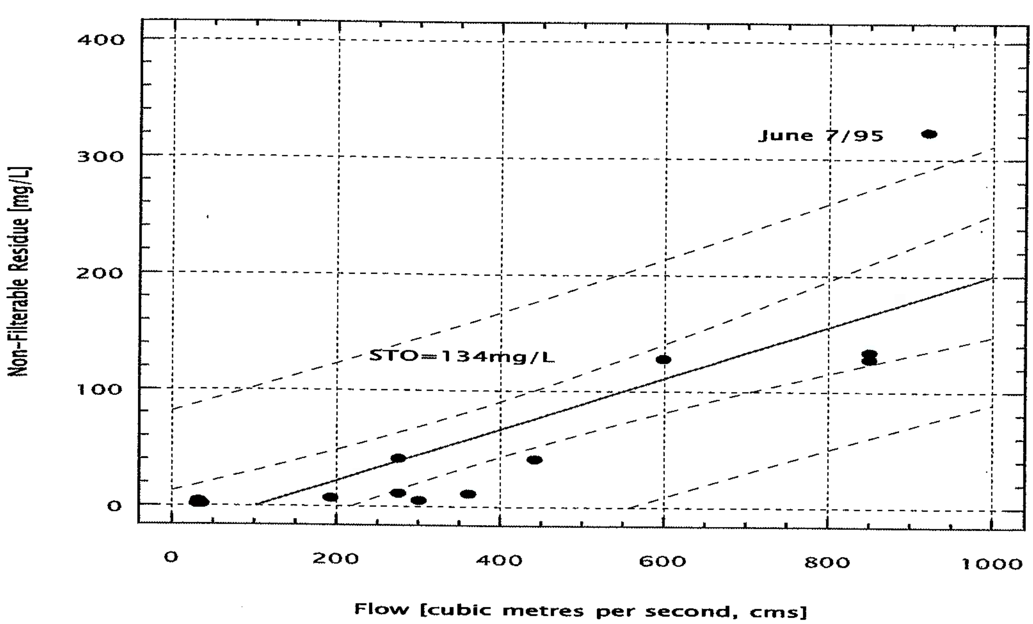


Figure 21. SNR/Virginia Falls, Total Copper vs Flow

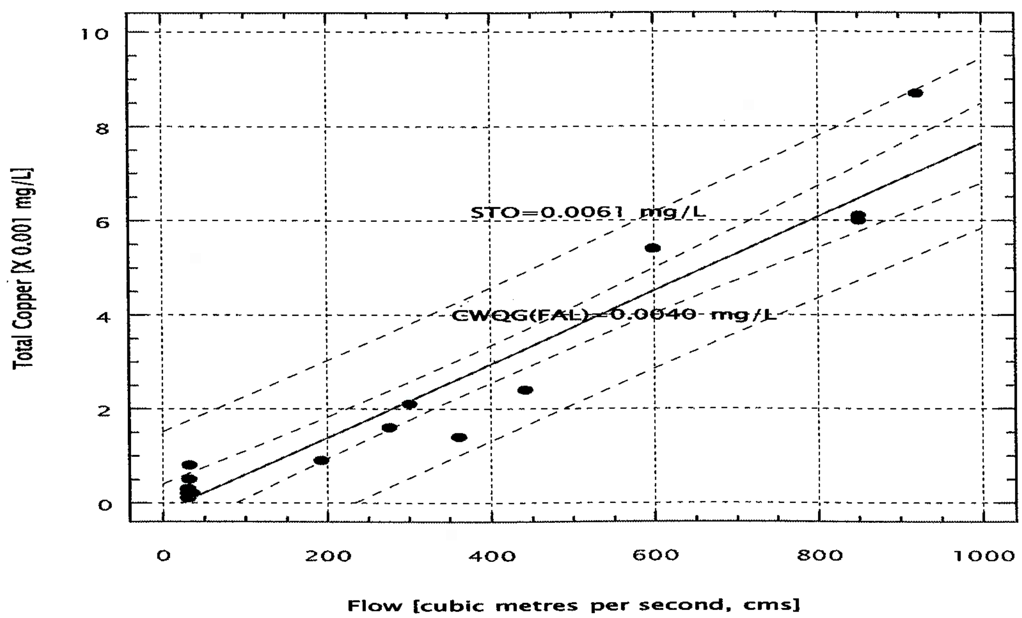
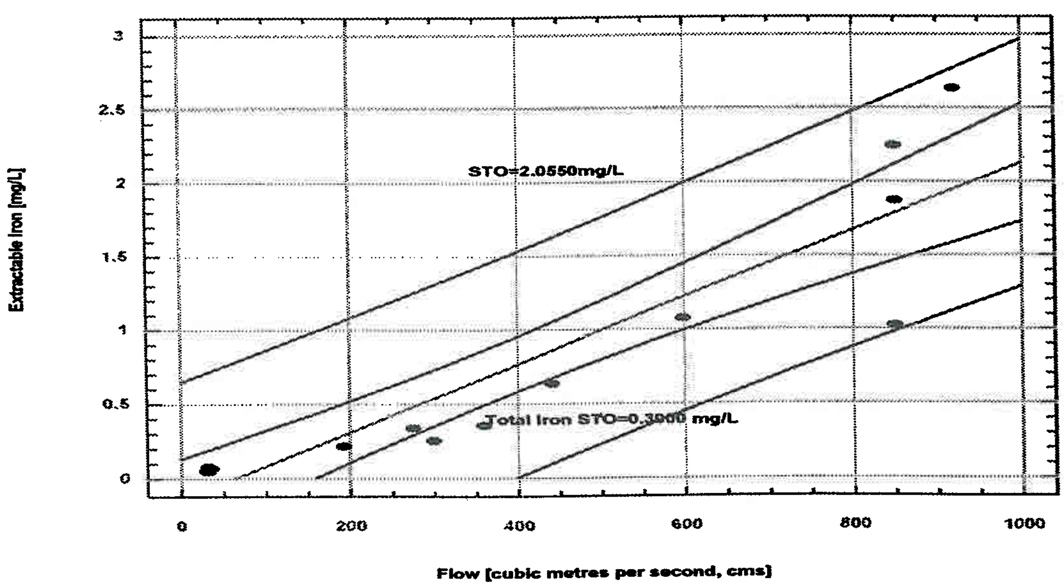


Figure 22. SNR/Virginia Falls, Extractable Iron vs Flow



Moderate to strong negative correlations appear to exist between flow and field conductivity; dissolved sulphate, barium, lithium, molybdenum, selenium, strontium and zinc. No correlations appear to exist between flow and other trace metals. Again, the small sample size makes some conclusions premature.

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 1994-1996. Linear regression of water quality variables was, therefore, carried out on field conductivity instead of flow. Field conductivities ranged from 130 to 290 µs/cm at the Flat River Park Boundary site between 1994 and 1996.

The small sample size of 11 makes any conclusions about flow dependence of water quality variables premature. It appears that negative correlations exist between field conductivity and NFR, turbidity; total aluminum (Figure 23), cadmium, cobalt, chromium, copper (Figure 24), nickel, lead, vanadium and zinc; dissolved arsenic and barium; and extractable iron and manganese. Positive correlations exist between dissolved sulphate, lithium, molybdenum, nickel selenium, strontium and zinc. No correlations exist between total ammonia; total barium; and dissolved cobalt, iron, lead and manganese. 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 the Flat River.

Figure 23. Flat R. Park Bdry., Tot.Aluminum vs Field Cond.

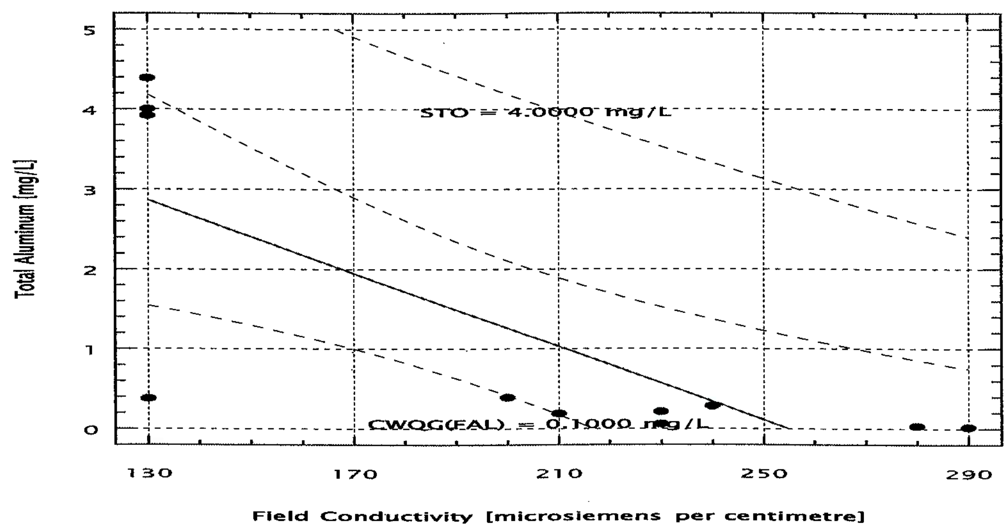
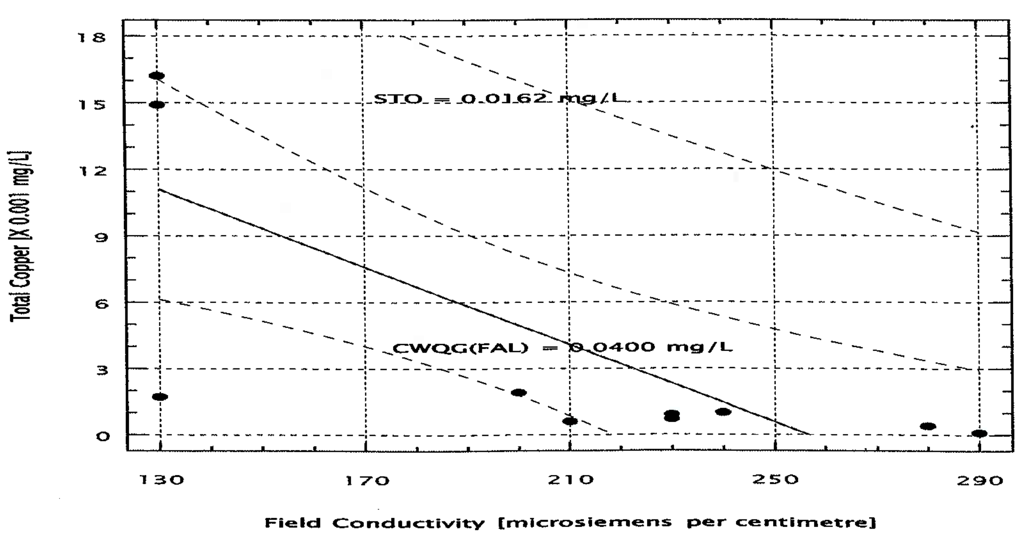


Figure 24. Flat R.Park Bdry., Tot.Copper vs Field Cond.



The Flat River at Park Boundary site results are used, in connection with the Flat River mouth site results to discern any spatial variability in the water quality between the sites due to the contribution of the Flat River's major tributary, the Caribou River, which flows into the Flat River between the two sites. This matter has been dealt with in a previous section of this report.

Flat River at Mouth Water Quality Station

The hydrograph (Figure 6) illustrates patterns of the annual flow at the Flat River at 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 maximum annual daily stream flows during summer depend upon summer rainfall, including rainstorms. Flat River at Mouth daily mean flows measured on days when water quality samples were collected over a 25 year period (1972-1996) have ranged from 4.8 (February 28, 1986) to nearly 900.0 (June 7, 1992) cubic metres per second (cms). Historic September to October flows are higher on the Flat River due to greater forest cover and retentive soils (Environment Canada, 1991).

Field conductivity has a strong negative correlation with flow at the Flat River Mouth site, like the South Nahanni River above Rabbitkettle River site. Over the 1988-1997 period, field conductivity values ranged from 110 to 496 microsiemens per centimetre (μs/cm).

At the Flat River Mouth site, 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. Field conductivity is directly proportional to total dissolved solids (TDS) and inversely proportional to non-filterable residue (NFR), sometimes known as total suspended solids (TSS). NFR correlates well with flow, with a Spearman's "rho" = +0.8168 for statistically large sample size N=149. Dissolved solids or minerals, such as carbonates and sulphates, are contributed from mineral springs via ground and surface water runoff.

Other water quality variables strongly to moderately positively correlated with flow (Spearman's "rho" >+0.65 and sample size in brackets) and from statistically large (N>30) sample sizes are extractable iron (+0.8322, N=148), turbidity (+0.8130, N=96), extractable manganese (+0.7471, N=151), total vanadium (+0.6993, N=142), and total cobalt (+0.6606, N=142). This behaviour is exemplified by extractable iron (Figure 25) and turbidity (Figure 26). Weaker positive flow correlation exists for total lead (+0.6212, N=146), total barium (+0.5926, N=139), and total copper (+0.5175, N=143, Figure 27).

Figure 25. Flat R./Mouth, Extractable Iron vs Flow

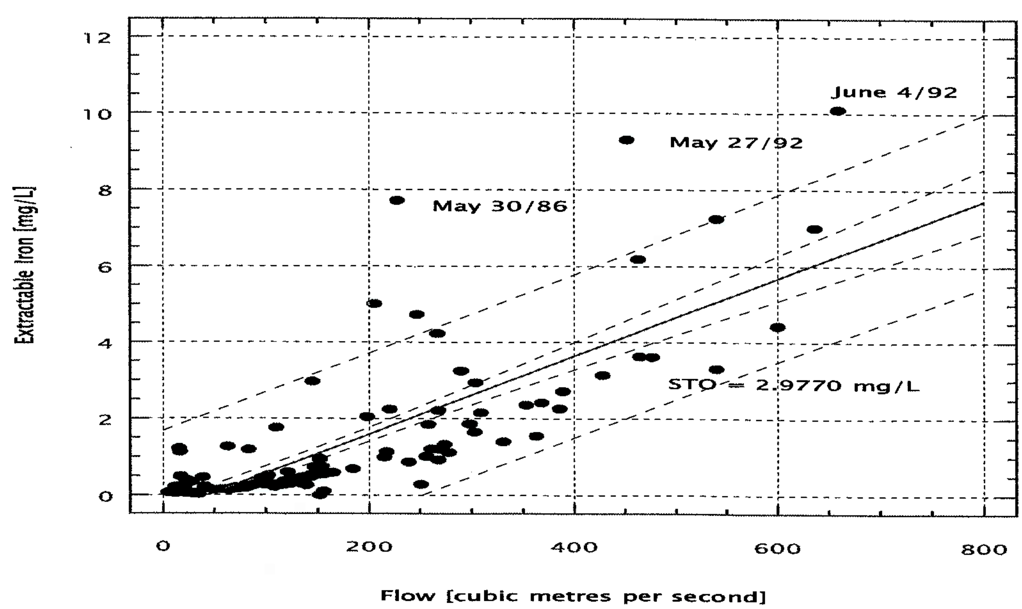


Figure 26. Flat R./Mouth, Turbidity vs Flow

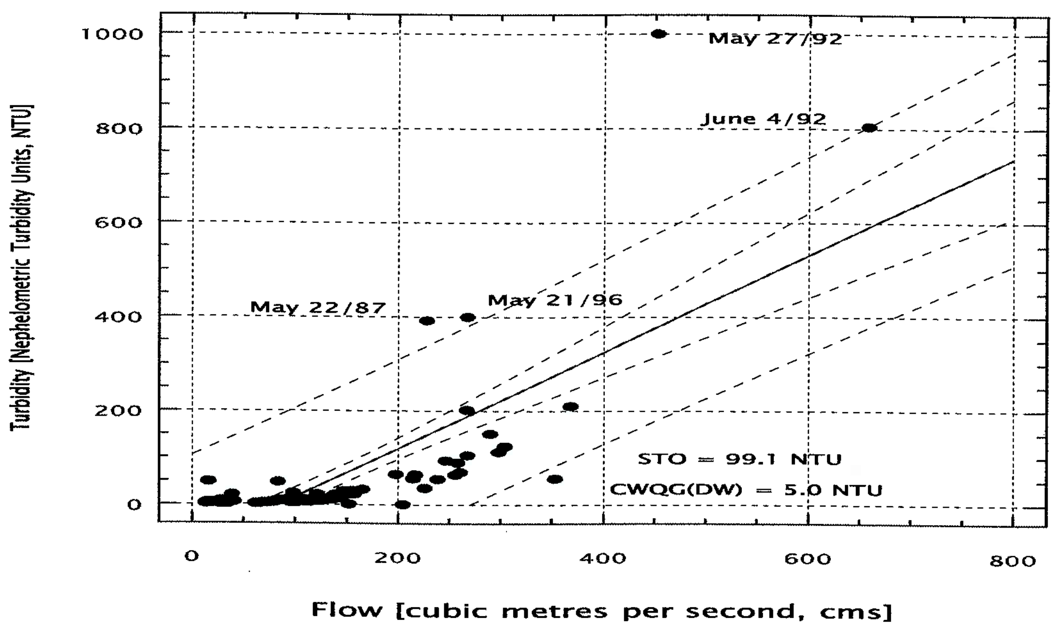
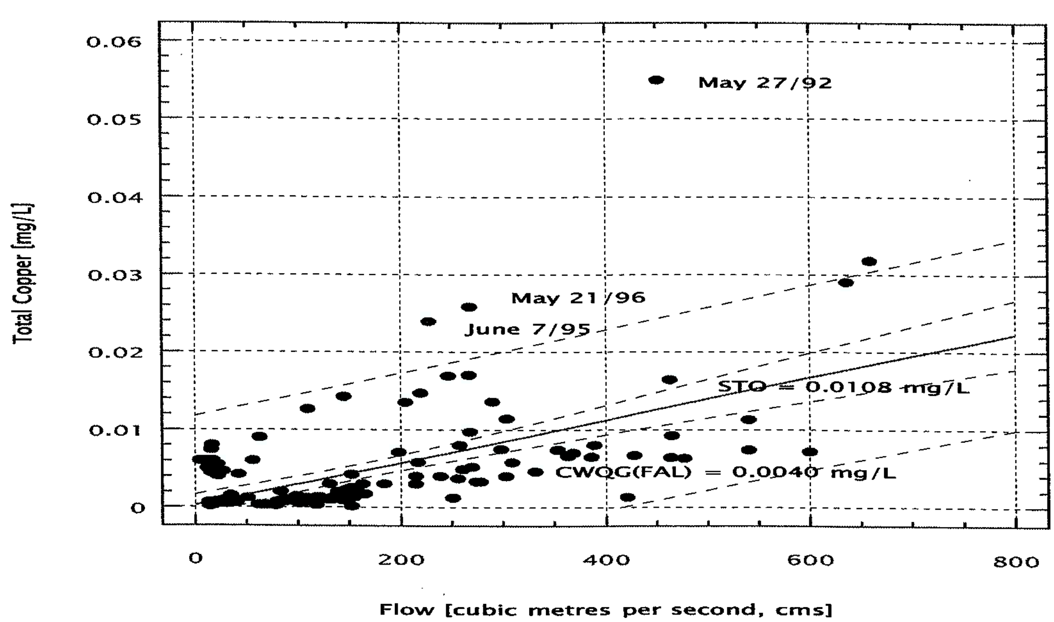


Figure 27. Flat R./Mouth, Total Copper vs Flow



Water quality variables **negatively** correlated with flow (Spearman's "rho" and sample size in brackets) and having statistically large sample sizes are field conductivity (-0.9027, N=159, Figure 15) and dissolved sulphate (-0.8969, N=154, Figure 28).

Figure 28. Flat R./Mouth, Dissolved Sulphate vs Flow

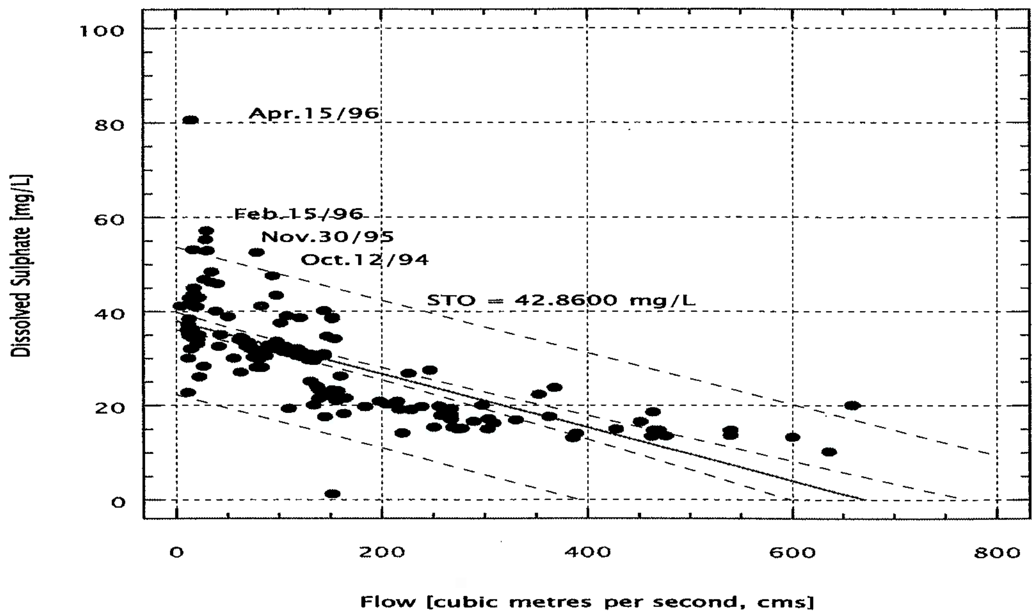


Figure 10 shows that total copper, zinc, lead, nickel, vanadium, cobalt, cadmium, and barium values **increase** with increasing flow. Dissolved lead and arsenic also increase with increasing flow, as do extractable iron and manganese, NFR, total ammonia, pH and total cyanide. Dissolved barium, cadmium, 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 6). Nearly half of the 28 water quality variables with objectives are moderately to strongly flow-controlled (i.e. $r >= +0.65$ or $r <= -0.65$). 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 Pearson's "rho" nonparametric 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 "rho" values exist between field conductivity and dissolved sulphate; both are negatively correlated with flow.

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 27 (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 (Figure 10). 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.

Earthquakes seem to have affected water quality in Nahanni NPR, as is illustrated at the long-lived (1972-1997) Flat River Mouth water quality site. According to Natural Resources Canada's Canadian National Earthquake Database's internet homepage, twelve earthquakes measuring between 5 and 6 on the Richter Scale occurred between October 6, 1985 and March 2, 1986 and their epicentres were in the eastern half of the Nahanni NPR-Ram Plateau area, all having a focus (source) of about 10 kilometres depth. Statistically large size samples of water quality results from both before and after this period of frequent earthquakes were compared at the Flat River Mouth site (located a few tens of kilometres from the epicentres). Water quality variable values were found to be higher after the frequent earthquake period for the following variables: true colour, non-filterable residue (NFR), turbidity, sulphate, dissolved trace metals (iron, manganese, lead), extractable trace metals (aluminum, manganese, vanadium), and, especially, total (mostly particulate) trace metals (barium, beryllium, cadmium, cobalt, copper, manganese, nickel, lead, vanadium, zinc).

The mothballed Cangtung (Tungsten) Mine, upstream from the Flat River/Mouth water quality site, contained nine million metric tonnes of ore grading 1.4% WO3 and 0.2% Cu (GSC, 1984), and operated between 1964 and 1986. A considerable amount of tailings were deposited along the Flat River prior to 1970. Time trend analysis was, therefore, carried out on the 1972-1996 Flat River/Mouth total flow and total copper data sets to determine whether there are any long-term trends in flow and/or total copper levels, total (mostly particulate) copper levels being somewhat controlled by flow (Spearman's "rho"=+0.5175 for N=143). Linear trend analyses, using StatsGraphics software, yielded 95% confidence level fitted models, showing a slight long-term increase in flow (Figure 29) and decrease in total copper levels (Figure 30). Therefore, there is no increase in total copper levels (i.e deterioration of water quality) with time. In fact, total copper is actually decreasing slightly despite the fact that flow is gradually increasing over a 25 year period.

Figure 29. Flat R./Mouth, Long-Term Trend Analysis, Flow

147.957+0.0508671*T

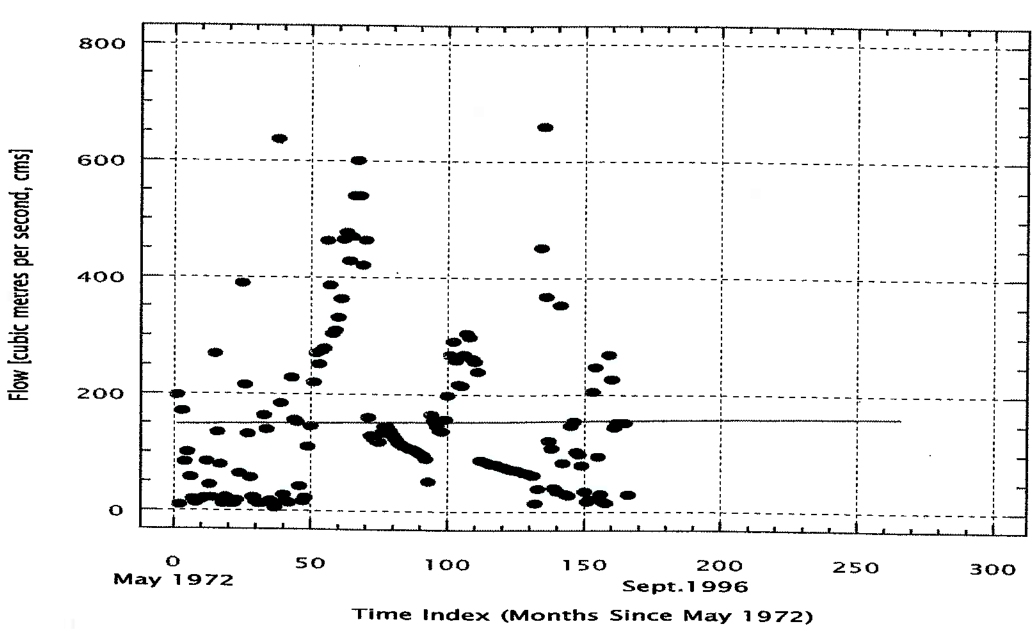
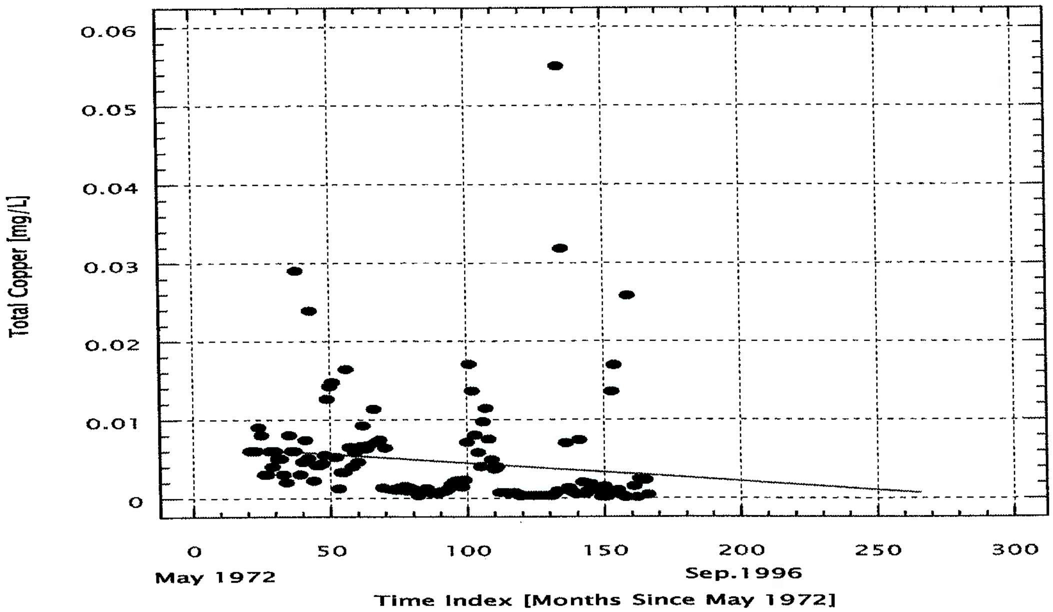


Figure 30. Flat R./Mouth, Trend Analysis, Total Copper

0.00676971-0.0000228955*T



StatsGraphics long-term total copper trend analyses were checked using Colorado State University WQ Stat II shareware software and Seasonal Kendall Tau Tests. A slope (Sen Slope Estimate) of -0.00015 mg/L total copper per year was obtained, indicating a slight decrease in total copper levels over time, for 1972-1993 data. The WQ Stat II software was also used to perform the Seasonal Kendall Tau Test for the 1972-1986 (Cantung Mine production) and 1986-1993 (Cantung Mine post-production) periods separately. Both periods yielded slopes of -0.00016 mg/L total copper per year, suggesting that the effects of Cantung Mine tungsten-copper production on copper levels cannot be detected at the Flat River/Mouth water quality site, downstream of it.

Prairie Creek at Mouth Water Quality Station

Similar relationships occur in Prairie Creek. Spring freshet and summer rainstorm 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 1988-1997, field conductivities ranged from 160 to 440 µs/cm. Much lower 1992 field conductivity values ranged from 160 to 395 µs/cm, reflecting higher flow rates in 1992. Manual flow measurements were made at this site between 1994 and 1997.

Figure 31 illustrates that dissolved copper is strongly to moderately negatively correlated with field conductivity (and **positively** correlated with flow), and having statistically large sample sizes. Such variables (Spearman's "rho" in brackets) include total copper (-0.6694, N=97), NFR (-0.6504, N=88), dissolved copper (-0.5661, N=59, Figure 31), and total zinc (-0.4210, N=97, Figure 32).

Figure 31. Prairie Ck./Mouth, Diss.Copper vs Field Cond.

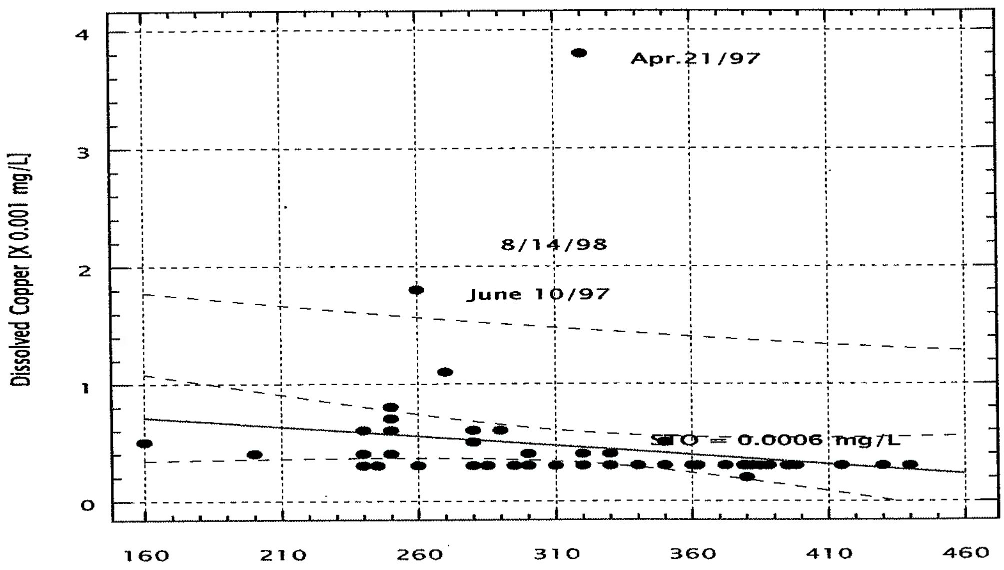
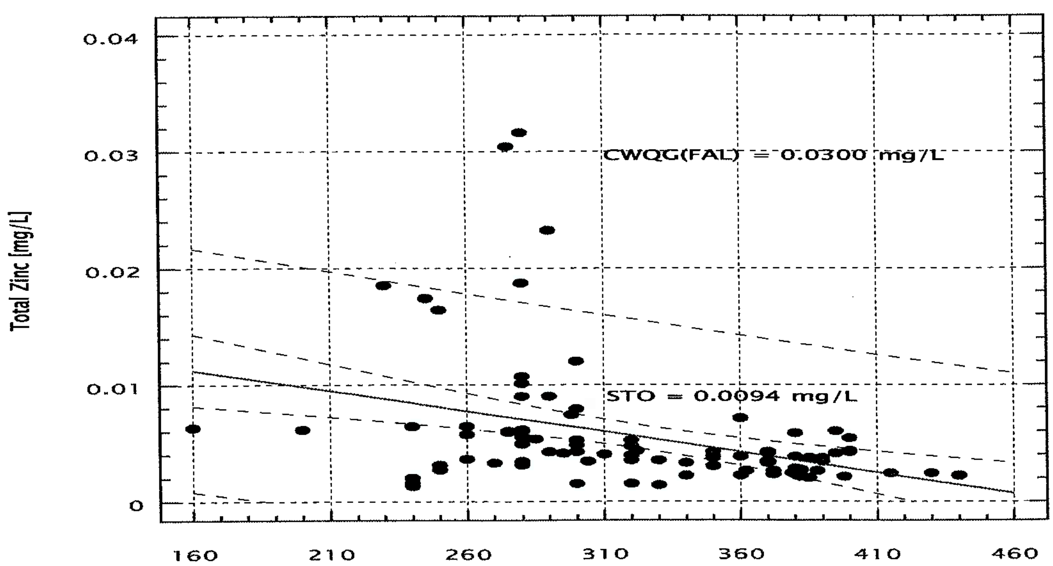
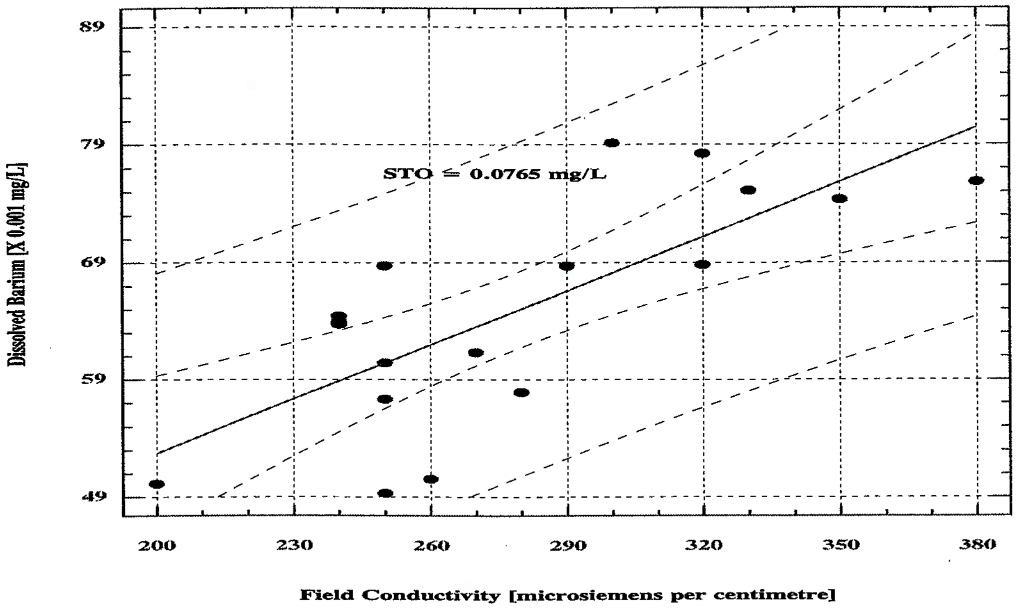


Figure 32. Prairie Ck./Mouth, Total Zinc vs Field Cond.



Water quality variables **positively** correlated with field conductivity (and **negatively** correlated with flow) include dissolved barium (+0.6863, N=59, Figure 33), selenium (+0.5658, N=59) and strontium (+0.5627, N=59). Dissolved arsenic, manganese, nickel, and zinc; and total ammonia exhibit no correlation with flow or field conductivity.

Figure 33. Prairie Ck./Mouth, Diss.Barium vs Field Cond.



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. rho = +0.65 to +0.80) with field conductivity while dissolved and total copper, and NFR exhibit a moderate negative correlation (i.e. r = -0.65 to -0.80). This is shown in Figure 10.

South Nahanni River above Nahanni Butte Water Quality Station

Field conductivities near Nahanni Butte ranged from 140 to 500 µs/cm. While flow data are not available for the Nahanni Butte water quality station, several methods can be used to compute flow at Nahanni Butte for the period of 1988-1995, using long-term data from the SNR above Clausen Creek gauge. From at least three available methods, the method described in the Appendix of this report was selected.

This method assumes the same unit runoff (flow per square kilometre) for the drainage area between SNR above Clausen Creek and SNR above Nahanni Butte as between SNR above Virginia Falls-Flat River Mouth and SNR above Clausen Creek. Relevant flows for days around the days on which flows at SNR above 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 above Virginia Falls-Flat River Mouth and SNR above Clausen Creek (i.e. Virginia + Flat - Clausen), multiplying this flow by the 5,100 to 7,940 square kilometre drainage area ratio, and adding the result to flows at SNR above Clausen Creek to obtain the flow at SNR above Nahanni Butte.

Because the SNR above Clausen Creek gauge did not operate in 1996 and 1997, synthetic daily flow estimates could not be calculated for these years. Therefore, linear regressions of water quality variables were carried out against field conductivity, not synthetic discharge (which could be used during 1988-89 and 1992-1995), in lieu of actual measured flows at Nahanni Butte in 1996 and 1997.

There were no water quality variables strongly to moderately **positively** or **negatively** correlated with flow (Spearman's "rho" <- 0.65 or >+0.65, respectively, for water quality variables versus field conductivity) for statistically large sample sizes. The positive correlation of physicals and total metals with flow, and the negative correlation of (dissolved) major ions and dissolved metals with flow, are both observed at the SNR above Nahanni Butte site, but the coefficients are lower than at other sites. This may be due to the fact that this site integrates all upstream effects, and is the least "flashy" of all the sites.

Extractable iron and manganese; NFR and turbidity (Figure 34); total cyanide; total aluminum (Figure 35), barium, cadmium, cobalt, copper (Figure 36), 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. Some conclusions (e.g. those involving total aluminum and Figure 35) may be premature due to the statistically small (i.e. N<30) sample size.

Figure 34. SNR/Nahanni Butte, Turbidity vs Field Cond.

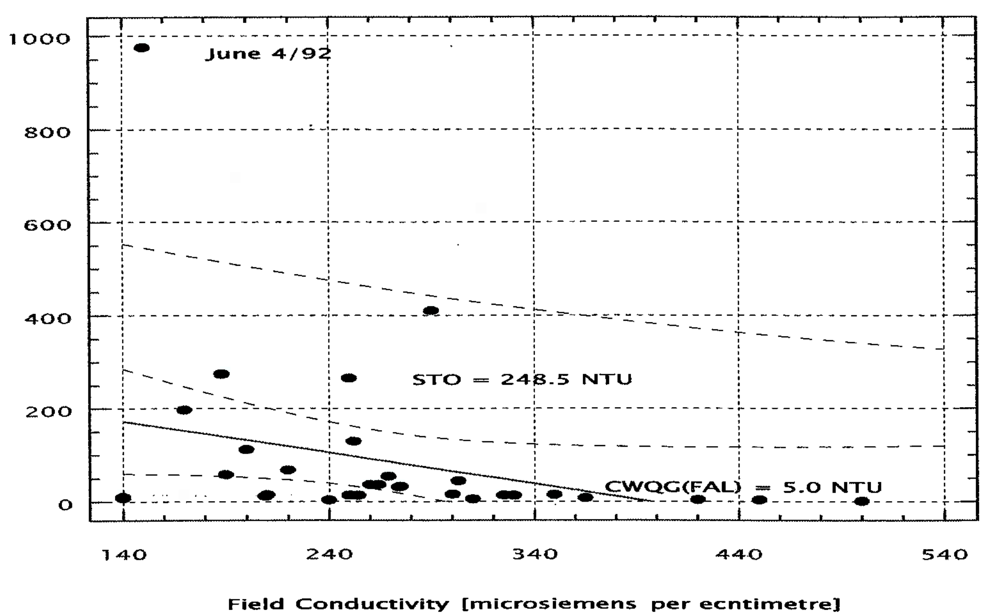


Figure 35. SNR/Nahanni Butte, Tot.Aluminum vs Field Cond.

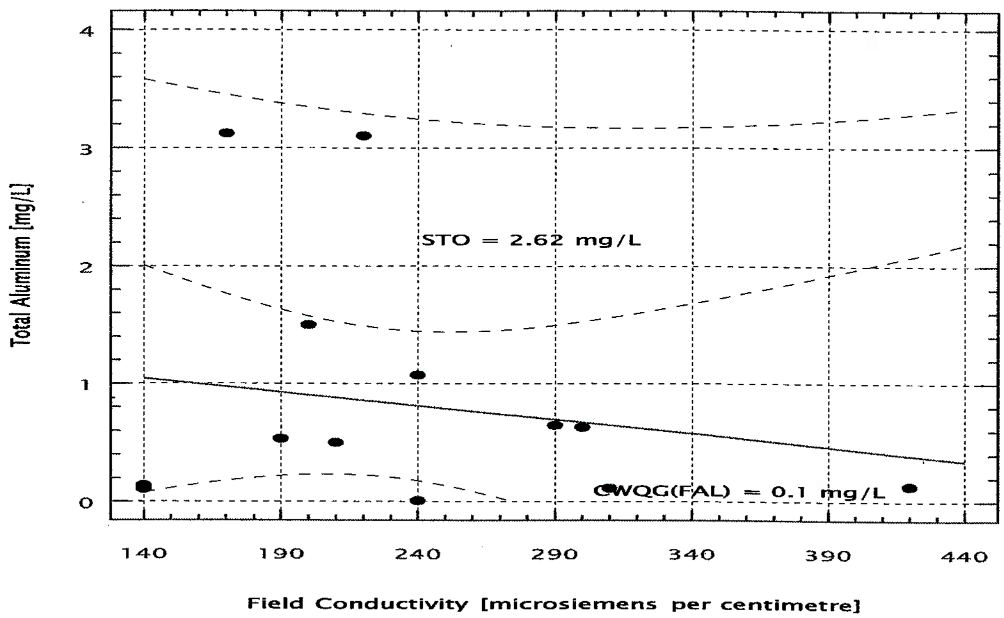
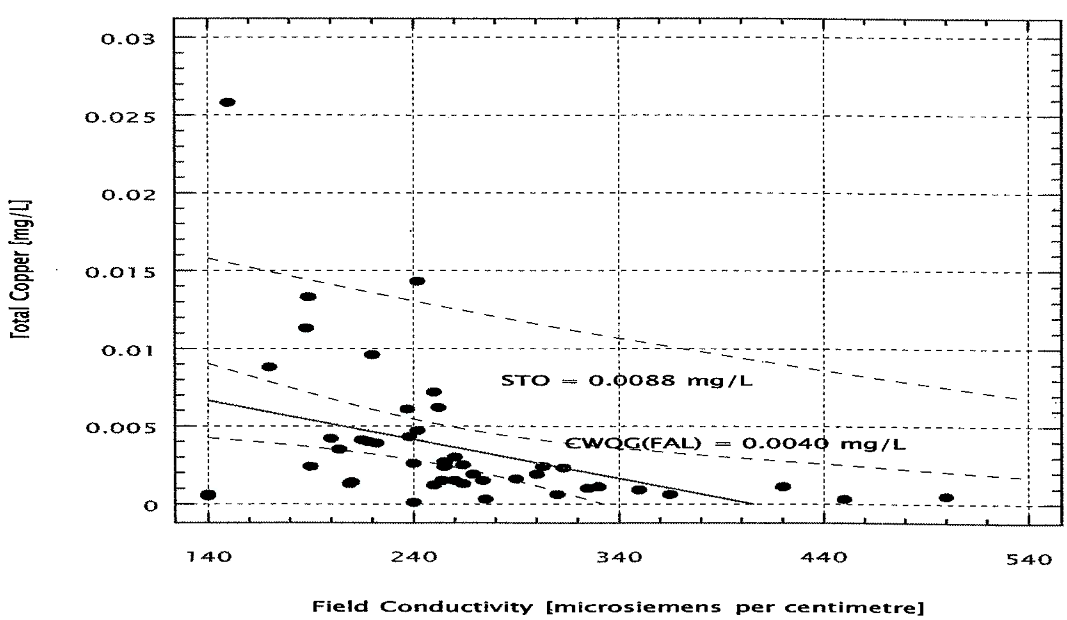


Figure 36. SNR/Nahanni Butte, Total Copper vs Field Cond.



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. 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. $r <= -0.65$). These relationships are also shown in Figure 10.

4.3 Significance of Metals and Other Results

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 1988-97, pH appeared unrelated to flow except at the Rabbitkettle River at Mouth, Flat River at 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, 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 later winter baseflow period appears to be negligible. The effect of surface waters appears to dominate. Gulley (1993) mentions that Nahanni NPR ground water did not quite reach boiling point, and that isotopic compositions of Nahanni NPR surface and ground water do not differ significantly. The same may be true for field pH values.

In the relative sense, lower pH values due to increased flow are not apparent in the 1988-89 and 1992-1997 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 metals 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.

Non-filterable residue (NFR) values, sometimes called total suspended solids (TSS) values are measures 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 (SNR) 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 peak flow at SNR, Flat River Rabbitkettle River, and, to a lesser extent, Prairie Creek. NFR may be lower at Prairie Creek because the 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 so that the rate of bank erosion is not related to flow. Later on in the summer, bank erosion is related to flow. Rainfall events and certain anthropogenic activities (e.g. road construction, exploration drilling, all known to be occurring in the Prairie Creek catchment basin) cause localized sediment contributions. 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).

Nutrient values, such as nitrogen, phosphorus and carbon values (the latter, in various chemical forms) exhibit both spatial and temporal variability. 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 for dissolved nitrate-nitrite and total ammonia at the five 1992-1997 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).

Total, extractable, particulate, and dissolved trace metals, especially in the bioavailable, dissolved forms, can pose a threat to the health of aquatic systems due to their toxicity to organisms, bioconcentration (bioaccumulation) occurring within organisms with time and biomagnification occurring within the food chain with trophic level. There are 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 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 catchment basins 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 adsorption 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. As 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. 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 in 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, 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). Thus, it is important to measure metals levels under late winter baseflow conditions, as was done during the 1992-1997 follow-up fieldwork.

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, and 1992-97 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 13-14).

Metal concentrations in the basin were almost always below water quality guidelines for the protection of aquatic life. More exceedances were noted during the 1992 and 1997 water years than during 1988, 1989 and 1993-1995, due to higher flows (Figures 5-7) and collection of samples during peak 1992 and 1997 spring freshet flows. Existing concentrations are not a threat to the health of the aquatic ecosystem.

Effective July 1995, evaluation of the importance 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). Setting of these freshwater CSQGs provides a context for results of suspended sediment sampling at SNR above Nahanni Butte and three other SNR sites of increased importance (Environment Canada, 1991). High (per cent) values have been recorded for total iron and aluminum.

High total iron values are believed to be due to bedrock 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.

When the high aluminum content of the suspended sediment samples was first observed, contamination was suspected. Field and laboratory contamination has been ruled out as sources of aluminum. It is, therefore, likely that these values do represent the levels of aluminum naturally present in these suspended sediments. High aluminum values are likely due to abundance of alumino-silicate clays from erosion of clay-rich tills and post-glacial lake deposits, and 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 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. As total aluminum levels in stream waters from Prairie Creek at Mouth site are not elevated relative to the other six Nahanni NPR water quality sites, alumino-silicate-rich drilling muds from diamond drilling by San Andreas Resources Corporation (SARC) (DIAND, 1994) are not believed to be 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 were made aware of this environmental concern. Suspended sediments also contained elevated levels of aluminum (Section 6.0).

During a September 1992 survey at two sites close to SNR below Prairie Creek and Dry Canyon Creek, scientists from Fisheries and Oceans Canada's Yellowknife office 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 (Section 7.0). 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 SNR below Prairie Creek (near Dry Canyon Creek) and at Flat River near MacLeod Creek (near the Park Boundary) in September 1994. A minimum of 10 specimens of each fish species were collected to assess levels of heavy metals in fish tissue. Analyses of these fish tissue samples was completed in January 1997. Some elevations in copper, cadmium, mercury and zinc were noted, and these are discussed in Section 7.0.

5.0 WATER QUALITY PROTECTION

5.1 Background

Water quality objectives have been set for the waters of Nahanni National Park Reserve, based on the 1988-1991 Environment Canada-Parks Canada study of Park water quality, and subsequent 1992-1997 Environment Canada-Parks Canada monitoring program.

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 collected from throughout Canada 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 water bodies 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.

The water quality objectives developed for five Nahanni NPR sites (Flat River Mouth, Nahanni Butte, Prairie Creek Mouth, Rabbitkettle River Mouth, above Rabbitkettle River) in 1991 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 Taiga Cordillera and Taiga Plain Ecozones, 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).

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 flow (discharge), 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 Taiga Cordillera and Taiga Plain Ecozones, and small portions of Nahanni NPR are above the treeline. 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.

In 1997, water quality objectives were re-calculated for all seven water quality quality sites, as well as the SNR above Nahanni Butte sediment quality site, using the same 90th percentile Short-Term Objective (STO) and 50th percentile Long-Term Objective (LTO). Refer to Table 9 in the Appendix.

Nahanni Park STOs were derived as the 90th percentile value from the 1988-1991 (or 1972-1991, at the Flat River/Mouth site) study period and 1992-1997 monitoring period data sets. 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 1989, 1992, 1996 and 1997 spring freshet peak flows within the Park significantly exceeded those of 1988, 1993, 1994 and 1995 spring freshet peak flows at three gauge sites in Nahanni NPR (Figures 5-7). Water quality samples were also collected at the peak of the 1988, 1992, 1996 and 1997 spring freshets, resulting in a large number of STO exceedances during those water years. The exceedances were related to lack of data for high flow conditions rather than any change in natural basin conditions.

5.3 Water Quality Objectives

In 1997, short-term and long-term water quality objectives were re-calculated for all seven water quality quality sites, as well as the SNR above Nahanni Butte sediment quality site, using the same 90th percentile Short-Term Objective (STO) and 50th percentile Long-Term Objective (LTO), using all available data. Refer to Table 9 in the Appendix.

Data from stations at the South Nahanni River-Rabbitkettle River confluence define quality of the water entering the Park. Both have mineral occurrences and claims in their headwaters. Data from the SNR Virginia Falls station defines water quality/quantity 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 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. 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. Long-term objectives show trends which may occur over a period of time, and involve comparison of annual or seasonal means to median values from historical and future data sets (Blachford, 1988).

Nahanni Park short-term objectives (STOs) are similar to short-term indicators, and were set, in 1991, at the 90th percentile value for the period of record. These values include almost all values on record, except for extreme outliers (Environment Canada, 1991). STOs were revised for the five original sites (and initially set for two other sites) to include more recent data to the end of the 1997/98 fiscal year, following six years of additional monitoring (fiscal years 1992/93 through 1997/98, inclusive). An additional, sixth year (1997) was added, at the request of PCH, to include high water flows in lower Nahanni NPR due to an avalanche/-landslide, and subsequent natural dam formation and breaching, near the Clearwater Creek-Cathedral Creek confluence, that caused flooding of campsites and Park buildings in the Deadman Valley area near the SNR/Prairie Creek confluence during August 1997.

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 (1972-1996 for Flat River, 1988-1997 for the other 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 were reset at the end of the 1992-1997 monitoring program to include more recent, non-redundant 1992-1997 data, and are no longer limited to the 1988-1990 data set.

Sediment quality objectives were set for Nahanni NPR at the SNR above Nahanni Butte site only, using the actual and interim Canadian Sediment Quality Guidelines newly established in 1995. 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 values appearing in Table 2, in the Appendix, with CCME Canadian Water Quality Guidelines (CWQGs) shows that the LTOs and STOs are well below CWQGs (CCREM, 1995) for freshwater aquatic life. There are exceptions where Nahanni NPR's STOs exceed the corresponding CWQGs for turbidity, total aluminum, total copper, total zinc, and extractable iron. This indicates that the local geochemical background for Nahanni NPR is higher than the regional background of the NWT/Nunavut and national background of Canada for certain water quality variables.

Overall, the water quality of the SNR and its major tributaries is good. Over half of all 1988-1997 water quality values for Park monitoring sites are near, at or below lower limits of detection (LLOD) and lower limits of quantitation (LLOQ) of modern-day laboratory methods. Values less than LLODs are described as "non-detects". Values between the LLODs and (slightly higher) LLOQs are sometimes described as "trace" amounts, but are, in this case, shown as having values at or near LLODs. Laboratory values between LLODs and LLOQs for laboratory instruments tend not to yield "robust" water quality values, and tend to be less accurate and less precise than higher values. Some labs refer to such "non-robust" values as "trace" values, or "traces".

It is important to understand limitations of laboratory analyses and results at such low concentrations. For example, total and **dissolved** metal values between LLODs and LLOQs for induced coupling argon plasma (ICAP) and, especially, atomic adsorption (AA) instruments lack precision (repeatability) and accuracy. This explains why the dissolved lead objectives of 0.0012 and 0.0056 mg/L at the Prairie Creek/Mouth and Rabbitkettle/Mouth sites, respectively, enigmatically exceed the total lead objectives of only 0.0011 and 0.0015 mg/L, respectively. Lab technology improvements (e.g. increased automation and cost-effectiveness, lower LLODs and LLOQs) 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. There are still frequent cases where dissolved major cation values exceed their corresponding total major cation value, a problem that NLET Burlington lab is aware of and is working on the problem. The latest trace metals analysis technology, induced coupling argon plasma (ICAP)-mass spectroscopy (MS), scans up to 60 elements of the Periodic Table, and has much lower LLODs and LLODs than ICAP-AES or AA. The technology only became available to DOE's NLET Burlington lab and DIAND's Taiga Environmental Lab in Yellowknife in 1995, mid-way through the 1992-1997 follow-up monitoring program.

Most of the values are so low as to be below the lower limit of quantitation (LLOQ) and just above the lower limit of detection (LLOD), and the data is **non-robust.** This phenomenon is common and was discussed by Canada-wide EC staff and NLET Burlington lab staff in a June 28, 1995 teleconference call. 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 sample results, 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 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, to represent spring freshet and fall recession conditions, as done in Nahanni Park in 1988-1989 and 1992-1997 (winter baseflow conditions were also documented in 1992-1997). Comparison is somewhat subjective because objectives are based upon a limited data set, 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.

StatGraphics Plus software was used to perform statistics and prepare graphics. Linear regressions of water quality variables on flow (discharge) for EC's Flat River at Mouth and SNR above Virginia Falls gauging stations, calculated, on "synthetic" flow for SNR above Nahanni Butte (calculated by routing flows from SNR above 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 25 year (N=159 sample) historic (1972-1997) Flat River at Mouth data set confirms this pattern for the Nahanni Park area (e.g. "r" of -0.7948, r2 of 63.17%, Spearman's "rho" non-parametric rank correlation of -0.9027, rho-squared of 81.49%).

For data through 1997, "natural factors" refers to 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 mitigating measures to ensure operations maintain these environmental targets.

Exploration and development activities in the NWT were, until recently, screened by the Regional Environmental Review Committee (RERC) and regulated by the NWT Water Board under the Canadian Environmental Assessment Act (CEAA). Environment Canada and the Parks Canada staff participate in these screenings. Effective December 22, 1998, all environmental reviews in the Nahanni area, and in the Mackenzie River Valley in general, will be handled by the Mackenzie Valley Environmental Impact Review Board (MVEIRB) under the Mackenzie Valley Resource Management Act (MVRMA).

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, Parks Canada, and Indian and Northern Affairs Canada 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 at all Nahanni NPR sites, and especially downstream from 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 Exceedances of Water Quality Guidelines and Objectives

Water quality variables are plotted against flow (discharge) (e.g. SNR above Virginia Falls, Flat River Mouth sites), 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 the Flat River at Mouth site (Figure 15).

<u>Long-Term Objective (LTO) Exceedances</u>

<u>For the SNR above Rabbitkettle River site</u>, LTO exceedances were observed in 1996 and/or 1997 for field conductivity and pH; NFR, turbidity; total ammonia; dissolved chloride, sulphate and nitrate-nitrite; total aluminum, barium, beryllium, cadmium, cobalt, chromium, copper, iron, lead, lithium, manganese, molybdenum, nickel, strontium, vanadium and zinc; extractable iron and manganese; and dissolved aluminum, arsenic, barium, beryllium, cadmium, cobalt, iron, lithium, manganese, nickel, selenium, vanadium, and zinc. LTO exceedances have been noted throughout 1992-1997 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 hot springs 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.

At the Rabbitkettle River at Mouth site, LTO exceedances were also observed in 1996 and/or 1997 for field conductivity and pH; NFR, turbidity; total ammonia and cyanide; dissolved sulphate and nitrate-nitrite; dissolved aluminum, arsenic, barium, beryllium, cadmium, chromium, copper, lead, lithium, manganese, molybdenum, nickel, selenium, strontium, vanadium, and zinc; extractable iron and manganese; and total aluminum, beryllium, barium, cadmium, chromium, copper, iron, lead, lithium, manganese, molybdenum, nickel, strontium, vanadium, and zinc. No recurrent LTO exceedances were noted throughout 1992-1997, 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. Flow is controlled by artesian pressures, localized 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 100∞∞C (Gulley, 1993).

At the relatively new SNR above Virginia Falls site and the newly re-instated Flat River Park Boundary site, 1996 and/or 1997 LTO exceedances occur for all water quality variables. A larger database is required prior to calculation of such water quality objectives. Future monitoring is required to define these LTOs.

At the Flat River at Mouth site, LTO exceedances were observed in 1996 for field conductivity and pH; NFR and turbidity; total ammonia and cyanide; dissolved nitrate-nitrite and sulphate; dissolved aluminum, arsenic, barium, beryllium, cadmium, cobalt, chromium, copper, iron, lithium, manganese, molybdenum, nickel, selenium, strontium, vanadium, and zinc; extractable iron and manganese, and total aluminum, barium, beryllium, cadmium, cobalt, chromium, copper, iron, lead, lithium, manganese, molybdenum, nickel, strontium, vanadium and zinc. LTO exceedances were also noted in the period 1992-1997 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. Hot springs 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 at Mouth site, LTO exceedances were noted in 1996 and/or 1997 for field conductivity and pH; total ammonia; dissolved sulphate and nitrate-nitrite; dissolved barium, beryllium, chromium, copper, iron, manganese, molybdenum, nickel, selenium, strontium, vanadium, and zinc; and total aluminum, barium, iron, manganese, and strontium. LTO exceedances were also noted through the 1992-1997 period for dissolved nitrate-nitrite, selenium and zinc. 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 the SNR above Nahanni Butte site, LTO exceedances were observed in 1996 and/or 1997 for field conductivity and pH; NFR and turbidity; total ammonia and cyanide; dissolved nitrate-nitrite and sulphate; dissolved aluminum, barium, cobalt, chromium, copper, iron, lead, lithium, manganese, molybdenum, nickel, strontium, vanadium, selenium and zinc; extractable iron and manganese; and total aluminum, barium, beryllium, cadmium, cobalt, chromium, copper, iron, lead, lithium, manganese, molybdenum, nickel, strontium, vanadium and zinc. LTO exceedances have been noted throughout 1992-1997 for dissolved sulphate;

total barium, cadmium and zinc; and dissolved 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.

Short-Term Objective (STO) and Canada Water Quality Guidelines (CWQGs) Exceedances

STO exceedances outside water quality variable/flow (or field conductivity) regression line confidence limits were observed at all seven sites, during 1988-1997 late winter baseflow, spring freshet, and summer-fall recession.

At the SNR above Rabbitkettle River site, STO exceedances, not readily explainable by natural flow or field conductivity variability, occurred during June 1989 and June 1992 spring freshet for total copper (Figure 16). Similar STO exceedances were observed in April 1995 and 1996 baseflow, and September 1995 and 1996 fall recession, for dissolved sulphate (Figure 17). The most frequent STO exceedances at this site during the 1988-1997 period occurred for turbidity (46 times), total zinc (14 times), field pH and NFR (10 times each), dissolved nitrate-nitrite and sulphate, and total barium and copper (9 times each), and field conductivity, total cobalt and nickel (8 times each).

The CWQG for drinking water was exceeded for turbidity eight times. The CWQGs for freshwater aquatic life were also exceeded for total copper and zinc under hard water conditions (nine times each), and field pH (once). 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 the Rabbitkettle River at Mouth site, STO exceedances not readily explainable by flow or field conductivity occurred during the June 1995 spring freshet for total copper (Figure 18) and total zinc (Figure 19). The most frequent STO exceedances at this site during the 1988-1997 period occurred for turbidity (17 times), total aluminum (12 times), total iron (11 times), total zinc (eight times), and total copper (seven times).

The CWQG for drinking water was exceeded for turbidity four times. The CWQGs for freshwater aquatic life were exceeded for total zinc (four times), total copper (three times), and total aluminum, beryllium, iron, and manganese (twice each). STO and CWQG exceedances, and abundant mineral deposits present upstream (Gordey and Anderson, 1993), are two reasons why careful monitoring is needed here in the future. There is a weather station nearby, and the site is close to several plant and animal study sites. This Taiga Cordillera Ecozone site may become a hub or anchor site for future long-term Ecological Monitoring and Assessment Network (EMAN) activities and, thus warrants future work.

At the SNR above Virginia Falls site, STO exceedances not readily explainable by flow occurred during June 1995 spring freshet for NFR (Figure 20). The most frequent STO exceedances at this site during the 1994-1997 period occurred for turbidity (nine times), total aluminum (seven times), total beryllium, copper and manganese (five times each), and total zinc (four times).

The CWQG for drinking water was exceeded for turbidity three times. The CWQGs for freshwater aquatic life were exceeded twice each for total aluminum, beryllium, manganese, and zinc. This water quality site has a very short four-year record, but is co-located with a water flow and level gauge, as well as a climatological station. Virginia Falls is the site most frequently visited by tourists and aircraft pilots in all of Nahanni NPR, and NNPR is the most frequently visited national park in the NWT, including Nunavut. This Taiga Cordillera Ecozone site may become a hub or anchor site for future long-term Ecological Monitoring and Assessment Network (EMAN) activities and, thus warrants future work.

At the Flat River at Park Boundary site, the most frequent STO exceedances occurred over the 1994-1996 period for total aluminum (seven times), turbidity (six times), total iron (four times), and true colour, total beryllium, total copper, and total zinc (thrice each). The CWQG for drinking water was exceeded for turbidity five times. The CWQGs for freshwater aquatic life were exceeded for total aluminum (seven times), and total copper and iron (thrice each). Water quality changes little between this site and the Flat River/Mouth site because the Caribou River has only a minor effect on water quality of the Flat River. No further work is believed necessary at this site unless the Tungsten Mine reopens or a new development occurs in the headwaters of the Flat River..

At the Flat River at Mouth site, STO exceedances not readily explainable by flow occurred during the April 1984 and November 1992 winter baseflow for field conductivity (Figure 15). Similar STO exceedances occurred during the May 1986 and May-June 1992 spring freshets (Figure 25); the former freshet followed 12 nearby earthquake events measuring 5-6 on the Richter Scale. Similar STO exceedances occurred during the May 1987, May-June 1992, and May 1996 spring freshets for turbidity (Figure 26). Similar STO exceedances occurred during the May 1992, June 1995, and May 1996 spring freshets for total copper (Figure 27). The October 1994, November 1995, February 1996, and April 1996 winter baseflows produced STO exceedances not readily explainable by flow for dissolved sulphate (Figure 28).

At this site, the most frequent STO exceedances occurred over the 25 year (1972-1996) period of record for turbidity (63 times), total zinc (39 times), total copper (26 times), dissolved iron (16 times), extractable iron and manganese (15 times each), NFR and total nickel (15 times each), total aluminum, barium, and vanadium (14 times each), dissolved nitrate-nitrite (13 times), and total cadmium and cobalt (12 times each).

The CWQG for drinking water was exceeded for turbidity 54 times, and for true colour eight times. The CWQGs for freshwater aquatic life were exceeded for total zinc (28 times), total copper (16 times), total aluminum and nickel (11 times each), total iron (10 times), total cadmium (seven times), and total lead (six times). The long water quality record of 25 years and 159 samples is adequate for the time being, but the site should be re-visited due to the large number of STO and CWQG exceedances, especially if there is upstream mining or other development.

At the Prairie Creek at Mouth site, STO exceedances not readily explainable by flow or field conductivity occurred both during the April 1997 late winter baseflow and the June 1997 spring freshet for dissolved copper (Figure 31). Similar STO exceedances occurred during the June 1988 and May-June 1989 spring freshets for total zinc (Figure 32). At this site, the most frequent STO occurrences occurred over the 1988-1997 period for field pH (27 times); turbidity (19 times); total barium (11 times); dissolved sulphate and extractable manganese (10 times each); total nickel, lead and zinc (10 times each); NFR and extractable iron (9 times each); and total cadmium, cobalt and copper (9 times each).

The CWQG for drinking water was exceeded for turbidity eight times. The CWQG for freshwater aquatic life was exceeded for field pH (10 times). Overall, there are few exceedances of CWQGs at the Prairie Creek/Mouth site. Prairie Creek is a very "flashy" creek with wide variability in flows, field conductivities, and trace metals values. The trace metals values tend to be highest during spring freshets and summer rainstorms, suggesting that metals are mostly in particulate, non-bioavailable forms. Prairie Creek is weakly basic in pH due to the combined effects of carbonate bedrock underlying the Creek, and contributions of alkalinity karst and ground water buffering the Creek waters from weakly acidic rain and snow.

Due to exploration upstream of this station near Cadillac Mine, additional opportunistic sampling by Parks Canada was carried out during some years. 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). Continued monitoring downstream from this future mining/milling development site is warranted, mostly to fulfil Parks Canada and DIAND, rather than DOE, federal mandates.

At the SNR above Nahanni Butte site, STO exceedances unrelated to flow or field conductivity occurred during June 1992 spring freshet for turbidity (Figure 34). Similar STO exceedances occurred during the June 1988, June 1992, June 1995, and June 1997 spring freshets for total copper (Figure 36). At this site, the most frequent STO exceedances occurred for turbidity (32 times), total copper (13 times), total aluminum (12 times), total zinc (10 times), and total iron (9 times).
The CWQG for drinking water was exceeded for turbidity four times. The CWQGs for freshwater aquatic life under hard water conditions were exceeded for total copper (seven times), total zinc (five times), total lead (four times), and total aluminum (thrice). Concerns about turbidity, aluminum, copper, zinc and iron were so great that they led to the decision by the nearby community of Nahanni Butte, near the Liard River-South Nahanni River confluence, to use ground water for their municipal water supply, following a study by Vista Engineering.

At all water quality sites, 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 spring freshets as well.

The higher flows during the 1988, 1992, and 1997 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.

STO and CWQG exceedances must always be interpreted in light of the following six baseline (ambient) stream water quality characteristics of Nahanni NPR:

- Nahanni NPR stream water is neutral to weakly alkaline due to the chemical composition of carbonate and clastic sedimentary bedrock and locally-derived overlying overburden, and has good buffering capacity against natural acidic precipitation, and natural or anthropogenic acid rock drainage.
- Nahanni NPR stream water is hard and conductive, due to the high concentrations of calcium and magnesium ions.
- Nahanni NPR stream water has naturally high turbidity, true colour, non-filterable residue (total suspended solids), and total dissolved solids, especially during spring freshet and summer-fall rainstorms.
- Nahanni NPR stream water naturally contains high levels of trace metals such as aluminum, barium, copper, iron and zinc throughout the water year, with dissolved metals levels peaking during late winter baseflow and total (mostly particulate and extractable) metals levels peaking during spring freshet and summer-fall rainstorms.
- Nahanni NPR stream water chemistry is effected by the chemistry of surface, karst (cave, pothole), and ground waters.
- Nahanni NPR karst and ground water chemistry has minor effects on water chemistry at the Rabbitkettle River/Mouth site and, possibly, elsewhere in the SNR and Flat River.

6.0 SEDIMENT QUALITY IN THE PARK

Metals are commonly found bound to particulate matter, in stream and lake sediments. Metals have a greater affinity for smaller particle sizes found in the suspended sediments commonly found in high-energy environments such as the South Nahanni River (SNR) and its tributaries. Suspended sediments can be collected using a continuous-flow centrifuges, such as the Alpha-Laval Sedi-Samp centrifuge (Ongley, 1992; Environment Canada, 1991).

Suspended sediments were sampled using a stainless steel Alfa-Laval flow-through centrifuge modified and thoroughly cleaned with acetone, dichloromethane (DCM), and deionized-demineralized water to avoid contamination. Sediment samples were collected at the South Nahanni River (SNR) above Nahanni Butte site (which integrates sediment quality for all of Nahanni NPR) every September from 1992 to 1996, inclusive, to examine medium- to long-term temporal variability. In 1993 and 1994, sediment samples were collected in July and September, to examine seasonal temporal variability. Finally, temporal variability of sediment quality was examined at three other sites along the main stem SNR by collecting suspended sediment samples at SNR above Clausen Creek, above Virginia Falls, and above Rabbitkettle River during the June-July period in 1994, 1995, and 1996; respectively. 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. DOE's National Water Research Institute (NWRI)'s sedimentology laboratory also performed particle-size distribution analysis. Sediment quality values may be obtained in diskette files.

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 were established in 1997 for the SNR above Nahanni Butte, despite the small sample size.

6.1 Spatial Variability

Stream channel bed sediments have proved to be such excellent geochemical sampling media, integrating both spatial and temporal natural variability, that they are the prime reconnaissance geochemical tools used by government agencies (such as the Geological Survey of Canada) and mineral exploration companies to explore for mineral deposits in mountainous areas. Lake sediments proved to be the preferred sampling media in the Canadian Shield and the larger, less mountainous areas in Canada. As a result, large stream sediment (and lake sediment) geochemistry databases exist.

The Selwyn Basin, just west of Nahanni NPR, 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). Geochemical catchment basin analysis, using databases and geographic information systems (GIS), was carried out to document metals values in stream sediments for streams underlain by various rock types in the basin. This data was used to predict expected metals levels at each site (representing each catchment basin), given the basin-specific "mixes' of rock types present, and then compare measured values to expected values to predict occurrences of various types of mineral deposits in each catchment basin. Catchment basin analysis is a chemistry-geology-database-GIS integrated technique for finding various mineral deposits using stream sediment and, to a lesser extent, stream water data. This was just one application of the value of collecting stream and lake samples throughout Canada as part of the National Geochemical Reconnaissance (NGR) Program.

Table 3 gives statistics on over 31,200 analyses of stream channel bed sediment samples in the <177μ size class collected throughout British Columbia and the Yukon Territory. These bed load stream sediments were collected in active stream channels in the Canadian Cordillera (Ballantyne, GSC, 1981). All values are total metal values. The National Geochemical Reconnaissance (NGR) data set bed load samples were typically collected by hand using Teflon or stainless steel scoops. The NGR data set involves stream sediments containing higher percentages of sand (and lower percentages of clay) than the suspended sediments collected by Alpha-Laval centrifuge. Relatively few suspended sediments have been collected and analyzed in Canada, so it is difficult to compare results with those from other areas. In the absence of similar stream suspended sediment data sets, the September 1992-1996 and July 1993-1994 suspended sediment data from the SNR above Nahanni Butte and other SNR main stem sites are compared to 31,200 coarse stream sediment samples in the NGR Canadian Cordillera data set (Table 3 in the Appendix).

Since the negatively-charged surface of clay particles form weak chemical bonds with positive-charged metal cations, it is not surprising that the clay-rich suspended sediments sampled in Nahanni NPR tend to be higher in total metals contents. The clay-rich suspended sediment samples collected in 1992-1996 at the SNR above Nahanni Butte and other SNR mainstem sites have anomalous high values for zinc, cobalt, nickel, arsenic, lead and iron contents. Samples might also have anomalous high values for cadmium and chromium, too, had these analyses been carried out and results shown in the NGR data set (Table 3).

All Nahanni NPR suspended sediment samples were found to contain anomalously high metals levels, when these values are compared to historic values from the NGR stream channel bed sediments collected in the Canadian Cordillera (Ballantyne, GSC, 1981). For example, the September 1995 and 1996 total zinc values from the SNR above Nahanni Butte site of 390-399 ppm (mg/kg dry weight) both lie near the 97th percentile of the larger GSC data set; the 84-85 ppm nickel values both lie near the 94th percentile, the 17.6-19.2 ppm cobalt values at the 85th to 92nd percentile; the 15.5-19.6 ppm arsenic value near the 85th percentile, the 1700-1760 ppm barium values near the 85th percentile, the 12-13 ppm lead values near the 75th percentile, and the 31-36 ppm copper values at the 68th to 75th percentile. The sediments also contain 6.50%-6.57% aluminum and 2.79%-3.13% iron (73rd to 82nd percentile). The July and September 1994 values from the SNR above Nahanni Butte site of 19.6-23.7 ppm (mg/kg) arsenic lie in the 85th to 92nd percentile range, while 1995 barium values of 957-1310 ppm lie in the 64th to 78th, 1995 lead values (both 12.6 ppm) at the 76th, cobalt values of 12.0-17.4 ppm in the 70th to 85th, copper values of 23.8-30.5 ppm in the 51st to 68th, iron values of 2.58%-3.75% in the 65th-90th, mercury values of 0.053-0.084 ppm in the 57th to 77th, nickel values of 54.2-85.8 ppm in the 88th-94th, and zinc values of 224-331 ppm in the 92nd to 97th percentile range. All total metal values from the 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.

The elevated total zinc values were the most anomalous of all metals, throughout 1992-1996. The elevated zinc may be related to high total and dissolved zinc values observed in stream waters at all seven stations during the above-mentioned years.

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 stopped. Despite changes in sampling procedures, high 1992 aluminum values were repeated 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 consist of particles measuring 6.0 to 10.0 microns (μ, a millionth of a metre) in diameter in September 1992, 1.0-8.0μ in July 1993, 0.5-6.0μ in September 1993, and 0.5-15.6μ in September 1995. All samples were in the minus 177 micron (μ) size class. Typical SNR suspended sediments are composed of 57.64%-63.53% clay, 32.35%-37.48% silt, 4.12%-4.88% sand, and 0% gravel. The 1995 SNR suspended sediments were slightly coarser than other sediments, being composed of 44.88% clay, 31.83% silt, 23.29% sand and 0% gravel. In the Shepard Classification, suspended sediments at the SNR above Nahanni Butte tended to be "silty clays" (i.e. clay>silt) while suspended sediments at the upstream SNR sites (e.g. SNR above Virginia Falls) tended to be slightly coarser "clayey silts" (i.e. silt>clay).

Comparison of suspended stream sediment results at the four SNR main stem sites reveals that most trace metals (i.e. cadmium, cobalt, chromium, copper, iron, lead, manganese, mercury, nickel, zinc) levels generally increased upstream from the SNR above Nahanni Butte site to the SNR above Rabbitkettle River site, presumably due to closer proximity of the stream sediment to bedrock sources in the headwaters.

Aluminum, arsenic and barium levels decreased going upstream from the SNR above Nahanni Butte site to the SNR above Rabbitkettle River site. The particle size distribution analyses, referred to above, revealed that suspended sediments from downstream sites were "silty clays" while those from upstream sites were slightly coarser "clayey silts". Considering the affinity of trace metals for finer sediments, the (downstream) SNR above Nahanni Butte site would be expected to have the highest trace metals values for metals chemically attracted to clay minerals or, in the case of aluminum, the metal which actually chemically "makes up" the (alumino-silicate) clay minerals. The two above-mentioned trends are obviously offsetting each other in Nahanni NPR suspended stream sediments.

6.2 Temporal Variability

Over the 1992-1997 period, trace metals levels remained constant, overall. This illustrates that suspended sediment is a good sampling media, integrating well over time. Government agencies and mineral exploration companies carrying out stream sediment geochemical surveys actually depend upon there being minimal long-term temporal variability in this sampling media when they explore for mineral deposits.

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 were expected to be higher in the finer September samples, and this was the case for all metals.

6.3 Significance of Metals and Other Results

Prior to the July 1995 drafting of (interim) freshwater Canadian Sediment Quality Guidelines (CSQGs) (Table 12), it was difficult to assess the relevance of the sediment quality data. 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 0.174 mg/kg (dry weight) for total mercury, and 0.596 mg/kg (dry weight) for total cadmium (Pers. Comm. Sherri Smith, 1995); these two ISQGs have since become official Canadian Sediment Quality Guidelines (CSQGs). 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 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 1992-1996 suspended sediments collected at the SNR Above Nahanni Butte site have ranged from 0.036 to 0.087 mg/kg (dry weight, dw) from samples collected in July 1993-1994 and September 1992-1996. The maximum value of 0.084 mg/kg (dw) mercury, obtained from suspended sediment on September 1994, is approximately half the (0.174 mg/kg (dw) mercury) interim CSQG for freshwater aquatic life. The lowest total mercury value (0.036 mg/kg dw) was obtained from the September 1996 sample. The SNR above Rabbitkettle River suspended sediment collected in June 1996 contained 0.057 mg/kg (dw) mercury. The SNR above Virginia Falls site suspended sediment collected in June 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.

The opposite is true for total cadmium. Every single suspended sediment ever collected at all four SNR main stem sites exceeds the 0.596 mg/kg (dw) cadmium CSQG for freshwater sediments. Total cadmium values from 1992-1996 suspended sediments collected at the SNR above Nahanni Butte and other SNR main stem sites have ranged from 1.11 kg/kg (dw) to 3.00 mg/kg (dw) from samples collected in July 1993-1994 and September 1992-1996. The maximum value of 3.00mg/kg (dw) cadmium, obtained from suspended sediment in September 1996, is five times the CSQG for freshwater aquatic life. The high local cadmium background along the NWT-YT border in the stream sediments 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), fish tissue and caribou (Pers. Comm. Lyle Lockhart, FOC, 1994).

All total zinc values from 1992-1996 suspended sediment samples collected at SNR/Nahanni Butte (seven samples), all other 1992-1997 SNR main stem sites (three samples), and all 1988-1989 samples exceed (and often 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. Nahanni NPR suspended sediment samples, from all four SNR main stem sites, 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. A preliminary STO and LTO, corresponding to the 90th and 50th percentiles, respectively, was set for the SNR/Nahanni Butte suspended sediment sample site only. It is, however, certain that Nahanni NPR has a natural local geochemical background that is different (higher for most metals) than the regional geochemical background for Canada.

7.0 FISH TISSUE QUALITY IN THE PARK

7.1 South Nahanni River Below Prairie Creek and Dry Canyon Creek Sites (1992, 1994)

In September 1992, Parks Canada and the Department of Fisheries & Oceans (DFO) staff used gill-netting techniques to sample 12 fish of similar age and size for trace metal analyses of fish muscle (fillet) and liver tissue. Sampling was carried out at two South Nahanni River (SNR) sites two kilometres apart, one just below Prairie Creek and one just below Dry Canyon Creek. Two 2.5 inch gill nets, 25 metres long, were set overnight (Lafontaine and Wilson, 1993).

All longnose suckers, some Arctic grayling (those not in good shape), and one accidentally-caught burbot were weighed, measured for fork length, and age/sex/maturity was determined. In all, 12 Arctic grayling, three longnose suckers and one burbot (lingcod) were caught and sampled, making for a statistically small sample population. Scales, pectoral fin rays, and otoliths were removed from the Arctic grayling, longnose suckers, and burbot, respectively, as ageing structures. Biological parameters were noted in the field and data was later entered onto spreadsheets (Lafontaine and Wilson, 1993).

Fish livers were removed and put into sterile, contaminant-free whirlpaks. Fish muscle tissue was cleaned and frozen. Tissues were shipped frozen to DFO's Freshwater Institute in Winnipeg for analyses by the Environmental Chemistry Lab for total arsenic, cadmium, copper, lead, mercury, nickel, and zinc. All analyses were done on a wet weight basis by atomic absorption (Lafontaine and Wilson, 1993).

The fish tissue quality sampling report, complete with results, appears in Appendix III of this report. Arsenic and lead were not detected in any fish tissue. Mercury and nickel were present in trace amounts. Total cadmium, copper and zinc were detected at levels similar to levels recorded for fish living in an environment modified by mining activities. The total cadmium levels are considered unusually high for an undisturbed system. Cadmium acts synergistically with copper and zinc, rendering the metals more toxic to fish and other aquatic biota. Effects of cadmium are not well documented, but increased vulnerability to predation, impaired swimming, and mortality of eggs and juveniles have been reported. Metals values were, not surprisingly, found to be higher in liver than in muscle tissue. Cadmium levels were enigmatically found to be elevated in young, female Arctic grayling specimens.(Lafontaine and Wilson, 1993).

Further heavy metal monitoring was recommended at two year intervals to better assess levels in Nahanni NPR fish tissue. Future sampling should include at least 10 specimens of each fish species present or, at least, fish species targeted by sport fishermen in Nahanni NPR. Fish tissue sampling was also recommended on the Flat River downstream of the now-mothballed Tungsten (tungsten-copper) Mine. Sampling of fish gill tissue was recommended (in addition to repeated sampling of muscle and liver tissue) since high levels of cadmium, copper, and zinc are known to have negative impacts on fish gill function (Lafontaine and Wilson, 1993; Rob Prosper, Parks Canada, Pers. Comm., 1994).

In September 1994, a similar gill-netting fish tissue sampling program was carried out at the two sites by Parks Canada and Environment Canada staff, following the above-mentioned recommendations. Twelve Arctic grayling, 10 longnose suckers, and one Dolly Varden were caught, sampled, and all three fish tissue types were analyzed. This time, gill tissue was analyzed as well as muscle and liver tissue. This time, analysis, again at FOC Freshwater Institute included selenium as an eighth trace metal (Marnie Fyten Pers. Comm., 1994). A lab analysis report was prepared by Sherilyn Friesen of the FOC Freshwater Institute in Winnipeg and sent to Parks Canada Fort Simpson in January 1997. No report has been prepared at the time of this writing.

Preliminary observations by this author are that the 1994 results are similar to the 1992 results from the two SNR sites below Prairie Creek and Dry Canyon Creek, suggesting that the 1992 and 1994 data is reproducible. Elevated cadmium, copper, and zinc levels were again detected in Arctic grayling and longnose sucker fish tissue. Although no statistical analyses were performed on the 1994 data set, some trace metals (e.g. mercury, selenium) metals appear to be higher in the Arctic grayling than the longnose suckers while other trace metals are higher in the bottom-feeding, sediment-dwelling longnose suckers. Cadmium, copper and zinc levels in Arctic grayling and longnose suckers were highest in liver tissue, then gill tissue, and lowest in muscle tissue.

No additional work was carried out in either 1996 or 1998. Additional work is, however, required to obtain statistically large populations and further investigate elevated cadmium, copper and zinc levels.

7.2 Flat River Near the Mouth Site (1994)

In September 1994, a similar gill-netting fish tissue sampling program was carried out at the two sites by Parks Canada and Environment Canada staff, following the above-mentioned recommendations. One Arctic grayling, three mountain whitefish, and 10 Dolly Varden were caught, sampled, and all three fish tissue types (including gills) were analyzed. This time, analysis, again at DFO Freshwater Institute included selenium as an eighth trace metal (Marnie Fyten Pers. Comm., 1994). A lab analysis report was prepared by Sherilyn Friesen of the DFO Freshwater Institute in Winnipeg and sent to PCH Fort Simpson in January 1997. No report has been prepared at the time of this writing.

Preliminary observations by the author are that whitefish and Dolly Varden livers contain elevated cadmium, copper, and zinc levels. Flat River Dolly Varden liver and muscle tissue also contain elevated total mercury levels, with three samples out of 10 having values in the 0.2 to 0.5 microgram per gram wet weight range (i.e. exceeding various mercury fish tissue quality guidelines).

No additional work was carried out in either 1996 or 1998, despite the fact that additional work is required.

8.0 SUMMARY AND RECOMMENDATIONS

8.1 Summary

The 1988-1989 water and suspended sediment quality sampling study did not capture and, therefore, is not completely representative of, the natural temporal variability of flows, and water and sediment quality, in Nahanni NPR. Some of the water quality data collected on consecutive days during the spring freshets and summer-fall recessions of 1988 and 1989 may be auto-correlated and redundant data. The 1988-1989 water quality data set excluded winter baseflow water quality, when the highest dissolved water quality values, and the lowest total (mostly particulate-associated) water quality values, are known to occur. In many cases, the 1988-1989 water quality sample sizes were not statistically large enough to draw conclusions without large uncertainty.

The 1992-1997 water and suspended sediment quality sampling follow-up monitoring program, especially when combined with the 1988-1989 study and previous data going back to 1972 (at the Flat River/Mouth site), was much more representative of the natural temporal and spatial variability of inorganic water and sediment quality variables. An average of ten years of data is now available for each site, and this report describes water and sediment quality variability during a wider range of natural conditions, especially a wider range of flows. Hydrographs (Figures 5-7) from three water gauge sites in Nahanni NPR illustrate the natural variability of flows, including high flow years (e.g. 1992 spring freshet, 1997 summer rainstorm), medium flow years, and low water flow years (e.g. 1994, 1995). Not surprisingly, there was a wider natural variability of water quality values, and, in certain years (e.g. 1992), a higher incidence of water quality values exceeding Canadian Water Quality Guidelines (CWQGs) for freshwater aquatic life and drinking water, and site-specific water quality objectives.

The 1992-1997 water quality data included, for the first time, winter baseflow water quality values, which add much to the knowledge of seasonal temporal variability (i.e. seasonality). None of the 1992-1997 water quality data was collected on consecutive days at the same site, so that all of the data represents independent variables, not auto-correlated with the previous days' data (and, thus, redundant. Finally, the larger 1988-1997 (1972-1996, at the Flat River/Mouth site) data set involves statistically large (N>30) sample sizes for most sites and under most water conditions. There is, still, a shortage of winter baseflow water quality data at most sites, because this data was not collected during the 1988-1989 study.

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 data set available and the variability of flows in the area. This suggests that it was useful to maintain all seven water quality sites and one suspended sediment site for the duration of the 1992-1997 follow-up monitoring program, to more thoroughly define the range of water and sediment conditions.

Flow, field conductivity and other water quality data from the 1988-1989 and 1992-1997 periods confirm that high spring freshet flows and rainstorm runoff events during the summer-fall recession period are responsible for most elevated total and dissolved trace metals levels. Relationships between water quality variables and water quantity (flow) appear to be stronger in the rugged terrain of Nahanni NPR and the Taiga Cordillera Ecozone than in most other ecozones, possibly due to increased groundwater contributions or floods being more important than erosion. Therefore, manual flow measurements were made during 1994-1997 at the ungauged Prairie Creek at Mouth, Flat River at Park Boundary and SNR above Rabbitkettle River water quality sites whenever water quality samples were collected (and when logistics permitted). After sufficient data (i.e. more than three points from one year)was collected, water quality variable/flow ratings curves were constructed (e.g. Flat River at Mouth site). These are broadly similar to water level/flow (stage-discharge, or S-Q) curves routinely used by hydrologists and hydrological technicians.

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 (Spearman's "Rho" >0.65 or <-0.65) with flow/field conductivity most of the time at the SNR above Rabbitkettle River, Rabbitkettle River Mouth, SNR above Virginia Falls, Flat River Park Boundary, 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.

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, 1992-1997 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 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 at Park Boundary, SNR above Virginia Falls), and only preliminary 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 their upper reaches and tributaries. The positive field pH/field conductivity correlation at the Rabbitkettle River at Mouth site and the close proximity (one kilometre) to the Rabbitkettle Hot Springs 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 surface water isotopic signature (Gulley, 1993).

With little data from a highly variable environment, it is reasonable to assume that most 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 correlation with flow) are likely natural in origin, unless they are so persistent as to be due to anthropogenic origin. The only drilling that occurred is at Prairie Creek, and is likely of minimal significance to water and sediment quality. The only other significant activities include Tungsten Mine (abandoned since 1986) and Union Carbide (inactive since 1984).

Suspended sediment values from SNR above Nahanni Butte and three other SNR sites in 1992-1996 (and 1988-1989 values) are routinely elevated for zinc, cobalt, nickel, arsenic, lead, and iron and exceed the 80th percentiles when compared to 31,000 bedload stream sediments from the Canadian Cordillera collected during the federal government National Geochemical Reconnaissance (NGR) Program. The total zinc content routinely falls between the 94th and 99th percentiles. All values measured from suspended sediment samples from the SNR above Nahanni Butte site during 1988-1989 and 1992-1996, and other upstream SNR sites (e.g. Clausen Creek, Virginia Falls, Rabbitkettle River) exceed the interim freshwater aquatic life Canadian Sediment Quality Guidelines (CSQGs) for arsenic, cadmium, chromium, nickel and zinc, probably due to natural sources/causes. The interim CSQG for cadmium has since become an actual CSQG. Aluminum and iron are very high (% levels, by weight), but freshwater CSQGs do not currently exist for these trace metals.

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, as well as total aluminum and iron, were routinely measured throughout the 1992-1996 follow-up monitoring period. Levels of most metals increased upstream from the SNR above Nahanni Butte site to the SNR above Rabbitkettle River site, due to closer proximity to bedrock and overburden sources. Some metals (e.g. aluminum) are associated with clay minerals and were most abundant in the silty clays at SNR above Nahanni Butte than the coarser clayey silts of the SNR upstream sites. Metal levels exhibited little long-term temporal trends over the 1988-1989 and 1992-1996 periods, but seasonal variability was observed in 1993 and 1994 at the SNR above Nahanni Butte site. In both years, the finer September suspended sediments contained higher concentrations of trace metals than the coarser July sediments. This reflects the affinity trace metals have for clay particles and more clay-rich sediments.

Fish tissue sampling surveys from the two Lower SNR sites (i.e. below Prairie and Dry Canyon Creeks), carried out in September 1992 and 1994, reveal that the elevated cadmium, copper, and zinc levels detected in water and suspended sediment has bioaccumulated in the liver, gill, and muscle tissue of bottom-feeding longnose suckers, and even Arctic grayling. The 1994 fish tissue sampling survey shows these are also found in Dolly Varden and whitefish of the lower Flat River.

Furthermore, fish species sampled at the Flat River site in 1994 were found to contain high (0.2-0.5 microgram per gram wet weight) levels of total mercury, much of may have been changed to organo (methyl) mercury by the fish and stored in muscle and other fish tissue. The results only became available in January 1997, and were a complete surprise. No Flat River water quality samples were collected and analyzed for total mercury in either 1988-1991 or 1992-1997 because levels are expected to be low. Mercury was analyzed for in 1992-1996 suspended sediments, but all sites were on the SNR, not the Flat River. Unfortunately, mercury was not analyzed for in 1988-1989 Flat River suspended sediments. While no total mercury values are available from either the suspended sediments from the SNR above Nahanni Butte site, or from fish tissue from the lower SNR, exceed CSQGs or fish tissue guidelines, the mercury problem seems to be localized to the Flat River-Caribou River area (and may be related to Tungsten Mine tailings).

Mineral and other development is still a pertinent issue for areas upstream of Nahanni NPR, with the Tungsten (tungsten-copper) and the Cadillac (silver-base metal) Mines currently mothballed, awaiting improving commodity prices, road access, and better mineral industry economics. Mineral exploration success for zinc-lead-copper along Prairie Creek, near the Cadillac Mine, has led to mineral development/road construction plans by San Andreas Resources Corporation (SARC) and a project description report being written by Rescan Environmental and SARC in 1994, triggering environmental impact assessment activity under the Canadian Environmental Assessment Act (CEAA). A 1993 GSC memoir inventories at least 31 mineral occurrences upstream of Nahanni NPR in the South Nahanni River, Flat River, and Rabbitkettle River basins.

8.2 Recommendations

1. All future water and sediment quality measured values should be compared to the new (i.e. 1998) long-term objectives (LTOs) and short-term objectives (STOs) for the seven 1992-1997 follow-up monitoring water quality sites and the SNR above Nahanni Butte suspended sediment quality site. Elevated values explicable by flow and other natural conditions can be down-played, with future efforts focusing on elevated values not explainable by flow and other natural variability.

2. All future water and sediment quality measured values should continue to be compared to CCME water and sediment quality guidelines, with special attention given to high water quality values not readily explainable by flow and other natural variability. Future mercury values measured in fish tissue should be compared to fish tissue guidelines for mercury.

3. 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.

4. More baseflow water quality data is needed to more closely examine seasonal spatial variability in the Nahanni NPR waters. Up to 24 more baseflow water quality samples are needed at some sites.

5. Additional sediment and fish tissue sampling is required in the Flat River basin to better understand uptake of mercury by bottom-feeding fish (e.g. whitefish) and other fish (e.g. Dolly Varden).

6. Additional (suspended and bedload) sediment and (fish and benthic invertebrate) biota tissue sampling is required in the lower SNR and Flat River to better understand uptake of cadmium, copper, and zinc by bottom-feeding and other fish species. Good environmental maintenance indicator (EMI) fish species which are of cultural importance, resident to different parts and reaches of streams, and spawning at different times of the water year should be sampled.

7. The effects of increased earthquake activity on aquatic quality in the more earthquake-prone eastern end of Nahanni NPR should be further investigated.

8. Manual (miscellaneous) flow measurements should be made when water quality samples are collected at sites lacking stream gauges or measurement transects.

9. Linkages between elevated metals levels in stream water, stream sediment, fish tissue, mammalian tissue (e.g. caribou), and humans should be investigated.

10. Meteorologic and hydrologic data collection programs at the SNR above Virginia Falls gauge site should be continued to support interpretation of aquatic quality data and help characterize the Taiga Cordillera and Taiga Plains Ecozones at this Ecological Monitoring and Assessment Network (EMAN) site. 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 natural geochemical/biochemical cycling and future anthropogenic activities.

11. Environment Canada is currently preparing a report on Nahanni NPR stream hydrology, including flood risk analysis. A summary report relating aquatic quality and stream hydrology in the South Nahanni River basin would be useful.

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10.0 APPENDICES

APPENDIX I: WATER, SEDIMENT AND FISH TISSUE QUALITY RESULTS

Refer to Diskette Spreadsheets Available from Author

Table 1. NAQUADAT/ENVIRODAT Field and Lab Parameter Codes. Water & Sediment Quality Samples
NAL=INAC Yellowknife Northern Analytical Lab (now Taiga Environmental Lab)
NLET=EC Burlington National Lab for Environmental Testing.

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 and Sediment Quality Objectives for Nahanni National Park Reserve.

Water Quality Variable			Flat River at Mouth		Prairie Creek at Mouth		South Nahanni River above Nahanni Butte		Rabbitkettle River at Mouth		South Nahanni River above Rabbitkettle River		Flat River at Park Boundary		South Nahanni River at Virginia Falls		South Nahanni River above Nahanni Butte		Sediment Quality Variable
			LTO	STO	LTO	STO	LTO	STO	LTO	STO	LTO	STO	LTO	STO	LTO	STO	LTO	STO	
Field Conductivity		us/cm	268.7688	390.0000	323.5408	390.0000	257.0638	338.0000	182.8125	259.0000	223.9329	280.0000	200.0000	280.0000	248.7500	305.0000	2.70	3.72	Organic Carbon %
Field pH		pHU	8.0654	8.4000	8.4423	8.8000	8.0376	8.3100	7.9977	8.3300	8.0168	8.3890	7.8540	8.0080	8.1075	8.5300	1.63	2.31	Inorganic Carbon %
Non-Filter. Residue		mg/l	85.0866	216.2000	22.6310	28.9000	149.6740	332.6000	73.7000	170.7000	68.3271	182.4000	73.1818	252.0000	57.4706	134.0000	0.14	0.18	Organic Nitrogen %
Turbidity		NTU	50.9896	99.1000	15.9522	20.9400	89.0389	248.5000	37.9677	118.0000	43.5062	153.3100	21.8091	68.6000	27.7375	77.0500	21.61	27.82	Total Arsenic mg/kg
Total Cyanide		mg/l	0.0011	0.0020	0.0009	0.0014	0.0012	0.0020	0.0012	0.0029	0.0080	0.0010	0.0013	0.0020	0.0012	0.0034	1.27	1.60	Total Selenium mg/kg
Chloride		mg/l	0.8674	0.9660	0.5346	0.6480	3.4621	7.1440	0.4188	0.6155	0.3745	0.4700	0.3882	0.4300	0.4085	0.5660	64242.86	74180.00	Tot. Aluminum mg/kg
Sulphate		mg/l	29.0368	42.8600	36.3629	49.4600	43.6960	74.4800	31.8344	52.2700	34.4695	49.2400	38.3909	50.5000	47.6706	67.6800	1536.17	1900.00	Total Barium mg/kg
Reactive Silica		mg/l	8.0257	7.1840	3.2692	3.3940	4.6571	5.2350	4.7381	6.4200	4.6091	5.3800	5.7300	7.4100	4.6824	5.8000	2.01	2.58	Total Cadmium mg/kg
Nitrate/Nitrite		mg/l	0.0702	0.1300	0.1347	0.1704	0.1069	0.1130	0.1215	0.1778	0.0539	0.0860	0.0842	0.1260	0.0804	0.1056	16.41	18.36	Total Cobalt mg/kg
Total Ammonia		mg/l	0.0119	0.0228	0.0065	0.0127	0.0138	0.0262	0.0071	0.0114	0.0061	0.0116	0.0073	0.0100	0.0114	0.0272	63.30	74.86	Tot. Chromium mg/kg
Silver	Dissolved	mg/l	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	29.79	33.54	Total Copper mg/kg
	Total	mg/l	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	30900.00	35820.00	Total Iron mg/kg
Aluminum	Dissolved	mg/l	0.0384	0.0796	0.0082	0.0116	0.5890	0.1111	0.0746	0.0940	0.0835	0.1220	0.0497	0.0770	0.0604	0.1035	422.14	467.60	Tot.Manganese mg/kg
	Total	mg/l	0.6950	0.6976	0.0459	0.1284	0.8346	2.6200	1.2644	3.1600	0.7601	1.9000	1.2607	4.0000	0.8729	2.1900	L10	L10	T.Molybdenum mg/kg
Barium	Dissolved	mg/l	0.0449	0.0664	0.0649	0.0765	0.0559	0.0707	0.0630	0.0678	0.0417	0.0593	0.0451	0.0716	0.0473	0.0680	74.59	85.32	Total Nickel mg/kg
	Total	mg/l	0.1061	0.1937	0.0667	0.0988	0.1041	0.1870	0.0773	0.1509	0.0555	0.0901	0.1323	0.1120	0.0734	0.0986	15.14	20.06	Total Lead mg/kg
Beryllium	Dissolved	mg/l	0.0228	0.0250	0.0233	0.0250	0.0250	0.0250	0.0266	0.0250	0.0168	0.0250	0.0168	0.0250	0.0250	0.0250	202.71	230.20	Tot. Vanadium mg/kg
	Total	mg/l	0.0822	0.2600	0.0250	0.0250	0.0736	0.1870	0.1003	0.2350	0.0632	0.1300	0.1218	0.3500	0.0697	0.1400	325.29	393.60	Total Zinc mg/kg
Calcium	Dissolved	mg/l	44.6018	63.7700	47.2692	51.6600	49.8143	66.7400	37.4375	53.7000	38.3091	51.8000	41.0455	58.7000	39.9250	54.2000	0.06	0.07	Total Mercury mg/kg
	Total	mg/l	49.6939	67.1000	47.5538	54.3800	57.7071	67.8700	44.4688	57.2500	40.8909	49.8000	43.5091	57.2000	46.1438	57.0000			
Cadmium	Dissolved	mg/l	0.0001	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0002	0.0001	0.0001	0.0001	0.0002			
	Total	mg/l	0.0006	0.0010	0.0001	0.0001	0.0004	0.0008	0.0004	0.0010	0.0002	0.0005	0.0003	0.0010	0.0004	0.0009			
Cobalt	Dissolved	mg/l	0.0003	0.0004	0.0002	0.0003	0.0002	0.0003	0.0003	0.0008	0.0004	0.0007	0.0002	0.0004	0.0002	0.0004			
	Total	mg/l	0.0015	0.0032	0.0004	0.0007	0.0015	0.0038	0.0015	0.0032	0.0012	0.0028	0.0018	0.0054	0.0015	0.0039			
Chromium	Dissolved	mg/l	0.0003	0.0002	0.0001	0.0002	0.0001	0.0002	0.0002	0.0004	0.0002	0.0002	0.0001	0.0001	0.0002	0.0004			
	Total	mg/l	0.0015	0.0047	0.0001	0.0002	0.0014	0.0040	0.0019	0.0029	0.0012	0.0030	0.0013	0.0041	0.0012	0.0042			
Copper	Dissolved	mg/l	0.0006	0.0010	0.0005	0.0006	0.0007	0.0015	0.0007	0.0016	0.0017	0.0011	0.0006	0.0008	0.0009	0.0013			
	Total	mg/l	0.0046	0.0108	0.0008	0.0017	0.0037	0.0088	0.0024	0.0052	0.0020	0.0050	0.0050	0.0162	0.0027	0.0061			
Iron	Dissolved	mg/l	0.0217	0.0400	0.0041	0.0068	0.0139	0.0358	0.0099	0.0226	0.0326	0.0499	0.0149	0.0248	0.0126	0.0266			
	Total	mg/l	1.3903	1.2760	0.0667	0.1782	1.5859	5.2740	1.6133	3.7600	1.1416	3.7000	2.4678	8.2800	1.4207	3.7000			
	Extract.	mg/l	1.0752	2.9770	0.1853	0.3488	1.4986	2.7500	1.1248	2.9440	0.5521	1.4180	1.2357	3.8400	0.6847	2.0550			
Potassium	Dissolved	mg/l	0.6836	0.9230	0.3118	0.3380	0.7343	1.1720	0.7151	1.2200	0.4845	0.7000	0.7291	1.0200	0.5119	0.7350			
	Total	mg/l	0.8104	1.1160	0.3423	0.4060	0.8607	1.2290	1.0631	1.4300	0.5864	0.6900	0.9018	1.1200	0.6575	0.8150			
Lithium	Dissolved	mg/l	0.0070	0.0105	0.0025	0.0032	0.0092	0.0163	0.0513	0.0088	0.0062	0.0086	0.0093	0.0157	0.0056	0.0080			
	Total	mg/l	0.0104	0.0194	0.0025	0.0028	0.0114	0.0163	0.0099	0.0190	0.0125	0.0114	0.0133	0.0171	0.0082	0.0090			
Magnesium	Dissolved	mg/l	8.6664	12.8800	17.5385	19.5000	13.4693	18.5700	5.7841	10.0950	9.9400	13.9000	6.5773	9.0800	10.0169	15.8000			
	Total	mg/l	9.3420	12.8200	17.7692	19.9200	15.4021	18.8700	7.4106	10.3500	10.7927	13.7000	6.9964	9.3900	11.7950	16.2500			
Manganese	Dissolved	mg/l	0.0028	0.0064	0.0512	0.0034	0.0500	0.0155	0.5415	1.6240	0.0514	0.0275	0.0080	0.0098	0.0771	0.0083			
	Total	mg/l	0.0400	0.1373	0.0010	0.0025	0.0401	0.1610	0.0385	0.0825	0.0388	0.0879	0.0572	0.1720	0.0367	0.0927			
	Extract.	mg/l	0.0435	0.1094	0.0083	0.0184	0.0626	0.1310	0.0420	0.0966	0.0308	0.0778	0.0568	0.1690	0.0365	0.0935			
Molybdenum	Dissolved	mg/l	0.0019	0.0025	0.0021	0.0024	0.0021	0.0026	0.0033	0.0035	0.0010	0.0015	0.0013	0.0018	0.0012	0.0018			
	Total	mg/l	0.0021	0.0027	0.0069	0.0230	0.0021	0.0027	0.0026	0.0035	0.0011	0.0015	0.0014	0.0017	0.0014	0.0019			
Sodium	Dissolved	mg/l	1.0950	1.5270	0.8562	1.0680	2.7357	5.4440	0.7184	1.7300	0.7327	1.6800	1.1045	2.6000	0.7738	1.6400			
	Total	mg/l	1.0713	1.4500	0.8346	1.1740	2.6357	5.3800	0.7175	1.3900	0.6564	1.1400	1.0182	1.9200	0.8013	1.8250			
Nickel	Dissolved	mg/l	0.0033	0.0054	0.0006	0.0010	0.0024	0.0037	0.0031	0.0068	0.0040	0.0064	0.0027	0.0045	0.0043	0.0069			
	Total	mg/l	0.0084	0.0140	0.0016	0.0029	0.0081	0.0153	0.0067	0.0140	0.0075	0.0128	0.0077	0.0182	0.0089	0.0147			
Lead	Dissolved	mg/l	0.0005	0.0012	0.0005	0.0012	0.0003	0.0006	0.0056	0.0017	0.0011	0.0020	0.0003	0.0010	0.0002	0.0004			
	Total	mg/l	0.0019	0.0054	0.0007	0.0011	0.0022	0.0050	0.0015	0.0031	0.0011	0.0030	0.0021	0.0070	0.0010	0.0027			
Strontium	Dissolved	mg/l	0.1446	0.2037	0.2502	0.3382	0.2356	0.3081	0.1160	0.1870	0.1458	0.1970	0.1305	0.1850	0.1431	0.1935			
	Total	mg/l	0.1614	0.2116	0.2542	0.3544	0.2533	0.3100	0.1353	0.1940	0.1510	0.1980	0.1427	0.1950	0.1563	0.2010			
Vanadium	Dissolved	mg/l	0.0003	0.0004	0.0002	0.0002	0.0002	0.0004	0.0012	0.0013	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003			
	Total	mg/l	0.0028	0.0071	0.0007	0.0014	0.0038	0.0100	0.0048	0.0120	0.0012	0.0035	0.0028	0.0088	0.0024	0.0059			
Zinc	Dissolved	mg/l	0.0063	0.0118	0.0021	0.0040	0.0040	0.0085	0.0149	0.0096	0.0135	0.0121	0.0067	0.0166	0.0079	0.0121			
	Total	mg/l	0.0328	0.0542	0.0054	0.0094	0.0286	0.0644	0.0299	0.0789	0.0215	0.0456	0.0271	0.0700	0.0310	0.0693			
Arsenic	Dissolved	mg/l	0.0006	0.0010	0.0002	0.0003	0.0005	0.0006	0.0016	0.0018	0.0004	0.0005	0.0006	0.0008	0.0006	0.0006			
Selenium	Dissolved	mg/l	0.0006	0.0008	0.0006	0.0010	0.0007	0.0010	0.0010	0.0016	0.0006	0.0009	0.0004	0.0005	0.0005	0.0007			

STO - Short Term Objectives (90th Percentile of Historical Values)
LTO - Long Term Objectives (Average Hestorical Values)

APPENDIX II:

MEMORANDUM OF UNDERSTANDING

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

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

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 to be followed by Inland Waters Directorate (IWD) of Conservation & Protection and Nahanni National Park Reserve of Canadian Parks Service (CPS) (herein referred to as the Parties) with respect to the implementation and management of the Environmental Water Quality Monitoring and Assessment Program (herein referred to as the Program) for the Nahanni National Park Reserve in the Northwest Territories. The annual program will be designed to meet the recommendations made in Section 7.0 of the December 1991 report entitled "Protecting the Waters of Nahanni National Park Reserve, N.W.T." However, other services can be negotiated on an as required basis.

The parties are committed to promoting shared utilization of resources to maximize the overall performance and effectiveness of the program under Canada's Green Plan.

2. ADMINISTRATION

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

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

2.3 The Administrators will meet at least once per year. Other Meetings will be held at such times as required for the effective planning and delivery of the Program.

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

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

4. FINANCIAL CONSIDERATIONS

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

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

4.3 Up-to-date information on the implementation of the Annual Work Plan and associated costs will be shared between the parties on a regular basis; and

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

NOTICE OF CHANGE

Notices of change in financial and/or for working practices and procedures, by either Party, will be provided immediately in writing to the other party for review and 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'

NAHANNI NATIONAL PARK RESERVE

ENVIRONMENTAL QUALITY MONITORING AND ASSESSMENT PROGRAM

MEMORANDUM OF UNDERSTANDING
between
Canadian Parks Service
Prairie & Northern Region
and
Conservation and Protection Service
Western & Northern Region
for
1993-94 Program Implentation

This schedule provides a summary of the annual financial contributions , made by Canadian Parks Service and Conservation & Protection Service of Environment Canada, for implementation of the 1993-94 Nahanni Environmental Monitoring and Assessment Program.

Canadian Parks Service	$15,000
Conservation & Protection Service	$15,000
	$30,000
	=======

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

Approved by Administrators:

For Conservation & Protection Service

J.N. Jasper

Jesse N. Jasper
Manager, Water Sciences
Inland Waters Directorate

For Canadian Parks Service

[signature] A/Sup

Erik Val
Superintendent
Nahanni National Park Service

March 2, 1993

SCHEDULE 'B'
1993-94 Annual Work Plan

NAHANNI NATIONAL PARK RESERVE

ENVIRONMENTAL WATER QUALITY MONITORING AND ASSESSMENT PROGRAM

MEMORANDUM OF UNDERSTANDING
between
Canadian Parks Service
Prairie & Northern Region
and
Conservation and Protection Service
Northern & Western Region
for
1993-94 Program Implementation

This schedule provides a summary of the Annual Work Plan, made by Canadian Parks Service and Conservation & Protection of Environment Canada, for implementation of the 1993-94 Nahanni Environmental Water Quality Monitoring and Assesment Program.

1.0 Sampling Stations

1.1 Water Quality:

00NW10EC0017 South Nahnni River above Nahanni Butte
00NW10EC0014 Prairie Creek at Mouth
00NW10EA0004 Flat River near Mouth
00NW10EB0013 Rabbitkettle River at Mouth
00NW10EB0012 South Nahnni River above Rabbitkettle River

1.2 Water Quantity

10EA003 Flat River near the Mouth

2.0 Sampling Parameters

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, Conductivity, Turbidity, Temperature & Colour (True), Non-Filterable Residue;
-Total Cyanide;
-Dissolved Metals: Barium, Cadmium, Cobalt, Copper, Iron, Lead, Manganese, Nickel, Selenium, Zinc;
-Total Metals: Barium, Cadmium, Cobalt, Copper, Lead, Nickel, Vanadium and Zinc;
-Extractable Metals: Iron and Manganese
-Nitrate-Nitrite
-Sulphate

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

2.2 Suspended Sediment Samples

A Sample will be collected by Centrifuge for analysis of the following:

-Total Metals: Barium, Cadmium, Cobalt, Lead, Nickel, Vanadium and Zinc, Arsenic, Selenium, Mercury, Copper, Iron, Manganese, Chromium;
-Organic Carbon and Nitrogen Content;
-Particle Size Distribution.

2.3 Snow Samples

Snow samples for atmospheric deposition of contaminants will be collected under a separate but complementary program for the National Water Research Institute, Environment Canada, Burlington, Ontario.

2.4 Water Quantity Measurements

Water levels, actual flow measurements and completed daily flows.

3.0 Sampling Frequency

3.1 Water Quality Grab Samples:

-Collected at each of the five(5) stations listed under 1.0 Sampling Stations during April, June and September 1993. Opportunistically sampled by CPS at Prairie Creek and elsewhere during July and August.
-Quality Assurance/ Quality Control Samples to be collected from the Flat River near Mouth and South Nahanni River above Nahanni Butte during June 1993 and April 1993, respectively.

3.2 Suspended Sediment Samples:

-Collected at South Nahanni River above Nahanni Butte in in July 1993 and, if warranted, September 1993. July 1993 suspended sediment sample should be analyzed as soon as possible so that data may be validated/ verified by Late August 1993.

3.3 Snow Samples

-Snow samples are to be collected on the South Nahanni River just upstream of the village of Nahanni Butte in March 1994 subject to meteorological conditions.

4.0 Responsibilities

All field activities will be implemented under the joint planning and management of the Chief Park Warden, Nahanni National Park Reserve for CPS and the Officer-In-Charge, IWD, Fort Simpson Office for C&P. 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 Environment Canada's National Water Laboratory in Burlington, Ontario for analysis according to standard procedures.

The Head, Water Quality, IWD, C&P in Yellowknife, NWT will be responsible for overall project management; and the verification, evaluation and distribution of data to CPS, Fort Simpson.

5.0 Financial Administration

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

- -Aircraft rental and direct fuel costs; and
- -Salary related to 0.15 person-years

Conservation & Protection Service will be responsible for the payment of costs associated with:

- -The operation and maintenance of the Water Quantity Station located at Flat River near the Mouth.
- -Sample shipping and Laboratory analysis costs associated with the Water Quality grab samples, Quality Assurance/ Quality Control and Suspended Sediment sampling; and
- -Aircraft fuel used from IWD fuel caches.

Approved by Administrators:

For Conservation & Protection Service

J.N. Jasper

Jesse N. Jasper
Manager, Water Sciences
Inland Waters Directorate

For Canadian Parks Service

Prosper A/Sup.

Erik Val
Superintendent
Nahanni National Park Service

March 2, 1993

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 Prosper
Departmental Operations Manager
Deh Cho

February 28, 1996

APPENDIX III:

SYNTHETIC FLOW OF CALCULATIONS FOR SNR ABOVE NAHANNI BUTTE SITE

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, what data he requires and what he is going to do with this data. The dates on which he requires discharge data at 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, and the Flat River at the Mouth. This gave me hope that the 1993 data would be available readily in an electronic medium, and even better, in a spreadsheet format. After some searching with Paul, we discovered the relevant files in Quattro Pro for DOS format. Unfortunately, Paul had only entered six months of data for each station (April to September).

I translated Paul's Quattro Pro files into Excel and extracted the relevant data. These data were copied to an Excel worksheet, \SNAHANNI.WQ\DSCHARGE.DAT\SNAHANNI.XLS. Using this data, I applied the appropriate formulae to determine the incremental flows and then generated the attached plots. Both June 7 and September 7 appear to fall while the river is in recession, and the ungauged flows just prior to the desired dates appear relatively steady (especially September 7). Please check the curves and give 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 discharges at the three hydrometric stations and enter them into my spreadsheet. This task should not take particularly long, and I would have completed it today, but I have found that keypunching and Friday afternoons do not mix well. I will get back to this on Monday morning.

RKM

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.

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.

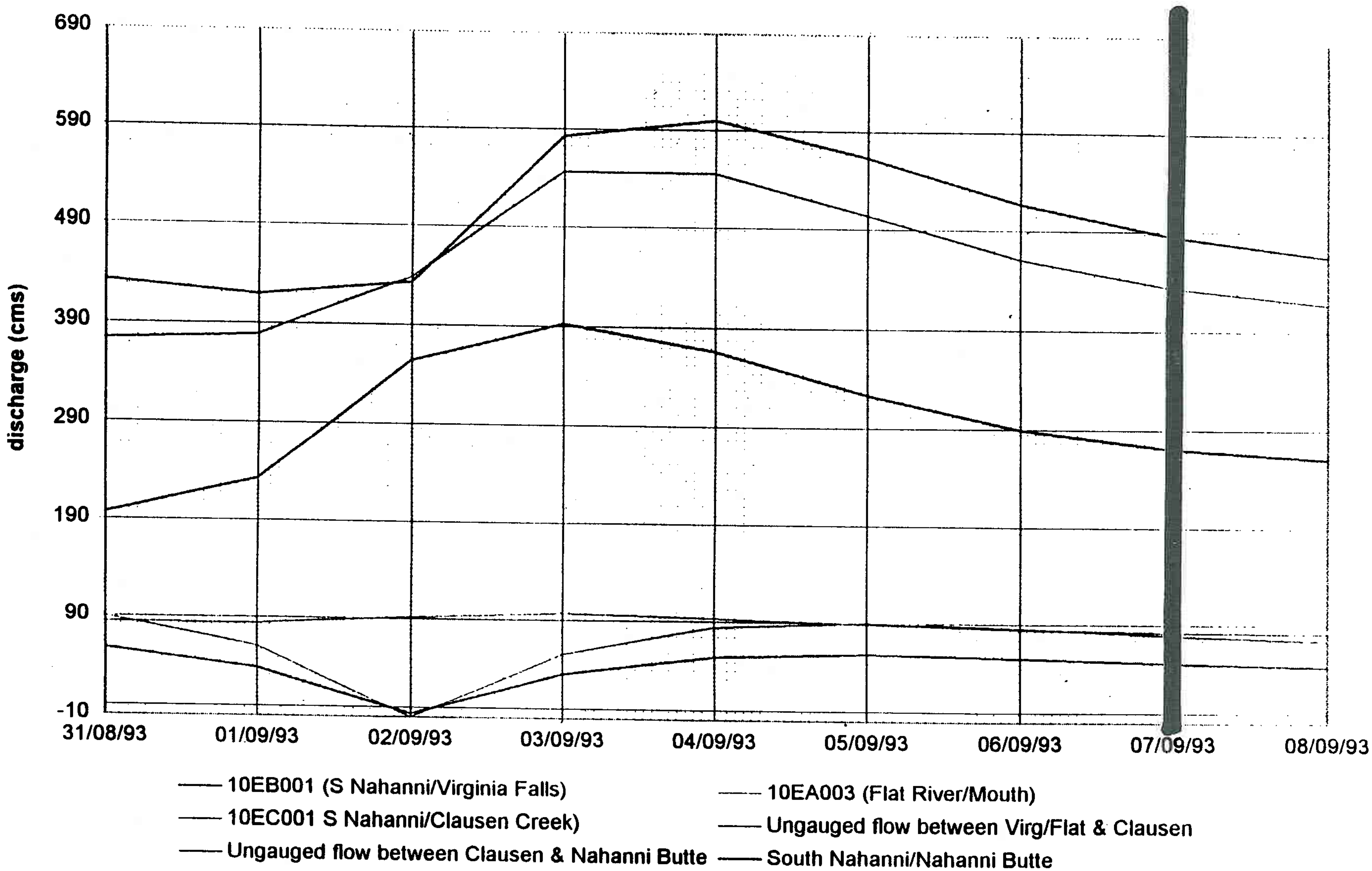
This suggests that on these two dates the unit flow (flow per square kilometer) was higher in the higher part of the basin than in the lower part (particularly in Jun/93), that is, that the unit flows for rivers such as the Cathedral, Clearwater, Mary, Meilleur, Prairie.and Wrigley were lower than the 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 and Sep 7/93, so that no adjustments to the procedures are required. An example of the need to plot the curves would be if the discharge at Butte had been requested for Sep 2/93. Here the Flat and S Nahanni/Virg have suddenly risen, but because of the time lag the S Nahanni/Clausen has not, causing the incremental flows to compute as negative when they are physically positive.

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

South Nahanni River at Nahanni Butte
Discharge analysis for September 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

Page 1

discharge data

DATE	10EB001 (1) (cms)	10EA003 (2) (cms)	10EC001 (3) (cms)	(3)-[(1)+(2)] (4) (cms)	(4)*5100/7940 (5) (cms)	(5)+(3) (6) (cms)
17/05/93	510	252	946	184	118.19	1064.19
18/05/93	777	225	1070	68	43.68	1113.68
19/05/93	848	190	1160	122	78.36	1238.36
20/05/93	860	205	1250	185	118.83	1368.83
21/05/93	808	229	1210	173	111.12	1321.12
22/05/93	677	193	1020	150	96.35	1116.35
23/05/93	534	168	861	159	102.13	963.13
24/05/93	493	163	773	117	75.15	848.15
25/05/93	527	166	768	75	48.17	816.17
26/05/93	633	173	847	41	26.34	873.34
27/05/93	732	205	1020	83	53.31	1073.31
28/05/93	997	258	1300	45	28.90	1328.90
29/05/93	1360	361	1750	29	18.63	1768.63
30/05/93	1560	384	2160	216	138.74	2298.74
31/05/93	1610	302	2180	268	172.14	2352.14
01/06/93	1440	249	2060	371	238.30	2298.30
02/06/93	1360	263	1900	277	177.92	2077.92
03/06/93	1520	341	2090	229	147.09	2237.09
04/06/93	1760	370	2260	130	83.50	2343.50
05/06/93	1790	357	2320	173	111.12	2431.12
06/06/93	1660	333	2220	227	145.81	2365.81
07/06/93	1590	353	2110	167	107.27	2217.27
08/06/93	1580	342	2080	158	101.49	2181.49
09/06/93	1520	307	2240	413	265.28	2505.28
10/06/93	1180	247	1820	393	252.43	2072.43
11/06/93	963	215	1460	282	181.13	1641.13
12/06/93	928	218	1350	204	131.03	1481.03
13/06/93	1030	244	1430	156	100.20	1530.20
14/06/93	1010	247	1470	213	136.81	1606.81
15/06/93	901	237	1350	212	136.17	1486.17
16/06/93	826	219	1230	185	118.83	1348.83
17/06/93	783	206	1150	161	103.41	1253.41
18/06/93	790	205	1130	135	86.71	1216.71
19/06/93	848	240	1180	92	59.09	1239.09
20/06/93	921	279	1320	120	77.08	1397.08
21/06/93	933	265	1290	92	59.09	1349.09
22/06/93	1030	274	1390	86	55.24	1445.24
23/06/93	935	269	1410	206	132.32	1542.32
24/06/93	806	238	1230	186	119.47	1349.47
25/06/93	750	219	1110	141	90.57	1200.57
26/06/93	732	210	1070	128	82.22	1152.22
27/06/93	768	220	1090	102	65.52	1155.52
28/06/93	780	227	1150	143	91.85	1241.85
29/06/93	767	220	1120	133	85.43	1205.43
30/06/93	774	218	1100	108	69.37	1169.37
01/07/93	772	214	1100	114	73.22	1173.22

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)+(3) (6) (cms)
17/08/93	292	123	544	129	82.86	626.86
18/08/93	287	117	529	125	80.29	609.29
19/08/93	283	112	512	117	75.15	587.15
20/08/93	277	110	503	116	74.51	577.51
21/08/93	261	107	486	118	75.79	561.79
22/08/93	252	103	465	110	70.65	535.65
23/08/93	247	101	455	107	68.73	523.73
24/08/93	254	101	458	103	66.16	524.16
25/08/93	259	98.5	457	99.5	63.91	520.91
26/08/93	250	96.7	453	106.3	68.28	521.28
27/08/93	236	94.4	439	108.6	69.76	508.76
28/08/93	223	91.6	421	106.4	68.34	489.34
29/08/93	211	89.1	403	102.9	66.09	469.09
30/08/93	201	87.2	387	98.8	63.46	450.46
31/08/93	198	85.7	375	91.3	58.64	433.64
01/09/93	233	85.2	380	61.8	39.70	419.70
02/09/93	355	92.7	439	-8.7	-5.59	433.41
03/09/93	393	98	547	56	35.97	582.97
04/09/93	367	94.3	546	84.7	54.40	600.40
05/09/93	324	89.7	505	91.3	58.64	563.64
06/09/93	290	85.6	462	86.4	55.50	517.50
07/09/93	271	83.1	434	79.9	51.32	485.32
08/09/93	261	82.2	418	74.8	48.05	466.05
09/09/93	289	83.6	411	38.4	24.66	435.66
10/09/93	309	86.5	452	56.5	36.29	488.29
11/09/93	296	87	462	79	50.74	512.74
12/09/93	294	88.8	461	78.2	50.23	511.23
13/09/93	300	87.7	463	75.3	48.37	511.37
14/09/93	304	86.5	467	76.5	49.14	516.14
15/09/93	298	84.8	462	79.2	50.87	512.87
16/09/93	286	82.8	449	80.2	51.51	500.51
17/09/93	271	80.3	434	82.7	53.12	487.12
18/09/93	258	78.2	413	76.8	49.33	462.33
19/09/93	247	76.5	398	74.5	47.85	445.85
20/09/93	241	74.5	382	66.5	42.71	424.71
21/09/93	231	73.1	370	65.9	42.33	412.33
22/09/93	220	71.7	358	66.3	42.59	400.59
23/09/93	213	70.5	346	62.5	40.14	386.14
24/09/93	205	70	338	63	40.47	378.47
25/09/93	196	69.1	331	65.9	42.33	373.33
26/09/93	187	68.3	323	67.7	43.48	366.48
27/09/93	182	67.9	317	67.1	43.10	360.10
28/09/93	182	68.1	311	60.9	39.12	350.12
29/09/93	182	68.6	312	61.4	39.44	351.44
30/09/93	182	70.4	313	60.6	38.92	351.92