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DEHCHO - GREAT RIVER:

The State of Science in the Mackenzie Basin (1960-1985)

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Trail River. Photo: Al Wiens, 1972.

Martin River slump. Photo: Al Wiens, 1974.

Forward

The Mackenzie River is one of the great rivers of the world. One of the names used by the Dene peoples that live in the basin is Dehcho, the Great River. Despite its large size, the Mackenzie River Basin is under threat from climate change, natural resource extraction, potential water diversion projects, and urban development. In 2013, there was an emphasis on the need to improve access to historical information on freshwater within the Mackenzie River Basin. This was echoed in the findings of the Rosenberg International Forum Report, which stated that "[the] inaccessibility of some major work done in the 1970s means that the working knowledge of the Mackenzie is smaller than that of other major rivers." To address this gap, The Gordon Foundation provided a grant to the United Nations University Institute for Water, Environment and Health (UNU-INWEH) to catalogue the information generated in past studies and find ways of making it more widely available.

This initiative proved to be timely. Cuts to federal libraries in 2013 led to the closure of the library at the Freshwater Institute in Winnipeg, which contained what has been described as a "treasure trove" of information on freshwater in Canada. UNU-INWEH salvaged a number of records from the collection at the Freshwater Institute that would have otherwise been lost from the public record. They also sourced documents from other libraries and received donations from researchers who were involved in studies between 1960 and 1985. UNU-INWEH prepared a summary of the research conducted over this period, that relates to water quality in the Basin, and also referenced landmark reports prepared over this period. This report entitled, "Dehcho-Great River: The State of Science in the Mackenzie Basin (1960-1985)" represents the culmination of this archiving project.

To ensure long-term accessibility to the collection compiled by UNU-INWEH, the documents are being added to the collection of the Arctic Institute of North America (AINA) at the University of Calgary. High-priority electronic documents will be included in AINA's online database, the Arctic Science and Technology Information System (ASTIS), which contains 81,000 records of publications and research projects about northern Canada and the circumpolar Arctic. ASTIS is publicly accessible online from a bilingual website[1]. Relevant documents gathered by UNU-INWEH are being referenced against the online database and any documents that are not currently part of the collection will be added to the archive at the University of Calgary.

> "The disintegration of managing historical data and documents in the Mackenzie Basin is a national disgrace."
>
> (Survey respondent)

[1] ASTIS website: www.aina.ucalgary.ca/astis. The collection itself is available here: http://www.aina.ucalgary.ca/scripts/mwimain.dll/144/proe/proeyd/BI+GOR?COMMANDSEARCH

Summary

The Mackenzie Basin is a unique eco-hydrological zone, a vast store of natural resources, and home to both Indigenous and non-Indigenous peoples. Historically, the Basin has been the subject of political controversy, protection, exploitation, and research in the natural and social sciences. While the Basin's future is unknown, there are real risks that records documenting past conditions in the Basin will be lost.

The goal of this project was to seek out historical documents and data pertaining to the quality of water in the Mackenzie Basin between 1960 and 1985. This initiative, sponsored by The Gordon Foundation, proved to be very timely because of cuts to federal libraries that resulted in the boxing up of large numbers of federal reports and other relevant documents. UNU-INWEH sourced thousands of references from various online databases and private collections. However, hard copies of documents were much more difficult to obtain. While librarians in public libraries and universities were extremely helpful, some documents were stored in locations where access is limited. Other documents could only be ordered through interlibrary loans, which are subject to a maximum number per request and a loan period of two weeks. Thus, the time to source even a small number of documents was in the order of months. There were fortunate developments that mitigated the slow erosion of historical documents. Retiring federal scientists and university professors with personal collections were willing to donate documents in the hope that they would be put to good use and kept safe.

This project sheds some light on the importance of historical documents. Trends in development can be aligned with patterns in water quality. Impacts predicted 40 years ago can be evaluated against what actually occurred. On the other hand, some calls for action appear to have gone unheeded. For instance, proposals to develop monitoring programs in the Basin are still being heard more than 40 years after these data gaps were originally recognized. UNU-INWEH feels fortunate to have been involved in this project and to have had an opportunity to evaluate documentation that may have been otherwise lost.

> "The Mackenzie River Basin covers a vast extent of Canada. It sustains local livelihoods and impacts hydrological regimes at continental and global levels. The Basin contains large, intact and functioning ecosystems - something that is becoming increasingly rare globally. We need good science to understand the rapid changes that are taking place in this part of the country due to climate change and natural resource development."
>
> (Tom Axworthy,
> The Gordon Foundation)

St. Martin River. Photo: Al Wiens, 1972.

The Study

Context

The purpose of this project was to identify, procure, and synthesize historical research on the Mackenzie River Basin to ensure broad access to older documents, provide analyses of historical trends, and enhance the evidence base for current decision-making.

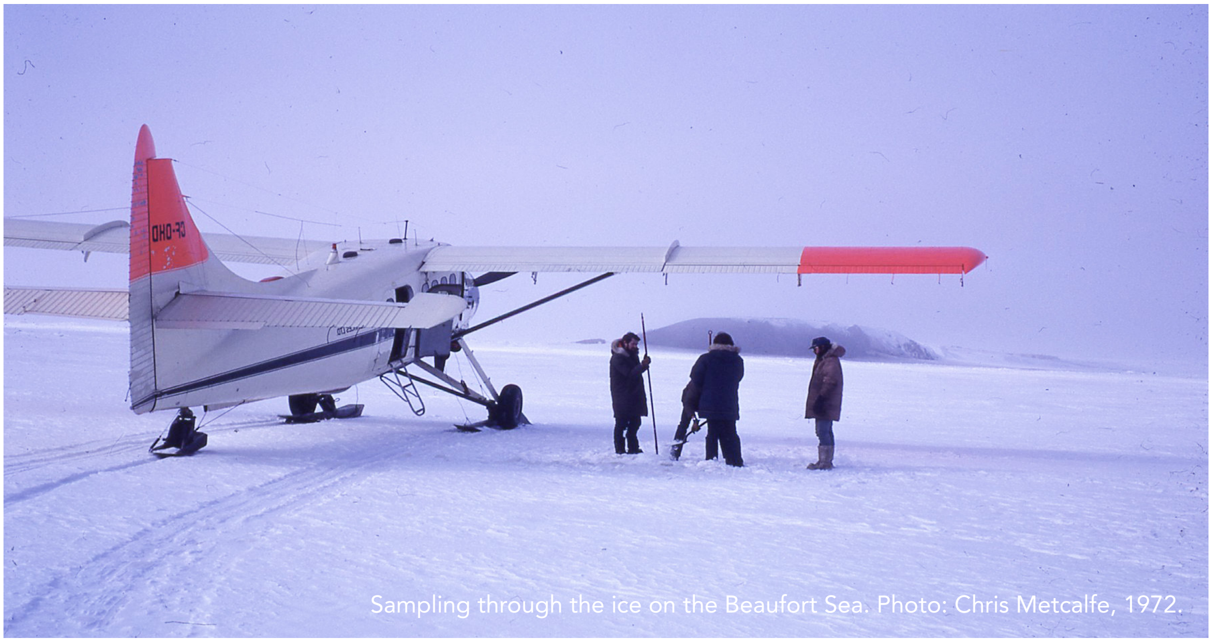
The project focused on:

- Research undertaken between 1960 and 1985, including the period 1970 – 1975 when the Norman Wells Pipeline was assessed and built;
- Research undertaken by Canadian-based institutes and organisations; and,
- Research on water quality and quantity, and associated data.

Introduction

Historical data and documents are useful and critical to assess current trends and provide context. It became clear during this project that many historical Mackenzie Basin documents are no longer easily available. While our online searches identified 5,000 relevant titles, attempts to obtain either hard copies or digitised versions revealed that many of the original documents associated with these titles were not readily accessible or had been placed in storage. This situation was exacerbated by federal government library closures, including the large archive of material on the Mackenzie Basin at the Freshwater Institute in Winnipeg, which was closed in 2014. Thus, even though the titles of these resources can still be identified through electronic databases, they are becoming increasingly more difficult to obtain. In addition, many of the research scientists who were active in the Basin at that time have retired, and valuable information and documentation that was in their possession is no longer available to the public.

Richardson Mountains. Photo: Chris Metcalfe, 1972.



Sampling through the ice on the Beaufort Sea. Photo: Chris Metcalfe, 1972.

Methods

The initial assessment was based on an Internet search (Google Scholar, institutional libraries) for the following purposes:

1. To identify literature using a keyword search (Appendix I) and constraining searches to the years 1960-1985.
2. To identify key organisations and researchers active in the Mackenzie Basin during the period 1960-1985, as well as author searches in documents identified in (1) above, (Appendix II).
3. To identify any searchable databases (Appendix III).

Following this, the literature was screened to narrow the scope of documents according to the overall scope of the project. References were mined from additional libraries and databases, as new organisations came to light, and requests were made to organisations who indicated that they had library resources. Documents were prioritised according to those that would provide the greatest benefit and be most relevant to current and future scientists and decision-makers within the Basin.

Organisations and Researchers

Based upon authorship of reports, Internet searches, and a key informant survey, 90 organisations active in environment-related initiatives in the Basin were identified during the selected period. This breaks down into a total of 29 government agencies, 38 private companies, 2 public organisations, and 2 academic institutions, as well as 10 boards or committees.

Resources

Over 5,000 documents were identified using four primary libraries/databases. Of these, approximately 2,400 titles were prioritised for inclusion in a repository and approximately 100 were flagged for immediate sourcing. These included summary and synthesis reports, as well as bibliographies and environmental impact assessments containing original data. It should be noted that many of the databases contained duplicate documents.

In terms of broad topics identified, a keyword search of titles indicated that over 900 documents referrred to water, but only 169 specifically referred to water quality. Far fewer (only 2) referred to water quantity. Most fauna references were for fish (approximately 500 documents), with 34 for invertebrates (indicators of water quality). Only 57 documents referred to Native/Indian/Band and there were no references to Aboriginal/First Nation in document titles (Appendix IV), which is consistent with the terminology used to refer to Indigenous peoples at the time.

Trends in Research and Water Quality

An initial assessment of the identified historical literature was undertaken through key text analysis and summary statistics, based on authors, titles, and keywords. The following texts were key environmental assessments chosen because they were undertaken at the beginning, middle, and end of the evaluation period, respectively:

- 1974 Environmental Impact Assessment of Mackenzie Gas Pipeline from Alaska to Alberta;
- Berger Report, 1977a and b, on the feasibility of the Mackenzie gas pipeline; and
- Mackenzie River Basin Report, 1985 (see Appendix V).

These texts were reviewed not only for the data trends that could be extracted, but also for the key topics, factors, and issues that were seen to be most important for each period. Observed trends in the literature include an early emphasis on methods and measurement techniques, which gave way to a focus on thresholds and recommended levels, particularly for contaminants and systematic monitoring. Another trend observed during the study period was a change in the types of developments being considered, from the specific gas pipeline proposal in the late 1960's, to oil and gas exploration, and other development activities in the Basin. It should be noted that there was already hydropower development in the Basin (the W.A.C. Bennett Dam at the head of the Peace River Canyon).

While not unexpected, it is important to recognise the emphasis that was placed on the "North", and the Mackenzie Basin in particular, as a unique environment, with an ecology and a heritage to be preserved for all Canadians, characterised by cultural and linguistic diversity, fishing, hunting and trapping, and recreation and tourism (Berger, 1977a). Moreover, the climate makes for a very unique hydrologic regime, with periods of low flow and frozen surfaces, areas of permafrost, and dynamic spring melt. These cold temperatures also restrict degradation of pollutants so they persist longer and may have more devastating effects in northern waters then they would in the South. Temperature also impacts growth of fauna and flora, meaning any perturbation requires a longer recovery period.

The Berger Report (1977a) was very clear in debunking the "myth" that terms and conditions can be imposed to protect the environment, no matter how large the resources applied to a project and how many studies and reports are conducted; asserting that this assumption does not hold true in the North. In particular, the northern pipeline decision was seen to be about more than just the pipeline itself. This decision was about the need to protect the northern environment and the future of northern peoples (Berger, 1977a). Within the Basin are tracts of land and water, which are of limited size, that are vital to the survival of whole populations of species of mammals, birds, and fish. Disturbances in these areas can have adverse biological effects, which stretch far beyond the area of impact. Furthermore, the start of development in the Basin (the Mackenzie gas pipeline), was seen as the thin end of the wedge for continued natural resource development. It was recognised that this project would pave the way for oil pipelines and other infrastructure associated with industrial development (e.g. roads and other transportation networks) (Berger, 1977a). Moreover, most of these development projects were based on non-renewable resources and were overwhelmingly large scale projects. Looking at a timeline of development in the region (Figure 1), large infrastructure development commenced with the construction of dams. Then, during the period studied, two energy corridors were considered for development: i) a corridor from Alaska across the Northern Yukon to the Mackenzie Delta; and, ii) a corridor along the Mackenzie Valley from the Delta to the Alberta border.

The Berger Report (1977a, b) was commended on its inclusion of Aboriginal perspectives. The regional importance of the Peace-Athabasca Delta was recognised to rest not only in its biological productivity, but in its role of providing food and income to the Aboriginal people. As such, comprehensive planning was seen to be linked to settlement of Aboriginal land claims and immediate protection of several land areas. This had important consequences for pipeline development. It was recognised that if approval occurred prior to a settlement of claims, the future of the North, and thus of the Aboriginal people, would be seen to have been decided for them, as opposed to by them. The industrial frontier versus homeland perspectives were clearly articulated. The pipeline companies saw development as an unqualified gain for the North, aligned with northern business that perceived it as an impetus for growth and expansion and a panacea for perceived economic troubles. Claims were made that development would create thousands of jobs for Aboriginal people, but Justice Berger found that the income derived from hunting, fishing, and trapping was a far more important element in the Northern economy than realised or appreciated. Meanwhile, Aboriginal people felt they were under increasing pressure to abandon their cultural values of respect for the wisdom of their Elders, their concept of family responsibilities and their willingness to share, and their relationship with the land. These social prices were seen to outweigh potential employment benefits.

Water Quality Trends

Water quality measurements fall into physical parameters, nutrients, metals, and organic contaminants. Aggregate values for water quality parameters for the sub-basins were calculated using values obtained from the various measuring stations within each of the sub-basins over a 20-year period (1960–1980) as reported in Appendix VI.1 – VI.6 (Environment Canada, 1985b). In general terms, of the seven Mackenzie sub-basins, Hay River appeared to consistently demonstrate the poorest water quality over the period 1960-1980, reflecting that this sub-basin was a key area for mining operations in the form of the Pine Point mine, and an area of oil production. Great Bear Lake, followed by Great Slave Lake, demonstrated the highest quality of water in the Basin, as these sub-basins were virtually free of mining, oil and gas, and agricultural activities. The Athabasca River has no major cities along its route, no developed hydroelectric sites, and little farming or other agricultural activities. However, baseline determination of water quality in the Athabasca River sub-basin is complicated by the influence of the oil sands area. It was anticipated that the emission of highly saline groundwater to waters of the Athabasca River would have serious effects downstream, especially in the Peace-Athabasca Delta (Environment Canada, 1985a). One of the main concerns in the late 1960's and early 1970's was the preservation of what was considered virtually pristine surface waters. Some of the difference in water quality parameters among the sub-basins is due to geologic formations.

> "We have an obligation to maintain the high quality of water where it now exists."
>
> (Berger, 1977b)

Physical parameters vary according to the physiographic sub-divisions found in the Basin. There is a geologic division through the Mackenzie Basin between the Canadian Precambrian Shield to the east and the younger sedimentary rocks to the west. Total dissolved solids (TDS) values are an order of magnitude higher (100's mg/L) in the sedimentary portion of the Basin versus the Shield (10's of mg/L), as described by How (1974). Specifically, rivers in the Western Cordillera have relatively high turbidity due to the sedimentary bedrock and high relief. Rivers in the Interior Plain have relatively higher values of TDS, specific conductivity, and colour. Both regions demonstrate seasonal variations in response to the discharge regime, with low turbidity and colour over the winter, peaks in the summer, and TDS and specific conductivity declines during open water periods (i.e. spring and summer) due to the dilution effects of high discharge. Meanwhile, rivers in

The 60s

- W.A.C. Bennett Dam construction on Peace River (1961-1967)
- Commercial oil production (Athabasca Oil Sands, Suncor mine (1967))
- W.A.C. Bennett Dam electricity generation (1968)

The 70s

- Energy Crisis
    - Call for alternate fuel sources
    - Application and permits for Mackenzie Valley Gas Pipeline
- Environmental Program Mackenzie Delta Impact Assessment; Imperial Oil (1972-1974)
- Environmental Impact Assessment of Mackenzie Gas Pipeline: Alaska - Alberta (1974)
- Berger Report commissioned on gas pipeline feasibility (1974)
    - Berger Report released: recommends 10-year delay on pipeline construction (1977)
- Peace Canyon Dam construction on Peace River (1975)
- Athabasca oil sands
    - Syncrude Mine oil production (1978)
- Trudeau government loses federal election before acting on Berger report (1979)

The 80s

- Peace Canyon Dam construction completed on Peace River (1980)
- Mackenzie River Basin Study Report (1981)
- BC Utilities Commission Hearing: Site C and Site E Dams plans rejected (1982)
- BC Utilities Commission Hearing: Site C Dam proposal rejected again (1989)

Figure 1: Timeline of development in the Mackenzie Basin (1960's – 1980's).

the Shield have low values for all of the physicochemical parameters (Environment Canada, 1985b) (Appendix VI-Table VI.2).

While metal concentrations in the rivers and lakes of the Mackenzie Basin were generally at natural levels and largely associated with suspended solids concentrations (Environment Canada, 1985b), comparisons were developed between some of the 90^{th} percentile parameter values measured in the rivers in the sub-basins from 1960 to 1980 and the guidelines for the protection of freshwater aquatic life that were in place at the time (Environment Canada, 1985b). When examined against the water quality guidelines that were in place at the time, some exceedances can be identified (below and Table 1). It should be noted that the values for several parameters were below detection limits, but these detection limits were in some cases higher than the water quality guidelines. In these cases, we cannot judge whether there were any exceedances. Specifically, the concentrations of organic contaminants (i.e. PCBs, pesticides, phenolics), which were only analysed in water collected in the Athabasca Basin and Peace Basin, were all below the detection limits, except for phenolic compounds.

Finally, all the exceedances for the various sub-basins were determined using the upper 90^{th} percentile values or the upper range concentration for the various water quality parameters (Appendix VI-Tables VI.4, 5, and 6), and not the median or mean values. Thus, these exceedances probably occurred under worst case scenarios, rather than under normal conditions:

- The upper range concentration of copper was nearly 37 times higher than the guideline in Great Slave Lake.
- The upper range concentration of Total Phosphorus (TP) in the Mackenzie River sub-basin was double the recommended maximum value.
- In the Liard River Basin, the upper range concentration for copper was ten times greater than guideline values.
- The upper range concentration for lead was double the recommended guideline in Great Bear Lake.

- In the Athabasca River and Peace River sub-basins, the upper 90th percentile value for phenolic compounds was more than 14 times the recommended limits.

For the inorganic elements, a slight trend of increasing mean concentrations of extractable manganese and iron were observed in the Athabasca Basin, as well as extractable manganese and zinc in the Smoky River sub-basin. These trends could have been caused by changes in measurement methods, or alternatively, could reflect the impacts of mining, oil, and gas development in these sub-basins.

In 1985, new water quality guidelines were developed for some parameters for the protection of freshwater aquatic life (Environment Canada, 1985b). These were based upon a combination of US Environmental Protection Agency and Environment Canada water quality criteria (Environment Canada, 1972; US EPA, 1976, 1979). In some cases, these new 1985 guidelines were more stringent and in one case, less stringent (Table 2). In the case of the exceedances for cadmium and copper, listed below under the old water quality guidelines, the upper range values would have exceeded the new guidelines by an even greater margin.

Trends in Development Concerns

Some of the activities that affected water quality in the region included mining, oil and gas, forestry, agriculture, rural expansion, and hydroelectric development. Agriculture and forestry are present only in the southern portion of the Basin. Hydroelectric development began in the 1960's with the W.A.C Bennett Dam. Some limited exploration began of oil reserves by Suncor, but it was not until the energy crisis of the 1970's that efforts for oil and gas exploration were redoubled in the Mackenzie Basin.

Agriculture

Agriculture in the Mackenzie River Basin was concentrated in the south, with approximately 1.1 million hectares of arable land in the Peace and Athabasca sub-basins. Of this, 1,000 hectares were irrigated. Agricultural practices can affect water quality through the introduction of fertilisers and pesticides and through their effects on erosion patterns.

Mining

The lead-zinc mine at Pine Point played a crucial role in developing Hay River as a major transfer point between 1964 and 1989 and could account for some of the exceedances of water quality parameters for

Table 1: Exceedances for upper range of concentrations of selected elements by river basin against recommended levels published by the Berger Report (1977a, b). The full data can be found in Appendix VI-Table VI.5

Element	Recommended Levels (Berger, 1977a, b)	Sub-basin Exceedances (Environment Canada, 1985b)
Cadmium	0.01 mg/L	Great Slave River
Copper	0.02 mg/L	Lake Athabasca, Great Slave Lake, Great Bear Lake
Iron	0.3 mg/L	Athabasca River, Peace River, Liard River, Hay River, Great Slave River, Mackenzie River
Manganese	0.05 mg/L	Athabasca River, Lake Athabasca, Peace River, Liard River, Hay River, Great Slave River, Mackenzie River

Table 2: Changes in water quality guideline thresholds for protection of freshwater aquatic life, 1977 versus 1985.

Element	Recommended Levels (Berger, 1977b)	Recommended Levels (Environment Canada, 1985b)	Difference
Silver	0.05 mg/L (50 μg/L)	0.1 μg/L	Berger tolerance 500 times higher
Cadmium	0.01 mg/L (10 μg/L)	0.2 μg/L	Berger tolerance 50 times higher
Chromium	0.05 mg/L	0.04 mg/L	Berger tolerance slightly higher
Copper	0.02 mg/L	0.002 mg/L	Berger tolerance 10 times higher
Mercury	0.001 mg/L (1 μg/L)	0.2 μg/L	Berger tolerance 5 times higher
Nickel	no guideline	0.25 mg/L	
Lead	0.015 mg/L	0.01 mg/L	Berger tolerance slightly higher
Selenium	0.01 mg/L	0.01 mg/L	
Zinc	0.05 mg/L	0.1 mg/L	Berger tolerance half of the new value

elements identified in the Hay River Basin. Other mines in the Basin included sites in the Camsel River and the east coast of Great Bear Lake. Some known elemental contaminants discharged into water from these mining operations included copper, lead, zinc, cadmium, arsenic and mercury, and free cyanide and metal-cyanide complexes formed during extraction of gold and silver. However, many of these elements may have been present in water as a result of natural geological deposits in the watershed.

Energy Extraction/Generation

There were four small oil producing sites located upstream from Pine Point Mine on the Hay River (Rainbow, Zama, Rainbow South and Virgo), as well as an oil producing site near the confluence of Great Bear River with the Mackenzie River (set back from the lake, so not considered in water quality assessments). There was no oil and gas production near the Slave River, consistent with excellent water quality in Great Slave Lake. Processing plants in the Peace, Athabasca, and Hay River sub-basins accounted for 85% of Canada's production of oil and gas, requiring large quantities of water. In addition to higher concentrations of suspended materials and organic substances in effluents than the original source water, large or multiple oil spills have the potential to influence albedo of snow and ice and therefore ice cover (Berger, 1977a), especially in the Beaufort Sea. Technology available at the time was seen to be insufficient to control or clean up a major oil spill in this remote area, especially in conditions of floating ice or rough water.

Hydroelectric and thermal-electric generating stations (six in total) were constructed throughout the Great Slave Lake sub-basin during the 1960s to supply power to the Pine Point Mine. These power plants affected both downstream and upstream hydrology and water quality. Vegetation complexes in the deltas (and therefore fauna) are intimately tied to the water levels. If a dam or chilled gas pipeline were built near the Lady Evelyn Falls area in particular, the water downstream of the falls would be colder and could thus delay the spawning time of some fish species. The fish species


Channel in the eastern Mackenzie Delta. Photo: Chris Metcalfe, 1971.

that live downstream of the falls would be affected, including walleye, northern pike, and sub-adult grayling. Two dams were proposed in the 1980s for hydroelectric development along the steeply sloping Whirlpool Canyon-Grand Canyon section of the Liard River, but were turned down by the BC Utilities Commission. If these dams were ever constructed, Liard Hot Springs would have been under 145 m of water and the Whirlpool Canyon area under about 100 m of water.

Emissions from thermal-electric generating stations may contain SO_2, polyaromatic hydrocarbons, some heavy metals, and other compounds, which are potentially harmful to the environment. There were two thermal-electric generating stations located very close to the Hay River.

Chilled Pipeline

In northern regions, oil and gas are chilled for transportation through pipelines to reduce melt associated with heat transfer. However, in permafrost, chilled gas pipelines can reduce the depth of the active layer lying above the pipeline axis. This raised active layer will form a barrier for subsurface flow, forcing water to run parallel to the gas pipeline or to surface and potentially cause frost heave. This disruption of groundwater and surface water flow as a result of ground and river icing could negatively affect the aquatic environment, especially in winter. However, it could positively affect the flood plains that benefit from high water levels (ice jam flooding) to nourish the soil and vegetation. Water forced to the surface by large ice lenses (ground icing) in the soil can lead to slope instability and failure, and ground subsidence or cut off flow to downstream wetlands.

Urbanisation

Construction crews, full time operations staff, and supporting services for development require housing and transportation networks. This results in the development of towns, increased population density, vehicular traffic, and demand for municipal services. These have significant impacts on flora and fauna, changing surface permeability and albedo, and interrupting animal movement. Domestic sewage along the pipeline was specifically considered to likely be the largest threat of poor water quality from organic material in the watercourses (How, 1974), as a result of urbanisation.

Construction

Impacts of construction range from those associated with clearing land for development, the actual construction itself, the construction of roads to access

sites and the dredging of local waterways for navigation or to procure construction materials. Land clearing results in large amounts of organic material waste. Their decay and subsequent leaching can change the content of dissolved solids and oxygen levels in the water. The destruction of the vegetative canopy below the treeline decreases the thermal insulation provided, leading to greater frost penetration, which could restrict drainage from surrounding areas, promoting wetter soils, and affecting regeneration in the area. Dredging not only contributes to mechanical destruction of aquatic and shoreline vegetation, but alters species composition on alluvial flats as a result of lower water levels.

Environmental Concerns

Fish

Fish are important not only to ecosystem stability and as an indicator of ecosystem health, but as a food source for Aboriginal people, an economic resource, and a platform for recreation and tourism in the region. A strong domestic fishing presence was identified on the western shorelines of Great Bear Lake and Great Slave Lake. The two important factors when examining fish populations are species diversity and stock levels. The Mackenzie River supports more fish species than most Arctic rivers (i.e. 34 species) because it originates in warmer latitudes. In northern environments, fish typically grow more slowly and reach sexual maturity at a later stage in their development. Thus, when a disturbance reduces fish populations in the North, the ability of the species to recover to its pre-disturbance numbers is limited relative to fish in warmer climates. Arctic grayling, in particular, are highly susceptible to overfishing as illustrated by a 1974 census (Falk and Gillman, 1974), which found that the average size and age of the Arctic grayling had declined significantly since 1967 when baseline studies were conducted by Bishop (Bishop, 1967).

There are two distinct spawning seasons for northern fish. The eggs of the fall spawners have to survive the hardships of the winter environment, lying in the gravel from October until ice break-up the following May or June. Spring spawners deposit their eggs at ice break-up and the young emerge within a few weeks. As a result of differences in spawning seasons, fish vary in their susceptibility to contaminants and other environmental disruptions. Fish recapture studies in the Great Bear River sub-basin indicated that fish may return to the same spawning area year after year (Environment Canada, 1985a), potentially making entire fish species vulnerable to the destruction of a spawning area.

While many metals are required for proper physiological functioning of aquatic organisms, including fish, bioaccumulation of metals may have direct and indirect effects on these organisms, such as impacts upon reproduction, growth and maturation, life spans, and species diversity. Other potential impacts of development on fish populations identified included fuel spills, gravel removal, blasting, changes in water temperature and chemistry, dissolved oxygen levels (see hypoxia section), and barriers to fish movement (culverts, dams etc.).

Sedimentation

Forestry (in the south), mining, and road building all increased sediment loading in rivers. The 1974 impact assessment concluded that changes in suspended sediment concentrations during and post-construction of roads were the single most important potential impact of the Mackenzie gas pipeline on local water resources. Development activities seen to have potential negative impacts included ditching and laying pipe through streams, cleaning the right-of-way, construction and temporary stream crossings, fording streams with vehicles, and mining of river sediments for construction (river borrowing). Identified impacts included sediment deposition in lakes and slow-moving streams, which threaten survival of bottom-dwelling aquatic organisms (e.g., benthic macroinvertebrates), decreased light penetration and therefore photosynthesis, reduced food production, temperature changes through increased energy absorption in surface layer, mobilisation of contaminants in the sediments, clogging of fish gills with fine particles, changes in fish migration and movement, reduced food availability in streams, and increased bank and bed erosion.

A predictive model was applied to 53 highly protected streams along the proposed pipeline (UNIES, 1974) to understand the potential for adverse effects from

sedimentation post-pipeline construction. Of the 53 streams, 11 (20%) met or exceeded the threshold level at which aquatic life is threatened. However, the 1974 Environmental Impact Assessment concluded that, on average, only 0.7% of the water surface area in the sub-basins along the route would be affected and that "the proposed effects of the sedimentation on aquatic organisms as a result of the proposed pipeline will be negligible" (How, 1974). However, conditions that may be tolerable for aquatic life in spring, when natural sediment loads are high, may be unacceptable in winter, when most northern rivers have low sediment loads.

Habitat loss and impairment of spawning grounds from sedimentation was found to have the largest impact on fish. Given that sedimentation loads are closely tied to construction, specific guidelines were put forward to minimise sediment release. In order to minimise impacts on freshwater fisheries, the upper threshold for maintaining healthy fisheries was identified as <80 ppm for suspended sediment. Rivers with suspended sediment >400 ppm were identified as unlikely to support fisheries (How, 1974).

Hypoxia

Oxygen in water is consumed through the break-down of organic compounds in waterways. Oxygen depletion is most commonly caused by discharges of domestic sewage, but can also be caused by the use of fertilisers, which increases vegetation growth and the amount of decaying organic matter in waterways. Living plants, on the other hand, re-oxygenate the water. Studies on walleye, northern pike, bluegill, and yellow perch have demonstrated stress reactions when exposed to dissolved oxygen concentrations below 6 ppm. Oxygen levels below 1 ppm are hypoxic and lethal to aquatic life (How, 1974).

Permafrost

Unique to Arctic environments, permafrost creates an engineering challenge. Permafrost degradation can lead to thermokarst subsidence, gullying, solifluction, and slumping. Moreover, permafrost restricts downward filtration, so any spilled contaminants will move laterally into surface waters rather than into the ground where natural degradation may occur, depending on the nature of the contaminant.

Data, Evidence, and Monitoring

Significant investments were made to understand and develop measurement methods, guidelines, and thresholds for contaminants to preserve healthy water ways, flora and fauna; particularly given the unique northern environment.

In 1974, methanol was suggested as an indicator contaminant for identifying development-related pollution of water bodies in the Mackenzie Basin (How, 1974). The Berger Report (1977a, b) provided recommended limits for changes to aesthetic, physical, organic, nutrient, and metal parameters as a result of development (Table 3). This was closely followed by the United States and Canadian Government guidelines for water quality objectives and standards[2], which formed the basis of guidelines for protecting fish and fisheries in the 1985 Report (Environment Canada, 1985b). These guidelines provided defined limits for parameters measured in the system and could be used to assess degradation in the status of the water bodies.

In 1974, a watershed classification system was developed based on climate and topography that described both discharge and travel times within each Basin (How, 1974) -- important factors in contaminant transport. In 1972, a sediment classification system (Environment Canada, 1972) was developed and applied to 53 streams that were considered pristine under the 1972 Guidelines for Water Quality Objectives and Standards (How, 1974).

The development of classification systems and models points to one of the most significant issues facing the Mackenzie Basin -- a lack of data. Given the unique physical environment, observed impacts and thresholds developed elsewhere could not be directly transferred to the Basin. Moreover, the lack of data for the Mackenzie Basin's waters made it impossible to formulate an accurate picture of stream flows

[2] 1976, 1977, 1979, and 1981 (United States Environmental Protection Agency, 1976, 1979; International Joint Commission, 1977; Environment Canada, 1981).

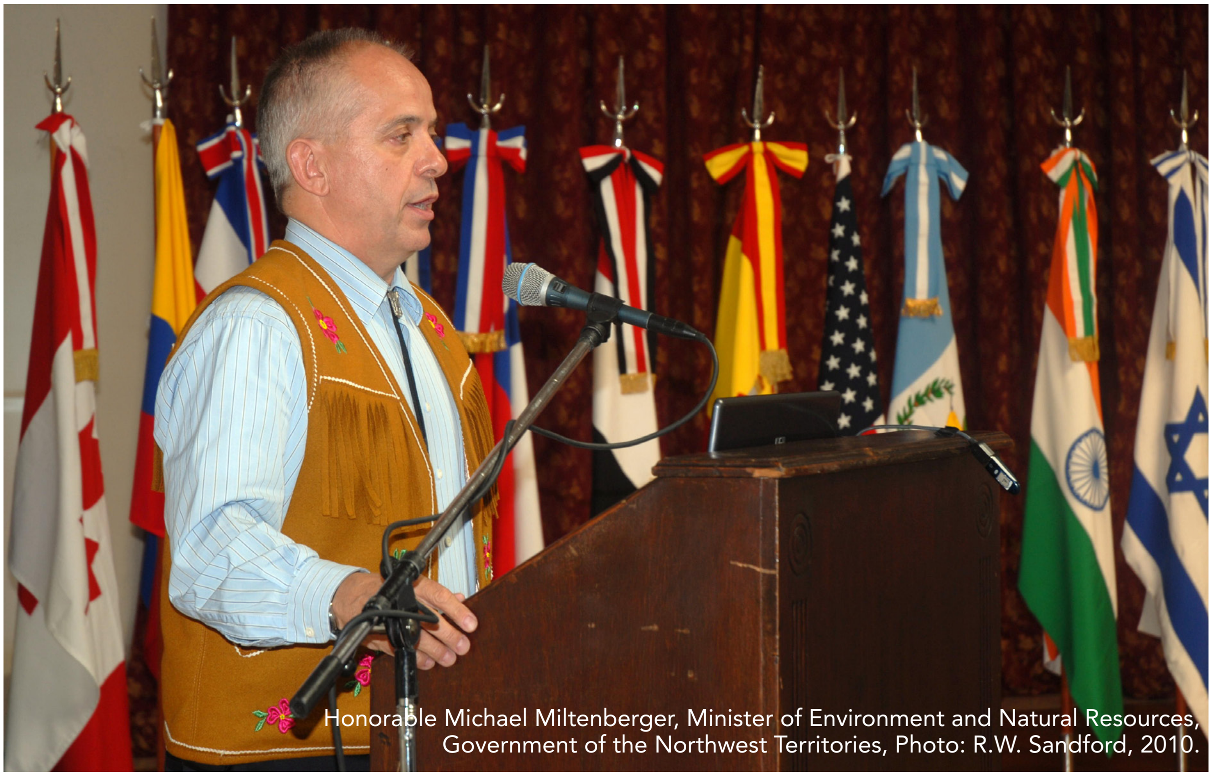
Table 3: Guidelines for changes in water quality and biodiversity within the Mackenzie Valley Basin recommended by Berger (1977b).

Parameter	Guideline
Bacteria	At least 90 percent of the samples have a total coliform density less than 5000/100mL and a fecal coliform density of less than 1000/100mL
Dissolved oxygen	Should not go below 6.0 mg/L or below the natural levels in a water body
pH	Not be altered by more than 0.5; and maintained within 6.5 – 8.5 range
Temperature	Not be altered by more than 3°C
Odour	Not exceed the threshold number 8 at 20°C
Colour	Not be increased by more than 30 colour units above background i) Values of <10 indicate essentially clear water ii) Values >200 characteristic of swamp, bog water, dystrophic lake
Turbidity	Not average more than 27 times the natural level during any 8-hour period; 9 times in a 96-hour period; and 3 times during a 30-day period
Phenolics	Not exceed more than 0.005 parts per million and the fish flesh not have any detectable change in taste and odour
Oil and Gases	No visible iridescent sheen present
Pesticides	Only air-fogging pesticides will be permitted, not persistent chemicals
Shannon Diversity Index	Not changed by more than 25% due to addition of finely-divided solids

and water quality, which in turn made it difficult to design the protective measures necessary to mitigate impacts of pipeline development. Another problem was the limitations in analytical methods to actually measure some of the parameters of concern. A positive outcome of the impact assessments and inquiries performed during this period was the collection of a body of data and knowledge about the Basin that did not previously exist. Many documents identified through this initiative refer to "baselines", census, or species lists indicating broad attempts to quantify and document the water quality, flora, and fauna status at the time, as demonstrated by the number of document titles referring to this type of data (approximately 200 between 1960 and 1985). The Berger Report in particular highlighted critical information gaps regarding the northern environment (e.g. water tables, flooding, and anthropogenic river icing) and environmental impacts, particularly engineering design and construction in permafrost terrain under Arctic conditions.

Another data issue that emerged was that of independence and interpretation, especially given the polarisation of competing interests. While some interested parties promoted the use of site-specific expert consultations to determine impacts, others felt this approach was inadequate and potentially biased. Instead, they called for more systematic, independent, and standards-based assessment approaches. This led Justice Berger to recommend a "comprehensive program of northern science and research".

West Channel in the Mackenzie Delta. Photo: Chris Metcalfe, 1971.



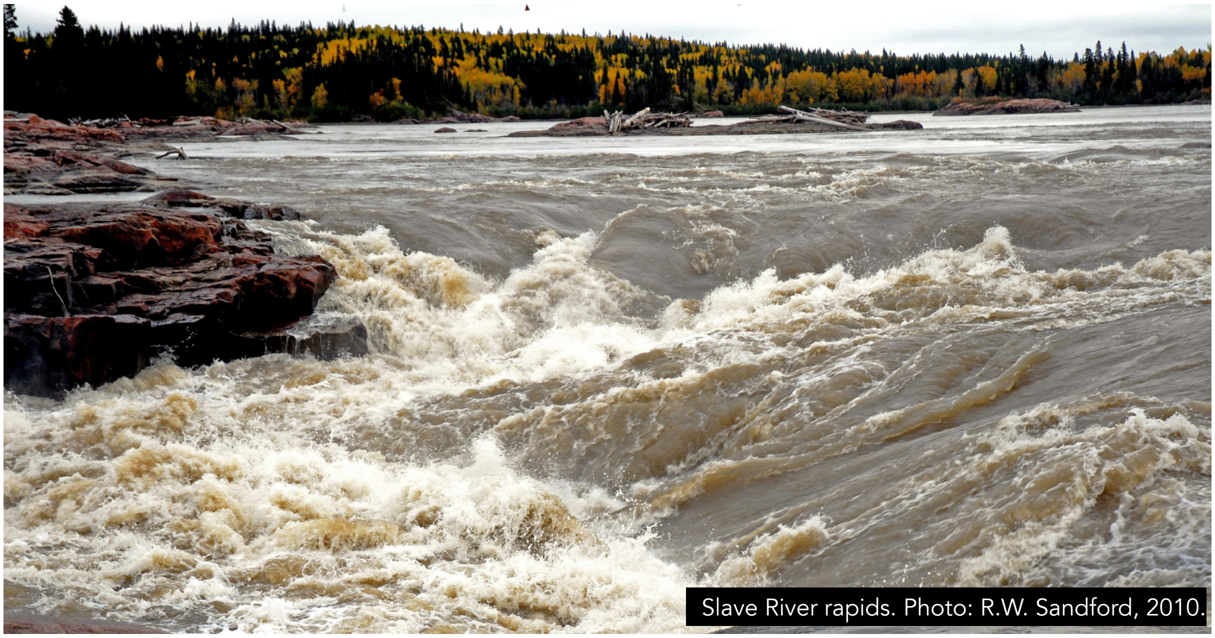
Honorable Michael Miltenberger, Minister of Environment and Natural Resources, Government of the Northwest Territories, Photo: R.W. Sandford, 2010.

Conclusion

Significant advances were made on several fronts between 1960 and 1985. Large volumes of data were collected, greatly advancing knowledge about the Mackenzie Basin ecosystems and resources. Large scale hydro, and oil and gas development also occurred, and emphasis was placed on the importance of Aboriginal rights. However, challenges still remained due to the absence of a systematic monitoring system, uncertainty about the costs and benefits of large scale developments from social, economic, and environmental perspectives, and the lack of a coherent plan for the Basin that balanced all interests. However, the rejection of two hydropower installations in the 1980's would suggest that some development projects were deemed to be too disruptive to the Indigenous peoples and the environment. The Berger Report recommended that an economy based on modernisation of hunting, fishing, and trapping, on efficient game and fisheries management, on small-scale enterprise, and on the orderly development of oil and gas resources over a period of years is a rational program for northern development, which is based on the ideals and aspirations of the northern Aboriginal people (Berger, 1977a).

However, in some ways, this intensive period of focus on the Mackenzie Basin did not have the lasting impact that might have been anticipated. While the Basin is still seen as the core of Indigenous cultural and economic life, development pressures are expected to intensify in the future. The Rosenberg International Forum on Water Policy Report, published in 2013, goes further in recognizing the importance of the Mackenzie Basin in the eco-hydrological balance of the Western Hemisphere.

Even today, one of the largest challenges is the lack of data. Despite the intensive studies undertaken between 1960 and 1985, and the call for systematic monitoring, the Rosenberg Report states that "the Mackenzie River system has been studied less than rivers in other regions…More science is needed" and again calls for a monitoring program in the Basin. Consistent with the Berger Report, the Rosenberg Report called for local and traditional knowledge to have a place in the Mackenzie River Basin management and decision-making and for Aboriginal representation at each stage of planning, management, and policy making processes.



Slave River rapids. Photo: R.W. Sandford, 2010.

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United States Environmental Protection Agency. (1979). *Quality Criteria for Water.* Washington (DC). Retrieved from: http://water.epa.gov/scitech/swguidance/standards/criteria/current/upload/2009_01_13_criteria_redbook.pdf

Appendix I - Database Search Terms

Time	Geography	Other
1960 to 1985	Mackenzie or any of the tributary rivers: Hay River Peace River Liard River Peel River Athabasca River Norman Wells Great Bear Lake Great Slave Lake Wilson Lake	Environment "Environmental Science" "Environmental Impact Assessment(s)", EIA Natural Resources River, Stream, Lake, Flood Water Aquatic, Hydrology, Limnology, Hydrography Fish Biology Oil, "Other Non-Renewable Fuels"

Appendix II - Organisations Active in Mackenzie Basin (1960-1985)

Acres Consulting Services
Ad Hoc Task Force
Alaskan Arctic Gas Study Company
Alberta Environment Conservation Authority
Alberta, Fish and Wildlife Division
Angus-Butler Engineering Ltd.
Aquatic Environments Limited
Arctic Biological Station
Arctic Gas
Arctic Petroleum Operators' Association
Avcon Aviation Consultants Ltd.
BBT Geotechnical Consultants Ltd
Beak Consultants
Beaufort Sea Environmental Assessment Panel (Canada)
Beaufort Sea Hydrocarbon Development Project (Canada)
Canada Lands Directorate
Canada Agriculture Canada
Canada Atmospheric Environment Service
Canada, Department of Indian Affairs and Northern Development
Canada Deptartment of Agriculture, Research Branch
Canada Deptartment of Energy, Mines and Resources

Canada Deptartment of Fisheries and Forestry
Canada Deptartment of Fisheries and Oceans
Canada Deptartment of Supply and Services
Canada Environmental Assessment Panel
Canada Fisheries Service
Canada Inland Waters Branch
Canada Inland Waters Directorate
Canada Pipeline Application Assessment Group
Canadian Arctic Resources Committee
Canadian Coast Guard
Canadian Hydrographic Service
Canadian Wildlife Service
Dome Petroleum Limited
Envirocon Ltd.
Environment Canada
Environment Protection Board, Winnipeg
Esso Resources Canada
F.F. Slaney & Company
Fedirchuk McCullough & Associates Ltd.
Fenco Consultants Limited
Fisheries and Marine Service
Fisheries Research Board of Canada
Forest Management Institute (Canada)
Freshwater Institute
Geological Survey of Canada
Gulf Canada Resources Inc.
Gulf Oil Canada Ltd.
GVM Geological Consultants Ltd.
Hardy Associates Ltd.
Ian Robertson Consulting Ltd.
Imperial Oil Limited
Institute of Ocean Sciences, Patricia Bay
J.D. Mollard and Associates Limited
Keith Consulting Engineers Ltd.
Kenting Exploration Services Ltd.
L.G.L. Limited
Mackenzie River Dredging Program
Mackenzie Valley Pipeline Inquiry
Mackenzie Basin Intergovernmental Liaison Committee (Canada)
MacKenzie River Basin Committee (Canada)
McCourt Management Ltd.
National Research Council of Canada, Division of Building Research
Norman Wells Operations
Northern Co-ordination and Research Centre (Canada)
Northern Engineering Services Company
Northwest Hydraulic Consultants Ltd.
Northwest Territories Deptartment of Renewable Resources
Northwest Territories Historical Advisory Board
Public Works Canada
R.J. Brown & Associates
R.M. Hardy and Associates
Renewable Resources Consulting Services, Canada.
Shell Canada Resources Limited
Stanley Associates Engineering
Sun Oil Company
Task Force on Northern Oil Development (Canada)
Templeton Engineering Company
Travacon Research Limited
Underwood, McLellan & Associates
University of British Columbia, School of Community and Regional Planning
University of Calgary, Deptartment of Archaeology
University of New Brunswick
Water Survey of Canada

Appendix III - Libraries, Databases and Bibliographies

The following is a list of accessible and relevant databases, libraries and bibliographies:

ASTIS
URL: http://www.arctic.ucalgary.ca/databases
# of relevant documents found: 445
# of critical documents identified: 38
The Arctic Science and Technology Information System (ASTIS) is an online database that contains 79,000 records describing publications and research projects about northern Canada. A project of the Arctic Institute of North America (AINA), ASTIS includes all subjects and covers the three territories, the northern parts of seven provinces and the adjacent marine areas. ASTIS records contain abstracts, detailed subject and geographic indexing terms and links to 21,000 publications that are available online.

Bibliography of the Athabasca River Basin (BARB)
URL: http://barbau.ca/content/home
# of relevant documents found: 402
# of critical documents identified: incomplete
The main goal of BARB is to provide the public with a comprehensive, free, online and searchable database of all the published materials that deal with the Athabasca River Basin. The objective is to help stakeholders make informed decisions about what happens in the area. BARB is a project of the Athabasca River Basin Research Institute (ARBRI), Athabasca University Library and various academic and other staff of Athabasca University.

Aurora College and Aurora Research Institute
Linked to NWT public library
Canadian Hydrographic Service
Individual requests for scanned documents; bathymetric surveys

Centre for Indigenous Environmental Resources (CIER)
URL: http://ils.yourcier.org/liberty3/opac/search.do
# of relevant documents found: 4 (may be updated due to earlier, repeated, technical errors)
# of critical documents identified: 0
This collection is focused on subjects relating to Aboriginal peoples and the environment.

Education and Research Archive (ERA)
URL: https://era.library.ualberta.ca/public/browse
# of relevant documents found: 33
# of critical documents identified: incomplete
Hosted by the University of Alberta, the ERA is a digital repository that collects, disseminates and preserves the intellectual output of the University of Alberta. The ERA is meant to hold material related to the teaching or research activities at the University of Alberta and associated items representing intellectual production. All work deposited in ERA must originate from a member of the University of Alberta community, with some exceptions. The database is open-access and contains online copies of all documents.

Regulatory Document Index, National Energy Board of Canada
URL: https://docs.neb-one.gc.ca/ll-eng/llisapi.dll?func=ll&objId=2000&objAction=browse
# of relevant documents found: 4
# of critical documents identified: 0
The RDI is a database of documents from the National Energy Board.

NWT Public Library
URL: http://www.nwtpls.gov.nt/ca
# of relevant documents found: 22
The PLS provides the automated library system for the NWT Library Network (Public Libraries, Legislative Library, Aurora College Libraries, Aurora Research Institute Library and PWNHC Reference Library).

Water Survey of Canada
URL: http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm
HYDAT is the archival database that contains all water information collected through the National Hydrometric Program. These data include: daily and monthly mean flow, water level and sediment concentration for over 2,500 active and 5,500 discontinued hydrometric monitoring station across Canada. Metadata were obtained for all stations in the Mackenzie Basin, including location, size, type of water body, period of record and hydrometric variables measured. The metadata were not included in the list of documents, but may contain useful information about water quantity in the Mackenzie River Basin.

WAVES
URL: http://waves-vagues.dfo-mpo.gc.ca/waves-vagues/
# of relevant documents found: 493
# of critical documents identified: incomplete
The Fisheries and Oceans Canada (DFO) Library collection is held at the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia, the Maurice Lamontagne Institute (MLI) in Mont-Joli, Quebec and at the Institute of Ocean Sciences (IOS) in Sidney, British Columbia. They are home to Canada's foremost collection in marine and freshwater science and collect books, journals and government documents which support the subject disciplines pertinent to the Department's mandate. WAVES is the DFO Library's online catalogue and is the main access point to over 600,000 books, journals and government documents. It is a comprehensive resource of DFO publications with links to over 30,000 DFO items in digital format. Many publications and resources are available in full text online.

Yukon Biodiversity Database
Branch of ASTIS
Yukon College Library
URL: http://yclibw.yukoncollege.yk.ca/TLC-Scripts/interpac.dll?SearchForm&Directions=1&Config=ysm
# of relevant documents found: 8 (may be updated due to earlier, repeated, technical errors)
# of critical documents identified: 0
Yukon College Library's main collection consists of more than 39,000 volumes, as well as e-books, maps, DVDs, videos, CDs and CD-ROMs and has a subject emphasis including environmental studies, First Nations studies, northern studies and women's studies. The library also subscribes to about 350 periodicals in print, as well as such as Academic Search Premier, PsycARTICLES and ERIC.

Yukon Geological Survey Integrated Data System
URL: http://data.geology.gov.yk.ca
# of relevant documents found: 4
# of critical documents identified: incomplete
This database contains material formally published by the Yukon Geological Survey (Geoscience Maps, Open Files, Bulletins, etc.), as well as publications managed, but not published by YGS or Energy, Mines and Resources including Mining Assessment Reports and Property Files.

Yukon Government Library (Environment/Energy, Mines & Resources)
URL: http://virtua.gov.yk.ca:8080/?theme=environment
# of relevant documents found: 8
# of critical documents identified: incomplete
The Government of Yukon has a library page that links to various government library databases. The Environment library and the Energy, Mines and Resources library appear to hold the same documents.

Appendix IV - Keyword Occurence in Document Titles

Key Words	Number of Documents
Water	904
Water management	28
Management	149
Water quality	169
Quality	182
Water quantity	2
Quantity	3
Water level	52
Environment	260
Environmental impact assessment	38
Environmental study	5
Impact assessment	50
EIA	1
Environmental study	4
Benthic	25
Invertebrate	34
Boil	144
Bibliography	37
Oil	162
Oil spill	11
Fish	470
Flow	55
Data	236
Geology	35
Geo	179
Board	34

Key Words	Number of Documents
First Nation	0
Aboriginal	0
Native	36
Indian	12
Pipeline	141
Norman wells	31
Watershed	67
Map	40
Eco	448
Aquatic	140
Dene	0
Flood	49
Methoxychlor	17
AOSERP	69
Band	9
Min(ing)	94 (36)
Sulphur dioxide	3
Reclamation	7
Asbestos	1
Baseline	32
Survey	183
Checklist	1
Model	18
Road	9
Wetland	3
Heavy metals	10
Hydroelectric	26
Dam	38


Mackenzie River rampart. Photo: Al Wiens, 1973.


Richardson Mountains, NWT. Photo: Chris Metcalfe, 1972.

Appendix V - Key Texts

Berger, T. R. (1977a). Northern Frontier Northern Homeland - The Report of the Mackenzie Valley Pipeline Inquiry: Volume One. Government of Canada.

Berger, T. R. (1977b). Northern Frontier Northern Homeland - The Report of the Mackenzie Valley Pipeline Inquiry: Volume Two. Government of Canada.

Justice Thomas Berger was appointed to the Supreme Court of British Columbia in 1971 and served there for over a decade. In 1974, the Federal Government of Pierre Turdeau appointed Justice Berger to head the 3-year long Mackenzie Valley Pipeline Inquiry. This was at the time going to be the largest private construction project in history. However, before a pipeline could be built to carry natural gas from the Beaufort Sea to the energy-craving markets in the south, the impact of the pipeline on the Northern people, specifically the Aboriginal peoples of the area, economy and environment had to be determined.

This Report was published in two volumes. Volume 1 addresses the broad social, economic and environmental impacts an energy corridor would have in the Mackenzie Valley and the Western Arctic. It highlighted the importance of taking into account the concerns of the Aboriginal people. Justice Berger argued that the energy corridor development would not provide permanent employment or benefit to the local Aboriginal people; instead it would tear the social fabric of the communities. For many, Justice Berger's Report was seen as "Canada's Native Charter of Rights."

Volume 2 highlighted many of the terms and conditions under which the pipeline should be built. There is a special emphasis on how construction and regular operational activities could affect the pristine water quality and the diverse fish population of the area. Justice Berger recommended threshold values for many water quality parameters. The overall recommendation of Justice Berger's Report was a 10-year moratorium on the project. The purpose was to use that time to settle Aboriginal land claims, set aside important conservation areas and address the environmental impact before attempting to build the pipeline and the subsequent energy corridor that would undoubtedly follow.

How, G. T. S. (1974). Environmental Impact Assessment of the portion of the Mackenzie Gas Pipeline from Alaska to Alberta: Volume IV - Research Reports. Templeton Engineering Company for the Environment Protection Board.

This Report specifically focused on the effects of the proposed chilled gas pipeline from Alaska to Alberta. It assesses the surface water and groundwater drainage disruption, the impact on river crossings, and effects on animals and mortality rates. Furthermore, this Report contains a watershed classification system and a sedimentation guidelines system, which classifies various water bodies. The sedimentation classification system is used to assess how water bodies will be under threat by sedimentation and siltation created due to the activity and construction of the gas pipeline. In fact, some of the water bodies would be expected to increase past

the threshold value and become unsuitable to sustain complex organisms and have harmful effects on the resident ecology. Sedimentation is believed to be the greatest threat to fish and the various water resources. This Report makes several recommendations, some of which include minimising the number of pipeline water crossings and monitoring water bodies, which are especially at risk from sedimentation.

Water Quality Branch, Inland Waters Directorate, Environment Canada. (1985a). A Report under the 1978-81 Federal-Provincial Study Agreement respecting the water and related resources of the Mackenzie River Basin": Sensitive Areas - Supplement 1.

Water Quality Branch, Inland Waters Directorate, Environment Canada. (1985b). A Report under the 1978-81 Federal-Provincial Study Agreement respecting the water and related resources of the Mackenzie River Basin": Water Quality - Supplement 9.

With regard to the 1985 Report, the impetus for its formulation goes back to 1972. In June of 1972, 40 delegates from around the country met to bring attention to the water resources of the Mackenzie Basin. The seminar identified the need for a permanent intergovernmental body to exchange information and data on a regular basis. The committee met on a regular basis until 1977 and identified a number of issues, the most significant of which being the lack of coordinated and integrated research knowledge on the huge river system. In 1978, Ministers representing Canada, British Columbia, Alberta and Saskatchewan signed the Mackenzie River Basin Study Agreement. This initiated a three-year program of studies at a shared cost of $1.6 million (MRBB History, 2010).

The overall Report identified the need for future cooperation among the six governments (Canada, Alberta, British Columbia, Saskatchewan, Yukon Territory and Northwest Territories) as the main issue in managing water and its associated resources. However, for the purposes of this Report, we chose to focus on the Sensitive Areas and Water Quality supplements to the main Report. The Sensitive Areas supplement contains information from areas within the Mackenzie River Basin that could be expected to suffer biological productivity and cultural and social values if changes occurred to the hydrological regime in the areas. Regarding each area, there is an analysis of hydrological characteristics, natural resources (wildlife, fisheries, etc.), socio-economic considerations, sensitivity to hydrological regime, knowledge gaps, and data deficiencies.

The Water Quality supplement analysed very specific water quality parameters related to the water bodies in the Mackenzie Basin. Historical data were compared, analysed and then assessed for how it might change with the construction of the energy corridor. The broad categories, which were addressed, include physical parameters, nutrients, metals, and organic parameters. Values of these various parameters in the various water bodies at the time were evaluated against the water quality guidelines in place at the time.

Appendix VI - Water Quality Data Tables

Table VI.1: Water quality data derived from Sub-basin hydrometric stations.
This table uses the Athabasca River Basin as an example (Environment Canada, 1985b). The values in section 1 are median values. The values in section 2 are listed in the following format (# of samples collected / (mean) / range / standard deviation about the mean).

	ATHABASCA RIVER SUB-BASIN						
	General Athabasca Rivers	Upstream from Sunwapta	At Athabasca	At Fort McMurray	At Bitumont	Fond du Lac River	Lake Athabasca
SECTION 1							
Turbidity (NTU)	10						2.3
Apparent Colour (relative units)	25						10
TDS (mg/L)	135						65
Specific Conductivity (µS/cm)	265						139
SECTION 2							
Turbidity (NTU)		20 / (24) / 1.7 - 88 / 26	201 / (33) / <0.1 - 110 / 98	79 / (14) / 4.0 - 30 / 15	5 / (40) / 1.0 - 650 / 77	31 / (1.3) / 0.2 - 5.6 / 1.2	
Apparent Colour (relative units)		20 / (9) / 5 - 40 / 10	200 / (29) / 5 - 200 / 26	77 / (41) / <5 - 200 / 28	NA	30 / (7) / <5 - 20 / 3	
TDS (mg/L)		20 / (85) / 52 - 113 / 13	191 / (169) / 57 - 288 / 48	78 / (143) / 117 - 168 / 25	3 / (164) / 96 - 280 / 48	31 / (18) / 12* - 28 / 3	
Specific Conductivity (µS/cm)		20 / (160) / 124 - 217 / 22	203 / (306) / 117 - 501 / 83	79 / (236) / 190 - 270 / 27	6 / (295) / 181 - 476 / 81	31 / (40) / 26 - 94 / 13	

Table VI.2: Difference in physicochemical parameters for water bodies in the Plains (e.g. Athabasca Basin) and the Shield (e.g. Hay River Basin). Note that only Athabasca Lake within the Athabasca Basin is fully within the Plains region (Environment Canada, 1985b).

Median value	General Athabasca Rivers	Lake Athabasca	General Hay River
Turbidity (NTU)	10	2.3	13
Apparent Colour (relative units)	25	10	130
TDS (mg/L)	135	65	216
Specific Conductivity (µS/cm)	265	139	383

Table VI.3: Physicochemical parameters in water from the Mackenzie sub-basins (Environment Canada, 1985b). The values are the median of several measurements.

Median value	General Athabasca Rivers	General Peace River	General Liard River	General Hay River
Turbidity (NTU)	10	16	6.2	13
Apparent Colour (relative units)	25	25	10	130
TDS (mg/L)	135	130	131	216
Specific Conductivity (µS/cm)	265	231	253	383

Median value	General Great Slave River	General Great Bear River	General Mackenzie River
Turbidity (NTU)	38	1.8	7
Apparent Colour (relative units)	30	5	15
TDS (mg/L)	119	76	131
Specific Conductivity (µS/cm)	224	143	244

Table VI.4: Nutrient parameters in water (mg per liter) of the sub-basins (Environment Canada, 1985b).
The values are listed in the following format (mean value / (range)).

Nutrient Parameters (mg/L)	General Athabasca Rivers	General Peace River	General Liard River	General Hay River	General Great Slave River	General Great Bear River	General Mackenzie River
Dissolved Nitrogen	0.30 (0.03 - 2.30)	0.22 (0.08 - 1.10)	0.12 (0.01 - 0.26)	0.82 (0.38 - 1.25)	0.24 (0.16 - 0.39)	0.17 (0.10 - 0.24)	0.15 (0.025 - 0.42)
Total Kjeldahl Nitrogen	0.42 (0.10 - 16.10)	0.98 (0.10 - 16.10)	0.71 (0.50 - 2.80)	1.03 (0.80 - 1.20)	0.64 (0.005 - 2.90)	0.36 (0.10 - 0.60)	0.72 (0.100 - 5.70)
Dissolved Phosphorus	0.009 (0.003 - 0.064)	0.012 (0.003 - 0.064)	0.0004 (0.003 - 0.013)	0.049 (0.003 - 0.062)	0.025 (0.002 - 0.063)	< 0.003 (0)	0.004 (0.003 - 0.016)
Total Phosphorus	0.050 (0.005 - 1.00)	0.072 (0.005 - 1.00)	0.072 (0.003 - 1.10)	0.058 (0.013 - 0.140)	0.054 (0.005 - 0.337)	0.008 (0.003- 0.051)	0.077 (0.003 - 3.0)
Dissolved Organic	5.6 (0.5 - 14.0)	6.0 (2.0 - 14.0)	30.5 (1.0 - 41)	24.0 (18.0 - 26)	12.5 (5.0 - 26)	3.4 (1.0 - 9.0)	4.9 (1.0 - 13.0)
Total Organic	22.3 (0.5 - 295)	12.5 (0.5 - 99)	7.3 (0.5 - 46)	33.2 (15.0 - 80)	15.1 (4.0 - 53)	6.6 (1.0 - 89)	10.8 (0.5 - 175)

Table VI.5: Median concentrations of organic contaminants in water for the Athabasca and Peace sub-basins (Environment Canada, 1985b).

	Guideline	Median values in the rivers of the Athabasca and Peace sub-basins
Phenolic Compunds	0.001 mg/L	0.014 mg/L
Aldrin and Dieldrin	0.001 µg/L	Below Detection Limits
ϒ - BHC	0.01 µg/L	Below Detection Limits
DDT	0.001 µg/L	Below Detection Limits
Diazinon	0.08 µg/L	Below Detection Limits
α - Endosulfan	0.003 µg/L	Below Detection Limits
β - Endosulfan	0.003 µg/L	Below Detection Limits
Endrin	0.002 µg/L	Below Detection Limits
Guthion	0.005 µg/L	Below Detection Limits
Malathion	0.1 µg/L	Below Detection Limits
p,p'-Methoxychlor	0.03 µg/L	Below Detection Limits
Mirex	0.001 µg/L	Below Detection Limits
Parathion	0.008 µg/L	Below Detection Limits
PCBs (total)	0.001 µg/L	Below Detection Limits


Great Slave Lake, the origin of the Mackenzie River.
Photo: R.W. Sandford, 2012.

Table VI.6: Concentrations of elements in water of the sub-basins (Environment Canada, 1985b).
The values are in mg per liter and are listed in the following format (# of samples / range / (mean)).

Element (mg/L)	General Athabasca Rivers	General Peace River	General Liard River	General Hay River	General Great Slave River	General Great Bear River	General Mackenzie River
AG	1623 / <0.004 - 0.05 / (0.01)	200 / <0.004 - 0.05 / (0.01)	29 / <0.004 - 0.01 / (0.009)	25 / <0.01 - 0.05 / (0.01)	NA	4 / <0.003 - <0.003 / (<0.003)	40 / <0.003 - 0.25 / (0.011)
AL	2044 / <0.006 - 146 / (1.09)	253 / <0.10 - 146.0 / (1.47)	25 / <0.06 - 3.70 / (0.69)	25 / <0.10 - 1.40 / (0.41)	11/ 0.10 - 3.00 / (0.82)	24 / <0.06 - 0.10 / (0.09)	59 / <0.06 - 5.50 / (0.29)
BA	2322 / <0.05 - 1.70 / (0.11)	259 / <0.05 - 1.70 / (0.12)	17 / <0.10 - 0.30 / (0.09)	28 / <0.05 - 0.10 / (0.09)	16 / <0.10 - 0.22 / (0.08)	31 / <0.05 - 0.10 / (0.07)	96 / <0.05 - 0.35 / (0.08)
CD	2001 / <0.001 - 0.01 / (0.001)	286 / <0.0002 - 0.01 / (0.001)	107 / <0.001 - 0.01 / (0.002)	41 / <0.001 - 0.003 / (0.001)	16 / <0.001 - 0.05 / (0.013)	71 / <0.001 - 0.02 / (0.002)	610 / <0.0001 - 0.39 / (0.001)
CO	2171 / <0.001 - 0.05 / (0.005)	331 / <0.001 - 0.05 / (0.005)	119 / <0.001 - 0.02 / (0.007)	46 / <0.001 - 0.019 / (0.004)	16 / <0.001 - 0.005 / (0.002)	76 / <0.001 - 0.015 / (0.003)	619 / <0.001 - 0.04 / (0.003)
CR	2279 / <0.01 - 0.07 / (0.012)	260 / <0.01 - 0.07 / (0.01)	125 / <0.006 - 0.34 / (0.014)	43 / <0.01 - 0.01 / (0.01)	10 / <0.01 - <0.01 / (<0.01)	51 / <0.006 - 0.015 / (0.011)	540 / <0.006 - 0.05 / (0.011)
CU	2961 / <0.001 - 0.20 / (0.006)	393 / <0.001 - 0.20 / (0.006)	179 / <0.001 - 0.09 / (0.01)	48 / <0.001 - 0.02 / (0.004)	28 / <0.01 - 0.02 / (0.007)	83 / <0.001 - 0.580 / (0.017)	789 / <0.001 - 0.58 / (0.007)
FE	2361 / <0.04 - >5.0 / (2.04)	335 / <0.04 - 34.4 / (2.25)	175 / <0.04 - 27.0 / (1.97)	44 / 0.69 - 11.60 / (2.47)	28 / 0.10 - >5.0 / (2.12)	76 / <0.04 - 1.80 / (0.18)	711 / <0.04 - 64.00 / (2.3)

Element (mg/L)	General Athabasca Rivers	General Peace River	General Liard River	General Hay River	General Great Slave River	General Great Bear River	General Mackenzie River
MN	5289 / <0.004 - 7.95 / (0.105)	397 / <0.008 - 2.10 / (0.105)	178 / <0.006 - 0.69 / (0.07)	48 / <0.01 - 0.37 / (0.07)	35 / <0.01 - 0.44 / (0.06)	77 / <0.01 - 0.06 / (0.01)	736 / <0.01 - 4.2 / (0.07)
MO	1816 / <0.05 - 0.10 / (0.06)	239 / <0.05 - 0.10 / (0.06)	109 / <0.01 - 0.31 / (0.06)	40 / <0.05 - 0.10 / (0.05)	10 / <0.10 - <0.10 / (<0.10)	53 / <0.05 - 0.05 / (<0.05)	528 / <0.01 - 0.56 / (0.06)
NI	2120 / <0.001 - 0.09 / (0.008)	334 / <0.001 - 0.09 / (0.008)	158 / <0.001 - 0.53 / (0.02)	44 / <0.001 - 0.027 / (0.009)	11 / <0.005 - 0.01 / (0.007)	66 / <0.001 - <0.012 / (<0.01)	608 / <0.001 - 0.08 / (0.008)
PB	2685 / <0.001 - 0.04 / (0.004)	370 / <0.001 - 0.03 / (0.004)	175 / <0.001 - 0.05 / (0.006)	49 / <0.001 - 0.008 / (0.003)	19 / <0.001 - 0.008 / (0.005)	77 / <0.001 - 0.006 / (0.004)	726 / <0.001 - 0.94 / (0.006)
SB	659 / <0.008 - 0.20 / (0.33)	90 / <0.008 - 0.50 / (0.34)	4 / <0.01 - 0.10 / (0.088)	13 / <0.008 - 0.50 / (0.35)	NA	NA	NA
SR	1935 / <0.01 - 1.50 / (0.19)	265 / <0.02 - 1.50 / (0.19)	86 / 0.09 - 0.33 / (0.16)	43 / 0.10 - 0.34 / (0.15)	3 / <0.05 - 0.10 / (0.06)	34 / 0.05 - 0.66 / (0.15)	491 / <0.005 - 5.10 / (0.42)
TL	849 / <0.10 - 0.30 / (0.16)	117 / <0.10 - 0.30 / (0.16)	4 / 0.001 - <0.001 / (<0.001)	16 / <0.10 - 0.20 / (0.16)	NA	NA	3 / <0.10 - 0.10 / (<0.10)
V	1148 / <0.001 - 0.45 / (0.03)	128 / <0.001 - 0.45 / (0.04)	84 / <0.001 - 0.36 / (0.06)	34 / <0.05 - <0.05 / (<0.005)	5 / <0.001 - 0.01 / (0.01)	40 / <0.001 - 0.05 / (0.04)	499 / <0.001 - 034 / (0.05)
ZN	2818 / <0.001 - 0.33 / (0.012)	371 / <0.001 - 0.27 / (0.013)	212 / <0.001 - 0.27 / (0.02)	48 / <0.001 - 0.050 / (0.008)	19 / <0.01 - 0.09 / (0.02)	84 / <0.001 - 0.29 / (0.006)	744 / <0.001 - 0.34 / (0.02)

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