Northern Aquatic Ecosystems and Mineral Development: Potential Impacts and Research Needs

Northern Water Resources Studies

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Northern Aquatic Ecosystems and Mineral Development: Potential Impacts and Research Needs

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D. Milburn, S. Kanomata and E. Leenders

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EXECUTIVE SUMMARY

The Department of Indian Affairs and Northern Development (DIAND) has responsibilities for encouraging economic development in Canada's two northern territories and ensuring that these activities are conducted in an environmentally responsible manner to prevent any deterioration to northern ecosystems. Interactions between mining and the environment are of prime importance, not only to resource managers and regulators, but also to residents who rely on natural resources for their lifestyle or for economic development opportunities.

DIAND provides funds for two programs that deal with mining and the environment: the Northern Water Resources Studies Program and the Mine Environment Neutral Drainage Program. To be effective, DIAND must bring together a broad range of interest groups to help set priorities for further mining and aquatic ecosystem studies. Over the last two years, the Water Resources Division has sponsored a series of workshops to review the current state of knowledge about the interactions between northern mineral development and aquatic ecosystems, to identify critical information or research gaps and to devise a study program to fill those gaps. This report synthesizes the findings of these workshops.

The assessment of the impact of northern mineral development on the aquatic ecosystem and a discussion of information gaps and research needs are preceded by a general discussion of the physical and biotic environments of the Northwest Territories and Yukon. This discussion is intended to show that Canada's two northern territories are distinct in themselves and present a vast and complicated landscape that challenges today's resource managers and mineral developers. Furthermore, because of uniquely northern differences, knowledge about the potential effect of mineral development activities on aquatic ecosystems cannot always be borrowed successfully from southern Canada.

The discussion of the potential impact of mineral development focusses on three broad stages of mining: exploration and development; mine site development and operation; and closure and reclamation. The potential impact of each stage varies according to the size and duration of the operation, and the knowledge about how the environment will respond and possible mitigation. Each mineral development operation has site-specific conditions that make any generalizations about broad potential impacts difficult. Even so, through the series of workshops that were attended by the mining industry, First Nations and Aboriginal groups, government agencies, universities and private consultants, some common themes emerged. It was found that of the three stages of mineral development, closure and reclamation have the highest potential for impacts and perhaps more important, the greatest need for information. Development and operations were seen to have a moderately high potential for impacts and a need for information, while exploration was ranked as the least intrusive environmentally and needed the least information.

Because research priorities are based on the magnitude of potential impact and the need for information, a range of possible avenues of research is presented. This suggested research is grouped according to water resources management, physical and hydrological processes and biological and ecosystem processes. While not exhaustive, it should serve to guide the Water Resources Division and others to understand the effects of northern mineral development on aquatic ecosystems and to meet departmental objectives of fostering economic development and protecting important northern aquatic ecosystems.

SOMMAIRE

Le ministère des Affaires indiennes et du Nord canadien (MAINC) a la responsabilité d'encourager le développement économique des deux territoires nordiques du Canada. Il doit aussi veiller à ce que les activités qui s'y rapportent se déroulent dans le respect de l'environnement afin d'empêcher toute détérioration des écosystèmes aquatiques du Nord. Les interactions entre l'activité minière et l'environnement revêtent une importance majeure non seulement pour les gestionnaires des ressources et les législateurs, mais aussi pour les habitants qui ont besoin de l'eau pour poursuivre leur mode de vie ou toute possibilité de développement économique.

Le MAINC finance actuellement deux programmes qui traitent de l'activité minière et de l'environnement, le Programme d'étude sur les eaux du Nord et le Programme de neutralisation des eaux de drainage dans l'environnement minier. Pour être efficace, le MAINC doit réunir de multiples groupes d'intérêts. Ceux-ci l'aident à établir des priorités concernant les études supplémentaires à entreprendre sur les mines et les écosystèmes aquatiques. Durant les deux dernières années, la Division des ressources hydrauliques a parrainé une série d'ateliers pour examiner l'état actuel des connaissances sur les interactions entre l'exploitation minière dans le Nord et les écosystèmes aquatiques, pour déterminer quelle information est essentielle et les lacunes au niveau des recherches et pour concevoir un programme d'études visant à combler ces lacunes. Ce rapport résume les conclusions de ces ateliers.

Les auteurs du rapport donnent un aperçu général des milieux biotiques et physiques des Territoires du Nord-Ouest et du Yukon. Ils procèdent ensuite à l'évaluation des éventuelles répercussions de l'exploitation minière sur les écosystèmes aquatiques du Nord et à une discussion sur les lacunes en matière d'information et sur les besoins en recherche. Ils tentent ainsi de montrer que les deux territoires nordiques du Canada se composent d'une vaste étendue

complexe qui constitue un défi pour les gestionnaires des ressources et les promoteurs miniers d'aujourd'hui. Les connaissances acquises dans le Sud du Canada sur les éventuelles répercussions de l'exploitation minière ne sont pas toujours applicables au Nord.

L'évaluation des répercussions éventuelles de l'activité minière porte principalement sur les trois grandes phases de cette industrie : la prospection et la mise en valeur; la préparation d'une mine et son exploitation; la fermeture de la mine et la remise en état du site. Chaque étape varie selon la durée de l'activité, la durée et l'étendue spatiale des répercussions qu'elle entraîne et la connaissance de la réaction de l'environnement et des mesures d'atténuation possibles.

De plus, à chaque activité minière se greffent des conditions particulières à l'emplacement qui rendent difficile toute généralisation sur les répercussions les plus importantes. Malgré cela, lors de la série d'ateliers auxquels ont participé l'industrie minière, les Premières nations, les organismes gouvernementaux, les universités et les experts-conseils privés, des thèmes communs ont émergé sur les répercussions éventuelles et les besoins en information. On a constaté que parmi les trois phases de l'activité minière, la fermeture de la mine et la remise en état du site était la plus susceptible d'entraîner des répercussions importantes et que c'est dans ce domaine que les besoins en information sont les plus grands. La mise en valeur et la prospection, n'entraînent pour leur part que peu de répercussions, et les besoins en information pour cette étape s'avèrent moyens. L'exploitation pourrait entraîner quelques répercussions et peu de besoins en information.

Les priorités en matière de recherche sont étroitement liées à l'ampleur des répercussions et des besoins en information et on présente une série d'avenues de recherche possibles pour comprendre les conséquences de l'exploitation minière dans le Nord et les écosystèmes aquatiques. La recherche proposée touche la gestion des ressources hydrauliques, le processus physique et hydrologique, les processus biologiques et l'écosystème. Bien que non exhaustifs, ces besoins devraient néanmoins guider les recherches qui aideront la Division des ressources hydrauliques et d'autres à comprendre les conséquences de l'exploitation minière dans le Nord et les écosystèmes aquatiques. Ainsi, ils pourront contribuer à l'atteinte des objectifs que s'est fixé le ministère pour promouvoir le développement économique et protéger les importants écosystèmes aquatiques du Nord.

ACKNOWLEDGEMENTS

The nature of this report required input from a number of specialists, and their contribution is acknowledged. First, the groundwork for this work was laid by the many participants who attended the various mining and environment workshops sponsored by the Water Resources Division and who convinced the authors that the two territories need a coherent studies program to address uniquely northern issues and concerns. We wish to thank Bruce Ott, Norecol, Dames and Moore; Fred Baker, Klohn Crippen; and Bob Chambers and Linda Broughton, Steffen Robertson and Kirsten, who conducted these workshops over the last two years. We also wish to thank the many people from within the Department who reviewed earlier drafts of this report and provided many useful comments and suggestions. These people include Martin Barnett and Tom Caine, Mineral Resources Directorate in Ottawa, and Diane Emond in Whitehorse; Kevin McDonnell and Greg Cooke, Water Resources Division in Yellowknife; and Dan Cornett and Bill Slater, Water Resources Division in Whitehorse. Finally, Julie Chouinard, Water Resources Division, Ottawa provided sections related to biological and ecosystem processes.

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1.0 NORTHERN RENEWABLE RESOURCES MANAGEMENT AND MINERAL DEVELOPMENT: THE CHALLENGE

Canada's two northern territories represent perhaps this country's last natural resources frontier. The history of resource development in the Northwest Territories and Yukon over the last hundred years ranges from the Klondike gold rush at the turn of the century to intensive oil and gas exploration in the Mackenzie River Valley and Beaufort Sea, the High Arctic mining in the late 1970s and early 1980s and more recently the intensive diamond exploration activities in the Slave Geologic Province of the Northwest Territories. Northern economic development in its purest sense can be constrained significantly by factors such as geography, accessibility, economy and political institutions (Huskey and Morehouse, 1992). Moreover, northern development frontiers are characterized by predominantly indigenous populations, limited market economies and dependence on resource exploitation and government assistance. Resource managers and resource developers must be knowledgeable about all these elements.

Barriers to development, such as the lack of transportation have only recently been improved to make the North accessible for resources development; however, the natural environment still presents formidable obstacles. In addition to these natural barriers, a new national public environmentalism has emerged during the last two decades focussing on wildlife protection, pollution control, limits to growth, economic sovereignty and awareness of Aboriginal rights. Resource accessibility and subsequent exploitation, and a strong environmental preservation ethic combine to create a dilemma of opportunism and idealism (Page, 1986). The challenge to natural resources management is how to balance sustainable economic development and environmental protection.

The physical barriers and obstacles to development challenged early resource developers, and many of these barriers still distinguish the northern territories from southern Canada and continue to challenge today's developers. The most striking feature and challenging factor is the northern natural environment. Arctic and northern ecosystems are physically and biologically distinct from southern ecosystems. As Sugden (1982) claims, the northern natural environment is analogous to the late Pleistocene environment with its severe climate, low abundance and distribution of species, propensity for sudden changes and remote access. Southern-based ecosystem management and resource development models, therefore, may not be completely appropriate for the North. New models may be required. Other distinguishing features of northern ecosystems are the relatively few food species but often large numbers of plants and animals within these species, simple food webs, speciation adaptations to environmental conditions and no effective buffers to prevent species collapse (Baird, 1976; Cooch et al, 1987; Ray and McCormick, 1981; Stonehouse, 1989). The swing between success and failure can be rapid and intense.

Canada's two northern territories are characterized by a sparse population in a vast area. Nowhere in Canada, or even North America, is there such a sparse population for such an immense land mass (Milburn, 1992). Even so, traditional peoples' attachment to the land, its natural resources and the harsh physical environment is probably one of the most distinctive features of northern lifestyles as suggested below:

> ... snow (and severe climate) gently reminding us that we are a northern people who have built a great nation in spite of an unpredictable, harsh and a sometimes downright cruel climate. Sometimes we need that reminder. Too often we forget the great legacy and the potential of our northern home, especially that vast area beyond 60 degrees parallel - the land we have come to call our North with a capital N (*Canada's North Today*, DIAND, 1978, pp.2-3).

This statement is perhaps even more relevant today than it was in 1978. The economy and cultures of northerners are highly dependent on preservation of sensitive natural environments, and northerners have overwhelmingly confirmed that they place a high value on these resources (GNWT and DIAND, 1990; TransNorthern Resources Management Consulting, 1992). While many northern communities have all the modern comforts and conveniences of small southern

southern communities, their local economies are markedly different. Northern economies are a mixture of cash and non-cash opportunities. While wages and cash derived from direct employment and commodity production, such as furs, fish, art and handicrafts, are important, much of the local economy is based on subsistence hunting, trapping and fishing (Science Council of Canada, 1991). These activities, based on natural resources, are often unmeasured and unrecorded, and go unnoticed in conventional economic accounting. As Bourque (1991) contends, the use of natural resources is the foundation of northern Aboriginal identity and is an important element in northern cultures. Northern development must therefore accommodate more than economic growth, it must also recognize and consider spiritual, social and cultural development (Chance, 1993). Because of the early stages of development and the unique socio-cultural identity of northerners, the clash between intrusive development and indigenous cultures is ever present (Sugden, 1982).

1.1 Northern Mineral Development

Canada, since the turn of the century, has been a world-class mineral and metal producer, although our history shows that mining was important locally even in colonial times (Government of Canada, 1991). Today, over 60 minerals and metals are mined, smelted and refined in Canada for use in manufacturing, construction and the service industry. Today's society, in its quest for new technologies, innovative conveniences and modern comforts will remain a net consumer of mineral products and Canada has an important role in filling this need (Figure 1.1). Through all stages of development, the minerals and metals industry accounts for almost 4.4 percent of Canada's gross domestic product (Mining Association of Canada, 1992). In addition, the industry provides direct employment for over 100,000 Canadians. Despite weakened metal prices on a global scale, over 114 metal mines continued to be active in Canada in 1991, a decline of 13 from 1990. In 1991, there were 111 non-metal mines, 240 structural material and 704 fuel industry establishments.

Mining and northern economic development are synonymous. Because the Northwest Territories and Yukon contain such diverse geological environments and mineral resources, the industry

THE IMPORTANCE OF MINERALS

We need mining!

Each year, every North American requires 40,000 pounds of new minerals. At this level of consumption, the average newborn infant will need a lifetime supply of:

795 pounds of lead, primarily for automotive batteries, solder and electrical components;

757 pounds of zinc, as an alloy with copper to make brass, as protective coatings on steel and as chemical compounds in rubber and paints;

1,500 pounds of copper for use mostly in electrical motors, generators, communications equipment and wiring;

3,593 pounds of aluminum for various uses, from beverage cans to folding lawn chairs to aircraft;

32,700 pounds of pig iron for kitchen utensils, automobiles, ships and large buildings;

26,550 pounds of clay, for making bricks, paper, paint, glass and pottery;

28,213 pounds of salt for cooking, plastics, highway de-icing, and detergents;

1,238,101 pounds of stone, sand, gravel and cement, for building roads, homes, schools, offices, and factories.

To reduce mining activity, as some people think should be done, we as citizens, must first reduce our wants and needs.

If it can't be grown, it has to be mined!

Few people realize that if it cannot be grown on our farms, taken from the sea or the forest (or the barren lands), it must be mined.

Figure 1.1 The Importance of Minerals on a Global Scale (N.W.T. Chamber of Mines, undated) is the leading non-government activity (Brown, 1992; Caine and Brown, 1987). Although furs, oil and gas and whaling have all had their important role in northern development, minerals and mining produced the modern North (N.W.T. Chamber of Mines, undated).

Faced with obstacles and barriers, such as the harsh climate, vast distances to markets, small populations and limited infrastructures, the northern mining industry continues to play a significant role in northern development. Although the value of minerals is set by the international market, their production in the Northwest Territories and Yukon contributes to the local economies through direct employment and secondary services, and other developments such as roads and railways, hydroelectric developments, creation of numerous mining communities and new technologies. Annual mineral production in both territories varies annually from one-half to over one billion dollars with zinc generally providing the largest value, followed by gold (Tables 1a and 1b).

Table 1.a Mineral Production in the Northwest Territories (Value in $000s)

	Total	Gold	Silver	Lead	Zinc
1993	607,349	192,630	14,833	179,760	41,738
1992	681,144	180,501	28,729	256,878	303,051
1991	703,178	222,504	30,080	328,781	191,194
1990	703,833	223,788	55,766	420,550	325,366
1989	934,861	177,260	41,323	708,009	341,649
1988	805,636	205,503	52,223	537,756	237,932
1987	696,258	223,456	139,370	328,781	187,336

Source: Natural Resources Canada, Mining Sector, 1994, *Value of Canada's Mineral Production*, and Government of the Northwest Territories, Bureau of Statistics, 1992, *...by the numbers*

Table 1.b Mineral Production in Yukon (Value in $000s)

	Total	Gold	Silver	Lead	Zinc
1993	135,824	50,426	5,027	13,908	41,738
1992	496,230	49,898	19,014	99,595	303,051
1991	348,651	51,573	12,890	79,825	191,194
1990	-	66,731	15,177	124,704	325,366
1989	534,458	80,504	13,384	-	341,649
1988	468,832	87,386	42,593	118,696	237,932
1987	434,862	88,970	40,965	117,000	187,336

Source: Natural Resources Canada, Mining Sector, 1994, *Value of Canada's Mineral Production*, and Yukon Executive Council Office, 1991, *Yukon Fact Sheet*

1.2 The Management Response

The physical, biological, cultural and socio-economic conditions in Canada's northern territories create a modern, two-sided management challenge. The Department of Indian Affairs and Northern Development (DIAND) has broad responsibilities to encourage economic development in Canada's two northern territories and to ensure that these activities are conducted in an environmentally responsible manner that will prevent any deterioration to the northern environment. In addition, the Department has fiduciary responsibilities for Aboriginal people that must be considered in any management decision. Thus, interactions and linkages between resource developers and the environment are of prime importance not only to resource managers and regulators, but also to residents who rely on natural resources for their lifestyle or for economic development opportunities.

One side of the management challenge is to encourage and support the mineral development sector, and DIAND, through its Northern Mineral Policy, is committed to "... establish the environment necessary for the [mining] industry to maintain and expand its significant contribution to the well-being of the territorial economies and northern residents" (DIAND, 1986, p. 10). A number of programs have been established to fulfil this commitment.

The Department also has a number of programs on the other side of the management challenge to protect important ecological resources and ensure integrity of northern cultures. Because the focus of this report is an assessment of the potential effects of northern mineral development on aquatic ecosystems, discussion will be limited to water-related programs and issues. The Water Resources Division of the Northern Affairs Program is responsible for co-ordinating, regulating and managing northern water resources. Management of northern water resources is complex. Through the *Yukon Waters Act* and the *Northwest Territories Waters Act*, DIAND manages northern waters. As Gibson (1990) explains, the purpose of the northern water legislation is to provide for equitable distribution and sharing of water use rights; to ensure that the allocation of these rights is consistent with immediate and long-term regional and national interests; to ensure all water-related works and undertakings are designed and constructed to acceptable engineering standards; and to establish and maintain the principle that water users accept full responsibility for maintaining its quality to acceptable standards before returning the water to its natural environment. These seemingly simple objectives are actually quite complex considering the size of the two territories to which the acts must be applied, the diversity of water uses and the vagaries of the resource itself.

Over the years, several studies have been carried out to assess the impact of mining on specific watercourses, but much information is still required to understand broader ecosystem effects and how to mitigate the impacts on the aquatic ecosystem. DIAND provides funds for two programs that deal directly with mining and the environment. The first program, the Northern Water Resource Studies Program, is wholly funded by DIAND's Water Resources Division to address important water-related issues in the Northwest Territories and Yukon. Many studies funded under this program are directly related to mining.

The second program, Mine Environment Neutral Drainage (MEND), is an industry-driven, national program that provides a comprehensive scientific, technical and economic basis for long-term management of potential sources of acid rock drainage. MEND also establishes techniques that will allow for the prediction, control and treatment of acid-generating tailings and waste rock. Because water is the primary medium of transport of acid rock drainage products, many of DIAND's MEND studies are directly related to water.

To fulfil DIAND's mandate for promotion of northern economic development and protection of aquatic ecosystems, and to assist in setting priorities for further mining-aquatic ecosystem studies, the Department has recently completed three separate studies related to northern mining. The first study comprised a workshop in Vancouver, British Columbia in January 1993 to set priorities for acid rock drainage research. The workshop was attended by representatives from mining companies, government agencies, consultants and academics from both southern Canada and the Northwest Territories. The results of the workshop are reported in Klohn Leonoff (1993).

A second regional workshop among key stakeholders in the Northwest Territories was held in Yellowknife, Northwest Territories in February 1993 to review the current state of knowledge about mining and water resources, to identify critical information or research gaps and to devise a study program to fill these gaps. The results of this workshop are reported in Norecol (1993). A discussion paper that focusses specifically on Yukon mining was prepared and distributed to the Yukon mining industry (Leenders, 1993).

Finally, a third study was completed recently on the design of a long-term research program for the Department that builds on joint ventures with the mining industry to understand better the generation, prediction, control and treatment of acid rock drainage in northern environments. This research plan is reported in Norecol, Dames and Moore (1994).

This report draws on the results of these studies and further identifies key water resources-related research and studies required to fill important research and information gaps and to set short- and long-term priorities for northern water resources studies. Although it is at times difficult to separate impacts on terrestrial and aquatic ecosystems, for the purposes of this paper, only aquatic ecosystems will be discussed.

1.3 Report Structure

As stated above, the northern natural environment is an important factor that not only limits or constrains economic development but also houses resources for economic development. The results of the three recent studies mentioned above clearly show that the Department's research requirements are almost exclusively related to unique northern conditions. Therefore, the natural environments of the N.W.T. and Yukon are described in some detail in sections 2 and 3 of this report to remind us that northern Canada is indeed different from southern Canada. A brief summary of northern mineral development in both territories is presented in Section 4 to illustrate the range and number of mining-related activities. The next section reviews the main stages of mineral development, assesses the potential impacts and identifies research and information gaps directly related to water resources management and an assessment of potential impacts. The three stages of mining discussed are exploration and development, operations, and closure and abandonment. Finally, Section 6 sets research priorities and provides a list of prospective studies. A compendium of mining operations in the N.W.T. and Yukon is found in Appendix A.

2.0 THE NORTHWEST TERRITORIES ENVIRONMENT

The Northwest Territories encompasses 3,376,698 square kilometres or about 30 percent of Canada's land surface. It is located predominantly between the southern border at 60°N and Canada's most northerly point on Ellesmere Island at 83°N latitude. The N.W.T. also includes the islands in Hudson and James bays. From Baffin Island in the east to the Yukon border in the west, the N.W.T. extends 3,283 kilometres and covers three time zones. The territory includes 24 percent of Canada's coastline and contains 133,294 square kilometres of Canada's fresh water supply (Outcrop, 1990). The N.W.T. is complex in terms of its physiography, climate, aquatic and terrestrial ecosystems and the socio-cultural make-up of its residents.

Although the N.W.T. is a vast area, the population is only 57,650 (1991). Most reside in Yellowknife and the Hay River and Fort Smith regions (Outcrop, 1990). The population density is approximately 64 persons per square kilometre and over half the residents are of Aboriginal descent (GNWT, 1992). This section describes the physiography, geology, hydrology, climate and flora and fauna of the N.W.T..

2.1 Physiography

The N.W.T. comprises eight physiographic regions (Figure 2.1). The largest contiguous land mass is the Canadian Shield in the central portion of the territory, which is characterized generally as an evenly eroded surface with sparse vegetation and numerous lakes and small streams. Three physiographic regions are found in the Shield: the Kazan region of massive rock outcrops; the Hudson region, which forms the chief depression in the Shield; and the Davis region, which is moderately deformed. The Cordilleran region in the west is a mountainous area of recent orogeny, while the Interior Plains, which were once part of the Devonian Sea, form a flat-lying tundra zone. The Arctic Archipelago in the far north contains the last three regions: the Arctic Lowlands; the Arctic Coastal Plains; and the Innutian region (Bostock, 1981). A characteristic feature of the N.W.T. is the many lakes, which provide evidence of glacial action

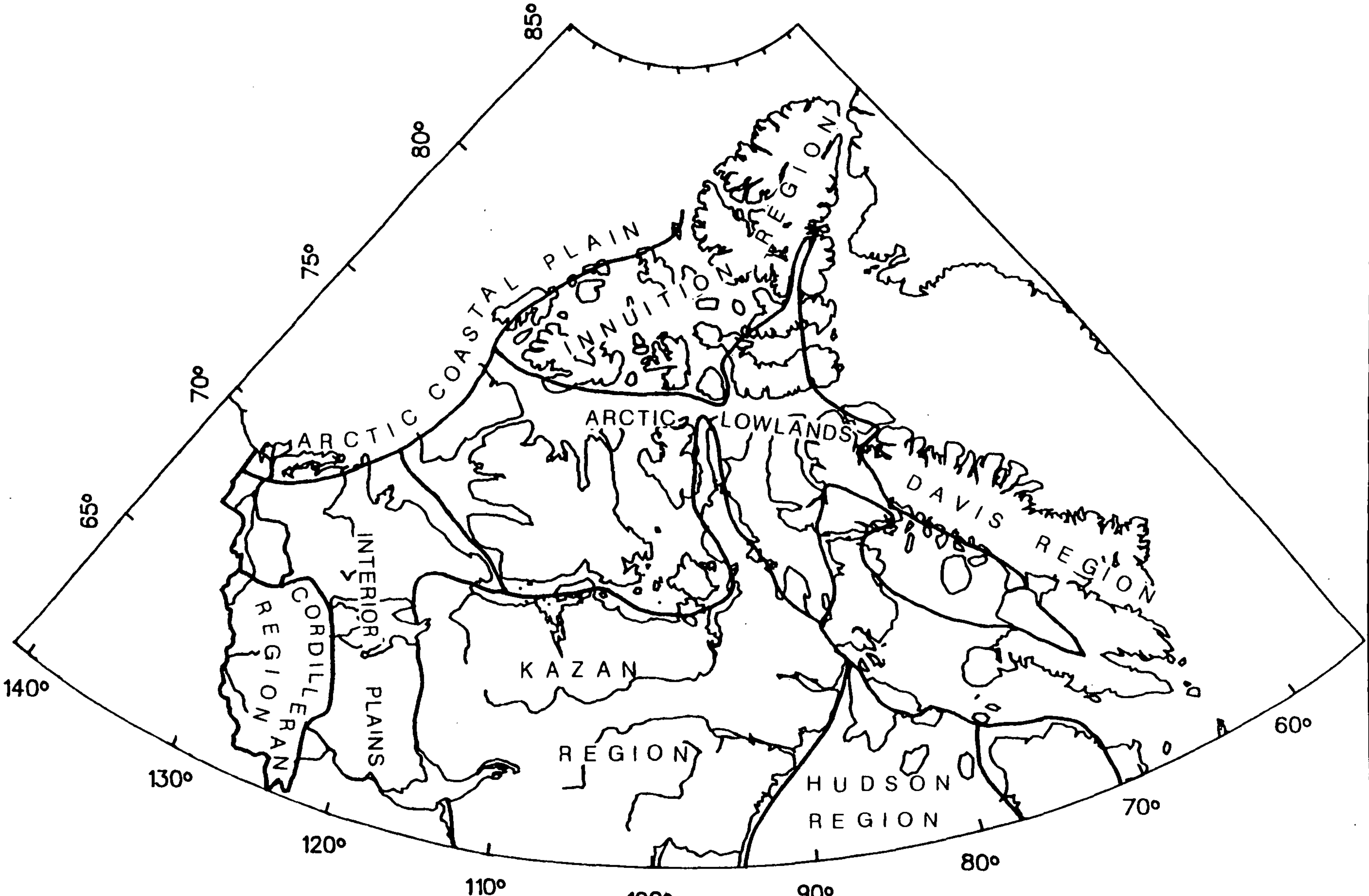


FIGURE 2.1
PHYSIOGRAPHIC REGIONS OF THE NORTHWEST TERRITORIES

that eroded previous landforms and created poorly drained shallow depressions (Outcrop, 1990). Great Slave and Great Bear lakes are part of the Great Lakes system that were also created during the last continental glaciation (Prest, 1981). Another common feature in the region is muskeg, which influences thermal characteristics of the ground and can enhance permafrost development. Muskeg, which is poorly drained, is widely distributed in southern N.W.T. (Steffen, Robertson and Kirsten, 1992a). Much of the terrain is also hummocky as a result of glacial activity.

Permafrost plays an important role in the physical and hydrological regime of the N.W.T.. The discontinuous permafrost zone is found in the southwestern corner of the N.W.T., while the remainder of the territory lies within the continuous permafrost zone (Figure 2.2).

2.2 Geology

The N.W.T. is divided into nine geologic regions or "structural provinces" that for the most part match the physiographic regions described above (Caine and Brown, 1987; Douglas, 1976; Steffen, Robertson and Kirsten, 1992a). The major geologic regions are the Arctic Coastal Plain, the Arctic Platform, the Interior Platform, the Hudson Platform, the Cordilleran Orogen, the Innuitian Orogen, the Bear Province, the Slave Province and the Churchill Province (Figure 2.3). Each region is distinct in structural style and orogenic history (Caine and Brown, 1987).

Three structural provinces form the central core of the N.W.T., the Bear, Slave and Churchill Provinces. The Bear Province includes the central western part of the N.W.T. and a portion of Victoria Island and it is one of the youngest, geologically simplest of the structural provinces (Klohn Leonoff, 1992a). The area possesses sedimentary rocks with some volcanic rocks variably deformed and metamorphosed (Geological Survey of Canada, 1992). Silver-rich veins of the Camsell River and the Echo Bay districts are contained in sedimentary rocks in this province (Klohn Leonoff, 1992a). A number of granitic outcrops are also evident in this province (Geological Survey of Canada, 1992). The border between the Bear and the Slave

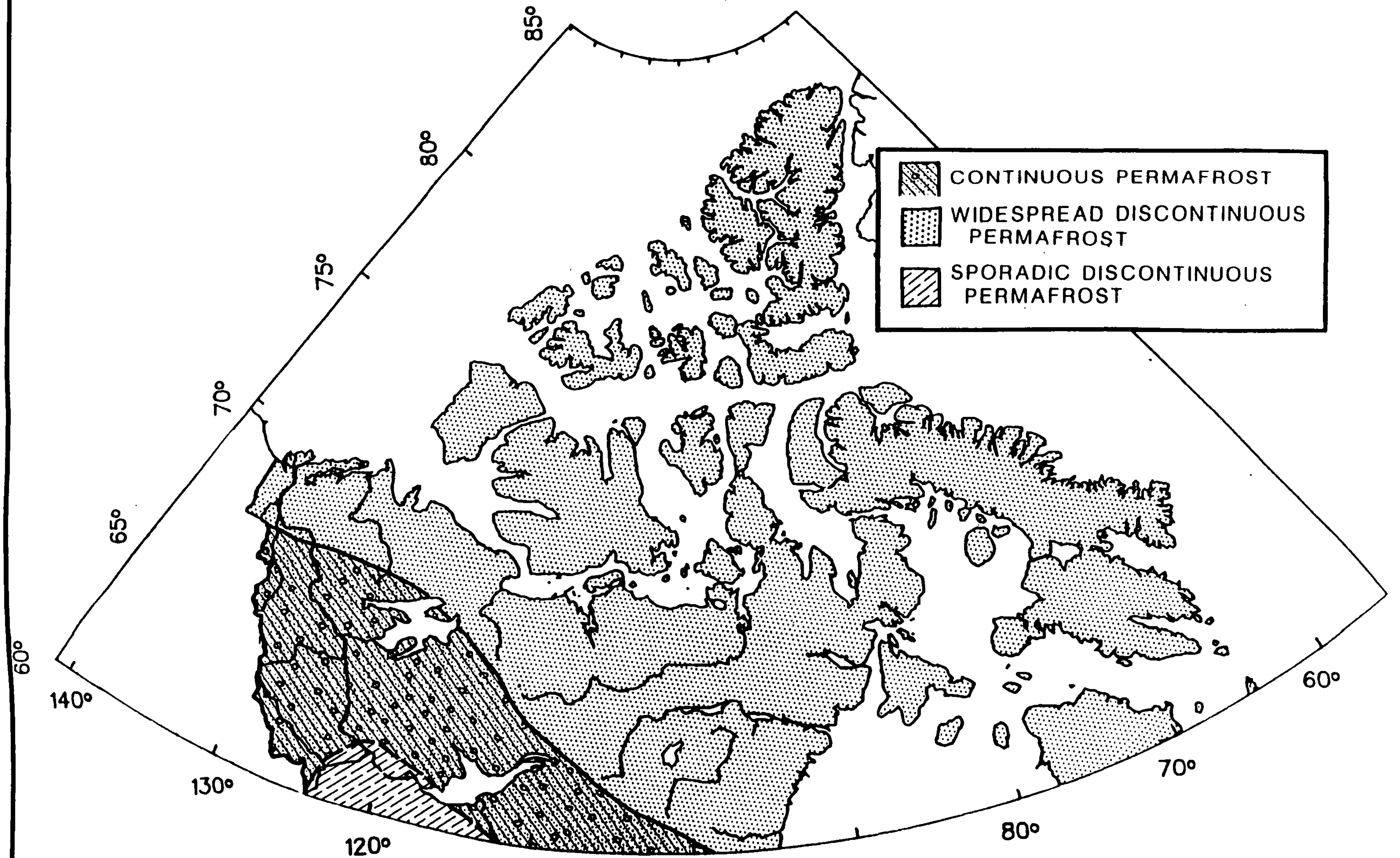


FIGURE 2.2
PERMAFROST DISTRIBUTION IN THE NORTHWEST TERRITORIES

structural provinces is delineated by a large unconformity (Bostock, 1981). The soil development of this region is limited in extent and depth (Wedel, 1990).

The Slave Province, the oldest structural province in the N.W.T., consists of Archean- and Aphebian-age rocks (Caine, 1993). Approximately two thirds of the region is underlain by granitic rocks, which are mostly basic. Volcanic basalt is common although poorly sorted and sedimentary rocks such as greywacke also exist (Bostock, 1981). The formation of soil in this area is limited in extent and depth (Wedel, 1990). Twenty-four gold mines located in this province have operated since 1935 (Klohn Leonoff, 1992a).

The Churchill Province includes most of Baffin Island, most of the eastern N.W.T. and parts of other Arctic islands (Bostock, 1981). All the rocks in this province are metamorphosed and deformed to some degree (Klohn Leonoff, 1992a). The predominant rock types in this province are granitic intrusions, gneiss, migmatite and charnockite with some volcanic and sedimentary rocks of variable deformity and metamorphism (Geological Survey of Canada, 1992). The only recent mine of significance was the Cullaton Lake gold mine at Kognak River (Klohn Leonoff, 1992a). In the eastern area of this structural province, the soil extent and depth is confined while the northern area has superficial soil formation in glacial tills and coastal marine sediments (Wedel, 1990).

Surrounding the Canadian Shield are three flat-lying sedimentary structural provinces known as platforms that were formed as deposits from shallow inland seas during the Palaeozoic and Mesozoic eras: the Arctic Platform; the Interior Platform and the Hudson Platform (Klohn Leonoff, 1992a).

The Arctic Platform forms the base of the Arctic Lowlands and it is found on flat-lying Palaeozoic and late Proterozoic sedimentary rocks. This platform occurs between the Canadian Shield in the south and Innuitian region in the north (Bostock, 1981). Most of the Arctic Islands, including Devon, Cornwallis and Victoria islands and the northern tip of Baffin Island,

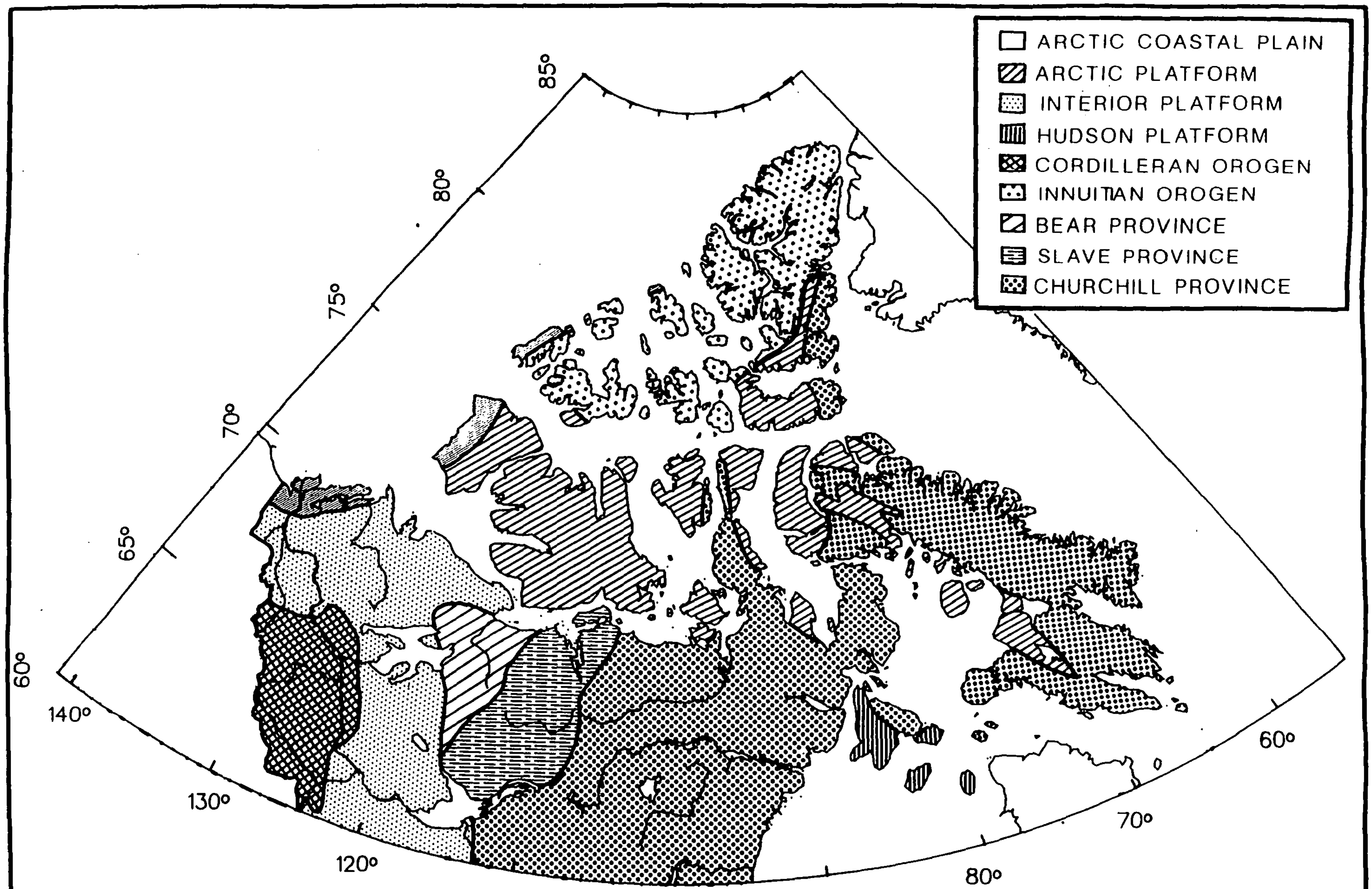


FIGURE 2.3

GEOLOGICAL REGIONS OF THE NORTHWEST TERRITORIES are found in this region. The most important mineral deposit in the Arctic Platform is the Polaris lead-zinc mine on Little Cornwallis Island (Klohn Leonoff, 1992a).

The Interior Platform includes the area between the Cordilleran region to the west and the Canadian Shield to the east. The area is covered by a combination of late Proterozoic, Palaeozoic, Mesozoic, and Tertiary rocks (Bostock, 1981). This region has mostly sedimentary rocks with some volcanic rocks that are somewhat deformed but mostly flat-lying (Geological Survey of Canada, 1992). Carbonate sediments in this province contain petroleum resources at Norman Wells and lead and zinc at Pine Point (Klohn Leonoff, 1992a). The soils of this region are dominantly poorly drained organics underlain by unconsolidated glacial material with few bedrock outcrops (Acres Consulting Services Limited, 1982).

The Hudson Platform region does not occupy a large portion of the N.W.T.. It consists mainly of a partially inundated envelope of unmetamorphosed, smooth-surfaced Palaeozoic and Proterozoic layers (Bostock, 1981).

The Arctic Coastal Plain, a relatively small province but rich in petroleum resources, is the most recently formed structural province. It includes the Tuktoyaktuk Peninsula and touches the Beaufort Sea (Caine and Brown, 1987). The area is composed generally of sedimentary rocks with some volcanic rocks of variable deformation (Geological Survey of Canada, 1992). The region also possesses large deposits of sand and gravel that have over time, created an undulating surface (Caine, 1993).

The Cordilleran Orogen, which extends along the west coast of North and South America, occupies much of the western N.W.T. between the Peel River in the north and the Liard River in the south (Klohn Leonoff, 1992a). This complex geological region consists of sedimentary rocks for the most part with some volcanic rocks and gabbro sills. The rocks are mostly folded and metamorphosed (Geological Survey of Canada, 1992). The suspended Canada Tungsten mine is located in this region (Klohn Leonoff, 1992a).

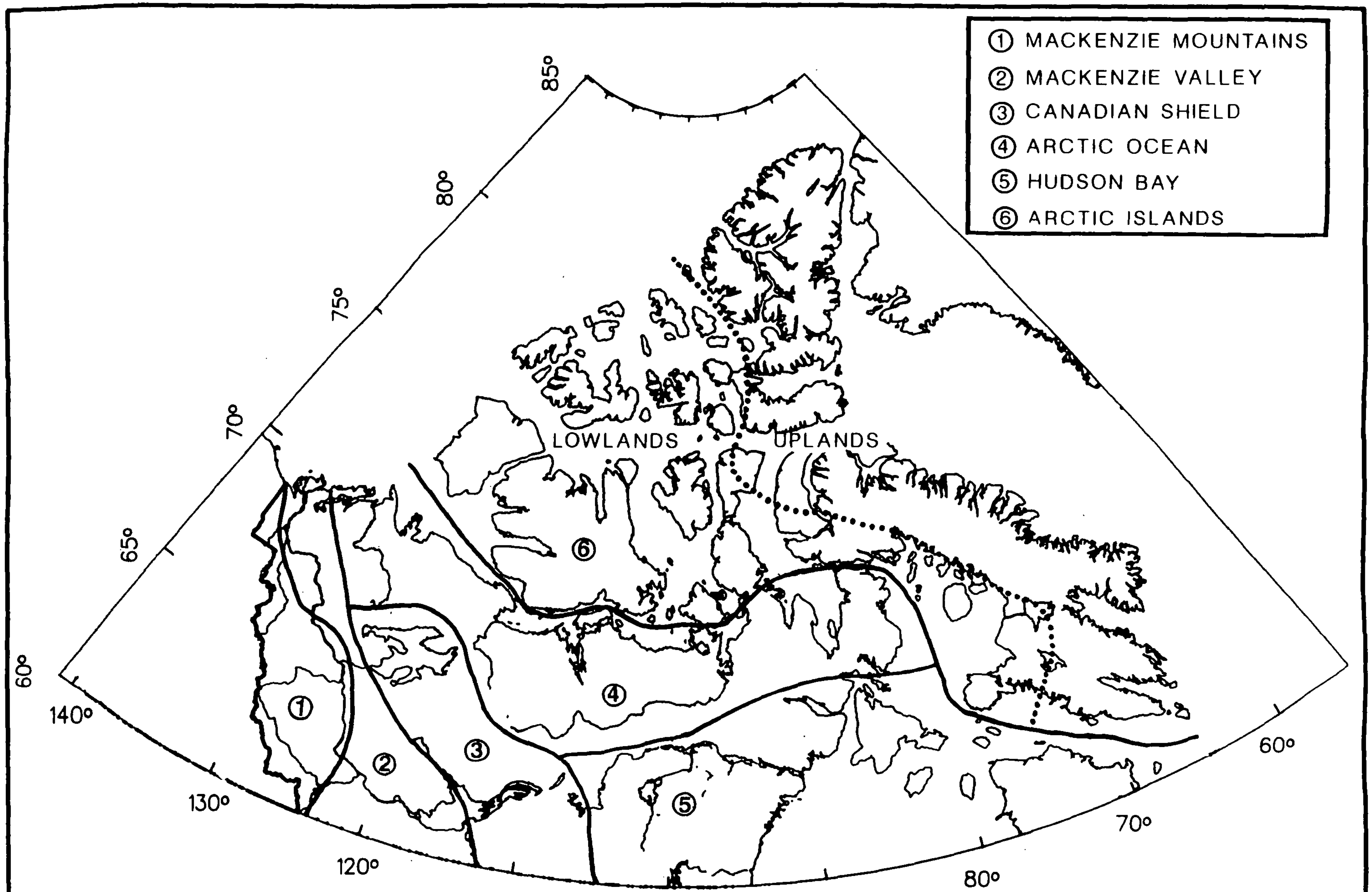


FIGURE 2.4

HYDROLOGIC REGIONS OF THE NORTHWEST TERRITORIES

The Innuitian Orogen in the High Arctic Islands manifests as a rugged terrain, caused by the accumulation of deformed sedimentary rock and a small number of intrusions. The area is at a relatively young or intermediate stage of development (Bostock, 1981). The Nanisivik lead-zinc mine on Baffin Island is the only significant mineral deposit in this region. This region, as well as most of the Arctic Islands, possesses marine sediments along the coast and superficial soil formation (Wedel, 1990).

2.3 Hydrology

No established hydrologic regions exist for the N.W.T., however, the broad divisions described by Wedel (1990) provide an adequate model for the purpose of this report (Figure 2.4). They are the Mackenzie Mountains (Cordillera), the Mackenzie Valley (Inland Plains), the Canadian Shield, the Arctic Ocean (Canadian Shield), the Hudson Bay (Canadian Shield) and the Lowlands/Uplands (Arctic Islands).

The largest river system in the N.W.T. is the Mackenzie River Basin. Approximately 20 percent of Canada's land surface is drained northward by the Basin. The Mackenzie River is the twelfth largest river in the world by drainage area, at 1,787,000 square kilometres, and eleventh largest in mean annual discharge at 9,630 cubic metres per second near its mouth at the Beaufort Sea (Lewis et al, 1991). The N.W.T. portion of the Basin also contains two of the world's largest subarctic lakes, Great Slave and Great Bear lakes. The Mackenzie River Delta is the world's tenth largest marine delta.

Also flowing northward into the Arctic Ocean are the waters from northern sections of the Canadian Shield, the Coastal Flatlands, and the Arctic Lowlands. A large portion of the waters from the Canadian Shield, the Interior Plains and the entire Hudson Bay Lowlands drains in the direction of Hudson Bay (Klohn Leonoff, 1992a).

Representative hydrographs for streams in the broad hydrologic regions are shown in Figures 2.5 and consist of the following: Liard River (Mackenzie Mountains); Mackenzie River

Figure 2.5. Mean Monthly Discharges for Select Northwest Territories Streams

Fig. 2.5a Liard River near the Mouth

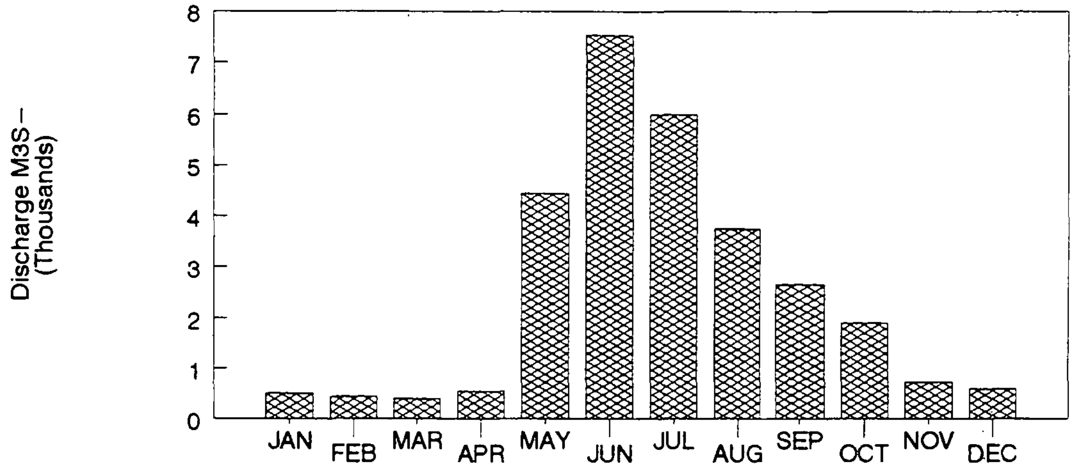


Fig. 2.5b Mackenzie River
at Arctic Red River

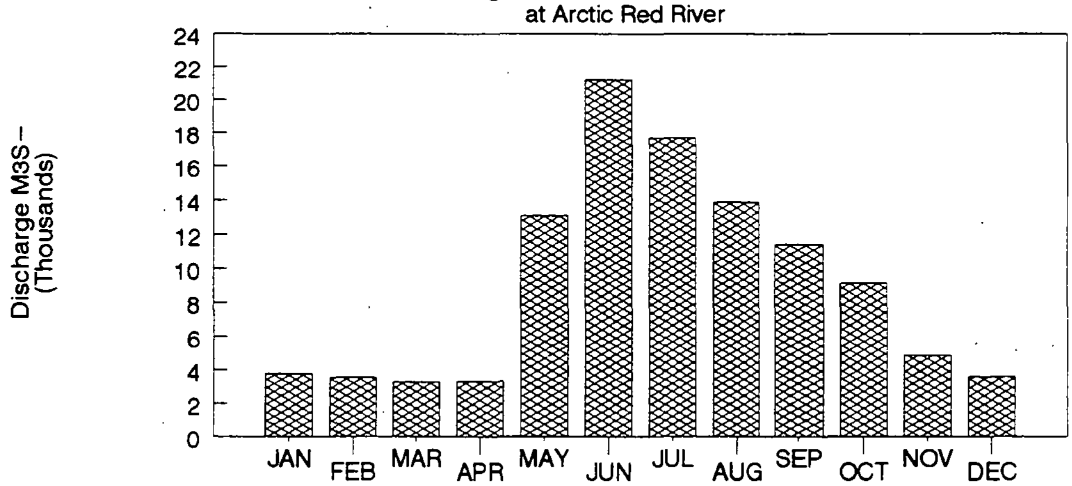


Fig. 2.5c Coppermine River
above Bloody Falls

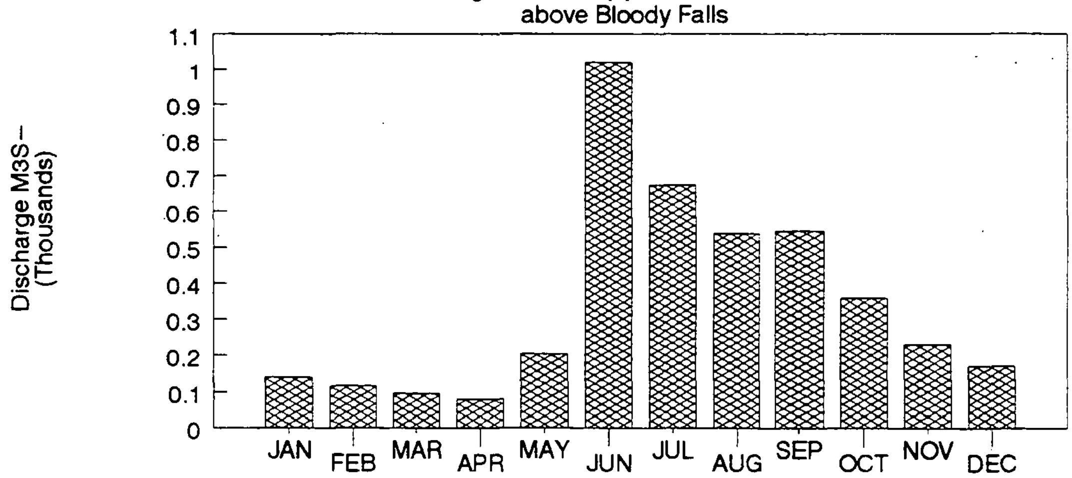


FIGURE 2.5 Mean Monthly Discharges for Select Northwest Territories Streams

Fig 2.5d Snowdrift River
at outlet of Siltaza Lake

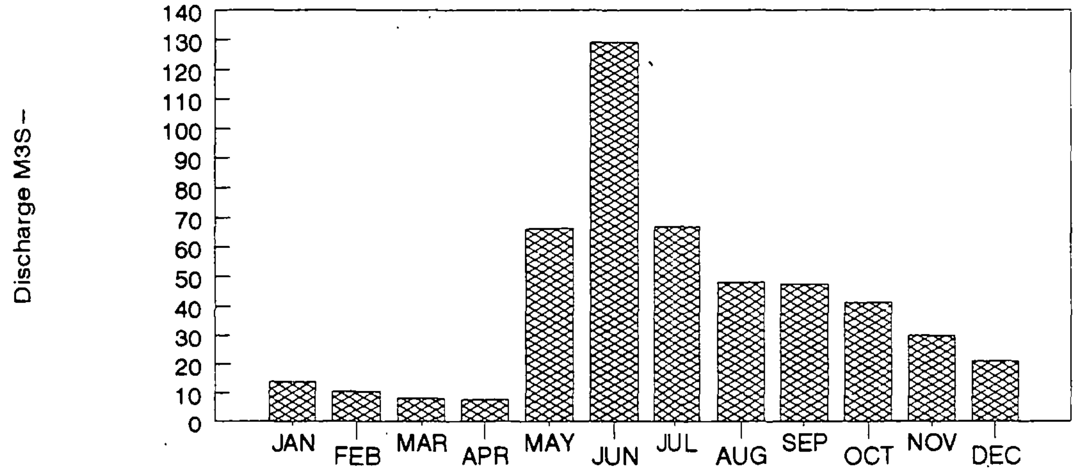


FIG 2.5e Thelon River
below Shultz Lake

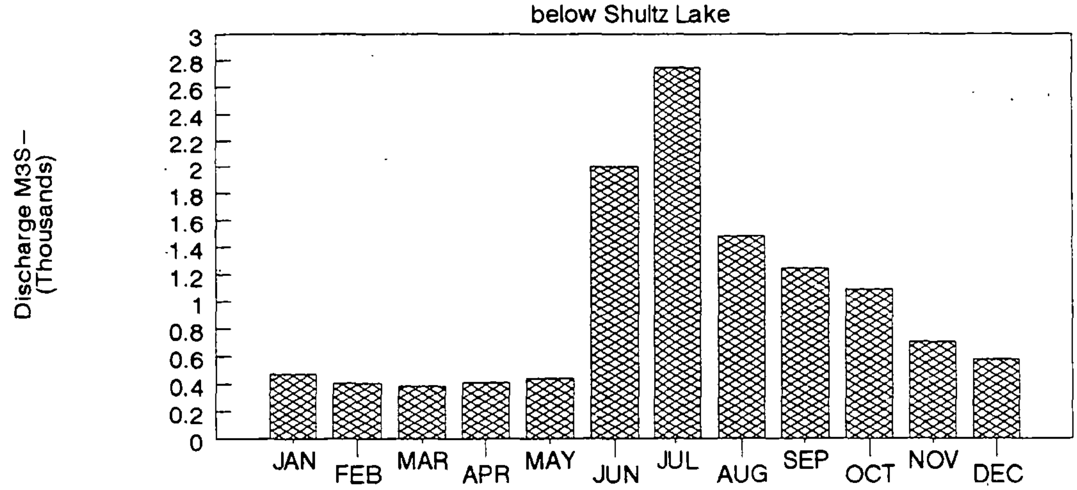
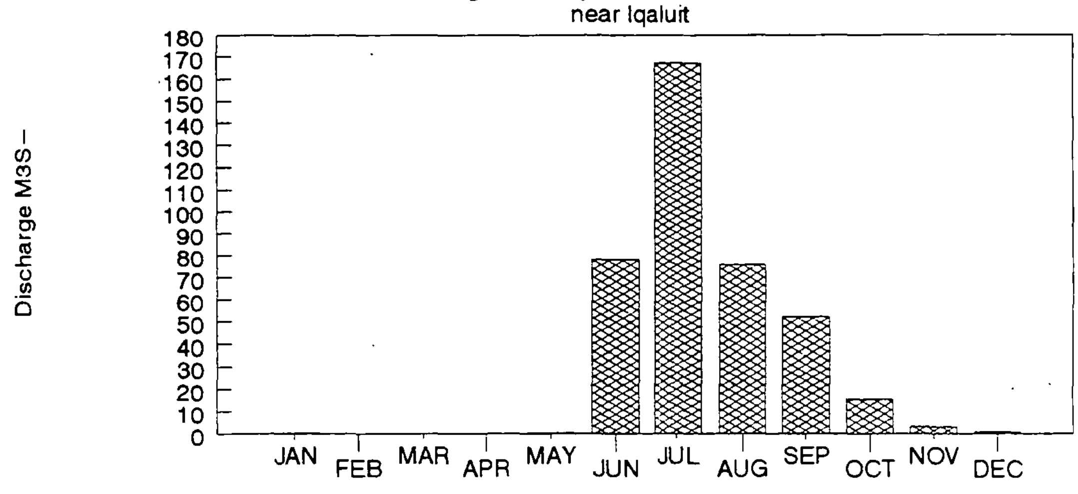


Fig. 2.5f Sylvia Grinnell River
near Iqaluit



Source: *Historical Streamflow Summary: Yukon and Northwest Territories to 1990*, Department of Environment (1991a)

(Mackenzie Valley); Snowdrift River (Canadian Shield); Coppermine River (Arctic Ocean); Thelon River (Hudson Bay); and Sylvia Grinnell (Arctic Islands). Hydrologic data for select streams in these regions are also presented in the following table.

Table 2.1 Historical Streamflow Data for Select Northwest Territories Rivers

River	Drainage Area (km^2)	Mean Annual (m^3s-)	Maximum Daily (m^3s-)	Minimum Daily (m^3s-)
Liard River at the mouth	277,000	2,470	14,400	280
Mackenzie River at Arctic Red River	1,660,000	9,130	24,800	2,230
Snowdrift River at outlet of Siltaza Lake	9,110	41.6	220	6.7
Coppermine River above Bloody Falls	50,700	338	2,270	65.1
Thelon River below Schultz Lake	152,000	1,040	3,240	451
Sylvia Grinnell River near Iqaluit	2,980	34.1	345	0

Source: *Historical Streamflow Summary Yukon and Northwest Territories to 1990.* Department of Environment (1991a)

Areas of steep gradient, such as the Mackenzie Mountains, invariably exhibit greater runoff levels creating dramatic peaks in the spring thaw season. Consequently, these steep or mountainous regions permit little groundwater storage. In contrast, areas where the geology permits greater infiltration, such as the Interior Plains, have increased groundwater flow. The Canadian Shield area possesses a large capacity to store water, but this water is stored in a myriad of lakes, resulting in reduced runoff. The lowlands and uplands of the Arctic islands respond rapidly to snowmelt and rainfall occurrences with a flow of near zero in the winter (Acres Consulting Services Limited, 1982). The swift hydrologic response in these areas to snowmelt is accentuated by the presence of permafrost (Woo, 1993). If large snow masses are present at the time of the spring thaw, significant concentrations of pollutants would be distributed in the water system over a short period (Marsh, 1990; Steffen, Robertson & Kirsten, 1992a).

Undoubtedly the geology, permafrost, topography and climate all have an effect on the variability of the hydrologic regime. All are interrelated and must be considered together when examining the hydrology of an area.

2.4 Climate

Two broad climatic zones have been described for the N.W.T.: the arctic region; and the subarctic region (GNWT, 1993). The arctic region extends from most of the mainland portion of the territory above the treeline and the entire Arctic Archipelago. This zone is characterized by a much colder and drier climate than the subarctic zone (GNWT, 1993). Both areas, however, are marked by severely cold temperatures that are frequently below zero degrees Celsius. The two regions have "low-energy" climates meaning that many physical, chemical or biological processes dependent on temperature or humidity proceed slowly (Hare and Thomas, 1979). Thus, chemical reactions associated with mining are delayed and difficult to observe in this severe environment (Klohn Leonoff, 1992a).

Climate in the N.W.T. is considered to be continental. The influence of the Pacific Ocean on temperature is limited by Yukon's eastern mountain ranges, while the Arctic Ocean is frequently covered by ice that does not allow effective moderation of temperatures (Steffen, Robertson and Kirsten, 1992). Other arctic seas and straits are also ice-packed for most of the year, which ultimately affects regional climates (DIAND, 1971). In spite of the vastness of the region, "climate diversity" does not occur and the severity of the climatic environment is widespread (Department of Environment, 1990).

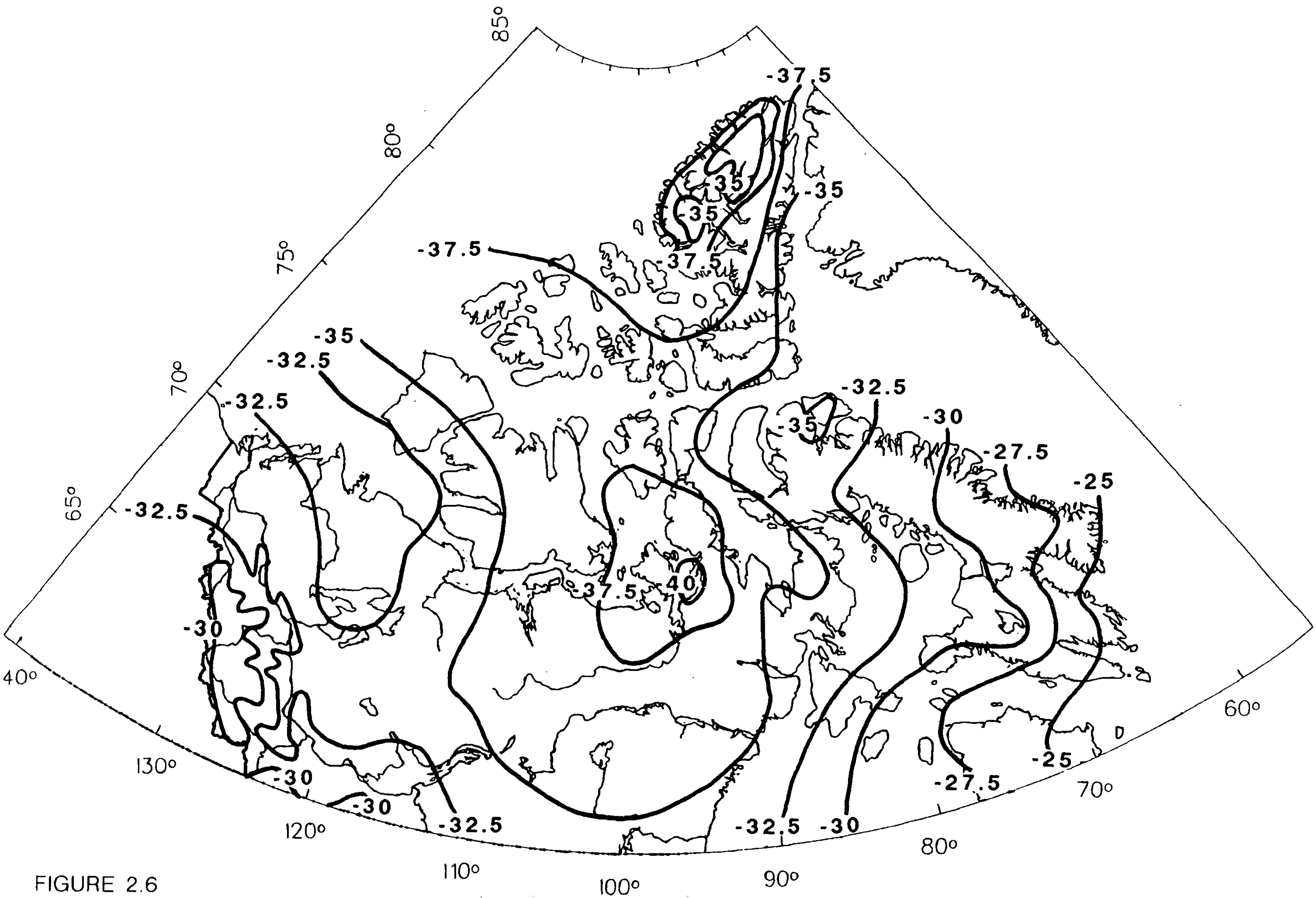


FIGURE 2.6

AVERAGE JANUARY NIGHTTIME TEMPERATURE (°C)

Temperature: The mean annual temperature throughout the N.W.T. is lower than the freezing point (Figures 2.6 and 2.7). Mean annual temperatures in the arctic zone range from -26 °C at Iqaluit to -33 °C for Melville Island in the Arctic Islands (GNWT, 1993). Within the arctic climatic zone, freezing temperatures can be reached during any month of the year. Because of its lower latitude, the subarctic zone experiences warmer temperatures but extreme, rare temperatures as low as -57 °C have been recorded.

Because the N.W.T. is so vast, regional differences are expected. Temperature records for various municipalities exhibit marked seasonal variations as shown in Table 2.2.

Table 2.2 Climate data for Northwest Territories Municipalities 1951-1980

		Temperature (°C)			Precipitation (mm)	
Municipality	Elevation (m)	Annual	January	July	Annual	June-August
Aklavik	11	-9.1	-29.4	14.0	207.8	30.6
Resolute	67	-16.6	-32.1	4.1	131.4	21.9
Yellowknife	205	-5.4	-28.8	16.3	266.7	31.5
Iqaluit	34	-9.3	-25.6	7.6	432.6	53.9
Baker Lake	12	-12.2	-33.0	11.0	234.6	32.1
Eureka	10	-19.7	-36.4	5.4	64.0	9.7
Fort Smith	131	-4.0	-28.1	17.2	332.7	43.87

Source: *Canadian Climate Normals: Temperature and Precipitation 1951-1980 (The North: Y.T. and N.W.T.)*, Department of Environment (1982)

Day length and sun strength are dependent on latitude, thus, some variability in mean monthly temperature is expected within the N.W.T.. During the summer months, longer days allow more latent heat to accrue. The number of frost-free days ranges from 40-60 days in the arctic region to 50-100 days in the subarctic region (GNWT, 1993). In the winter, however,

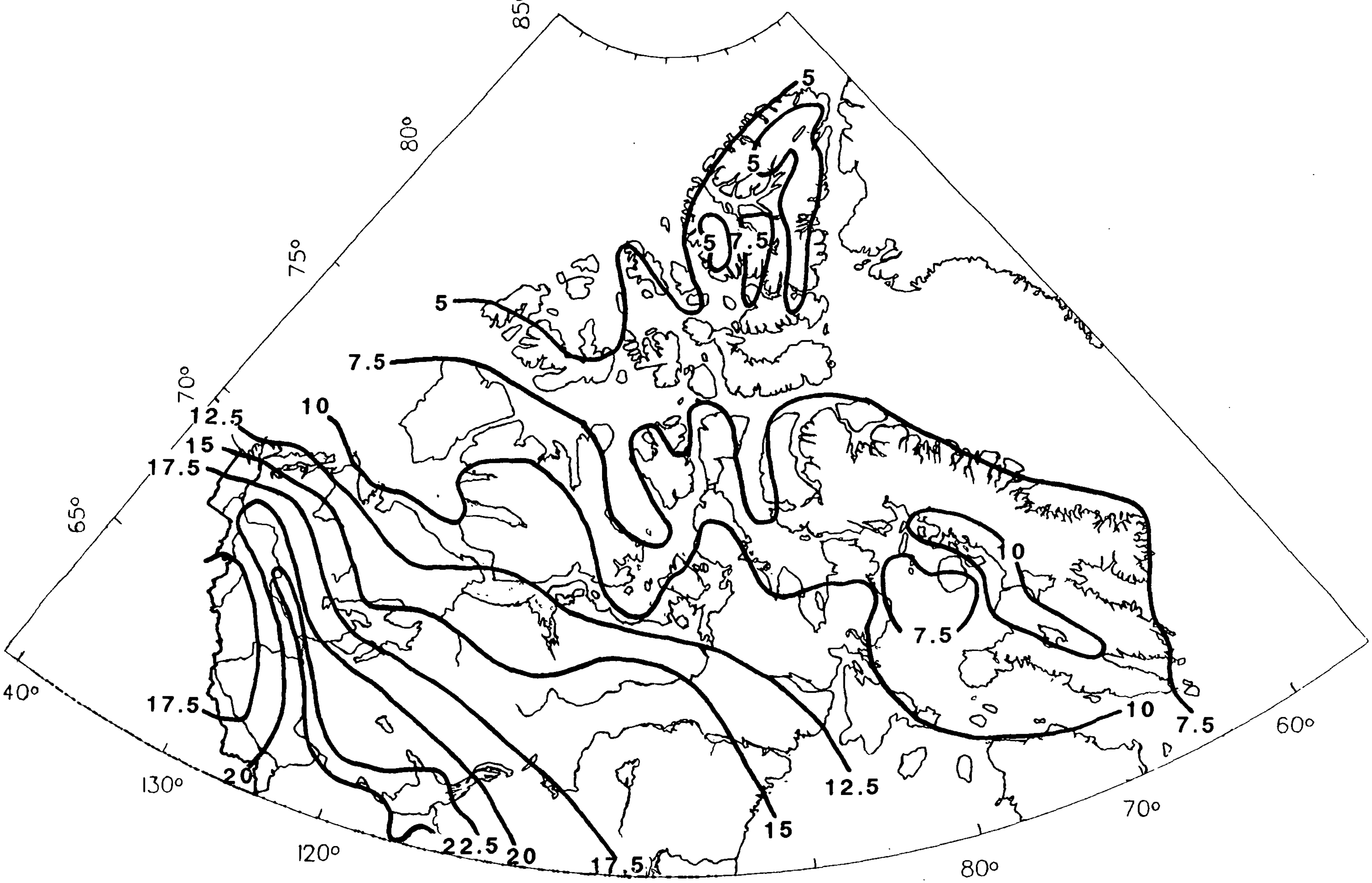


FIGURE 2.7

AVERAGE JULY DAYTIME TEMPERATURE (°C)

days are shorter and incoming energy allows minimal heat accumulation. Warmer temperatures and longer days in the spring affect the melting of snow and ice masses, which in turn influence the hydrologic regime. This effect is most dramatic in the southern N.W.T.. Breakup on major north-flowing streams normally occurs in early to mid-May and open water conditions are seen in mid- to late June. The rivers freeze between September and the end of November (Steffen, Robertson and Kirsten, 1992a).

Precipitation: The N.W.T. experiences relatively low rates of precipitation, which generally occurs in the temperate months. The mean annual precipitation is approximately 100 mm for the entire territory (Department of Environment, 1990). In the arctic region, annual snowfall is normally less than 75 cm with only an additional 12-15 cm of rain during June, July and August (GNWT, 1993). Interestingly, the Arctic Archipelago is one of the driest regions in the world.

Precipitation in the subarctic region usually occurs in the summer months and total precipitation in lower latitude areas is greater than precipitation in northern regions as seen in Table 2.2. The total mean annual precipitation for all the N.W.T. between 1951 and 1980 ranged from 100 to 500 mm (Figure 2.8).

Although these precipitation rates are low, surface water is widely distributed as a result of several factors including moderate topography, a "perched water table" on permafrost and low evaporation rates. Furthermore, with longer periods of daylight and markedly increased solar insolation, spring floods occur in a short time period (Woo, 1993). Climatic factors such as extremely low temperatures and an intense frost period can prove to be a serious constraint to northern mining development (Steffen, Robertson and Kirsten, 1992b). Even so, mines have overcome these limitations, but only at an increased cost of operations.

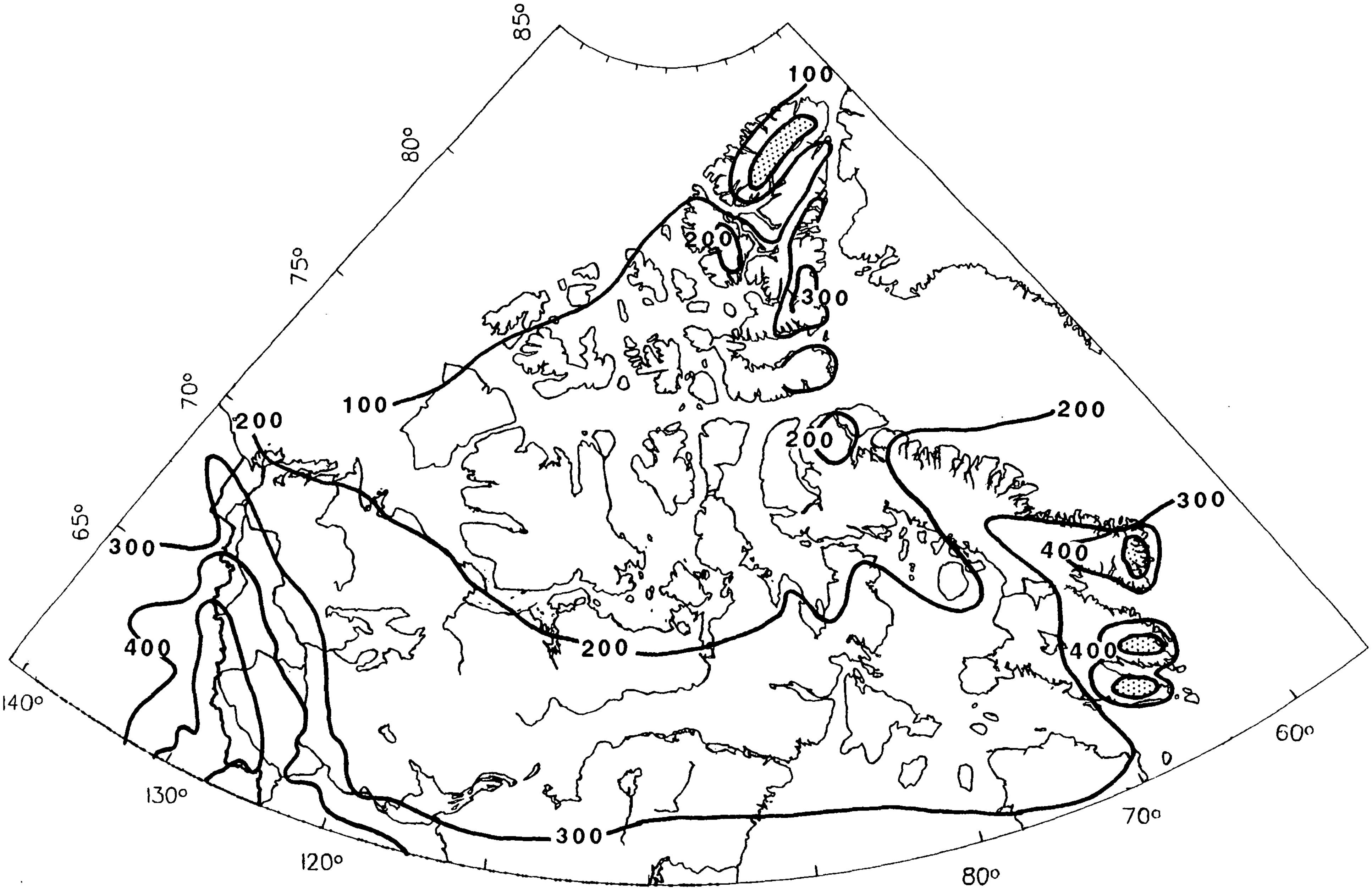


FIGURE 2.8

MEAN ANNUAL TOTAL PRECIPITATION (MM) 1951-1980

2.5 Flora and Fauna

Because of its large and diverse land mass, many species of arctic flora and fauna are found in the N.W.T.. As expected, many of these species are restricted to specific habitats. The following discussion describes briefly the main flora and fauna of the N.W.T..

Flora: Three primary vegetation zones or ecotones exist in the N.W.T.: the arctic tundra; the subarctic forest tundra; and the taiga or boreal forest (GNWT, 1987). Vegetation in the Arctic tundra, or the land above the treeline, is affected by cold temperatures for most of the year, the presence of permafrost and generally poor soils, long summer days, strong winds and low nitrogen supply (Baird, 1976). The dense, low plants common in this region exhibit many arctic floral adaptive features such as shallow root systems, new growth sprouting from existing stems and root systems, hairy stems and woolly seed covers, dark pigmentation to absorb solar radiation and the requirement of 24 hours of summer sunlight for reproduction (Baird, 1976; GNWT, 1987). Examples are bearberry (*Arctostaphylos uva-ursi*), labrador tea (*Ledum palustre*), cotton grass (*Eriophorum scheuchzeri Hoppe*) and mountain avens (*Dryas octopetala*).

The subarctic forest tundra is a transition zone dominated by scattered coniferous trees and shrubs combined with tundra foliage (GNWT, 1987). Because of cold temperatures and low rates of precipitation, plants in this zone are typically stunted. Predominant species are spruce, larch and white birch. Other minor species such as lodgepole pine, alpine fir and jack pine are restricted to the Mackenzie River Valley (GNWT, 1987). Peat bogs and moss are also abundant in this zone, which can be attributed to cold climate, discontinuous permafrost and poor drainage (Outcrop, 1990).

The taiga or boreal forest occurs in discontinuous permafrost areas at southern latitudes with species ranging from lichens, feather mosses and berries to a number of coniferous and deciduous trees (Outcrop, 1990).

Fauna: Northern fauna, as compared to southern fauna, has some unique characteristics. Insects generally follow the northern vegetation patterns and no northern species carries human disease (Outcrop, 1990). Also, certain insect species are abnormally populous, for example, blackflies (Department of Environment, 1991b).

Reptiles and amphibians are scarce throughout most of the mainland of the N.W.T. and do not exist in the Arctic Islands (Ray and McCormick, 1981). Their distribution is significantly limited by colder northern temperatures, unsuitable habitat and short length of the summer season (Outcrop, 1984). Garter snakes are the only reptiles found in subarctic N.W.T. and they have special adaptations to these colder climates by giving birth to live offspring rather than by laying eggs (Outcrop, 1984). Amphibians in the N.W.T. are also northern-adapted in that they tend to remain active during the warm, bright summer days rather than cool nights in southern latitudes (Outcrop, 1990). Their eggs are laid in submerged masses to avoid surface freezing and they are larger and darker to increase absorption of radiant energy. There are no uniquely northern species of reptiles or amphibians.

Generally, there are relatively fewer fish species in the N.W.T. compared to southern latitudes and because of long periods of ice cover, reduced sunlight and nutrient-poor waters, these northern species are characterized as slow growing (Outcrop, 1984). The key fish species are arctic char, dolly varden and lake trout in the *Salmonidae family*; great northern pike (*Esocidae*); arctic grayling (*Thymallide*); whitefish, inconnu and shallowwater cisco (*Coregonidae*); yellow walleye (*Parched*); and burbot (*Lota lota*). All fish are widely distributed across the N.W.T. although species such as char are almost an exclusively northern fish ranging from Baffin Island to the Yukon coast (Outcrop, 1984). Fish are a critical component of traditional diets in the north, and there are important domestic, commercial and sport fish industries in the N.W.T..

Marine mammals are abundant throughout the N.W.T. and some varieties include seals, walrus and whales. The most abundant and widespread marine mammal is the seal. Five species of true seals exist in the N.W.T.: ringed seal, which is the most common seal species; harp seal;

bearded seal; harbour seal; and hooded seal. Seals are found throughout the N.W.T. and they are a dietary staple in most coastal communities. (GNWT, 1992b).

The Atlantic walrus is restricted to the waters of the eastern Arctic. These large animals may grow to 3.6 metres in length and 1,400 kilograms in weight with a main staple of bivalve mollusca (GNWT, 1991d). There has been a significant decrease in the walrus population over the last decade, but they are not yet threatened to the point of endangerment.

Four species of whales are found in Arctic waters. They are the bowhead, beluga, narwhal and killer whale (GNWT, 1988). Bowhead whales are found throughout northern coastal waters including the Beaufort Sea, Amundsen Gulf and Bering Sea in the west and Lancaster Sound, Davis Strait and northern Hudson Bay in the eastern Arctic. Because bowhead whales are considered an endangered species, they are not hunted.

Beluga whales are also widespread in the N.W.T. and are found in Lancaster Sound in the east, Ungava and Hudson bays in the south and in the Beaufort Sea in the west. The skin and blubber of the beluga are used to make "muktuk," which is considered an arctic delicacy. Narwhals are restricted to Lancaster Sound and areas off the northeast coast of Baffin Island. Their tusks are valued by local carvers. The killer whale, which is a natural predator of the beluga whale and narwhal, is restricted to the eastern Arctic where it ranges from Davis Strait to Lancaster Sound, and in Hudson Bay.

The arctic area of the N.W.T. is home to 49 species of shorebirds that migrate from distant regions to breed. Some of these shorebirds include plovers, sandpipers and turnstones. The greater snow goose, the lesser snow goose and the Canada goose are some of the species of geese that also breed in the Arctic. These populations have shown an increase in the last 40 years (Department of Environment, 1991b).

In the arctic zone, the Barren ground caribou population appears to be stable or increasing. Also, approximately 85 percent of all wood bison are thriving in the Mackenzie Bison Sanctuary of the Northwest Territories. (Department of Environment Canada, 1991b). Endangered species, however, include the Eskimo curlew and the Peary caribou of the High Arctic and Banks Island. These populations have declined as a result of excessive hunting, habitat destruction and extreme climatic stresses (Department of Environment, 1991b).

Black and grizzly bears are located in the boreal forests and further north, and still inhabit their "historic range." Their population appears to be stable or increasing due to their adaptability (Department of Environment, 1991b). There are four unique populations of grizzlies in the N.W.T.: arctic coastal grizzlies; arctic mountain grizzlies; Barren ground grizzlies; and the northern interior grizzlies. Grizzlies generally favour open or partly forested regions and they are found in alpine and subalpine territory, or on the tundra area. They are sometimes found in the boreal forest region (GNWT, 1991b).

Polar bears are the largest members of the bear family; males may weigh up to 500-600 kilograms. They are found as far north as 88°N and travel as far south as the Gulf of St. Lawrence southern boundary. These bears usually dwell near the coast and in areas of seasonally broken ice (GNWT, 1991c).

Arctic fox are widespread throughout the arctic tundra of the N.W.T. as well as the Arctic Islands and they move over the polar ice cap. The southern limit of the arctic fox is the tree line, but there is evidence of foxes entering the boreal forest when food is low. The red fox, however, is found below the tree line with a feeding range of three to 25 square kilometres (GNWT, 1991a).

Wolves in the region live mostly on the mainland where caribou reside, while smaller populations live in the Arctic Islands. Hunting of wolves is limited to the winter to safeguard the wolf population when the pups are being nurtured or when the fur is not yet of fine quality (GNWT, 1991e).

Other terrestrial mammals such as shrews, hares and mice are found throughout the N.W.T. but generally below the tree line. Beavers, though, are found beyond the tree line and the Mackenzie Delta (Outcrop, 1990).

The N.W.T. has little biological diversity because of the severity of the climate, which means that the ecosystem is highly sensitive to changes in the environment. An ecosystem approach to resources management and development will help sustain the flora and fauna that exist at present.

2.6 Summary

The N.W.T. is as complex as it is large. It contains a wide range of rich geological environments and particularly northern physiographic features and environmental conditions that produce a unique ecosystem. An important consideration in any discussion of these ecosystems is the joint reliance of industry and traditional users on these natural resources, whether it be subsurface mineral deposits or subsistence fisheries in important river systems. While mineral resources seem widespread in range and economic potential, so do the floral and faunal resources that are the life blood for northerners.

3.0 THE YUKON ENVIRONMENT

Yukon comprises a land mass of 482,515 square kilometres and is described as a rugged land of plateaus and mountain ranges (DIAND, 1971). Steeped in myths and legends about explorers, traders, gold miners and native ancestors, the beauty and extremes of the Yukon environment are common themes. Yukon is bounded by the Beaufort Sea in the north, the province of British Columbia and the Alaska Panhandle in the south, the Northwest Territories to the east and Alaska to the west (Outcrop, 1986).

Compared to the rest of Canada, which has a steady population growth rate, the Yukon population has seen wide shifts in population and growth rate that are linked to resource developments such as the Klondike Gold Rush, the building of the Alaska Highway during World War II and, more recently, increased mineral exploration and development (Outcrop, 1986). In 1994, Yukon's population was 31,197, of which the majority are English-speaking, non-Native residents (Government of Yukon, 1994). Whitehorse, the territorial capital, is the largest centre with a population of 22,768 people.

3.1 Physiography

Three physiographic regions are described for Yukon: the Cordilleran region; the Interior Plains region; and the Arctic Coastal region (Bostock, 1981; Outcrop, 1986). As shown in Figure 3.1, within these three main regions are 25 sub-regions (Outcrop, 1986). The Cordilleran region encompasses almost all of the territory and is composed of numerous mountain ranges and plateaus and major faults or trenches. The St. Elias Range in the southwest corner of Yukon contains some of the most massive mountains in the world (Bostock, 1976; Demuth, 1992). At 5,959 metres in height, Mount Logan is Canada's highest mountain and the second highest in North America. Only Alaska's Mount McKinley, which is also in the St. Elias Range, is taller at 6,193 metres high. Not only are these mountains the tallest on the continent, but they are also the youngest with some rocks formed during the late Tertiary Period. The Ice Field Ranges in this region also have a number of unique physiographic features including surging glaciers, glacier-dammed lakes and flow-reversed rivers (Demuth, 1992; Johnson, 1990).

PHYSIOGRAPHIC REGIONS OF THE YUKON

CORDILLERAN REGION

1. Ice Field Ranges
2. Kluane Ranges
3. Shakwak Trench
4. Yukon Plateau
5. Pelly Mountains
6. Cassiar Mountains
7. Tintina Trench
8. Ogilvie Mountains
9. Coast Mountains
10. Selwyn Mountains
11. Liard Plain
12. Hyland Plateau
13. Liard Plateau
14. Mackenzie Mountains
15. Wernecke Mountains
16. Taiga Ranges
17. Porcupine Plateau
18. Porcupine Ranges
19. Eagle Plain
20. Richardson Mountains
21. Old Crow Range
22. Old Crow Plain
23. British Mountains

INTERIOR PLAINS REGION

Peel Plateau

ARCTIC COASTAL PLAIN

Yukon Coastal Plain

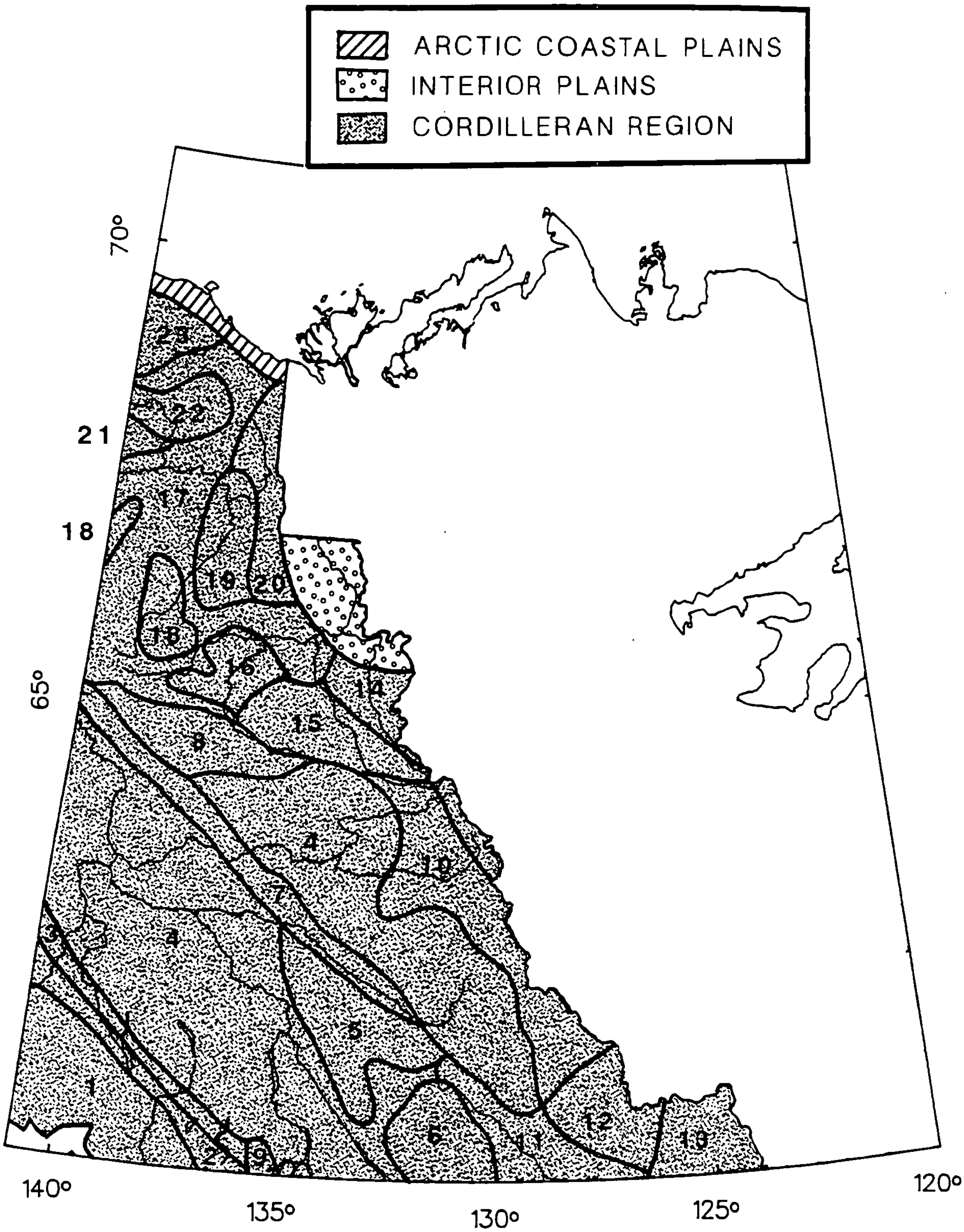


FIGURE 3.1
PHYSIOGRAPHIC REGIONS OF YUKON

Northeast of the Ice Field Ranges, and separated by the Shakwak Trench, is the largest physiographic sub-region in Yukon, the Interior Plains. The second major fault in Yukon, the Tintina Fault, also crosses this massive plateau. To the east, the plateau is bordered by the Selwyn and Mackenzie Mountains, which form Yukon's eastern boundary with the Northwest Territories. The British, Porcupine, Richardson and Wernecke mountains border the plateau on the north.

The Coast and St. Elias mountains within the Cordilleran region provide a western barrier to the maritime influences from the Pacific Ocean; similarly, the Mackenzie Mountains form a barrier on the east, toward the N.W.T. Other important mountain ranges in this physiographic region include the Ogilvie Mountains in north central Yukon and the Selwyn Mountains in the east. Coastal plains are found in the extreme north, and perhaps the most significant physiographic feature is the Yukon Interior Plateau that cuts through the mountain systems.

Beyond these mountain ranges are the two other main physiographic regions in Yukon although these are considerably smaller than the Cordilleran region. The Peel Plateau is the only Yukon sub-region in the Interior Plains region and the Yukon Coastal Plain is the only sub-region in the Arctic Coastal Plain.

Yukon's topography was formed as a result of erosion, glaciation, solifluction, and aeolian and volcanic ash. During the last ice age, ice masses that covered the southern and eastern Yukon shaped the landscape. The vast areas in the northwestern part of the territory that were not glaciated during the Pleistocene Epoch as a result of the rainshadow effect of the St. Elias Mountains are a distinctive feature of Yukon's physiography. As stated by Bostock (1981), these areas give a unique indication of the character of the Cordillera plateau before the Pleistocene glaciation. Topography was generally shaped by normal sub-aerial erosion processes at northern latitudes, natural weathering of local bedrock, and aeolian and fluvial erosion and deposition (Oswald and Senyk, 1977). Perhaps the best example of these unglaciated areas is the Klondike River in the Yukon Plateau. Here, placer gold deposits of the Klondike survived because they escaped the geomorphic action of the continental glaciers.

3.2 Geology

Geologically, Yukon is located almost exclusively in the Canadian Cordillera, a mountainous belt of metamorphosed sedimentary and volcanic rocks (Bostock, 1981). The Cordillera is divided into three systems, all present in Yukon (Figure 3.2). The eastern system is further subdivided into three areas that include the Richardson Mountains and Porcupine Plateau of the Porcupine area; the Taiga Ranges and Wernecke Mountains, Mackenzie Mountains, Mackenzie Plain, Franklin Mountains and Liard Plateau of the Mackenzie Mountain area; and the relatively small Rocky Mountain area, which extends from the Liard River to 49°N. The eastern system is composed primarily of folded sedimentary rocks.

The western system, which is dominated by intrusive rocks, is the smallest portion of the Cordillera in Yukon. This area contain two large geologic areas, the Coast Mountain area and the Outer Mountain and Coastal Lowlands area. The Coast Mountain area comprises two great mountain groups -- the Coast and Cascade Mountains -- although only the Boundary Ranges of the Coast Mountains are in Yukon. Within the Outer Mountain area, however, rise the St. Elias Mountains, one of the great mountain belts in the world (Bostock, 1981).

Between the eastern and western systems lies an interior system composed of a complex mixture of volcanic, sedimentary and metamorphic rocks, as well as outcroppings of intrusive rock (Oswald and Senyk, 1977). The main geologic areas of this system are the Brooks Range area that includes the British Mountains and Old Crow Range; the Northern Plateau and Mountain Area that includes the Ogilvie and Selwyn mountains and the Yukon and Hyland plateaus; and the smaller Central Plateau and Mountain Area, which within Yukon, is a southern continuation of the Yukon Plateau (Bostock, 1981).

Despite Yukon's many distinctive features and geologic complexity, its stratigraphies are similar to the Cordillera as a whole. The Yukon mountain chain, which possesses an eastern and western part, has two different stratigraphies: the eastern part is the old edge of the North American continent and the southwestern half is formed of rocks from a Palaeozoic ocean. These two plates collided 180 million years ago and are joined at the Teslin Suture, a line

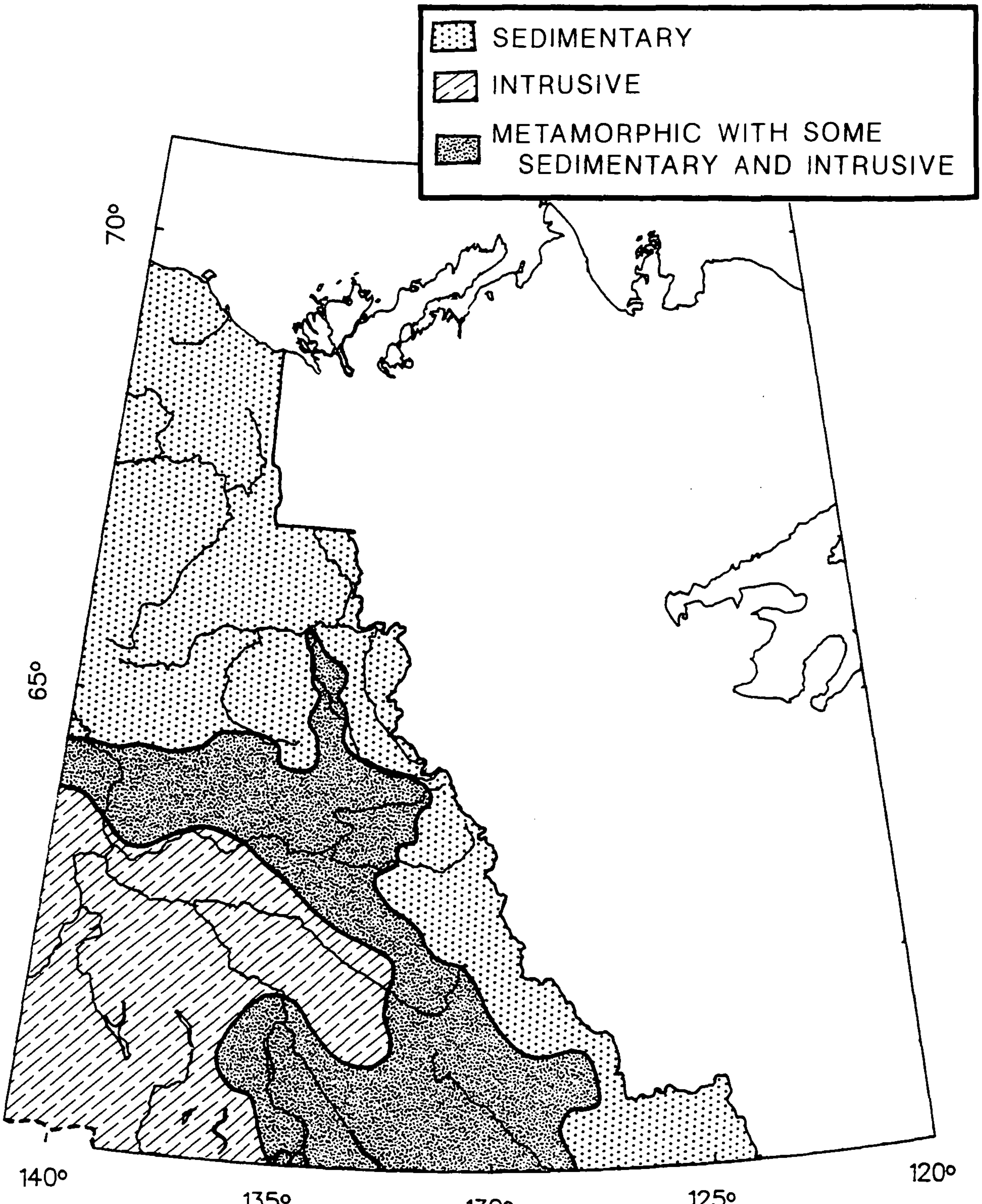


FIGURE 3.2

GENERALIZED GEOLOGY OF YUKON

extending northwest and southeast of Teslin Lake. Two other major tectonic features are the 450-kilometre Tintina Fault, which extends from a point 200 kilometres west of the Alaska-Yukon border southeasterly across Yukon to Watson Lake, continuing in British Columbia as the Rocky Mountain Trench, and the 2,200-kilometre Denali Fault that starts in the south-eastern Alaska Panhandle and runs through southwestern Yukon and into Alaska (Outcrop, 1986). The northern coast of Yukon is a western extension of the Arctic Coastal Plain. This continental shelf is composed of fine-grained sediments and volcanics deposited in recent geologic time and still accumulating (Wahl et al, 1987).

There are many mineral occurrences in Yukon including world-class deposits of silver, lead and zinc at Faro and Howard's Pass, tungsten and molybdenum at Mactung and Red Mountains, silver and lead at Elsa and Rancheria and gold at Mount Skukum, Ketza River and the Dawson Range (Outcrop, 1986). There are also a number of minor occurrences of barite, copper, coal, uranium, iron, nickel, platinum and oil and gas. None of these mines is current producing. Further details of Yukon's mineral development are found in Section 4 of this report.

3.3 Hydrology

Yukon has six major drainage basins: the Yukon; the Peel; the Porcupine; the Liard; the Alsek; and the North Slope. The largest river system is the Yukon River, which rises in northern British Columbia and flows for a distance of more than 3,185 kilometres (Outcrop, 1986). The river drains 287,000 square kilometres, or 54 percent, of Yukon, flowing to the northwest before crossings into Alaska and eventually emptying into the Bering Sea (Oswald and Senyk, 1977). Major tributaries of this river are the White, Donjek, Nordenskiold, Takhini, Teslin, Nisling, Pelly, MacMillan, Stewart and Klondike rivers. The mean annual discharge for the Yukon River at Eagle is 2,460 cubic metres per second (Department of Environment, 1991a).

The second largest drainage basin is the Peel River watershed, which drains an area of 67,580 square kilometres, or 14 percent, of Yukon. It includes the main part of the Wernecke Mountains and portions of the Ogilvie and Richardson mountains. The main tributaries of the Peel River are the Ogilvie, Blackstone, Hart, Wind, Bonnet Plume, Snake and Vittekwa rivers.

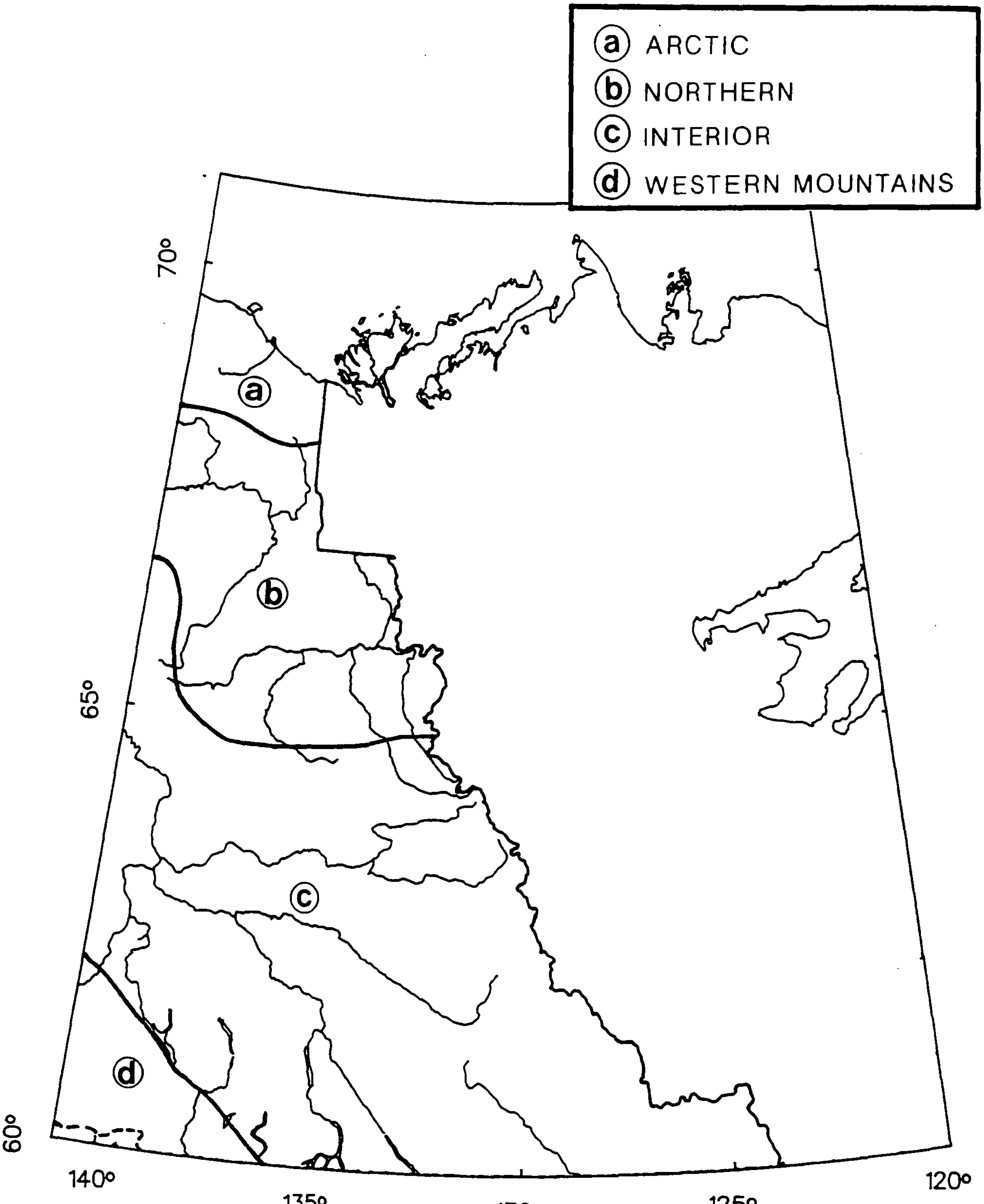


FIGURE 3.3

HYDROLOGIC REGIONS OF YUKON

These rivers are all part of the Mackenzie River Basin.

The Porcupine River, another major watershed that is actually a sub-basin of the Yukon River system, drains 57,922 square kilometres or 12 percent of Yukon. Parts of the British, Richardson and Ogilvie mountains are drained by the Porcupine River, which meets the Yukon River at Fort Yukon, Alaska. Major tributaries of the Porcupine River include the Eagle, Rock, Whitestone, Miner, Bluefish, Bell and Old Crow rivers.

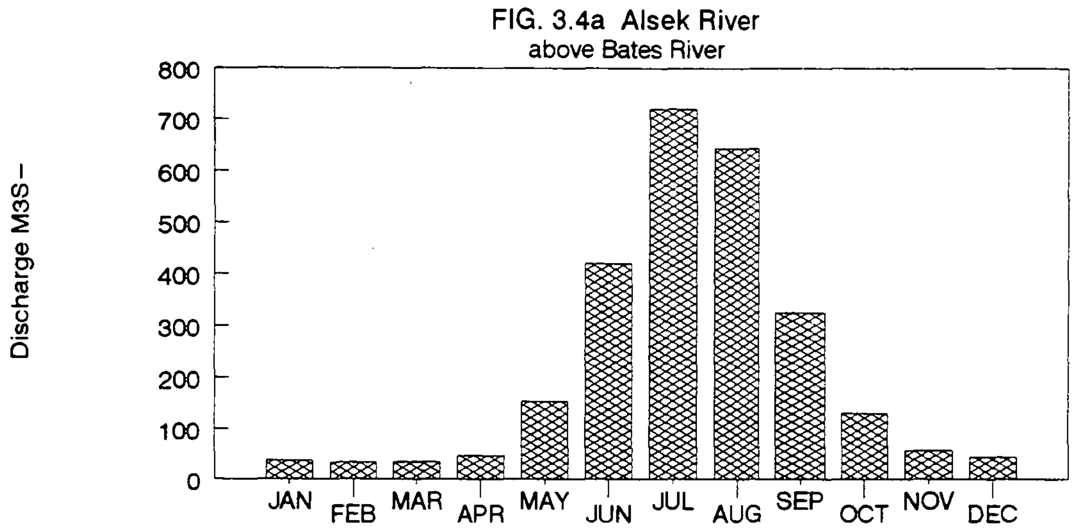
The Liard River, which is an important tributary to the Mackenzie River, rises in the southeast corner of Yukon and drains south through British Columbia before turning north at Fort Nelson to flow through the N.W.T. to meet the Mackenzie River at Fort Simpson. Similar in size to the Porcupine River watershed, with a drainage basin of 57,922 square kilometres, or 12 percent of Yukon, the major tributaries of the Liard River are the Rancheria, Meister, Frances, Hyland, Coal, Rock, Beaver and Labiche rivers (Oswald and Senyk, 1977). The Liard River watershed drains most of the Logan and Cassiar mountains and the southeast portion of the St. Cyr Range.

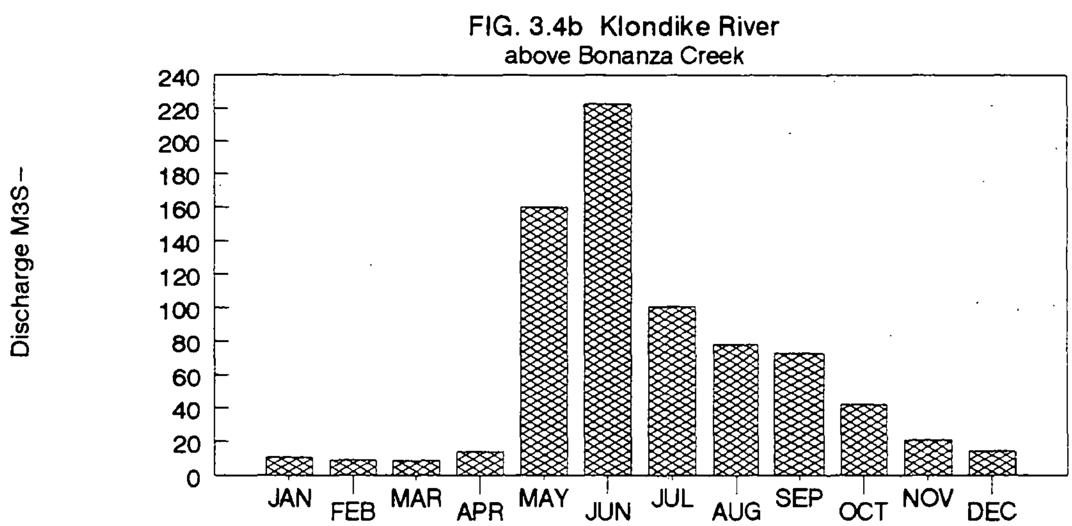
The fifth largest watershed in Yukon is the Alsek in the eastern portion of the St. Elias Mountains and the northwestern part of the Coast Mountains. This basin is the only one in Yukon that drains south to the Gulf of Alaska. Its drainage area is 19,302 square kilometres, or four percent, of Yukon (Oswald and Senyk, 1977). The major tributaries of the Alsek River are the Aishihik, Dezadeash, Kaskawulsh and Dusty rivers.

Finally, the remaining four percent of Yukon, or 19,302 square kilometres, drains north along the North Slope to the Beaufort Sea. Major drainages include the Big Fish, Blow, Babbage, Firth and Malcolm rivers.

Streamflow in any area is affected primarily by climatic or physical variables such as precipitation, snow water equivalent of snowpacks, temperature, evaporation, watershed area, slope, soil type and vegetation (Janowicz, 1989). Using the stream slope variable, Janowicz (1989) defines two hydrologic regions in Yukon south of the Ogilvie Mountains: the Western

Figure 3.4 Mean Monthly Discharges for Select Yukon Streams





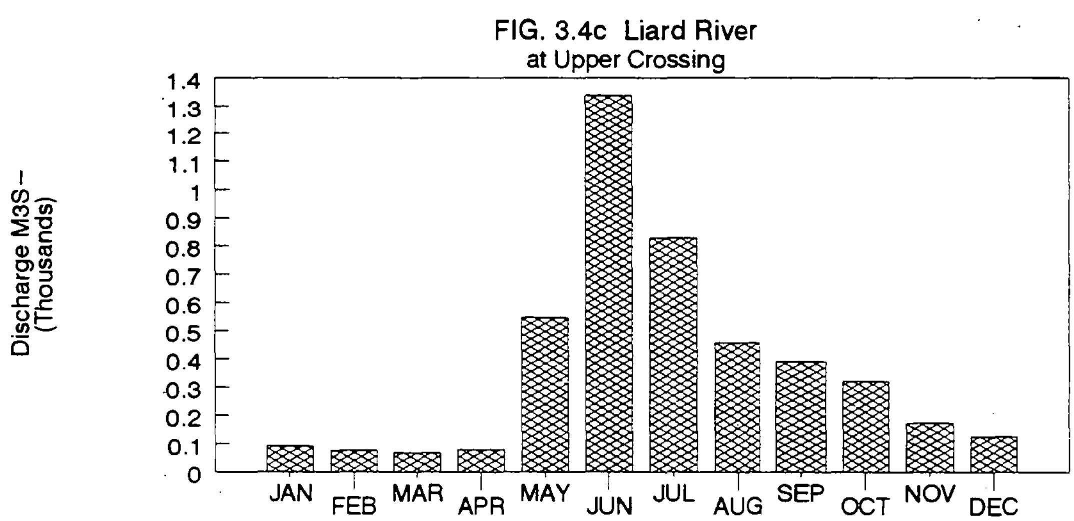
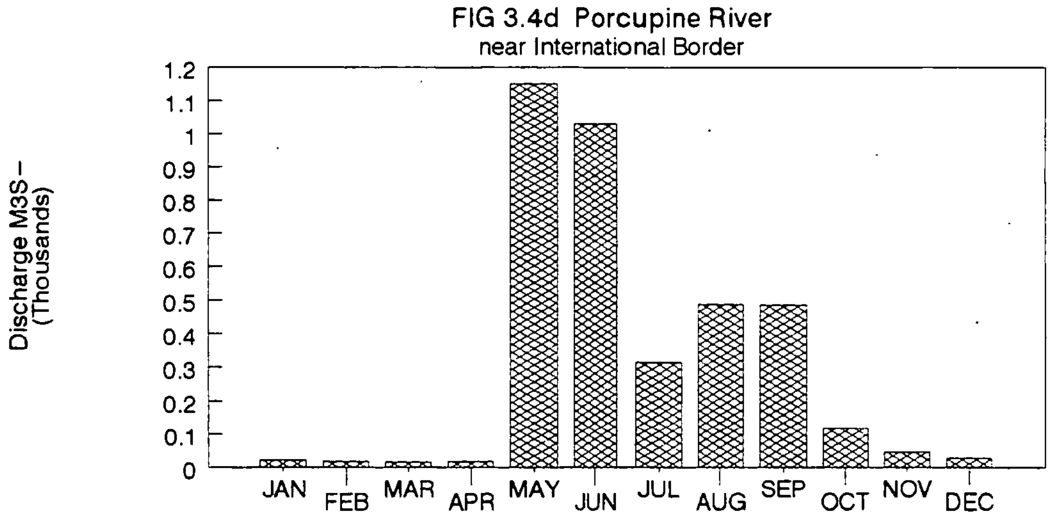
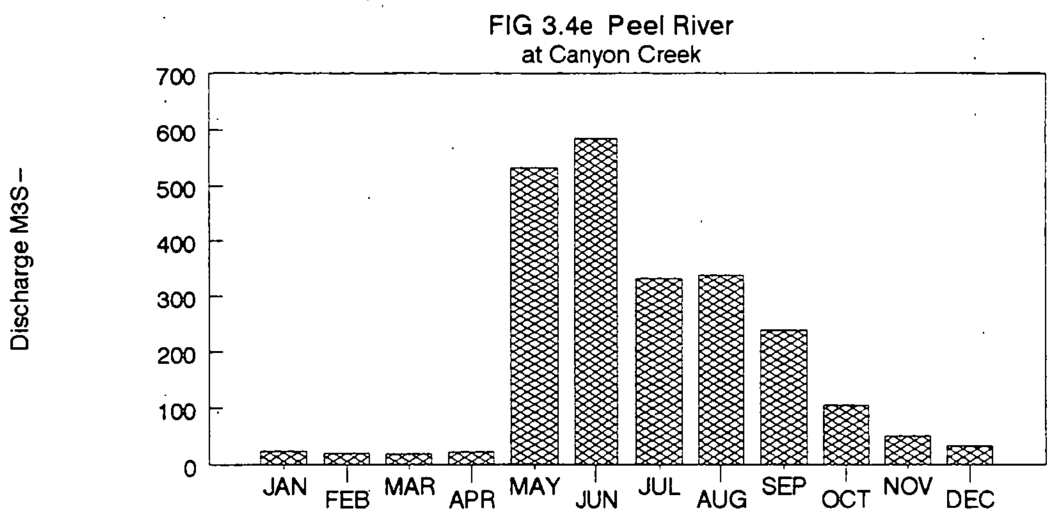
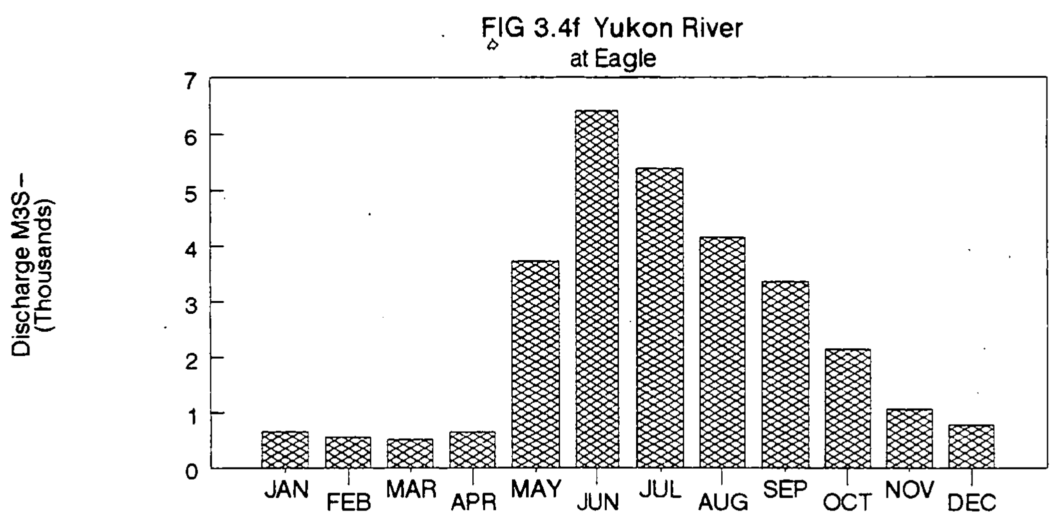


FIGURE 3.4 Mean Monthly Discharges for Select Yukon Streams







Source: *Historical Streamflow Summary: Yukon and Northwest Territories to 1990*, Department of Environment (1991a)

Mountain region and the Interior region. North of the Ogilvie Mountains, two other regions are identified: the Arctic or North Slope region and the Northern region (Figure 3.3). Streamflow data and hydrographs for select Yukon streams are shown in Table 3.1 and Figure 3.4.

Table 3.1 Historical Streamflow Data for Select Yukon Streams to 1990

River	Drainage Area (km^2)	Mean Annual (m^3s^-)	Maximum Daily (m^3s^-)	Minimum Daily (m^3s^-)
Alsek River above Bates River	16,200	270	1,170	35.1
Klondike River above Bonanza Creek	7,800	74.1	436	7 000
Liard River at Upper Crossing	33,400	360	2,700	62.1
Porcupine River near International Border	59,000	337	4,740	13.3
Peel River at Canyon Creek	25,700	189	1,300	18.7
Yukon River at Eagle	294,000	2,610	7,990	481

Source: *Historical Streamflow Summary: Yukon and Northwest Territories to 1990*
Department of Environment (1991a)

Permafrost plays an important role in the northern hydrologic regime by increasing runoff peaks and decreasing base flows (Woo, 1990). The combination of permafrost, steep slopes and glacier meltwater can be readily seem in the hydrographs in Figure 3.4. Yukon has continuous permafrost in the Arctic region as well as in the high elevations of the southwestern mountains (Figure 3.5). Frequent discontinuous permafrost is found in central Yukon, and widely scattered discontinuous permafrost in southern Yukon (Oswald and Senyk, 1977). The active layer above the permafrost yields groundwater supplies seasonally for municipal water use. Over 60 percent all Yukoners rely on groundwater for municipal and household water supplies (Prowse, 1990).

3.4 Climate

The Yukon climate is classified as subarctic continental with long, cold winters and short, warm summers characterized by large daily and day-to-day ranges of temperature, low relative humidity and irregular, low-to-moderate precipitation (Wahl and Goos, 1987). The climate is harsh and variable due to many complex geographic and physiographic factors. Mountainous conditions cause variations in temperature and precipitation throughout the territory. There are severe cold spells brought about by air masses from the Arctic Ocean, however, southeastern Yukon, because of its proximity to the Pacific Ocean, has frequent mild spells.

The mean annual temperature for all Yukon is below zero degrees celsius (Figure 3.6). Daily temperatures can fluctuate widely, thus, summer frosts and winter thaws are common. Most areas in Yukon have a frost-free period of between 40-60 days in the northern and elevated regions, and between 75-95 days in southern and central regions (Wahl and Goos, 1987). Climate data for select Yukon municipalities are presented in Table 3.2.

Precipitation in Yukon varies significantly from north to south and with elevation (Figure 3.7). Western and southern slopes of the major mountain barriers receive the most precipitation, while the northern and eastern faces are arid. Precipitation is generally low, ranging from 225 to 425 mm per year, although parts of the St. Elias and Coast mountains can receive as much as 3,500 mm per year (Oswald and Senyk, 1977). The St. Elias and Coastal mountains in southwestern Yukon act as a barrier to the Pacific Ocean influence, which means that southern Yukon receives much less precipitation than west central Yukon. The summer season, from mid-May to early October, has the most precipitation. In the winter, snowfall is heaviest in the St. Elias Mountains, followed by the Liard River valley and the westward slopes of the Selwyn Mountains (Outcrop, 1986).

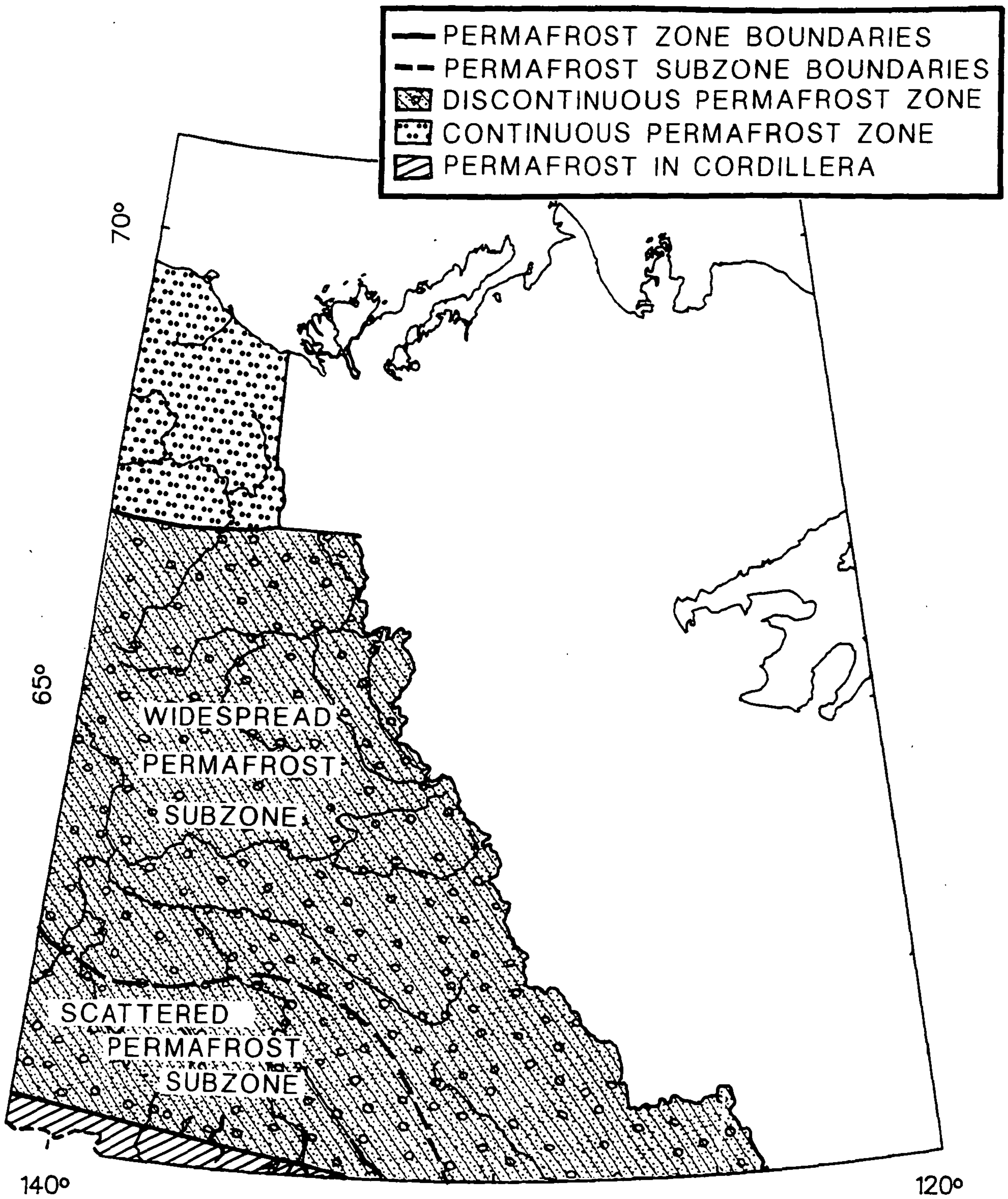


FIGURE 3.5

PERMAFROST ZONES AND SUBZONES OF YUKON

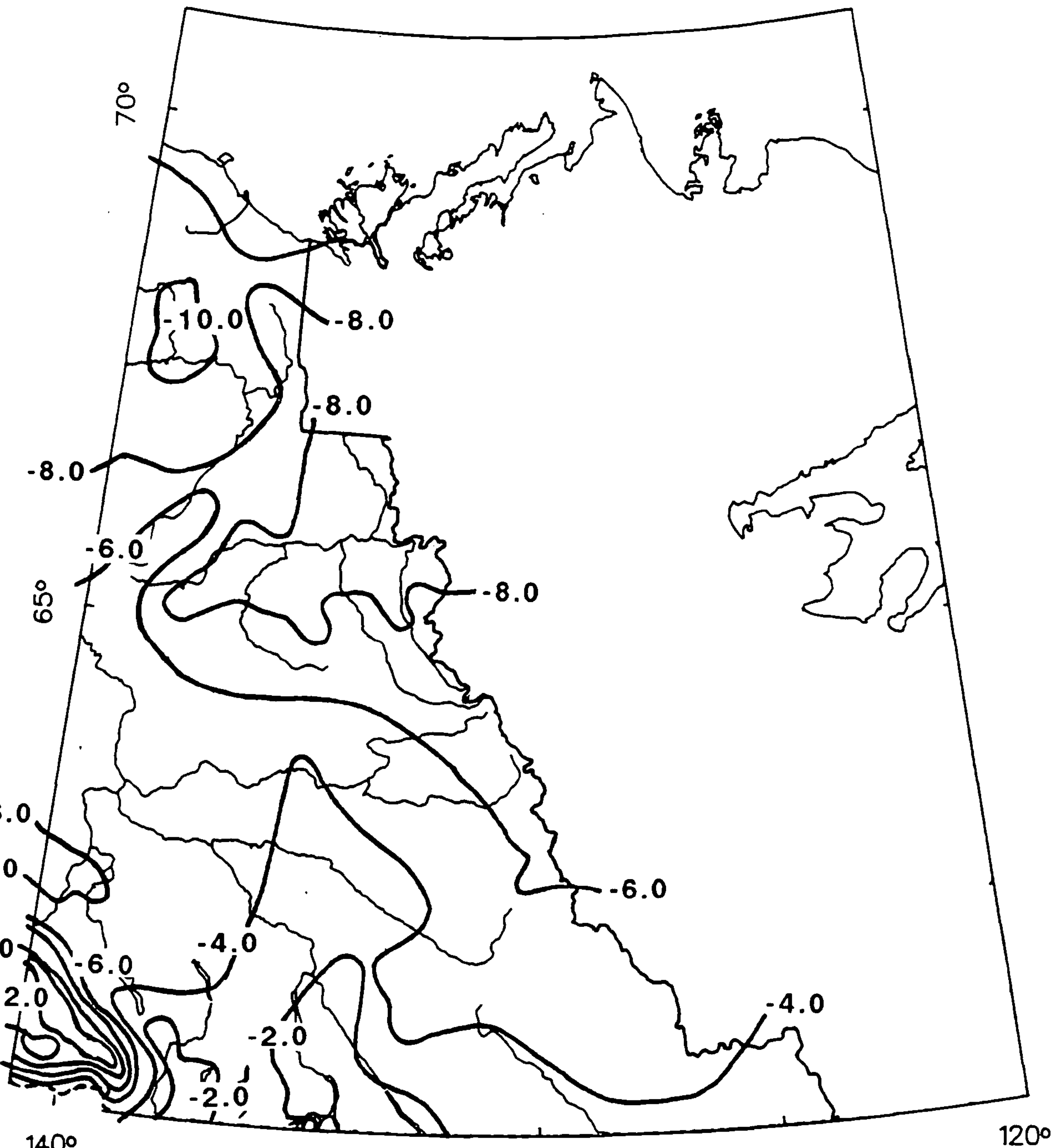


FIGURE 3.6

ANNUAL MEAN DAILY TEMPERATURES (°C)

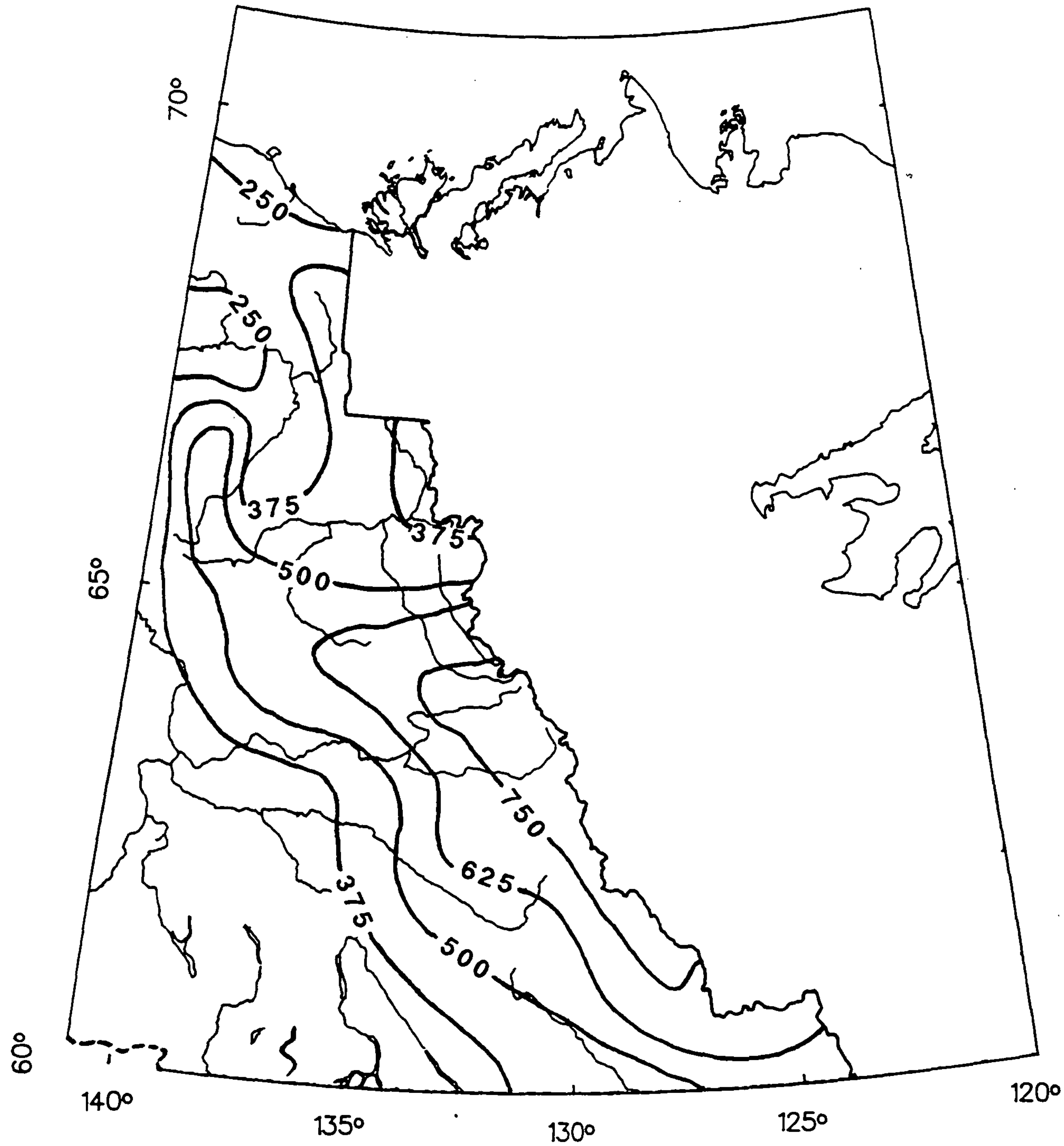


FIGURE 3.7

ANNUAL MEAN PRECIPITATION ISOHYETS (mm)

Table 3.2 Climate Data for Yukon Municipalities

Municipality	Elevation (m)	Temperature (° C) Annual	Temperature (° C) January	Temperature (° C) July	Precipitation (mm) Annual	Precipitation (mm) June-August
Carcross	661	-1	-19	13	226	69
Carmacks	521	-5	-34	14	247	107
Dawson	324	-5	-29	16	325	140
Mayo	495	-4	-27	15	293	117
Ross River	698	-7	-35	13	253	102
Teslin	701	-1	-20	13	326	99
Whitehorse	698	-1	-19	14	260	98

Source: *Ecoregions of the Yukon Territory*, Oswald and Senyk, 1977

3.5 Flora and Fauna

The flora and fauna of Yukon are characteristic of northern latitudes. Species number very few, possess slow growth rates and have adapted to the harsh climate. Vegetation consists primarily of boreal forest, alpine forest and arctic tundra, and it is estimated that over 1,300 plant species exist in Yukon (Government of Yukon, 1992). Trees cover most of the plateaus and valleys up to 1500 metres elevation in southern mountain ranges and up to 450 metres elevation in north Yukon near the Beaufort Sea. Productive forest areas lie south of the Ogilvie and Wernecke mountains and account for over 75,000 square kilometres of inventoried land. Spruce, pine and poplar are the predominant tree species and harvestable resources are concentrated along major river systems. Almost 60 percent of merchantable timber is located in southeast Yukon, east of the Cassiar Range (Outcrop, 1986).

Shrubs occur in the forested areas as well as in the tundra and at higher elevations. Coverage by mosses and lichens, the dominant vegetation in the arctic tundra, increases northward and with increasing elevation. Species such as arctic heath (*Ericacae*), alpine bearberry (*Arctostaphylos alpina*), and Labrador tea (*Ledum palustre*) form a scrubby underbrush, especially on sheltered slopes (Outcrop, 1986). Lichens, sedges and grasses are found in areas of high permafrost. More than 100 species of wildflowers are found throughout Yukon including many alpine varieties such as avens and campions.

Because of mountainous topography and severe and widely variable climate, only small areas along major river valleys and near Watson Lake are suitable for cultivation (Wahl and Goos, 1987). Even so, there are currently 12 agricultural water licenses issued in Yukon (Doering, 1993). Over 7,500 square kilometres of land is considered suitable for agriculture (Government of Yukon, 1992). Agricultural areas for cereals and grains include Dawson, Stewart Crossing, Carmacks, Pelly Crossing and Watson Lake (Outcrop, 1986).

A wide variety of wildlife species are found in Yukon including large mammals, furbearers and bird species. Yukon wildlife and grizzly bears are synonymous. These bears inhabit the entire territory from the British Columbia border to Herschel Island on the Arctic coast and their numbers range from 6,000 to 10,000 animals (Government of Yukon, undated a). Although not as widely distributed, black bears outnumber grizzly bears with an estimated population of 10,000 animals (Government of Yukon, undated b). Polar bears are restricted to the Arctic coast and have an estimated population of only 2,000 animals (Government of Yukon, undated c).

Other important large mammals in Yukon include both Barren-ground and woodland caribou of which the Porcupine herd is the most abundant with a population of 165,000 (Government of Yukon, undated d); moose that inhabit most of the territory but are generally most numerous in the southern regions (Government of Yukon, undated e); and wood bison, which according to archaeological evidence, were once abundant in Yukon but were only recently re-introduced in the Nisling-Aishihik Lake area (Government of Yukon, undated f). Other large mammals include mule deer, thinhorn sheep, mountain goats, and small populations of cougars. Wolves are found throughout Yukon, while the distribution of other animals is limited (Government of Yukon, undated g). Arctic fox, for example, are found only along the Arctic coast and Herschel Island (Government of Yukon, undated h) while mountain goats and both Dall and Stone sheep are restricted to mountainous areas (Government of Yukon, undated i; Government of Yukon, undated j). Although not year-round residents, musk-oxen from the Alaskan Coastal Plain often move into the northeastern corner of Yukon.

A number of small animals are trapped in Yukon and are an important element in Yukon's traditional economy. These include beaver, muskrat, ermine, mink, otter, red fox, coyote, wolf, red squirrel, weasel, fisher, marten, lynx and wolverine. The most widely distributed furbearers are beaver, marten, muskrat, lynx and wolverine (Outcrop, 1986).

Because the Yukon section of Canada's Arctic coast is less than 250 kilometres wide, only a small number of marine mammals occupy this zone. Even so, Herschel Island was once an important whaling settlement during the 19^{th} century. Whales that are found off the Yukon coast include bowhead, beluga and killer whales (Government of Yukon, undated k).

There are over 200 species of birds in Yukon. Nineteen birds of prey, including the endangered peregrine falcon, are found in Yukon. Hawks, owls, bald eagles, golden eagles and gyrfalcons are the most abundant. Upland game birds and waterfowl are also found in large numbers; grouse are the most common game bird in Yukon (Outcrop, 1986). A major waterfowl migration route is located along the Tintina Trench and is used annually by sandhill cranes, swans, geese and a variety of ducks. The Old Crow Flats and the North Slope are major waterfowl breeding, moulting and staging areas.

There are many species of freshwater fish widely distributed in the rivers and lakes of Yukon (Government of Yukon, 1991; Wahl and Goos, 1987). Perhaps the most important species are the salmonids. Species such as sockeye, coho, chinook and chum salmon, rainbow trout and steelhead, and arctic char are found in major Yukon drainages. Other abundant species of fish in Yukon include whitefish, northern pike, arctic grayling, inconnu, burbot, suckers and cisco (Outcrop, 1986). The distribution patterns of many fish species seem to conform to the physiography of major drainage basins, which probably reflects their post-glacial entry to these systems (Lindsey et al, 1981).

3.6 Summary

In summary, Yukon's natural environment is rich and varied. As Coutts (1980) states, Yukon is a hard and demanding country. While Yukon is similar in many respects to the N.W.T. in terms of general climate and flora and fauna, there are marked differences, especially in Yukon's physiography, geology and hydrology. At first glance it may be easy to make generalizations about the similarities of the natural environments of Canada's two northern territories; however, the many important differences make direct comparisons difficult. One common aspect of these natural environments is that they are rich in mineral resources and support healthy and diverse ecosystems. The importance of mineral development in both territories is discussed in the next section.

4.0 MINERAL DEVELOPMENT IN CANADA'S NORTH

Mineral development is the leading industry in Canada's North, accounting for over 30 percent of the value of all goods and services (Brown, 1992). Although only eight percent of the work force is directly employed in mining operations, there are significant benefits to the economy from mineral development activities through transportation, construction and other service sectors. In 1993, the value of metals and construction materials mined in both territories exceeded $520 million. The following section provides a brief overview of mining in the Northwest Territories and Yukon. The Department of Indian Affairs and Northern Development publishes annually, a mines and minerals activities report that provides more in depth information. A series of summary tables is presented to show the extent of mineral development activities in the two territories.

4.1 Mining in the Northwest Territories

The Northwest Territories (N.W.T.) possesses a number of important mineral deposits that are being mined, as well as many other deposits that could possibly be developed (DIAND, 1987). Active mines are lead and zinc at the Polaris Mine on Little Cornwallis Island, zinc, lead and silver at the Nanisivik Mine at Nanisivik, and gold at the Lupin Mine at Contwoyto Lake, the Giant Mine in Yellowknife and the Con Mine in Yellowknife (Brown, 1992). In addition to these active developments, other promising deposits or areas under intensive exploration include gold exploration in the Yellowknife, Coronation Gulf and Keewatin areas, copper, lead and zinc exploration along the boundary between the Bear and Slave structural provinces, and diamond exploration in the Lac de Gras area.

Active and closed mines in the N.W.T. are listed in Appendix A. Figure 4.1 shows mines in theN.W.T. that were in production in 1991: two lead-zinc mines and four gold mines (Brown, 1992). Table 4.1 indicates the production quantities of these active mines. Lead and zinc production accounted for 60 percent of the absolute value of the mineral yield in the N.W.T., while gold accounted for 39 percent. N.W.T.'s mineral production is also important in a

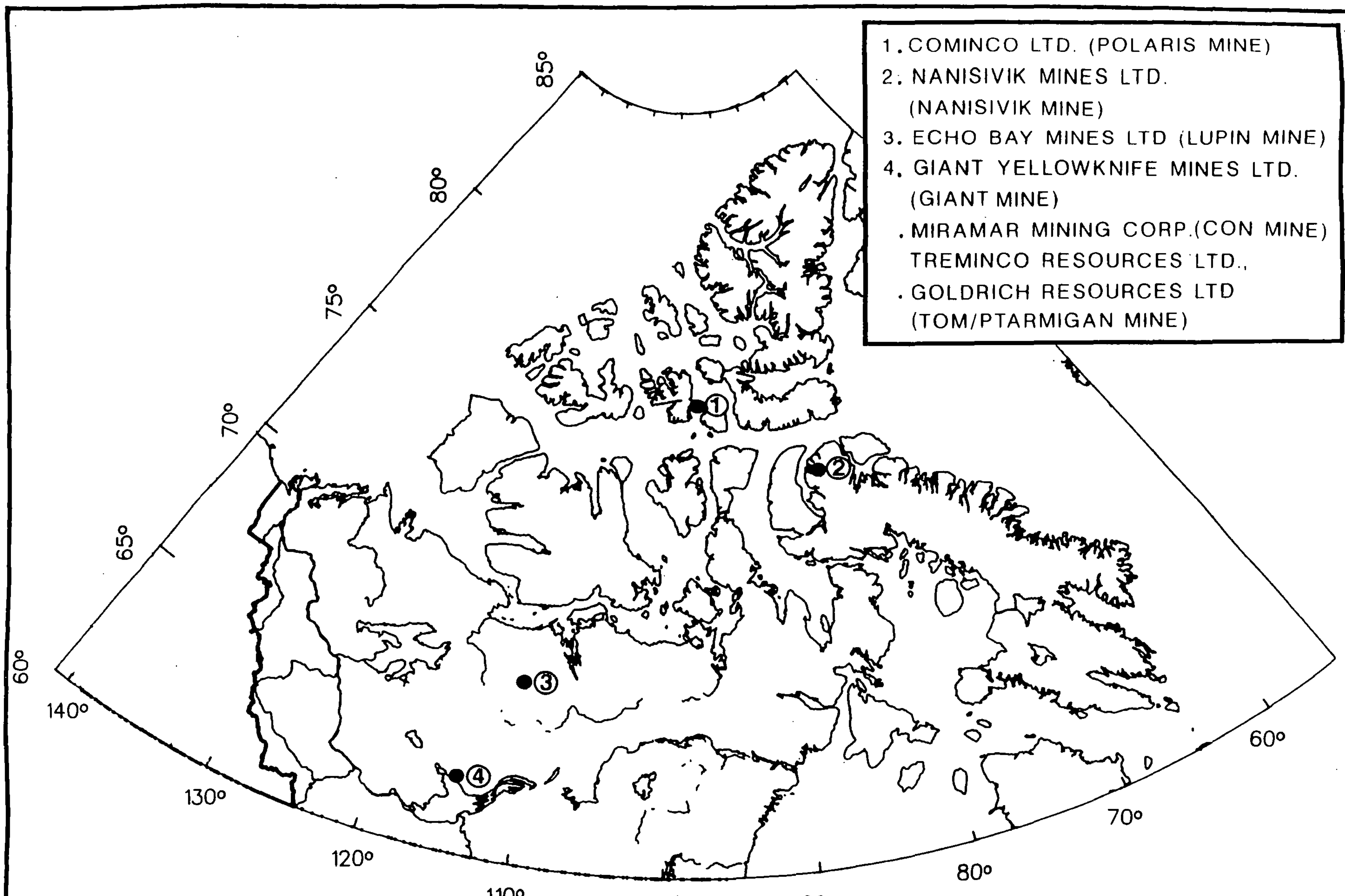


FIGURE 4.1

ACTIVE MINE SITES IN THE NORTHWEST TERRITORIES national context. Of Canada's national mineral production in 1992, the N.W.T. produced 15.2 percent of the zinc, 12.3 percent of the lead and 8.8 percent of the gold. Together, these minerals from the N.W.T. made up 4.66 percent of Canada's metallic mineral production value in 1992, in contrast to 4.56 percent in 1991 (Brown, 1993).

Table 4.1 Mineral Production of Operating Mines, Northwest Territories, 1991

Company, Mine	Commodity	Quantity
Cominco Ltd. Polaris Mine	zinc lead	100,384 tonnes 24,398 tonnes
Echo Bay Mines Ltd. Lupin Mine	gold	6,746 kg
Nanisivik Mines Ltd. Nanisivik Mine	zinc lead silver	54,800 tonnes 400 tonnes 18,500 kg
NERCO Con Mine Ltd. Con Mine	gold silver	3,825 kg N/A
Northwest Gold Corporation Colomac Mine	gold	2,423 kg
Royal Oak Mines Inc. Giant Mine	gold	3,183 kg
Treminco Resources Ltd. Ptarmigan Mine	gold	462 kg

Source: *Mines and Mineral Activities 1991*, DIAND, Ottawa (1992)

The above table does not quite give an accurate picture of mineral development activities in the N.W.T.. In addition to actual mining and milling operations, an important measure of development activity is the number of claims staked annually, the number of prospecting permits issued and their corresponding land surface area, and the metres of diamond drilling (Table 4.2 and 4.3).

Table 4.2 Mineral Claims, Leased Claims and Prospecting Permits, Northwest Territories, 1991 and 1992

	1991	1992
Claims Recorded (hectares)	831 (666,374)	7,913 (7,178,096)
Number of Leased Claims (hectares)	11,396 (277,280)	10,348 (256,824)
Prospecting Permits Issued (hectares)	34 (634,940)	22 (408,115)
Number of Claims and Leases in Good Standing (hectares)	3,859 (2,519,428)	10,974 (9,227,521)
Prospecting Permits in Good Standing (hectares)	91 (1,760,551)	270 (1,322,935)

Source: *Mines and Mineral Activities 1992*, DIAND, Ottawa (Brown, 1993)

Table 4.3 Diamond Drilling Activity, Northwest Territories, 1991 and 1992

	1991	1992
Surface Drilling	110,527	96,098
Underground Drilling	73,347	75,540
Total Drilling	183,874	169,638

Source: *Mines and Mineral Activities 1992*, DIAND, Ottawa (Brown, 1993)

There was a significant increase in the number of mineral claims recorded in 1992 and 1993 compared to the previous years. The increased activity is attributed to the massive diamond staking in the Lac de Gras area. Nine of 12 diamondiferous pipes discovered in this area are located on the BHP Minerals/DiaMet discovery property at Lac de Gras (Brown, 1993). There are accounts of gem quality diamonds of varying sizes and quality. Recent reports indicate that up to 33 percent of the diamonds found in some kimberlites are of gem quality.

In addition to the increased activity in this area, a number of exploration companies have examined known kimberlite diatremes in the Mackenzie Mountains and on Somerset Island. A diamond-bearing kimberlite diatreme was found at Dubawnt Lake in the District of Keewatin. Because of the 1992 diamond discoveries in central Slave Province, it is expected that there will be potential for continuous diamond exploration in the future (Brown, 1993).

4.2 Mining Operations in Yukon

Yukon has a vast wealth of mineral resources. Both hardrock and placer mining have taken place since the turn of the century. Important deposits in Yukon include world-class reserves of silver, lead and zinc at Faro and Howard's Pass, tungsten at MacTung, molybdenum at Red Mountain, silver and lead at Elsa and Rancheria and gold at Mount Skukum, Ketza River and in the Dawson Range (Outcrop, 1986). Today there are few active, operating mines in Yukon; however, there are a number of economically promising hardrock mines including properties at Brewery Creek, Williams Creek and Casino. The only active or recently active hardrock mines in Yukon are Curragh Resources Limited's mines at Faro, Vangorda, Grum and Sa Dena Hes. Together, they produced lead, zinc, silver, and coal. Coal, bismuth, platinum, asbestos and antimony were produced in the past (Appendix A). The 1991 mineral production of Curragh's mines is shown in Table 4.4. Mine sites that were active in 1991 are shown in Figure 4.2.

Yukon mines, like all other, are sensitive to economic conditions and with metal prices and the current trends in price stabilization, there are diminished possibilities for the short term in Yukon. However, there is still considerable mineral claim staking and continuing interest in existing claims as shown in Tables 4.5 and 4.6. Another important measure of mineral development activity is the actual amount of exploration drilling. As seen in Table 4.7, there was active drilling at 11 properties in Yukon in 1992. Drilling increased to 19 properties in 1993 and included most of these listed in Tables 4.7.

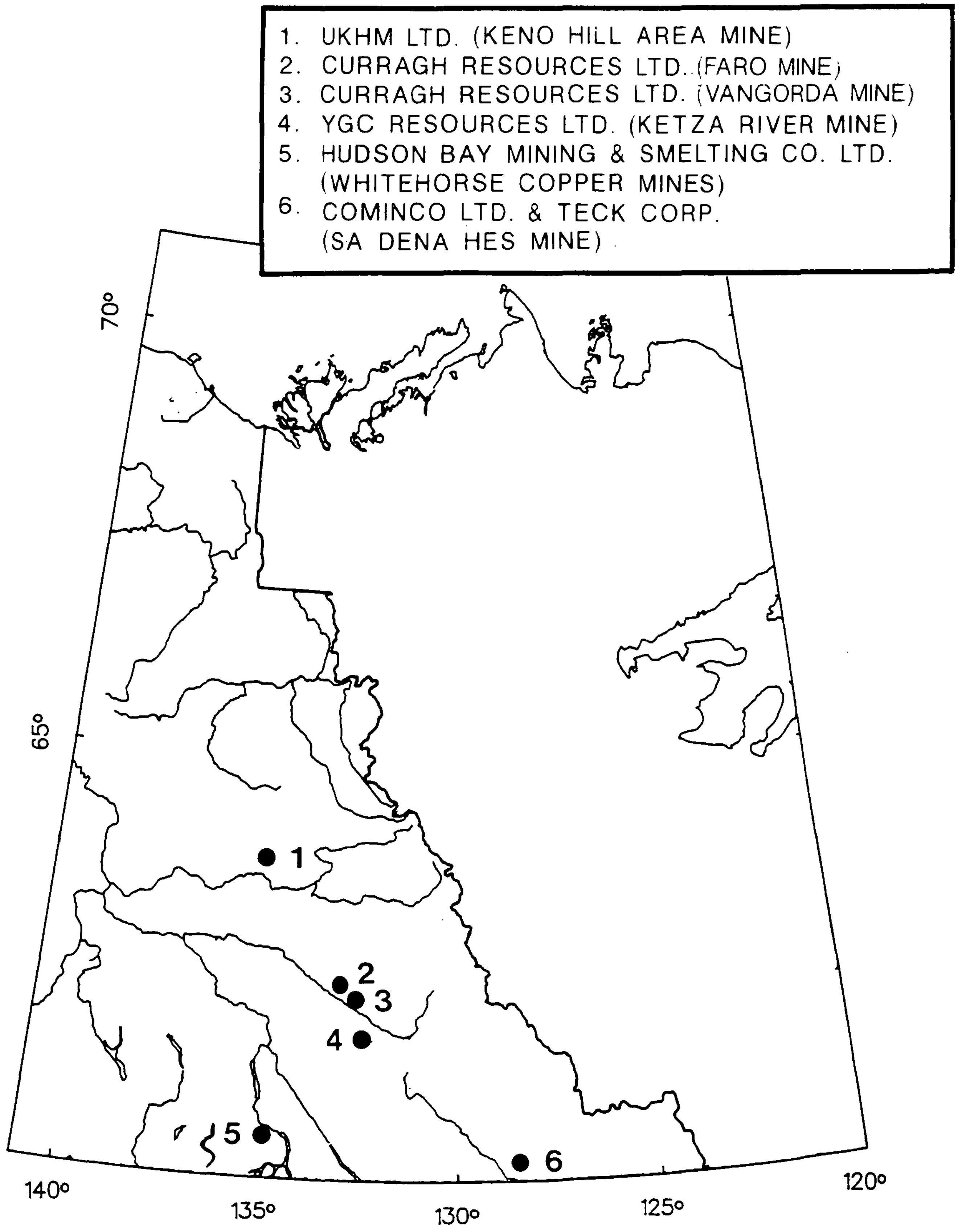


FIGURE 4.2

ACTIVE, RECENTLY CLOSED AND SUSPENDED MINES IN YUKON

Table 4.4 Mineral Production of Operating Mines, Yukon, 1991

Company, Mine	Commodity	Quantity
Curragh Resources Inc.	zinc	135,442 tonnes
Faro, Sa Dena Hes and	lead	31,599 tonnes
Vangorda Mines	silver	N/A

Source: *Mines and Mineral Activities 1991*, DIAND, Ottawa (1992).

Table 4.5 Mineral Dispositions Staked and Lapsed, Yukon, 1991, 1992 and 1993

	1991 Staked (Lapsed)	1992 Staked (Lapsed)	1993 Staked (Lapsed)
Quartz Claims	4,761 (7,658)	4,488 (4,882)	4,963 (7,378)
Placer Claims	1,197 (1,272)	867 (1,534)	1,047 (1,149)
Placer Leases to Prospect	186 (25)	186 (133)	200 (175)

Source: *Mines and Mineral Activities 1992*, DIAND, Ottawa (Brown, 1993),
Mines and Mineral Activities 1993 DIAND, Ottawa (Brown, 1994) and Caine (1994)

Table 4.6 Mineral Dispositions in Good Standing, Yukon, 1991, 1992 and 1993

	1991	1992	1993
Quartz Claims	42,268	43,231	40,231
Placer Claims	17,801	17,115	17,338
Placer Leases to Prospect	251	239	303
Iron and Mica Claims	525	525	525
Coal Leases and Licences	36	36	41
Dredging Leases	7	7	6
Total	60,888	61,153	58,661

Source: *Mines and Mineral Activities 1992*, DIAND, Ottawa (1993) and Caine 1994

Table 4.7 Exploration Drilling, Yukon, 1992

		Diamond Drilling		Percussion Drilling	
Project	Company	Metres (m)	Number of Holes	Metres (m)	Number of Holes
Brewery Creek	Noranda/Loki			1,233	19
Williams Creek	WHC/Thermal	3,781	11	2,805	11
Dublin Gulch	Amax Gold			5,639	46
Clear Lake	Total Energold/ Mitsui Kinzoku	3,100	10		
Clear Creek	Noranda			644	6
Bor	Kennecott	796	5		
Sa Dena Hes	Curragh	16,460	79		
Fin	Cominco	600	6		
Trail Hill	Carmack Gold	623	8		
Casino	Big Creek Resources	4,572	21		
Lone Star	Kennecott	1,212	20		

Source: *Mines and Mineral Activities 1992*, DIAND, Ottawa (1993)

Placer mining still remains active in Yukon, although gold production has declined since 1989 (Latoski, 1993). In 1992, royalties were paid on over 100,000 ounces of crude gold, which was markedly less than the 1989 record production year in which 165,571 crude ounces were recovered. Following this period of declining production from 1990 to 1992, gold production increased to 109,000 ounces of crude gold in 1993 (Caine, 1994). This increase was probably a reflection of a much improved world price for gold of $460 per ounce Canadian in 1993 compared to $395 in 1992 and $416 in 1991. Latoski (1993) states that there was no single reason for the lower production in 1992, but that it can be attributed to the combination of a shorter mining season, declining reserves and lower gold prices. Even so, only 185 placer mines were in operation in 1992 compared to 219 in 1991. The number of water licences issued by the Yukon Territory Water Board were also down from 423 in 1991 to 394 in 1992.

4.3 Summary

The mineral development industry, while long a mainstay of the N.W.T. and Yukon economies, has experienced a slight decline over the last few years, especially in terms of the number of mines operating. To offset this decline, however, there has been renewed interest in base metal exploration in both territories and a significant increase in staking, leasing and drilling in the N.W.T., which can be attributed to the recent surge in diamond exploration. While information has not been presented here to compare the minerals industry to other northern economic development sectors, it is still the leading industry in Canada's North as it has been in the past. And, it has considerable promise for the future.

5.0 POTENTIAL IMPACTS FROM NORTHERN MINERAL DEVELOPMENT

Environmental changes are associated with mineral development activities in the Northwest Territories (N.W.T.) and Yukon. However, the range and severity of these changes have not been fully understood or documented (Kalin, 1987). Moreover, the full impacts are often more complex than first anticipated, particularly with acid rock drainage problems or if impacts are cumulative. While strict limitations on mineral development may be one way to preserve and protect the northern ecosystem absolutely, this approach is unrealistic.

This section describes three broad stages in mineral development and assesses their potential for impacts on the aquatic ecosystem. The three stages of mineral development are exploration, development and operation, and closure and reclamation. The focus of this discussion is on hardrock mining, although it is recognized that there are potential impacts from placer mining operations that are economically significant in Yukon. These potential impacts are discussed thoroughly in the multi-volume report prepared by the Seakem Group for the Yukon Placer Mining Implementation Review Committee (Seakem, 1992), and they will not be repeated here. It can be stated, however, that through the *Yukon Placer Authorization* (Government of Canada, 1993), a new regime has recently been implemented to provide greater legal certainty for the industry while minimizing potential impacts on aquatic resources.

For clarity, in this discussion, the significance of an impact on the aquatic ecosystem is assessed according to the following factors:

- the duration of the operation that causes the impact;
- the duration of the impact;
- the nature of mitigative measures or control technology available to reduce the impact;
- the spatial extent of the impact; and
- the ability of the receiving environment to respond or recover from the impact.

These factors are ranked as low, medium or high for each of the three main stages of mineral development. These rankings represent the collective views of workshop participants and a number of specialists from within the Department. Because of the broad scope of any mineral development and the wider range of site-specific factors, it is difficult to assign broad rankings that fit all mineral developments. Therefore, the rankings used in this exercise are considered subjective and are used only broadly to identify and focus research needs that are discussed in the next section.

It must be stressed that mineral development activities in the N.W.T. and Yukon are subject to a wide range of environmental legislation, regulations, guidelines and policies that are intended to minimize environmental impacts. It must also be recognized that examples of serious environmental impacts from mineral development are few, although every mining operation has the potential to alter environmental quality seriously. Northern mineral development is a good example of governments and industry working together to ensure that economic development occurs in an environmentally responsible manner. The following assessment identifies the potential for impacts of mineral development on aquatic ecosystems.

5.1 Exploration

5.1.1 *Geophysical/geochemical sampling* - the first step in any mineral development is a geological library search followed by prospecting and geophysical-geochemical sampling to determine the nature and extent of potential mineral resources. Today, exploration companies use modern, sophisticated techniques for "scientific prospecting" that include magnetometers, induced polarization resistivity, electromagnetism, gravity, radiometry and, geochemistry (Northern Miner, 1982). For the most part, all these techniques are environmentally passive; that is, they do not have direct, negative environmental effects (Leenders, 1993).

The most common environmental alteration from geophysical-geochemical sampling is the clearing of brush in forested areas to construct temporary survey lines and camps to support geophysical surveys, and the movement of equipment across sensitive tundra areas (Lynch, 1992). Tundra areas require special consideration because of the presence of extensive permafrost, the relatively thin soils and the little vegetative cover. If this cover is disturbed, terrain slumping can occur, especially in ice-rich permafrost soils. Increased soil erosion and increased sedimentation to nearby waterbodies may also result. The combined effects of such an initial sampling, however, are considered minimal and if proper care and procedures are taken, damage can be easily avoided (DIAND, 1983; Northern Miner, 1982).

5.1.2 _Drilling and trenching_ - positive results from geophysical sampling usually lead to drilling and trenching programs to delineate mineral resources better. Drilling rigs are mobilized to obtain subsurface cores for detailed geological assessment. Trenches may also be bulldozed or blasted to expose the extent of any mineralization.

The impacts of drilling and trenching on aquatic ecosystems are considered minimal. The most serious threat would be extensive drilling in areas of ice-rich permafrost that may cause slumping and increased erosion. If groundwater aquifers of poor water quality are intercepted while drilling, contamination of surface water may occur. Other environmental effects can include accidental uncontained fuel spills and drilling wastes, groundwater contamination from leaching of sump drilling fluids and continual erosion and sedimentation from abandoned exploration sites (Northern Miner, 1982).

Trenching may result in greater environmental effects through surface disturbance when overburden is removed to reach the target mineralization. Increased erosion and sedimentation may occur as a result, especially in areas of sensitive terrain. If the trenching area is obstructed by a water course, stream diversion may be necessary, which can alter streamflow and water quality. Because of the increased surface area of exposed rocks, there is potential for increased acid rock drainage (Barrie and Carr, 1988; Steffen, Robertson and Kirsten, 1992a).

5.1.3 _Bulk sampling_ - bulk samples are taken when samples from drilling and trenching show promise but are not sufficient or accurate mineral metallurgical studies. Further, large-scale sampling is required to test the mineral metallurgy thoroughly. The potential impacts from bulk sampling are similar to those from drilling and trenching, but on a larger scale. Deforestation

Table 5.1 Asessment of Impacts - Exploration and Development

FACTOR	OPERATION			
	Geophysical Sampling	Drilling and Trenching	Bulk Sampling	Exploration Camps
Duration of operation	LOW	LOW	LOW	LOW
Duration of impact	LOW	LOW	LOW	LOW
Unknown or limited mitigative measures	LOW	LOW	LOW	LOW
Spatial extent of impact	LOW	LOW	LOW	LOW
Unknown or limited environmental response	LOW	LOW	LOW	LOW
SUMMARY	LOW	LOW	LOW	LOW

and habitat loss may also result (Barrie and Carr, 1988). Because larger quantities of petroleum products are transported to and stored on the site, there is increased potential for uncontained spills.

5.1.4 *Exploration camps* - exploration camps are required to support various stages of mineral development. Their size depends on the level of activity. Environmental effects are generally similar to those previously discussed, but other human-induced effects may include untreated sewage discharge and wind-blown camp refuse. Because of increased human activity, there is potential for more human-wildlife encounters. Surface disturbances occur over larger areas and if measures to reclaim the area after use are not taken, increased erosion and sedimentation may begin or continue.

5.1.5 *Assessment of impacts and information needs* - exploration activities often represent the last of the potential environmental disturbances if it is determined that mineralization does not exist at the site. Although few deposits are actually developed and mined, there is still potential for many areas to be disturbed. An assessment of potential impacts (Table 5.1) suggests that there are minimal aquatic ecosystem impacts. All environmental effects are normally of short duration and they are usually restricted to relatively small areas. The period of operation is also generally short. Known effects such as terrain disturbance, sedimentation, habitat loss and waste discharge can be mitigated. The most significant potential for environmental effects lies in poorly operated and maintained facilities, or in poor handling of petroleum products and chemical reagents.

Information requirements for activities associated with exploration and development are considered low. Any potential impacts can be mitigated with known technology and they are, for the most part, related to terrestrial disturbance. Much research has been and continues to be conducted on the effects of human use and development of northern resources, but overall, the potential impact on aquatic ecosystems is considered low.

5.2 Mine Site Development and Operation

When resource assessment points to a potential and economically feasible mineral deposit, the scale of activity increases rapidly and markedly, not only for mining companies but also for regulatory agencies. Larger temporary camps are required to house the development and construction crews, to construct haul roads and airstrips, to establish borrow pits or other sources of granular material, and to build mine and mill facilities. The time scale and spatial extent of development and operations are also significantly greater than exploration activities. So, there is a greater potential for impacts to the aquatic ecosystem. The following discussion looks at six main activities associated with mine site development and operations: infrastructure; site drainage; underground mines; open-pit mines; mills; and waste management.

5.2.1 *Infrastructure* - the infrastructure required to support mine site development can include haul roads to the site, a network of roads to access various sites on the property, airstrips, accommodation complexes and various on-site storage buildings, pipelines, power lines and power-generating facilities. Road and airstrip construction normally result in physical effects on aquatic ecosystems such as habitat loss and increased sedimentation. Problems arise when roads are improperly constructed and operated, especially in areas of permafrost, or are constructed in poor locations that are prone to washout and slumping (DIAND, 1984). Both winter and permanent roads can severely affect the northern environment if improperly located and designed. Minimal impacts are associated with construction of various on-site buildings. Any impact will depend on the site; although special care is required in areas of permafrost, even if the building is on bedrock. Initial site selection, therefore, is an important consideration to minimize impacts.

The environmental implications of the installation of power lines and pipelines are similar to those of roads, but to a lesser degree. To reduce environmental effects, these lines should be located along existing roads to avoid erosion, increased sedimentation and loss of habitat. Again, proper design in permafrost areas is necessary to reduce impacts.

Because of their remote locations, mine sites will generate power on-site either through diesel generators or small hydro-electric plants. If diesel generators are used, large volumes of fuel are stored on site. Although there are stringent requirements for containment berms and dykes, fuel spills can occur and fuel may enter the freshwater environments either directly or through groundwater. It is not clear how cold temperatures and permafrost affect bioremediation of fuel spills and potential impacts on the aquatic environment. For example, the organic nature of permafrost soils means that fuel is retained longer and released slower over long periods.

As an alternative power source, a small hydro-electric station might be built depending on the size and the location of the mine and the proximity to a water source. To date, there have not been any small stations serving single mines in either the N.W.T. or Yukon. If such plants are to be built, however, both the timing and magnitude of streamflow can be affected. Potential environmental effects can include increased bank and bed erosion and sediment transport, smothering of important fish habitat, increased temperatures and reduced summer flows. These potential effects are site-dependent.

5.2.2 _Site drainage_ - northern conditions pose unique problems for site drainage. In areas of permafrost or thin soils, significant overland flooding can result from minor precipitation. Moreover, because of thin vegetative cover, increased sediment loadings of streams can result from annual snowmelt or minor rainfall. Ideally, a mine site should be located and constructed so it does not obstruct natural drainage patterns. Drainage ditches are sometimes used to control flooding, but they may be responsible for the direct release of contaminated site runoff to the aquatic environment. Road construction can create similar effects. Removal of vegetation on slopes to increase drainage can result in long-term instability and can ultimately lead to increased, uncontrolled erosion and sedimentation. These problems can be avoided by proper location, excavation and planning (MacLaren Plansearch, 1982).

5.2.3 _Underground mines_ - in an underground mining operation, only the mill and loading facilities, concentrate storage and other storage buildings occupy the surface area. As a result, less of the surface is disturbed and less waste rock generated than in open-pit mining (Northern Miner, 1982). The extraction of the ore, depending on the size of the mine, can result in the interception of natural groundwater flow in mine workings and the subsequent release of contaminated mine water to surface waters. If untreated, this discharge may result in the contamination of major aquifers (Barrie and Carr, 1988).

Chemical impacts from underground mines occur primarily from blasting and drilling. Underground mines generally use less explosives for blasting than open-pit mines, thus there is less likelihood of the chemical contamination associated with explosives. However, if the mine is located in an area of permafrost, a higher level of explosives may be required (Dubnie, 1972). In these permafrost areas, saline water may be used to prevent drill holes from freezing and methyl hydrate may also be added to the underground pipelines to prevent mine waters from freezing. The effects of these discharges on aquatic biota are unknown, but are not considered to be significant.

Acid rock drainage may also be a potential problem in underground mines if sulphitic rock is exposed (Steffen, Robertson and Kirsten, 1992a). Acid rock drainage also poses a major potential problem in waste rock dumps. Contamination can be so severe that treatment is required before discharge to the aquatic environment.

5.2.4 *Open-pit mines* - the very nature of open-pit mining results in large-scale surface disturbance, which can have significant localized terrestrial impacts. Factors such as steep slopes, thin or poor soils, short growing season, severe climate, sparse vegetation and permafrost make the environment vulnerable to increased erosion and destabilization, and the consequent increased sedimentation in aquatic environments (Lynch, 1992). In addition, because of their large size, open pits require large waste dumps for overburden or waste rock.

Many hydrologic changes can take place in open-pit mining. For example, the water table in areas of extensive discontinuous permafrost may be purposely lowered to allow deeper excavation without flooding. The volume of pumped water may be large, and there is no assurance that its quality will be high. Consequently, diversion channels and treatment systems may be required. The removal of overburden in open pits may also degrade overall groundwater quality through mixing of several groundwater layers. Natural streams may also be diverted and water courses drained to allow open-pit development (Barrie and Carr, 1988). Removal of riparian vegetation may lead to greater extremes in water temperatures and consequent changes to the aquatic ecosystem (Dubnie, 1972).

Chemical-related effects on aquatic systems from open-pit mining also occur, but are usually limited to the use of explosives and acid rock drainage. Because large quantities of explosives are used, nitrogen compounds may be released into ground or surface waters, which can lead to eutrophication and a loss of fish habitat (Norecol, 1993), but because most northern surface waters are nutrient-poor, this nutrient enrichment is not likely to be a problem. In addition, there is also greater potential for acid rock drainage in open pits because more rock surface is exposed (Dubnie, 1972; Steffen, Robertson and Kirsten, 1992a). Mine water is normally collected and treated before being used in the mill, or it is discharged into the tailings pond for treatment.

5.2.5 *Mills/concentrators/heap leaching* - ore from underground workings and open pits is sent to the mill or concentrator for milling or processing. Milling can involve a series of primary jaw and secondary crushers, and ball mills to reduce ore size. Large quantities of water can be used in this process. In the ball mills, a number of chemicals are added to suppress or enhance certain reactions to concentrate or separate mineral from the host rock. Sodium cyanide is often used in milling processes, especially in gold mills where it is used to dissolve gold from the host rock. Waste streams include various overflows or underflows from mills and separators. This waste, or tailings, is characterized as a slurry containing many chemical compounds and fine particles, and having an alkaline pH.

Impacts from mills and concentrators are generally chemical related and of short-term duration.

Contaminants will vary depending on the type of ore mined and the process chemicals used and can reach the aquatic environment through spills or breaks in tailings lines. These problems can be avoided through preventive safety measures and proper planning and operations (Norecol, 1993).

Heap leaching is a relatively new technique in the north that replaces much of the mill concentration process, the use of liquid-solid separations and tailings impoundments. The water use per unit of ore is generally much lower. However, there are drawbacks. According to McElroy (1989), the construction of a permanent heap leach pad involves laying a sloped granular subgrade bed, excavating drainage channels and installing an impervious liner and a granular protective layer. The solution channels and retention ponds are similarly lined, which may result in a loss of terrestrial and aquatic habitat (McElroy, 1989).

The heap leach pads, which ideally are impermeable, can leak and result in the discharge of potentially toxic effluents to the aquatic ecosystem. The long-term effects from the construction of heap leach pads in permafrost, or heap leach pad leakage, are unknown. The long-term success of heap leaching and potential impacts in northern cold regions are not yet fully understood.

5.2.6 _Waste management_ - the mining industry is the largest creator of industrial waste in the North. As stated by Prowse (1990), "... the treatment and disposal of mining wastes is especially a problem in the north because the cold environment slows many of the degradation processes. Storage and release problems are complicated by the presence of permafrost and a lack of knowledge about the related groundwater flow regimes, i.e., long term effects of 'warm' wastes on permafrost encapsulated ponds" (pp.31-32). These arctic or northern conditions must therefore be recognized in any assessment of potential impacts. Practices and solutions from mines in temperate climates do not necessarily have the same success in northern cold regions. For example, northern ecosystems have low assimilative capacities for mine and mill wastes and effluent quality standards for northern mines may be considerably more stringent than for southern mines. Conversely, environmental problems in temperate climates may be minimal or non-existent in cold regions simply because colder ambient temperatures affect the rates of chemical and biological reactions. Even so, a problem such as acid rock drainage in northern mining, is a reality, but factors such as temperature, humidity and solar insolation that affect generation kinetics are poorly understood in cold regions. Environmental problems from waste management are associated with waste rock dumps, tailings impoundments and sewage treatment systems.

The greatest potential for environmental impacts from waste rock dumps is chemical-related. Runoff from the active slopes of a waste rock dump can transport and release metals into areas of permafrost, groundwater and nearby surface waters (Norecol, 1993). Waste rock produced from open-pit mines is more subject to acid rock drainage because the volume of rock removed and exposed is much larger than from underground mines. The extent of acid rock drainage is dependent on the sulphur content of the rock, the surface-to-mass ratio, presence of ferro-bacteria and ambient climatic conditions (Klohn Leonoff, 1993). Acid rock drainage can be minimized if natural neutralizing agents such as limestone or other carbonates are present or if non-acid generating waste rock is segregated from acid generating rocks. To fully understand, prevent and control acid rock drainage in cold regions, it is first necessary to understand regional geology and optimum methods of handling waste material.

Although mitigative and treatment measures for acid rock drainage are generally well known, the generation and control processes, especially in northern regions, are poorly understood. For example, the effects of low annual precipitation and temperatures on acid rock drainage generation have not been studied extensively. Southern techniques for control are not entirely applicable to cold regions. In some cases, permafrost may be enhanced in rock piles to control acid rock drainage, although contaminants may still be released into aquatic ecosystems through the active layer or to groundwater during the summer months. These permafrost-related effects are not fully understood.

The tailings impoundment system, or tailings pond, is the most common treatment system for metal mines. Tailings ponds are commonly located in natural depressions or existing waterbodies, and most will ultimately discharge to naturally occurring watercourses. Treatment theory for mill wastes, in its simplest form, consists of gravity separation of solids in a retention pond. Often, however, lime or other neutralizing agents, or flocculants or coagulants are added to tailings slurries to precipitate metals from solution. In most northern mines, treated waste from the tailings pond that meets stringent water quality standards is normally discharged or decanted during summer months when the tailings pond surface is ice-free. At times, it is necessary to add other chemicals such as ferric sulphate to precipitate arsenic compounds, or in extreme cases, separate treatment systems are required to remove cyanide or other potentially toxic substances. Even so, treatment plants, if required, are expensive and treatment technology may not be sufficiently advanced to reduce some compounds such as ammonia to non-toxic levels.

Many reactions in tailings ponds depend on natural degradation processes. Climatic conditions in the North, however, can affect these natural degradation processes. Cyanide and ammonia degradation, for example, are accelerated in summer months but essentially stop in winter months because of ice cover, shortened periods of sunlight and near-freezing water temperatures. To combat the lack of natural degradation of cyanide, hydrogen peroxide may be added to the tailings stream to alter cyanide chemically to form a stable thiosulphate. Problems can occur if elevated levels of cyanide and other metals remain in the tailings pond during spring. In addition, tailings pond failure in the spring can cause flooding and the release of high levels of contaminants (Higgs, 1989).

Embankment failures and the subsequent release of tailings from impoundment structures are not uncommon, although tailings dams are designed and constructed to solve potential problems. If, however, any part of the tailings impoundment structures leaks or fails, downstream contamination could be severe depending on the metals involved (Norecol, 1993). Lynch (1992) states that "tailings impoundments pose threats to the immediate and surrounding drainage systems through the contamination of ground and surface waters, as well as the possible sudden or gradual release and transportation of tailings outside of the impoundment" (p. 98). While the effects of long-term discharge of treated effluent are minimal, the short-term effects of sudden, large-scale releases are not well known. Many of these problems can be minimized if the impoundments are designed for physical and chemical stability.

The third waste management area is the sewage treatment system required for camp waste. The most significant potential for environmental impacts lies in upsets or spills from sewage treatment systems and the discharge of untreated wastes to the environment. In addition, if facilities are treating sewage wastes improperly and organic nutrients in the receiving waters are limited, eutrophication may occur (Norecol, 1993). Because most northern lakes are oligotrophic, this problem is generally not significant.

Wetlands may be used in some instances to treat waste waters. Although practised in southern, temperate climates, the success of wetland treatment in the north remains questionable. Flood plains, bottom lands, and wetlands, which are normally the locations for wetland treatment, are environmentally sensitive areas because of a great diversity of plant and animal species. They may be capable of handling low volumes of waste, but high volumes can have detrimental effects on aquatic biota (Lynch, 1992) although long-term, downstream bacteriological impacts are not fully understood.

5.2.7 _Assessment of impacts_ - mine site development and actual operation represents the stage of mining of greatest activity, and their potential to create impacts on the aquatic ecosystem is greater than exploration and development, mostly because of the duration of the operations (Table 5.2). The life of a mine can range from three to over 30 years when mineral resources are rich and extensive. Consequently, the duration of any significant impacts can also cover a considerable time period. Overall, however, the ability to cope with or mitigate any environmental problems and their rather limited spatial extent are relatively low. The environmental response to potential impacts is generally known or of low significance. Of the

Table 5.2 Assessment of Impacts - Mine Site Development and Operations

	OPERATION					
FACTOR	Infrastructure	Site Drainage	Underground Mines	Open- Pit Mines	Mills	Waste Management
Duration of operation	LOW	MEDIUM	MED-HIGH	MED-HIGH	MED-HIGH	MED-HIGH
Duration of impact	LOW	MEDIUM	MED-HIGH	MED-HIGH	MED-HIGH	MEDIUM
Unknown or limited mitigative measures	LOW	LOW	LOW	MEDIUM	MED-HIGH	MEDIUM
Spatial extent of impact	MEDIUM	LOW	LOW-MED	MEDIUM	LOW	MEDIUM
Unknown or limited environmental response	LOW	LOW	LOW	MEDIUM	MEDIUM	HIGH
SUMMARY	LOW	LOW	LOW-MED	MED-HIGH	MEDIUM	MED-HIGH

six components of development and operations described above, open-pit mines, tailings impoundment area, and mills and heap leach pads represent the activities with the greatest potential impacts. These impacts are mostly chemical in nature and, if uncontrolled, can result in the release of acutely toxic concentrations of metals and cyanide complexes into the aquatic ecosystem. The nature and rate of biomagnification of these metals and complexes and sub-lethal effects in cold regions are poorly understood. Thus, the potential impacts from development and operation are considered to be medium to high.

There are a number of information deficiencies identified for the development and operations phase of northern mineral development. Specifically, more information is required to understand the effects of cold temperatures on bioremediation of fuel spills, the effects of northern climatic factors on the generation, control and treatment of acid rock drainage, the relationship between permafrost and heap leaching operations, the short-term effects of sudden, large volume release of treated effluents to aquatic ecosystems and the suitability of wetlands for sewage treatment in cold regions. These deficiencies pertain to cold regions. Much similar research has been or is being conducted in temperate regions and many research results can be transferred directly to cold regions. For these reasons, it is felt that information needs for the development and operations phase of northern mineral development are medium to high.

5.3 Closure and Reclamation

The final stage of mineral development is closure and reclamation. The ultimate goal of this activity is the prevention of progressive environmental degradation and the enhancement of natural recovery of affected areas (Northwest Territories Water Board, 1990). Specifically, closure and reclamation are intended to reduce long-term site maintenance and minimize liabilities and risks to the mining companies and government agencies. Closure and abandonment problems can be minimized by designing for closure; that is, throughout the life of the mine, closure and abandonment requirements should be considered in the engineering design of all structures or any other mine site activity.

Although the time required to reclaim the mine site may be relatively short, the impacts of improper reclamation can last for many years. A unique problem with closure and reclamation is that the mine site will be left unattended for long periods of time. Problems that appear may go undetected for a long time. In addition, some mine sites, especially those with severe acid rock drainage problems, may require long-term treatment facilities that must operate efficiently with minimal attention.

Closure and reclamation of northern mine sites is especially important because of the number of mines closing in recent years. Many of these mines have closure plans built into the original mine designs, and these plans are intended to minimize impacts on aquatic ecosystems. There is also concern for abandoned mines that did not have adequate reclamation plans. Fortunately, many of these operations were relatively small and their problems were associated with improper fuel and waste handling procedures. Thus, their impact on the aquatic environment should be significantly less than larger mines. A summary of abandoned mines in Yukon and N.W.T. is reported in Kalin (1985).

The final discussion of this section focusses on six mine site closure and reclamation components: infrastructure; underground works; open-pit mines; tailings impoundment systems; buildings and equipment; and waste rock dumps, landfills and other minor wastes. A brief discussion of short-term closure is also provided. It should be noted that many suggestions are given below for reclamation practices and procedures. These suggestions do not represent official departmental policy. At this time DIAND has released a discussion paper for mine site reclamation for hard rock mines in Yukon (DIAND, 1993) and has started work on a similar discussion paper for the N.W.T. It is anticipated that these discussion papers will lead to departmental policy statements.

5.3.1 *Infrastructure* - Roads, railways and airstrips constructed during the operations stage may be left and maintained for future use; otherwise, plans for abandonment should be made. Access roads that will be permanently abandoned should allow for natural surface drainage to prevent erosion and sedimentation and in cases where streams have been crossed, culverts should be removed to allow fish passage. There is also a requirement to decontaminate all fuel and chemical storage sites. If increased erosion and sedimentation are likely on stable slopes, revegetation using indigenous species should be considered. Similar processes can be used for airstrips and railways (Steffen, Robertson and Kirsten, 1992b).

5.3.2 Underground works - one of the greatest problems of derelict underground works is the potential for acid rock drainage. Although it is standard procedure to plug shafts and portals during reclamation, problems may arise from groundwater interception that could lead to acid generation (Grisak, 1980). While flooding the mine reduces the chance of acid rock drainage, any water in the works will likely have elevated levels of metals. Precautions are necessary to minimize permafrost thawing from "warm" water and subsequent subsidence. Backfilling is an acceptable method for closure if settlement is minimized (Steffen, Robertson and Kirsten, 1992b).

The influence of mine site reclamation on the quality and distribution of surface and groundwater depends largely on a number of factors including the extent of disturbance to the original surface flow system, the hydrologic properties of soil material, and the availability of groundwater recharge (Barrie and Carr, 1988). The long-term environmental response, especially in areas of groundwater interception are unknown, but any impacts will be site-specific.

5.3.3 *Open-pits* - reclamation practices for open pits are generally related to slope stabilization, although problems can occur if pit walls have the potential to generate acidic drainage. Slope stability in the north is a unique problem after mining ceases because of freeze-thaw effects and potential changes to permafrost (Steffen, Robertson and Kirsten, 1992b). Disturbed surfaces can alter normal hydrologic conditions and can degrade water quality. Moreover, because much larger areas are disturbed, there are fewer cost-effective options for reclamation. Again, designing for closure can minimize future problems.

It is usual practice to let open pits flood naturally when the potential for acid rock drainage is minimal. Otherwise, filling the pit with water, revegetating or contouring can be used to stabilize slopes and control erosion (Barrie and Carr, 1988; Steffen, Robertson and Kirsten, 1992b). If acid rock drainage is a potential problem, long-term monitoring and treatment may be required, especially if groundwater was intercepted during pit excavation.

5.3.4 *Tailings impoundment system* - tailings impoundments must be secured at mine closure to prevent uncontrolled releases of tailings. Total containment of tailings is generally the preferred method of reclamation, which requires the proper stabilization of embankments and spillways for long-term tailings confinement.

Because tailings ponds contain essentially all the solid mill waste from the life of the mine, they normally cover large surface areas and contain large volumes of metal-bearing wastes. Standard reclamation practices for the actual tailings are to cover them with water to prevent wind blown erosion of dry tailings or to cap, contour and revegetate the surface cover (Steffen, Robertson and Kirsten, 1992b). Revegetation encourages stable, self-sustaining plant cover and reinvasion of natural native species is preferable over non-native species. In the North, however, it is often difficult to encourage revegetation because of severe climatic conditions; it has been estimated that restoration of original vegetation and drainage patterns may take hundreds of years (Peterson and Peterson, 1977).

Acid generation in tailings ponds is a potential problem that can be minimized with a permanent water cover or an impermeable seal. If tailings ponds are not properly reclaimed, contamination of the aquatic environment could be severe (Steffen, Robertson and Kirsten, 1992b). While much work has been done in temperate regions to understand the effectiveness of controlling acid rock drainage from reclaimed tailings ponds (Filion and Ferguson, 1990), the effectiveness of these methods in northern, cold regions is not fully understood (Klohn Leonoff, 1993).

Other components of a tailings impoundment system include ditches, culverts, pipelines and storage tanks. With proper reclamation procedures, the potential impacts, which are related to surface drainage and erosion and contaminants remaining in the pipelines and tanks, can be minimized (Steffen, Robertson and Kirsten, 1992b).

5.3.5 _Buildings and equipment_ - the reclamation of site buildings in the north is different from temperate areas. Buildings are seen as resources for future activities; however, all buildings not considered potentially useful should be decontaminated and all chemicals removed. All pipes, pumps and tanks should be drained, any mechanical equipment left in a no-load condition and all building entrances barricaded for safety reasons (Steffen, Robertson and Kirsten, 1992b). It has been a normal practice of mining companies to remove any mine structures and to rehabilitate the mine site. In some areas, only the airstrip remains for air emergencies.

It is not known what the effects of demolition and decontamination practices are on the aquatic environment, but they should be minimal. However, if the structures are left as they are, there is a greater likelihood of environmental impacts.

5.3.6 _Waste rock dumps, landfills and other wastes_ - waste rock piles on slopes may be prone to instability after closure due to foundation thawing. Measures should be taken to stabilize these piles to prevent mass movement and increased erosion (Steffen, Robertson and Kirsten, 1992b).

Other wastes may cause chemical-related problems in the aquatic environment. They include industrial and camp wastes, fuels, sewage, contaminated soils, chemicals and water treatment sludge. Such wastes must be dealt with individually and either isolated from the environment until they are in suitable shape to be released, or buried at an approved landfill site (Steffen, Robertson and Kirsten, 1992).

Studies done on mines in temperate areas note that a more serious deterioration in water quality occurred in 30-year old mine sites than in newer mine spoils (Barrie and Carr, 1988). This

Table 5.3 Assessment of Impacts - Closure and Reclamation

	OPERATION					
FACTOR	Infrastructure	Underground Works	Open-Pits	Tailings Impoundments	Buildings and Equipment	Waste Rock Dumps, Landfills and Other Wastes
Duration of operation	MED-HIGH	MED-HIGH	HIGH	HIGH	LOW-MED	HIGH
Duration of impact	MED-HIGH	MED-HIGH	HIGH	HIGH	LOW-MED	HIGH
Unknown or limited mitigative measures	LOW	MEDIUM	MED	MED-HIGH	LOW	MED-HIGH
Spatial extent of impact	MEDIUM	LOW	LOW-MED	MEDIUM	LOW	LOW-MED
Unknown or limited environmental response	LOW	MED-HIGH	MED-HIGH	HIGH	LOW	HIGH
SUMMARY	LOW	MED-HIGH	HIGH	HIGH	LOW	HIGH

important effect should be considered in closure plans.

5.3.7 _Short-term closure_ - this section is applicable to many sites that operate seasonally or are temporarily closed for other reasons. The planning of short-term closure will depend on the anticipated duration of the closure. It will be site-specific and in some cases, unknown. The goal is to minimize the effort required to maintain all operating activities that are necessary to protect the environment (Steffen, Robertson and Kirsten, 1992b).

Temporary abandonment should include drainage and erosion control to avoid contamination and increased sedimentation (MacLaren Plansearch, 1982). This may involve the operation of water management and treatment systems, monitoring and sampling stations, and an inventory of chemicals that may be removed from the site or securely contained (Steffen, Robertson and Kirsten, 1992b).

5.3.8 _Assessment of impacts_ - the range of potential impacts from mine site closure and reclamation are similar to those expected from development and operation, but because the reclaimed site may go for long periods without inspection or monitoring and the risk of environmental degradation is higher, the overall assessment of impacts is considered high (Table 5.3). In this assessment, it is assumed that all reclamation procedures comply with the current state of knowledge and regulatory requirements. Even if continual on-site maintenance such as ongoing treatment of acid rock drainage wastes is required, the potential for environmental damage from upsets is greater than the other stages of mineral development. To compound these realities, the long-term effects of closure and reclamation on the aquatic ecosystem are generally not known or not studied, thus any predictions about environmental response and recovery are conjectural at best.

Of the six components of closure and recovery discussed, only infrastructure and buildings and equipment are identified as having low potential impacts. Underground works are ranked medium to high because of the long-term duration and unknown environmental response to closure and reclamation. All other components are ranked high. The duration of the operation, duration of impacts, and knowledge about environmental response are high. The latter factor is particularly important in northern mineral development.

Information requirements for closure and abandonment are high, especially in terms of long-term environmental response to surface disturbances on terrestrial and aquatic ecosystems, the long-term effects of modern reclamation practices and, perhaps most important, the efficiencies of acid rock drainage control and treatment in cold regions. While these information needs are being addressed in temperate regions, there is no adequate long-term research record for cold regions.

5.4. Summary

Potential impacts on aquatic ecosystems from northern mineral development and associated information and research needs were assessed in the above discussion. Judgements were made on the potential for impacts based on the duration of the operation, the duration of impacts, knowledge of mitigation and treatment methods, spatial extent of impacts and environmental response to potential impacts. The results of this assessment are shown in Table 5.4.

It is clear that the potential for impacts and information needs are lowest for the exploration and development stage of mineral development and highest for closure and reclamation.

Table 5.4 Summary of Potential Impacts and Information Needs from Stages of Mineral Development

STAGES OF MINERAL DEVELOPMENT

	Exploration and Development	Mine Site Development and Operations	Closure and Reclamation
Potential for impacts	LOW	MED-HIGH	HIGH
Information needs	LOW	MED-HIGH	HIGH

The next section of this report discusses research needs related to aquatic ecosystems and northern mineral development.

6.0 RESEARCH NEEDS AND PROSPECTIVE STUDIES

The preceding four sections of this report described in a general fashion the physical and biotic environments of the Northwest Territories and Yukon, listed the present and past mineral development activities in both territories and assessed the range of potential impacts from three broad stages of mineral development. This section synthesizes much of that information to discuss and set research priorities for water resources studies related to the northern aquatic ecosystems. Research priorities are broadly grouped according to water resources management needs, hydrological and physical processes, and biological and ecosystem processes. These priorities are derived from an assessment of the magnitude of potential impacts identified in Section 5 of the report and the perceived information needs.

Relevant, timely and valid information is required for water resources management decisions. In the case of potential impacts on aquatic ecosystems from northern mineral development activities, a large body of information already exists on the nature of mineral developments and northern aquatic ecosystems. Unfortunately, much of this information is inadequate to meet the present needs of decision makers. In general terms, decision makers require information that is geographically relevant, timely and scientifically valid. Any research must therefore address these modern information needs.

6.1 Research Needs

A number of prospective areas of aquatic environmental research were identified by Klohn Leonoff (1993), Norecol (1993), and Norecol, Dames and Moore (1994) (Tables 6.1, 6.2 and 6.3). In many instances, these broad areas of research may not be particularly relevant to the Department generally or for the Water Resources Division specifically. To reduce the overall research focus to fit the needs of the Water Resources Division, the results of the workshops and the foregoing sections of this report are used to develop specific research priorities based on information needs and potential impacts on the aquatic environment. In this context, a research priority for any area of mining is identified as any activity that has a measurable potential for significant impact on the aquatic environment and has a high requirement for further information

Table 6.1

Candidate Research Projects Identified by Acid Rock Drainage Workshop (Klohn Leonoff, 1993)

1. extrapolation of laboratory tests to the field;
2. prediction of ARD in tailings;
3. prediction of ARD in waste rock;
4. waste dump design to control ARD and maximize permafrost control;
5. insulation cover to maintain permafrost conditions;
6. depth of dry covers; and
7. evaluation of sub-aqueous disposal under northern conditions.

Table 6.2

Major Priorities for Mine-related Aquatic Impacts Research (Norecol, 1993)

1. tailings and aqueous process wastes;
2. tailings management;
3. permafrost studies;
4. acid rock drainage potential;
5. hazardous wastes;
6. community involvement;
7. development of guidelines, standards and protocols;
8. development and assessment of compliance monitoring;
9. data management; and
10. transportation and access.

Table 6.3

Research Project Outlines (Norecol, Dames and Moore, 1994)

1. acid-base accounting for cold wastes;
2. temperature control on reaction rates in sub-aerial and buried wastes;
3. sub-aqueous disposal of mine wastes;
4. dry covers and freezing of mine wastes;
5. evaluation of material for dry covers;
6. sub-aqueous disposal of potentially acid generating wastes;
7. blending of waste rock in sub-aerial dumps; and
8. water treatment.

to minimize or remove the potential impact. The assessment of potential impacts from mineral development and the perceived information needs were discussed in Section 5. From this assessment, research priorities for the various stages of mining can be identified (Figure 6.1).

From this exercise it can be seen that the highest priority for aquatic environment research is related to mine abandonment and closure. Research is also required on mining operations but to a lesser extent. Because the potential impacts and information needs from exploration and development are low, this activity has a low priority for research. As stated above, the priorities for mining and aquatic environment research can be grouped according to the following three broad categories: water resources management; hydrological and physical processes; and biological and ecosystem processes.

6.2 Water Resources Management

Water management in its simplest form is described as the decision-making process that allocates resources for the most beneficial societal use (Getches, 1984; Mitchell, 1979). In a northern context such decision making must consider the temporal and spatial availability of water resources and the broad ranges of uses including industrial developments, traditional uses by Aboriginal people, community and municipal requirements and the maintenance of aquatic and terrestrial organisms that rely on the aquatic ecosystems. Management information needs must therefore draw on and synthesize hydrological and biological needs. A number of management questions can be raised:

- What are the management priorities and how are they set?
- What are the primary water uses and is their a hierarchy for water uses?
- What documentation is available to guide industrial development to achieve the broad goals of sustainable development?
- How does management define, identify and quantify potential impacts on the aquatic environment?
- What remedial measures are available to minimize impacts?

IDENTIFICATION OF RESEARCH PRIORITIES

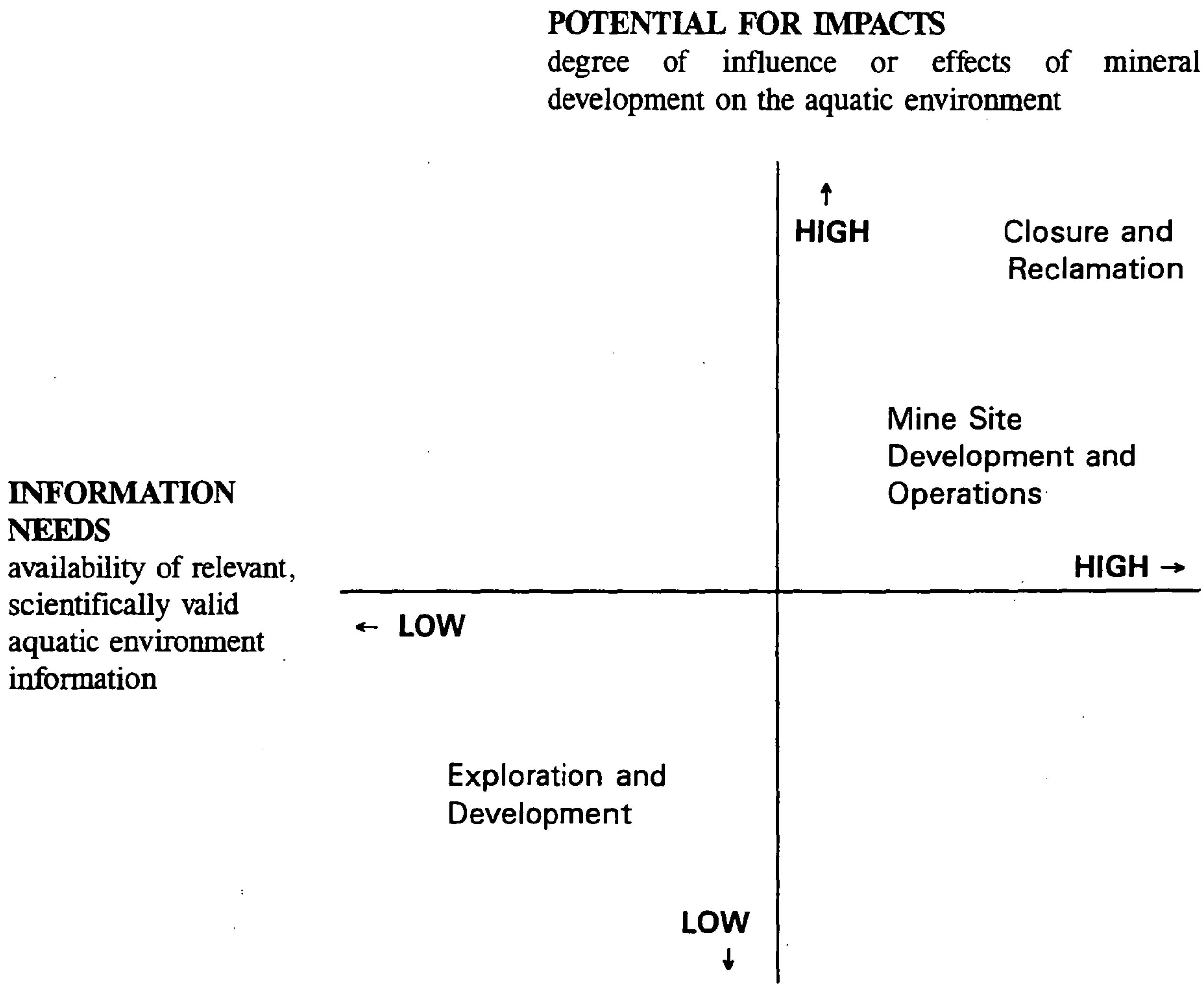


Figure 6.1 Identification of Research Priorities
For this model, research priorities are a function of the potential impact from the three main stages of mineral development and the availability of relevant, scientifically valid information on the processes that create the impact. Highest priority for research are those areas with high potential for impacts and high information needs.

The following areas of study related to water resources management are suggested:

- produce an annotated bibliography of works that deal with mining and impacts on the aquatic environment with particular reference to northern conditions

- prepare a critical literature review on select topics such as state-of-the-art treatment systems in cold regions for potentially toxic substances such as ammonia, cyanide and metal compounds and determine their effectiveness in the North;

- develop protocols to ensure traditional environmental knowledge is incorporated in resource management decision making;

- develop biological and operational protocols for baseline data collection, impact assessment and biological effects testing;

- identify permafrost studies to understand the effects of permafrost disturbance on the aquatic environment, the role of permafrost as an integral part of a tailings pond structure, the long-term stability of permafrost and the long-term effects of wastes on permafrost;

- develop and assess compliance monitoring studies to determine the adequacy of existing regimes that are based on water as a measuring medium and identify appropriate data collection requirements;

- develop inexpensive but effective acid rock drainage prediction, control and treatment methodologies that rely on ambient environmental conditions such as low precipitation rates, low temperatures, presence of permafrost and long periods of darkness;

- test and assess the use of wet and dry covers for waste rock and tailings to minimize acid rock drainage;

- develop better, faster in situ toxicity tests for cold regions;

- develop methods of remediation and bioremediation of petroleum spills in cold regions and assess the effects of spills on permafrost;

- determine the feasibility of recycling tailings ponds and process water in a cold climate, the effects of wind-blown tailings on the aquatic environment and the significance of surface changes to drainage and habitat from construction and operation of tailings ponds; and

- produce guidelines or codes of good practice for the various stages of mineral development including exploration and development, operations, and abandonment and closure

6.3 Hydrological and Physical Processes

Knowledge of northern water resources, their distribution and physical behaviour, the physical processes that operate in the North and the inherent variability among the components of the hydrological cycle are all essential for sound water management and sustainable development. Without adequate information on basic hydrological processes, additional costs or burdens will be placed on the mining industry because of the overdesign of structures. Conversely, the aquatic ecosystem may be placed at risk because of reduced factors of safety. All too often, this basic requirement for hydrological information is a major shortcoming in any industrial development activity. This problem has not gone unnoticed.

Prowse (1990), in his review of evolving water-related issues in the north, states that in the mining sector, limited knowledge about northern water balances necessitates wide margins of safety to avoid problems associated with tailings ponds overtopping after mine closure. Pond storage and release problems are compounded by the presence of permafrost and the lack of knowledge about related groundwater flow regimes. Because most advances in northern groundwater research are related to past development proposals and activities such as pipelines, highways and hydro-electric dams, great gaps remain in our knowledge about groundwater, especially in permafrost areas (van Everdingen, 1990). These problems are further compounded by the functioning and interrelationships of soils and permafrost in cold regions.

Further, Woo (1990) states that the Canadian contribution to hydrology in areas of permafrost has dwindled, and major problems are foreseen because of the lack of long-term records, the unreliability of high flow data and a scanty gauging network. Woo is not necessarily referring to flowing water. Marsh (1990) states that the effect of snow storage release is the single most important feature of the hydrologic cycle everywhere in the North.

Other components of the water balance are equally important but poorly understood. Sublimation, for example, is often thought to be minimal in arctic and subarctic regions, yet Woo (1993) shows that sublimation losses can account for up to 20 percent of annual precipitation.

Gerard (1990) states critically that "given the importance of floating ice hydrology, it is astounding to note the lack of interest shown in the subject by the hydrologic community." Our knowledge about snow processes has increased dramatically over the last two decades, but there are still major knowledge gaps that limit our predictive capabilities (Marsh, 1990).

There are a number of reasons to explain information deficiencies. These include the difficulty of establishing comprehensive data collection networks over vast areas, the extreme climatological conditions experienced in the north and the inherent variability that precludes long-term trend assessment. There are also limitations on instrumentation and equipment, and the inappropriateness of applying southern models to northern conditions. If we cannot accept the deficiencies in our knowledge about basic water balance components, it is incumbent on industry and water resources managers to develop a coherent and comprehensive study program to meet these information needs. Some areas of potential research are listed below:

- analyze each portion of the hydrologic cycle in a northern context to determine the value of data already collected, and devise better methodologies and instrumentation to make appropriate corrections;
- determine the significance of evaporation in northern water balances, identify influencing factors and establish spatial differences in evaporation;
- determine the role of sublimation in the hydrologic cycle especially as it affects tailings pond water balances;
- identify regional regimes based on differences in major hydrological variables such as precipitation, runoff and evaporation;
- develop better ways to measure total annual precipitation that account for sublimation of accumulated snow in the spring; and
- determine the role of hydrologic and meteorological variables such as humidity, windspeed, solar insolation and temperature on acid rock drainage generation in cold regions.

6.4 Biological and Ecosystem Processes

The major goal in any sustainable development strategy is to ensure that ecosystems remain healthy, diverse and productive; that is, management decisions must ensure that biological productivity is not hindered. As shown in Section 4 of this report, there is a range of effects from mineral development that could alter biological productivity and ecosystem integrity. The primary effects are habitat loss, release of toxic compounds and increased sedimentation. Kelly (1988) notes two common impacts of mine pollution on aquatic ecosystems: a decrease in species numbers and an increase in the density of tolerant species, each of which leads to a gradual change in community composition. To be relevant to a discussion of northern conditions, a distinction must be made, whenever possible, between the magnitude of these effects in cold as opposed to temperate regions. A number of obvious and important information gaps further bring into question the validity of applying knowledge based on temperate regions to cold regions.

There are fundamental differences that distinguish cold, freshwater ecosystems from their temperate counterparts. Northern lakes, for example, are characterized by low water temperature, oligotrophic conditions and long-term ice and snow cover (Hammer, 1989). Under ice cover, oxygen consumed is not replenished and, often, a negative oxygen balance results by the end of the winter season (Remmert, 1980). Also, the ice-free period is of short duration and the hours of daylight are considerably longer than in temperate regions. Cold region ecosystems generally have lower species diversity and lower primary productivity (Barrie et al, 1992). Food chains in cold regions are relatively short and are associated with simple predator-prey relationships (Barrie et al, 1992). A cold freshwater ecosystem will typically consist of large numbers of a few long-lived species (Baird, 1976).

Habitat loss in cold regions can have significant impacts on biological productivity. The destruction of habitat can lead to the depletion of key species as well as extinctions. Because ecosystems in cold regions are relatively simple, that is, they have fewer species than temperate regions, the loss of habitat for a single species may have a serious impact on the ecosystem as a whole. Many species in cold regions migrate to escape brutal winter conditions (Baird, 1976). These species will use selected areas at various times of the year and the disruption of these migratory patterns, understandably, can have detrimental effects on entire populations.

Organisms in cold climates are fundamentally different from their temperate region counterparts. In general, cold climate organisms have greater insulation as body fat, smaller appendages and smaller surface area per unit mass than organisms in temperate regions (Baird, 1976). These adaptive strategies permit the organisms to survive the cold conditions. There is reason to believe that the differences between cold and temperate region organisms may also result in differences in the manner in which contaminants accumulate and circulate within the organism. Research on the accumulation of lipophilic contaminants, such as a number of organochlorines, indicates that a greater percentage of body fat, or lipid material, results in increased contaminant loads or burdens per individual. The toxic compounds that are specific to mining do not include such lipophilic chemicals; rather, they are trace metals such as cadmium, copper, mercury and zinc, and metalloids such as arsenic. These compounds accumulate in organs such as liver, kidney and brain. Because organisms in cold climates are slower to reach sexual maturity and are generally longer-lived than those in temperate regions, metal concentrations may increase with organism size or age (Barrie et al., 1992). The relationship between increased size or age and increased metal concentrations is well-known with several species of fish (McMurty et al, 1989; Bendell Young et al, 1986).

The accumulation and biomagnification of metals in cold regions is not well-understood. The mechanisms involved are poorly understood, at best, in temperate ecosystems. Given the special characteristics of cold ecosystems, there appears to be no evidence to suggest that knowledge gained in temperate regions can be simply transferred to cold regions. Reduced productivity, increased sedimentation and simpler food chains must surely result in key differences in the mobility and trophic transfer of metals in these systems.

The behaviour of mercury in its methylated form differs greatly from that of other metals in that it is the only metal that has shown clear evidence of biomagnification or increasing concentrations in successive trophic levels. Higher concentrations are typically found in piscivorous fish (Verdon et al, 1991). Although the use of mercury in gold milling was suspended in the 1960s, mercury concentrations in sediment have been slow to decline (Sutherland and Thompson, 1986). Mercury can still be elevated in aquatic ecosystems. The granite of the Canadian Shield contains naturally occurring inorganic mercury. Various biotic and abiotic factors can lead to its transition from the inorganic to the methylated form.

Trace metals found in aquatic ecosystems are generally associated with the suspended or bottom sediments; however, only a small portion of trace metals remains in the soluble fraction (Luoma, 1988). Loads of metals bound to sediment may affect the quality of receiving waters when desorption processes occur. These processes are brought about by changes in acidity, complex agents or turbidity (Lietz and Galling, 1989). Metals in sediment can also be released through uptake by biota such as benthic invertebrates. Once accumulated like this, metals may be taken up by predators. When considering the accumulation of metals by benthic insects, the potential for export of metals to the terrestrial ecosystem via emerging adults must also be considered.

It has recently been recognized that there is limited information on the toxicity of metals in cold ecosystems (Chapman and McPherson, 1993). Lockhart et al (1992) note that there is almost no experimental toxicology research done with northern freshwater species, especially metal toxicology. Chapman and McPherson (1993) conclude that northern invertebrates are relatively insensitive to dissolved lead and zinc but it is clear that more work is required on chronic toxicity and on higher trophic level organisms. Lockhart et al (1992) suggest that northern ecosystems with low biological diversity and dominance of large, long-lived species may be particularly sensitive to stress from toxic chemicals as compared to temperate ecosystems. Chemicals released from northern mines, such as ammonia, cyanide, mercury and arsenic, may therefore have greater effects on cold region ecosystems. According to Lockhart et al (1992) large animals with long lifespans and low fecundity are most susceptible to injury from toxic chemicals.

Many aspects of hardrock mining can result in increased sedimentation, such as mineral exploration and mine development. Increased mobilization of silt and clay can increase turbidity in aquatic ecosystems, which can reduce significantly the amount of light available for photosynthesis (Kelly, 1988). Productivity is thereby reduced and oligotrophic conditions are promoted. In cold region ecosystems, primary productivity is already low, hampered by the short ice-free season and other factors. Further decreases to already oligotrophic systems could have serious consequences to the entire ecosystem.

Higher levels of the food chain, such as fish, are also detrimentally affected by increased sedimentation. In a species such as arctic grayling, increased sedimentation has been found to negatively impact behaviour, reproduction and physiological processes (Kelly, 1988). One of the more serious effects noted, however, is on reproduction. Silt deposited in gravel beds fills interstitial places where eggs are laid. The increased silt reduces the amount of dissolved oxygen for both eggs and fry (Kelly, 1988). Fry that do survive have to compete for reduced resources due to lower productivity. Finally, greater concentrations of suspended solids can have detrimental effects on adult fish by leading to abnormal gill development. The latter has been observed in arctic char effected by increased sedimentation. Because increased sedimentation can have impacts on both overall productivity, by decreasing photosynthesis, and on specific species, there is no doubt that ecosystem integrity can be at risk.

There are many areas where more information is required to enable a more complete assessment of the effects of northern mineral development on aquatic ecosystems. The following areas of research are suggested:

- determine the nature of bioavailability of metals in cold regions including the effects of temperature, longer ice cover, a shorter growing season, increased sedimentation rates and increased anoxic conditions in periods of prolonged ice cover;

- determine the biological differences between cold and temperate zone organisms with regard to metal bioavailability, and investigate if greater metal concentrations result because of differences in growth rates, life cycle, life span, smaller surface-to-volume ratio and shorter activity periods;

- investigate if major differences at the ecosystem level result in greater (or lesser) metal cycling within the ecosystem. Factors such as oligotrophic conditions and low species diversity should be considered;

- determine acute and chronic effects of metals, metal mixtures, ammonia and cyanide on cold climate freshwater biota to determine the relationships between accumulation and toxicity, and improve knowledge of mechanisms involved;

- compare concentration factors for mercury in cold versus temperate freshwater ecosystems;

- investigate the potential significance and effects of metal-contaminated groundwater and permafrost soil;

- investigate the response of aquatic biota to the spring discharge of large volumes of treated tailing effluent;

- determine the toxic effects of metals, such as nickel, copper and zinc, which are essential macronutrients and determine the fine line between a concentration that is required and a concentration that is toxic;

- investigate the amelioration of metal toxicity by calcium and the physiological mechanisms that enable amelioration.

6.5 Summary and Conclusions

The overall purpose of this report was to develop a broad framework for research and studies related to northern mineral development and aquatic ecosystems, primarily for use by DIAND. For this research to be relevant, it must recognize the distinct physical and biological components of the northern ecosystems. It must also address some known or potential impact from northern mineral development. This report provided an overview of the distinct physical and ecological characteristics of the Northwest Territories and Yukon. To set a management context, the importance of the mineral development industry to northern Canada was presented and discussed, and an assessment of potential impacts from three broad stages of mining was presented. It was concluded that closure and reclamation represents the stage of mining with greatest potential for impacts, plus it is an area within which there are major information gaps. Research must therefore be directed to fill these gaps. Actual mine site development and operation also has significant potential to affect adversely the aquatic ecosystem, and further information is required on the range and magnitude of possible impacts.

A number of studies or research areas have been proposed to address water resource management issues and to understand physical and hydrological process, and biological and ecosystem processes. This studies list is not considered to be exhaustive; it is a starting point for a better understanding of northern processes that will lead to better, more informed management decisions.

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APPENDIX A

Mines in the Northwest Territories and Yukon

MINES IN THE NORTHWEST TERRITORIES - ACTIVE, INACTIVE, SUSPENDED

Mine: Camlaren
Owner: Discovery West Corporation, Camlaren Mines Limited
Lat/Long: Lat 62^0 59' 05" Long 113^0 12' 05"
Status: Inactive
Minerals: Gold, Silver
Production: 1962-1963, 1979-1981

Mine: Cantung
Owner: Canada Tungsten Mining Corporation
Lat/Long: Lat 61^0 57' Long 128^0 15'
Status: Suspended
Minerals: Copper
Production: 1962-1986

Mine: Coal mine (Aklavik)
Owner: --------------------
Lat/Long: Lat 68^0 12' Long 135^0 25'
Status: Closed
Minerals: Sub-bituminous a
Production: Prior to 1939

Mine: Coal mine (Paulatuk)
Owner: ----------------------
Lat/Long: Lat 69^0 22' 03" Long 123^0 33' 41"
Status: Closed
Minerals: Lignite
Production: 1936-1941, 1941-1955

Mine: Coal Mine Lake
Owner: ----------------------
Lat/Long: Lat 68^0 42' Long 81^0 41'
Status: Closed
Minerals: Bituminous C to sub-bituminous A
Production: 1930 to late 1940s

Mine: Colomac
Owner: Royal Oak Mines Inc.
Lat/Long: Lat 64^0 23' 55" Long 115^0 05' 08"
Status: Suspended, re-opened in 1994
Minerals: Gold
Production: 1989-1990, 1994

Mine:	Con
Owner:	Miramar Mining Corp.
Lat/Long:	Lat 62° 26' 22" Long 114° 22' 08"
Status:	Active
Minerals:	Gold, Silver
Production:	1938-1994
Mine:	Contact Lake
Owner:	Echo Bay Mines Limited, Ulster Petroleums Limited
Lat/Long:	Lat 65° 59' 40" Long 117° 48' 00"
Status:	Closed
Minerals:	Uranium, Silver
Production:	1934, 1936-1939, 1947, 1977, 1979
Mine:	Cullaton Lake
Owner:	Royex Gold Mining Corporation
Lat/Long:	Lat 62° 17' Long 98° 30'
Status:	Inactive
Minerals:	Gold
Production:	1981-1984
Mine:	Daf (mq)
Owner:	Blackridge Gold Limited, Cruiser Minerals Limited
Lat/Long:	Lat 62° 54' 21" Long 113° 13' 58"
Status:	Closed
Minerals:	Gold, Silver
Production:	1947-1985
Mine:	Discovery
Owner:	Discovery Mines Limited
Lat/Long:	63° 11' 12" Long 113° 53' 30"
Status:	Closed
Minerals:	Gold
Production:	1946-1968
Mine:	Echo Bay
Owner:	Echo Bay Mines Limited
Lat/Long:	Lat 66° 06' Long 118° 00'
Status:	Closed
Minerals:	Silver, Copper
Production:	1964-1976
Mine:	El-bonanza
Owner:	El-bonanza Mining Corporation
Lat/Long:	Lat 66° 00' 10" Long 118° 04' 30"
Status:	Closed
Minerals:	Silver, Copper, Uranium
Production:	1934-1936, 1965

Mine:	Eldorado
Owner:	Echo Bay Mines Limited
Lat/Long:	Lat 66^0 05' 05" Long 118^0 02' 10"
Status:	Closed
Minerals:	Uranium, Copper, Silver
Production:	1931-1940, 1942-1960, 1977-1982

Mine:	Galena Point
Owner:	----------------------
Lat/Long:	Lat 67^0 54' 15" Long 109^0 46' 32"
Status:	Closed
Minerals:	Silver, Lead, Zinc
Production:	1966

Mine:	Giant
Owner:	Royal Oak Mines Inc.
Lat/Long:	Lat 62^0 30' 10" Long 114^0 21' 25"
Status:	Active
Minerals:	Gold, Silver
Production:	1948-1994

Mine:	Hope Bay
Owner:	Hope Bay Mines Limited
Lat/Long:	Lat 68^0 11' 00" Long 106^0 32' 45"
Status:	Closed
Minerals:	Silver
Production:	1973-1975

Mine:	Hottah Lake (Cormac)
Owner:	----------------------
Lat/Long:	Lat 64^0 44' 05" Long 118^0 11' 10"
Status:	Closed
Minerals:	Uranium
Production:	1934

Mine:	Joon (June)
Owner:	D. Nickerson
Lat/Long:	Lat 62^0 25' 07" Long 112^0 51' 08"
Status:	Closed
Minerals:	Gold
Production:	1977-1978

Mine:	Lolor
Owner:	Giant Yellowknife Mines Limited (Royal Oak Mines Inc.)
Lat/Long:	Lat 62^0 30' 10" Long 115^0 21' 25"
Status:	Closed
Minerals:	Gold
Production:	1967-1983

Mine: Lupin
Owner: Echo Bay Mines Limited
Lat/Long: Lat 65° 45' 52" Long 110° 13' 35"
Status: Active
Minerals: Gold
Production: 1982-1994

Mine: Mon
Owner: Ger-mac Contracting Ltd.
Lat/Long: Lat 62° 46' 36" Long 114° 00' 53"
Status: Closed
Minerals: Gold
Production: 1992-1994

Mine: Moose (Best Bet)
Owner: Equinox Resources Limited
Lat/Long: Lat 62° 10' 30" Long 112° 13' 24"
Status: Closed
Minerals: Rare Earth Metals
Production: 1947-1948, 1953-1954

Mine: Nanisivik
Owner: Nanisivik Mines Limited
Lat/Long: Lat 73° 02' Long 84° 30'
Status: Active
Minerals: Zinc, Lead, Silver, Cadmium
Production: 1976-1994

Mine: Negus
Owner: Cominco Limited (Miramar Mining Corp.)
Lat/Long: Lat 62° 26' 10" Long 114° 21'
Status: Closed
Minerals: Gold, Silver
Production: 1939-1952

Mine: Niante Harbour
Owner: -------------------------
Lat/Long: Lat 64° 53' Long 66° 18'
Status: Closed
Minerals: Mica
Production: 1876

Mine: Norma (Beaulieu Yellowknife, Brandy)
Owner: Genesis Resources Corporation
Lat/Long: Lat 62° 24' 46" Long 112° 54' 22"
Status: Closed
Minerals: Gold
Production: 1942, 1944-48, 1978

Mine:	Nose
Owner:	Sheild Resources Limited
Lat/Long:	Lat 62° 54' 50" Long 114° 14'
Status:	Closed
Minerals:	Gold, Silver
Production:	1967

Mine:	Old Parr
Owner:	-----------------
Lat/Long:	Lat 62° 44' Long 113° 31'
Status:	Closed
Minerals:	Gold, Silver
Production:	1963-1965

Mine:	Outpost Island
Owner:	Tungsten Corporation of Canada Limited
Lat/Long:	Lat 61° 44' Long 113° 28'
Status:	Closed
Minerals:	Gold, Silver, Copper, Tungsten
Production:	1941-1942

Mine:	Peg (Toke)
Owner:	International Bibis Tin Mines Limited
Lat/Long:	Lat 62° 43' 40" Long 113° 06' 50"
Status:	Closed
Minerals:	Rare Earth Metals
Production:	1946-1947

Mine:	Pensive
Owner:	------------------
Lat/Long:	Lat 64° 44' 10" Long 113° 20'
Status:	Closed
Minerals:	Gold
Production:	1939

Mine:	Pine Point
Owner:	Pine Point Mines Limited
Lat/Long:	Lat 60° 50' Long 114° 25'
Status:	Closed
Minerals:	Lead, Zinc
Production:	1964-1986

Mine:	Polaris
Owner:	Cominco Limited
Lat/Long:	Lat 75° 26' Long 96° 25'
Status:	Active
Minerals:	Zinc, Lead
Production:	1982-1994

Mine:	Ptarmigan
Owner:	Treminco Resources Limited
Lat/Long:	Lat 62^0 31' 10" Long 114^0 11' 50"
Status:	Closed
Minerals:	Gold
Production:	1941-1942, 1983

Mine:	Rankin Nickel
Owner:	Borealis Exploration Limited, Asamera Minerals Incorporated, Comaplex Resources International Limited
Lat/Long:	Lat 62^0 49' 12" Long 92^0 04' 48"
Status:	Closed
Minerals:	Copper, Nickel, Platinum
Production:	1957-1962

Mine:	Rayrock
Owner:	------------------------
Lat/Long:	Lat 63^0 27' 10" Long 116^0 33'
Status:	Closed
Minerals:	Uranium
Production:	1957-1959

Mine:	Rich (Burwash)
Owner:	-------------------------
Lat/Long:	Lat 62^0 27' 50" Long 114^0 18' 50"
Status:	Closed
Minerals:	Gold
Production:	1935

Mine:	Rod
Owner:	D. Nickerson
Lat/Long:	Lat 62^0 29' 50" Long 114^0 26'
Status:	Closed
Minerals:	Gold
Production:	1978-1979

Mine:	Ruth
Owner:	Hidden Lake Gold Mines Ltd.
Lat/Long:	Lat 62^0 27' 45" Long 112^0 34' 15"
Status:	Closed
Minerals:	Gold
Production:	1942, 1959

Mine:	Sachowia Lake (Gogo)
Owner:	Copper Pass Mines Limited
Lat/Long:	Lat 62^0 24' 40" Long 111^0 51' 30"
Status:	Closed
Minerals:	Nickel, Cobalt, Bismuth
Production:	1957, 1969-1970

Mine:	Salmita
Owner:	Giant Yellowknife Mines Limited
Lat/Long:	Lat 64^0 04' Long 111^0 14'
Status:	Closed
Minerals:	Gold
Production:	1983-1987

Mine:	Shear Lake
Owner:	Royex Gold Mining Corporation
Lat/Long:	Lat 61^0 18' 24" Long 98^0 30' 12"
Status:	Inactive
Minerals:	Gold
Production:	1984-1985

Mine:	Silver Bay
Owner:	Northrim Mines Limited
Lat/Long:	Lat 65^0 35' 45" Long 117^0 58' 35"
Status:	Closed
Minerals:	Silver
Production:	1971-1972, 1976-1979

Mine:	Supercrest (Akaitcho)
Owner:	Giant Yellowknife Mines Limited (Royal Oak Mines Inc.)
Lat/Long:	Lat 62^0 31' 30" Long 114^0 21'
Status:	Closed
Minerals:	Gold
Production:	1973-1981

Mine:	Ta (Bullmoose Lake)
Owner:	Terra Mines Limited
Lat/Long:	Lat 62^0 20' 40" Long 112^0 44' 50"
Status:	Closed
Minerals:	Gold
Production:	1940-1941, 1986-1987

Mine:	Term Point
Owner:	Faraway Gold Mines Limited
Lat/Long:	Lat 62^0 08' Long 113^0 28'
Status:	Closed
Minerals:	Gold
Production:	1918, 1928, 1987

Mine:	Terra (Norex, Smallwood)
Owner:	Terra Mines Limited
Lat/Long:	Lat 65^0 35' 15" Long 117^0 57' 25"
Status:	Closed
Minerals:	Silver, Copper, Lead
Production:	1970-1971, 1978-1983

Mine:	Terra (North)
Owner:	Terra Mines Limited
Lat/Long:	Lat 65^0 36’ 28" Long 118^0 06’ 55"
Status:	Closed
Minerals:	Silver, Copper
Production:	1979-1982
Mine:	Terra (Silver Bear)
Owner:	Terra Mines Limited
Lat/Long:	Lat 65^0 36’ 15" Long 118^0 06’ 55"
Status:	Closed
Minerals:	Silver, Copper, Bismuth, Uranium
Production:	1969-1985
Mine:	Thompson-Lundmark
Owner:	Thompson-Lundmark Gold Mines Limited, Ardic Exploration and Development Limited, Inc.
Lat/Long:	Lat 62^0 36’ 45" Long 113^0 28’ 15"
Status:	Closed
Minerals:	Gold, Silver
Production:	1941-1943, 1947-49
Mine:	Tin
Owner:	Consolidated Five Star Resources Limited
Lat/Long:	Lat 62^0 32’ 35" Long 114^0 10’ 55"
Status:	Closed
Minerals:	Gold
Production:	1950
Mine:	Tom
Owner:	Treminco Resources Limited
Lat/Long:	Lat 62^0 32’ 08" Long 114^0 11’ 50"
Status:	Active
Minerals:	Gold
Production:	1986-1994
Mine:	Tundra (Taurcanis, Bulldog)
Owner:	Giant Yellowknife Mines Limited
Lat/Long:	Lat 64^0 02’ 12" Long 111^0 11’ 36"
Status:	Closed
Minerals:	Gold, Silver
Production:	1964-1968
Mine:	Vol
Owner:	Nerco Con Mine Limited
Lat/Long:	Lat 62^0 27’ Long 114^0 21’ 30"
Status:	Closed
Minerals:	Gold
Production:	1964-1967

Mine:	Watercourse Valley
Owner:	----------------------
Lat/Long:	Lat 81^0 44' 18" Long 64^0 24'
Status:	Closed
Minerals:	High Volatile Bituminous A
Production:	1875-1876

MINES IN YUKON - ACTIVE, INACTIVE, SUSPENDED

Mine:	Arctic Caribou
Owner::	Feather Gold Resources Ltd. & Amcorp Industries.
Lat/Long:	Lat 60^0 05' Long 134^0 41'
Status:	Inactive
Minerals:	Silver, Gold
Production:	1910-1911, 1925, 1968-1969

Mine:	Bomber
Owner:	Pacific Sentinel Gold Corp.
Lat/Long:	Lat 62^0 43' Long 138^0 50'
Status:	Inactive
Minerals:	Silver, Gold, Lead, Zinc, Copper, Bismuth
Production:	1965, 1987-1980

Mine:	Caley
Owner:	R. Gillespie
Lat/Long:	Lat 64^0 18' Long 140^0 12'
Status:	Inactive
Minerals:	Asbestos
Production:	1978

Mine:	Clinton Creek
Owner:	Brinco Ltd.
Lat/Long:	Lat 64^0 27' Long 140^0 43'
Status:	Inactive
Minerals:	Asbestos
Production:	1967-1978

Mine:	Dale (Lola)
Owner:	Butler Mountain Minerals Corp.
Lat/Long:	Lat 60^0 01' Long 130^0 29'
Status:	Inactive
Minerals:	Silver, Gold, Lead, Zinc, Copper
Production:	1968, 1970

Mine:	Faro
Owner:	Curragh Resources Ltd.
Lat/Long:	Lat 62^0 21' Long 133^0 22'
Status:	Suspended
Minerals:	Lead, Zinc, Silver, Copper, Gold
Production:	1965-1992

Mine:	Five Fingers
Owner:	Unknown
Lat/Long:	Lat 62^0 12' Long 136^0 20'
Status:	Inactive
Minerals:	Coal
Production:	1904, 1907-1908

Mine:	Holliday
Owner:	Klondike Silver Mines Ltd.
Lat/Long:	Lat 60^0 00' Long 130^0 34'
Status:	Inactive
Minerals:	Silver, Gold, Lead, Zinc, Copper
Production:	1979, 1980, 1982

Mine:	Johobo
Owner:	Government of Canada (Parks Canada)
Lat/Long:	Lat 60^0 29' Long 137^0 34'
Status:	Inactive
Minerals:	Copper
Production:	1958-1962

Mine:	Kane
Owner:	Northern Horizon Resources Corp. & Everest Resources Ltd.
Lat/Long:	Lat 60^0 05' Long 137^0 09'
Status:	Inactive
Minerals:	Silver, Lead, Zinc
Production:	1984

Mine:	Ketza River
Owner:	Ygc Resources Ltd.
Lat/Long:	Lat 61^0 32' Long 132^0 16'
Status:	Inactive
Minerals:	Gold
Production:	1989-1991

Mine:	Lone Star
Owner:	Arbor Resources Ltd.
Lat/Long:	Lat 63^0 54' Long 139^0 14'
Status:	Inactive
Minerals:	Gold
Production:	1909-1914, 1925, 1929-1931

Mine:	Keno Hill Area
Owner:	United Keno Hills Mines Ltd.
Lat/Long:	Lat 63^0 54' Long 135^0 29'
Status:	Inactive
Minerals:	Lead, Silver, Zinc
Production:	1947-1989

Mine:	Laforma
Owner:	Discovery West Corporation and Ark La Tex Ltd.
Lat/Long:	Lat 62^0 16' Long 137^0 06'
Status:	Inactive
Minerals:	Gold, Silver
Production:	1939-1940, 1965-1966

Mine:	Mt. Nansen
Owner:	Byg Natural Resources
Lat/Long:	Lat 62^0 03' Long 137^0 10'
Status:	Inactive
Minerals:	Gold, Silver, Lead, Zinc
Production:	1968-1969, 1975-1976

Mine:	Mt. Skukum
Owner:	Wheaton River Minerals Ltd.
Lat/Long:	Lat 60^0 14' Long 135^0 25'
Status:	Inactive
Minerals:	Gold, Silver
Production:	1986-1988

Mine:	Mosquito
Owner:	A.F. Tottrup
Lat/Long:	Lat 63^0 55' Long 140^0 48'
Status:	Inactive
Minerals:	Silver, Lead
Production:	1966, 1974-1976

Mine:	Plata-Inca
Owner:	Curragh Resources Ltd.
Lat/Long:	Lat 63^0 35' Long 132^0 02'
Status:	Inactive
Minerals:	Silver, Gold
Production:	1976-1977, 1983-1986

Mine:	Sa Dena Hes (Mt. Hundere)
Owner:	Cominco Ltd. & Teck Corp.
Lat/Long:	Lat 60^0 31' Long 128^0 53'
Status:	Suspended
Minerals:	Lead, Zinc, Silver
Production:	1991-1992

Mine:	Sourdough
Owner:	Unknown
Lat/Long:	Lat 64^0 08' Long 138^0 57'
Status:	Inactive
Minerals:	Lignite (coal)
Production:	1899-1903, 1939-1940

Mine:	Tally-ho
Owner:	Tally-ho Exploration Ltd.
Lat/Long:	Lat 60^0 15' Long 135^0 04'
Status:	Inactive
Minerals:	Gold, Silver, Lead
Production:	1909-1922

Mine:	Tantalus
Owner:	Unknown
Lat/Long:	Lat 62^0 06' Long 136^0 16'
Status:	Inactive
Minerals:	Coal
Production:	1905-1922

Mine:	Tantalus Butte
Owner:	Curragh Resources Ltd.
Lat/Long:	Lat 62^0 07' Long 136^0 16'
Status:	Inactive
Minerals:	Coal
Production:	1948-1981

Mine:	Tea
Owner:	Coyne & Sons Ltd.
Lat/Long:	Lat 63^0 01' Long 130^0 36'
Status:	Inactive
Minerals:	Barite
Production:	1982

Mine:	Vangorda
Owner:	Curragh Resources Ltd.
Lat/Long:	Lat 62^0 15' Long 133^0 11'
Status:	Suspended
Minerals:	Lead, Silver, Copper, Zinc, Gold
Production:	1991-1993

Mine:	Venus
Owner:	United Keno Hills Mines Ltd.
Lat/Long:	Lat 60^0 01' Long 134^0 38'
Status:	Inactive
Minerals:	Gold, Silver, Lead,
Production:	1908-1911, 1919, 1970-1971

Mine:	Wellgreen
Owner:	All North Resources Ltd.
Lat/Long:	Lat 61⁰ 28' Long 139⁰ 32'
Status:	Inactive
Minerals:	Copper, Nickel, Cobalt, Platinum, Gold, Palladium
Production:	1972-1973

Mine:	Whiskey Lake
Owner:	Curragh Resources
Lat/Long:	Lat 61⁰ 57' Long 132⁰ 36'
Status:	Suspended
Minerals:	Coal
Production:	1986-1990, 1991-1992

Mine:	Whitehorse Copper Mines
Owner:	Hudson Bay Mining & Smelting Co. Ltd.
Lat/Long:	Lat 60⁰ 40' Long 135⁰ 10'
Status:	Inactive
Minerals	Copper, Gold, Silver
Production:	1967-1982

Mine:	Wil
Owner:	The Golden Shamrock Resources Corp.
Lat/Long:	Lat 60⁰ 08' Long 137⁰ 07'
Status:	Inactive
Minerals:	Silver, Gold, Lead, Zinc, Copper
Production:	1985

Sources: Brown, 1994; Brown and Caine, 1987; Caine, 1994; Paget, 1994.