Table of Contents

Volume II

NWT Diamonds Project

Environmental Setting

Overview - Environmental Setting

Volume II summarizes the most important aspects of the physical, biological and socioeconomic environment surrounding the NWT Diamonds Project. The characteristics of the Southern Arctic tundra and the organisms and processes that interact within this northern region are described and analyzed. The communities that benefit from the resources sustained by the project area are presented.

The volume begins with a description of the approach used to compile information. The Aboriginal context of the setting is discussed within this approach. The remainder of the volume summarizes the project environment according to its physical, biological and socioeconomic setting.

The Environmental Setting provides a summary of the existing baseline environment as characterized before the proposed project development. Some of this baseline information was obtained during early exploration stages. The area surrounding the NWT Diamonds Project site is relatively pristine, however, and the pre-exploration environment is not deemed to be significantly different than initial baseline conditions.

The description of the physical and biological setting is based largely on fieldwork conducted within the project claim block from 1993 until 1995. Other relevant studies are cited to provide background regional information for comparative purposes. Traditional knowledge has been incorporated where relevant and available. Ongoing data collection will integrate indigenous information into future environmental monitoring and planning.

The description of the socioeconomic setting of the project is based on interviews and research conducted within communities in the Northwest Territories during 1994 and 1995. Traditional knowledge has been included to ensure a comprehensive assessment of the existing socioeconomic environment.

VOLUME II - ENVIRONMENTAL SETTING

TABLE OF CONTENTS

List of Tables

List of Figures

List of Plates

List of Appendices

The Appendices to this volume are contained in a supplementary report entitled Volume II - Appendices.

Table of Conformity

The following table indicates how the design and contents of the EIS conform to the requirements of the "Final Guidelines for the Preparation of an EIS" issued by the BHP Diamond Mine Environmental Assessment Panel in May 1995.

EIS Guideline Requirements	**EIS Reference**	
4.0 EIS Overview	EIS Summary, Volumes I - IV	
4.1 Study Strategy and Methods	Vol. II, Sec. 1.1	Methods
	Vol. IV, Sec. 1.1	Methods
Traditional Knowledge	Vol. I, Sec. 1.2	Indigenous Knowledge
	Vol. I, Sec. 5.1.1.4	Traditional Knowledge Meetings, Workshops and Studies
	Vol. II, Sec. 1.2	The Aboriginal Context
	Vol. II, Sec. 4.1.3	The Traditional Economy
	Vol. II, Sec. 4.1.4	Emergence of the Mixed Economy
	Vol. II, Sec. 4.1.5	The Current Economy
	Vol. II, Sec. 4.1.6	Concerns
	Vol. III, Sec. 1.2	Role of Indigenous Peoples & Knowledge in Environmental Management
	Vol. IV, Sec. 4.1	Local and Regional Perceptions of the project
	Vol. IV, Sec. 4.2	Aboriginal Employee Perceptions of the Project
	Vol. IV, Sec. 4.8	Traditional Economies/Lifestyles
4.2 EIS Presentation		
Conformity with Guidelines	Table of Conformity	
Keywords	List of Keywords	
References	Reference List	
Preparation	Acknowledgments	
Glossary	Glossary	
4.3 EIS Summary	EIS Summary Volume	

10.0 Mitigation Measures and Residual Effects	Vol. I, Sec. 1.3 Vol. IV, Sec. 2 Vol. IV, Sec. 3 Vol. IV, Sec. 4	Project Economic Analysis Physical Impacts and Mitigation Biological Impacts and Mitigation Socioeconomic Impacts and Mitigation
11.0 Monitoring Programs	Vol. III, Sec. 10	Environmental Monitoring Strategy
12.0 Alternatives and Future Development	Vol. I, Sec. 3.1 Vol. I, Sec. 3.2 Vol. I, Sec. 3.3 Vol. I, Sec. 3.4 Vol. I, Sec. 3.5 Vol. I, Sec. 3.6 Vol. I, Sec. 3.7 Vol. I, Sec. 3.8 Vol. I, Sec. 3.9 Vol. I, Sec. 3.10	Fly-In/Fly-Out Work Force Versus Permanent Mining Town Open Pit and Underground Mining Backfilling of Open Pits Plant Site Location Mineral Processing Options Ore Treatment Production Rates Alternative Tailings Disposal Site and Facility Assessment Power Generation Options Transportation Options Future Development
13.0 Information Programs & Public Involvement	Vol. I, Sec. 5	Communications

Acknowledgments

Preparation of the Environmental Impact Statement (EIS) for the NWT Diamonds Project involved a significant effort by many of Canada's leading consultants, specialists and support companies. The Proponent wishes to acknowledge the contribution that these groups have made and the high standard of work and support given to this project.

BHP, as Operator of the project and on behalf of the Proponent, initiated environmental studies and the community consultation process in 1992. Since the summer of 1993, Rescan Environmental Services Ltd. (Rescan) was contracted to conduct field sampling for the baseline environmental studies. Rescan, with BHP's direction, has also been responsible for document preparation and the coordination of the many facets of this study. Outcrop Northern Agency Ltd. of Yellowknife has been the principal consultant with respect to the socioeconomic assessment of the project. Various sub-consultants provided specialist services for components of this EIS document, including the following:

Consultants	**Contribution**
ARA Consulting Group Inc. Vancouver, B.C.	Economic Analysis
Agra Earth and Environmental Calgary, AB	Fish Habitat Evaluation
Applied Technical Services Victoria, B.C.	Benthic Invertebrates and Zooplankton Identification
ASL Laboratory Services Vancouver, B.C.	Water Quality, Sediment and Tissue Analysis
Jerry W. Bair Houston, TX	Communications, Government Affairs, Traditional Knowledge
Barb Brown Community Development Associates Vancouver, B.C.	Community Assessment and Community Mobilization
Barron Kennedy Lyzun and Associates Vancouver, B.C.	Noise Assessment
BC Research Laboratory Vancouver, B.C.	Toxicity Testwork

Consultants	**Contribution**
Bruce Geotechnical Consultants Inc. Vancouver, B.C.	Groundwater Modelling and Permafrost
Canadian Circumpolar Institute University of Alberta Edmonton, AB	Dene and Inuit Traditional Knowledge Literature Review
Chemex Laboratory North Vancouver, B.C.	Acid Base Accounting Testwork
Chris Hanks Victor, Colorado	Indigenous and Traditional Knowledge
Davis & Co. Vancouver, B.C. Yellowknife, NWT	Legal Services
Dene Cultural Institute Hay River, NWT	Traditional Knowledge
Dene Nation Yellowknife, NWT	Traditional Land Use Maps
EBA Engineering Consultants Ltd. Edmonton, AB	Geotechnical Engineering and Permafrost Assessment
Elemental Research Laboratory North Vancouver, B.C.	ICP/MS Low Level Water Quality Analyses
Fluor Daniel Wright Ltd./ Signet Engineering Pty Ltd. Vancouver, B.C.	Infrastructure and Process Design
Fraser Taxonomic Services Vancouver, B.C.	Periphyton and Phytoplankton Identification
Hamlet of Coppermine Coppermine, NWT	Indigenous and Traditional Knowledge
Inuvik Fisheries Consulting and Age Laboratory Inuvik, NWT	Fish Aging, Scales

Consultants	Contribution
Janet Kidd ABR Inc. Fairbanks, Alaska	Reclamation Literature Review and Research Design
George Kurilko LSA Richmond, Ca.	Socioeconomics
Lockhart Risk Management Vancouver, B.C.	Industrial Hygiene
Metis Heritage Association Yellowknife, NWT	Traditional and Indigenous Knowledge
Dr. Kevin Morin President Morwijk Enterprises Ltd. Vancouver, B.C.	Acid Base Accounting
MORWIJK Enterprises Ltd. Vancouver, B.C.	Geochemistry and Acid Generation Evaluation
Oikos Ecological Group Vancouver, B.C.	Ecosystem Mapping
Elizabeth Wyman Office Compliments Yellowknife, NWT	Long Distance Labour Commuting
Points West Consulting Vancouver, B.C.	Archaeological Assessment
Polster Reclamation Services Vancouver, B.C.	Reclamation
Sandwell Inc. Calgary, AB	Winter Road and Ice Assessment
SRK Geotechnical Engineers Vancouver, B.C.	Geotechnical Assessment for Open Pits and Underground Mines

Consultants	**Contribution**
Dr. Marc Stevenson Canadian Circumpolar Institute University of Alberta Edmonton, AB	Indigenous and Traditional Ecological Knowledge
The Training Group Edmonton, AB	Training Modules for Human Resource Assessment
Treaty 11 Band Council Rae-Edzo, NWT	Traditional Knowledge
UBC Mineral Laboratory University of British Columbia Vancouver, B.C.	Tailings Settling Testwork

Invaluable assistance was provided by specialist advisors in ecology, wildlife, fisheries, permafrost/terrain, tailings, air quality, hydrology and socioeconomics:

Advisors	**Contribution**
Dr. Peter Boothroyd Associate Professor Centre for Human Settlements University of British Columbia Vancouver, B.C.	Social Issues
Dr. Peter Byrne, P.Eng. Professor of Civil Engineering University of British Columbia Vancouver, B.C.	Tailings Structures and Seismicity
Dr. Bill Freedman Professor of Ecology Dalhousie University Halifax, Nova Scotia	Valued Ecosystems, Sustainable Development, Cumulative Effects, Ecosystem Linkages
Dr. Lionel Johnson Retired Arctic Fisheries Biologist Victoria, B.C.	Fisheries and Aquatics (Lake Trout Specialist)

Advisors	Contribution
Walter Keys President Intertec Management Ltd. Regina, Sask.	EIS Report Presentation
Dr. Peter McCreath, P.Eng. Hydrologist Clearwater Consultants Ltd. Vancouver, B.C.	Hydrology and Water Management
Dr. François Messier Professor of Wildlife Ecology University of Saskatchewan Saskatoon, Sask.	Grizzly Bears, Caribou and Wildlife Habitat
Dr. Holly Peterson Associate Professor Environmental Engineering Department University of Montana Butte, Montana	Air Quality and Dispersion Modelling
Dr. Wayne Savigny, P.Eng. Professor Geology and Geomorphology University of British Columbia Vancouver, B.C.	Terrain and Permafrost
Dr. David Sego, P.Eng. Professor of Civil Engineering University of Alberta, Edmonton, AB	Tailings in Northern Climates

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- staff of the City of Yellowknife and the Town of Hay River

- staff of RCMP, Yellowknife
- Human Resources Managers: Colomac, Lupin, Nanisivik, Polaris

A series of field sampling protocols were developed with the assistance of the Department of Indian and Northern Affairs' Regional Environmental Review Committee (RERC) in the fall of 1993. The environmental baseline studies protocol document was screened and amended by the RERC. The protocol document outlined the biophysical study parameters, methodologies, sampling frequencies and locations proposed for the baseline studies. Members of the RERC provided comments on the draft protocol document that were incorporated in the final baseline studies protocols. The following RERC members participated in the development of the protocols:

Department of Indian and Northern Affairs

Land Resources Division

Water Resource Division

Environment and Conservation Division

Environment Canada

Environmental Protection Service

Canadian Wildlife Service

Atmospheric Environment Service

Inland Water Directorate

Fisheries and Oceans

Government of Northwest Territories

Department of Renewable Resources

Department of Energy

Mines and Petroleum Resources

Policy and Directive Office

Education, Culture and Employment

Aboriginal Communities

Dogrib Treaty 11 Environment Committee

Yellowknives Dene Treaty 8 Environment Committee

Dene Metis Nation

NWT Chamber of Mines

The assistance provided by the above groups was greatly appreciated and particularly important in scoping the environmental baseline studies. A special acknowledgement goes to Environment Canada's Freshwater Institute in Winnipeg and particularly to Dr. Harold (Buster) Welch, Dr. Jack Klaverkamp and Mr. Chris Katopodies.

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In summary, the Proponent wishes to thank all the many individuals named and unnamed that assisted in the preparation of this document.

Disclaimer

The material contained in this E.I.S. has been prepared in response to guidelines issued by the Panel established by the Government of Canada pursuant to the Environmental Assessment and Review Process Guidelines Order. The contents hereof represent the Proponent's best estimate of its prospects for developing the project on its mineral claim block in the Lac de Gras area, based on information currently available and believed by management to be reliable. Any estimates or forecasts of levels of production, ore grades and reserves have been prepared for purposes of the environmental review process only. They have not been prepared in accordance with securities regulatory requirements pertaining to disclosure of future-oriented financial information and accordingly may not be relied upon for investment purposes.

1. Approach to Environmental Assessment

The NWT Diamonds Project is located in the Northwest Territories, approximately halfway between Great Slave and Great Bear lakes. Mine development will take place north of Lac de Gras in the tundra environment, approximately 200 km south of the Arctic Circle (Figure 1-1). The environmental assessment of the setting surrounding the NWT Diamonds Project consists of an evaluation of the characteristics of the project site as well as an analysis of the conditions existing in communities that may be affected by project development.

The proposed project would be undertaken in a relatively undisturbed portion of the "Barren Grounds". This region consists of the central portion of the Northwest Territories above the treeline. Since there are no permanent settlements in the immediate vicinity of the project area, the assessment of the socioeconomic setting requires an examination of the closest communities, the communities that may be affected by project-related employment and the City of Yellowknife, which will provide important goods and services to the project site.

1.1 Methods

The assessment of the physical and biological setting is based largely on fieldwork completed specifically for the NWT Diamonds Project. Due to the remote location of the mine development site in an unpopulated area, there are few previous studies that describe the physical and biological characteristics at the project site. Since Dene and Inuit groups and their ancestors have historically used the Lac de Gras area, their traditional knowledge of the biophysical conditions surrounding the project site provides an important source of information. Regional studies of various components of the terrestrial and aquatic environment have also been used to validate the baseline information.

An intensive field sampling program conducted in August and September 1993 resulted in a report entitled *Baseline Environmental Study Protocols* (BHP 1993). This report describes the sampling and monitoring programs required to complete a thorough assessment of the baseline physical and biological setting. Communities and government have been kept involved and informed of the extent of environmental baseline studies undertaken for the NWT Diamonds Project. Comments from the NWT Regional Environmental Review Committee are contained in Appendix II-A7.

Field studies were initiated in 1993 and are ongoing. Extensive field work was conducted during the summer of 1994 and has provided the basis for the identification of ongoing research needs. Additional field studies in the summer of 1995 will provide more information on specific site characteristics.

◎ Table of Contents

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NWT DIAMONDS PROJECT

Figure 1-1.
The NWT Diamonds Project

Source: BHP

The Proponent has begun to document traditional ecological knowledge relevant to understanding the environmental setting of the project area through several approaches, including a literature review, compiling the results of the Proponent's communications program, accessing traditional land use information from the Dene Nation and interviewing members of various Aboriginal communities. Interviews with Inuit residents in Coppermine and members of the Dogrib Treaty 11 and Metis Nations have begun to provide useful knowledge on baseline environmental conditions in the project area. Traditional knowledge specific to various activities and valued ecosystem components (VECs) are integrated throughout this volume, while knowledge of general land use patterns by Aboriginal people is presented in the following section. Traditional land use trails, locations and activities relevant to the project area have been documented on maps obtained from the Dogrib Treaty 11 contribution to this report (Appendix I-A1: Maps 1 to 4), the Dene Nations' Mapping Project data base (Appendix I-A3) and the Inuit Land Use and Occupancy Study (Freeman 1976).

The assessment of the existing socioeconomic environment is based on the evaluation of semi-structured interviews, government statistics and information obtained from various documented reports. A socioeconomic study was initiated in 1994 to determine the characteristics of the human environment that could be affected by mine development near Lac de Gras. Previously documented information such as federal, territorial and community statistics, and reports from previous studies on relevant communities, provided the basis for much of the information on baseline socioeconomic conditions.

Information on community issues and demographics, as well as specific project-related concerns, was obtained through community visits and semi-structured interviews with key representatives of communities. Interviews with residents of Coppermine and Yellowknife contributed much recent and meaningful information.

The results from the Proponent's communications program and interviews conducted as part of the traditional knowledge studies provided insights into community concerns relating to existing socioeconomic conditions as well as those specifically relating to project development.

In addition to the analysis of impacts to communities, the economic benefits of project development for the Northwest Territories and Canada were estimated. This evaluation was based on consideration of employment, economic development and related fiscal implications.

Since the assessment of the environmental setting of the NWT Diamonds Project requires the analysis of a wide range of subjects, this volume introduces the use of valued ecosystem components (VECs). VECs have been defined as "the environmental attributes or components identified as a result of a social scoping exercise as having scientific, social, cultural, economic or aesthetic value" (FEARO 1986). The use of VECs enables the Environmental Impact Statement

(EIS) document to focus on subjects of particular concern. The term "VEC" refers to ecosystems, which also embrace components of social systems such as human values, cultures and lifestyles.

VECs were documented as a result of the scoping meetings conducted by the federal Environmental Assessment Panel during March and April 1995 and the interviews that were undertaken to document the concerns and knowledge of Aboriginal people. VECs were selected according to one of the following criteria: public concern, professional concern or cultural/economic concern. VECs were identified through the analysis of issues and the type or source of the specific concern raised during scoping meetings. Particular components or issues designated as VECs are identified throughout the discussion of environmental setting and are summarized in Table 1.1-1.

The spatial boundaries of the environmental setting have been determined according to the characteristics of particular environmental components and the nature of the potential interaction of the project with environmental components. Physical and biological components were studied most intensively within the boundaries of the project claim block and specifically around the main development areas. However, consideration was given to movements and interactions with other elements outside of the claim block. For example, water parameters were studied within the context of relevant drainage basins or watersheds (e.g., the Koala and Coppermine basins). Individual species such as caribou have been described with respect to their seasonal movements or migration routes.

Socioeconomic components and issues were studied at the project site and in the communities that could be affected by project development. The study of human issues at the project site was limited to an examination of the issues affecting project employees and issues relating to outfitters operating within the Lac de Gras area. Outside the claim block area, various communities within the Northwest Territories were studied due to their relative proximity to the project site and the resources they sustain, and/or their role as a potential source of goods and services. The overall effects of project development on the Northwest Territories and Canada were also examined.

1.2 The Aboriginal Context

A cultural perspective is required to provide an appropriate context for understanding the physical, biological and socioeconomic environments prior to proposed project development. The manner in which the Aboriginal people of the region once used, now use and currently view the project area are important for providing baseline data on the nature of these environments. They are also

Table 1.1-1
Valued Ecosystem Components

Valued Ecosystem Components	Selection Criteria: Public Concern	Professional Concern	Cultural/ Economic Concern
Air Quality	X	X	
Aquatic Habitat	X	X	X
Benefit Sharing/Partnership	X		X
Biodiversity		X	X
Caribou	X	X	X
Climate	X	X	X
Community Stability/Immigration	X	X	X
Culture			X
Economic Development	X	X	X
Employment/Training	X	X	X
Eskers	X	X	X
Families	X	X	X
Fish	X	X	X
Grizzly Bear	X		X
Groundwater		X	
Historic Sites/Burial Grounds	X	X	X
Human Health	X	X	X
Hydrology	X	X	
Land Use and Stewardship	X	X	X
Outfitters	X	X	X
Permafrost		X	
Territorial Lands	X	X	X
Traditional Knowledge	X	X	X
Traditional Lifestyle	X	X	X
Vegetation		X	
Wage Economy	X		X
Water Quality	X	X	X
Wilderness	X		X
Wildlife	X	X	X
Wildlife Habitat	X	X	X

important by way of illustrating why these environments are intimately connected in the minds of Aboriginal people, and how the impact on one environment may affect another. By considering the importance of these environments, and their interrelationships, from an Aboriginal point of view, the Proponent can better appreciate, address and mitigate the concerns that Aboriginal people might have about the environmental and socioeconomic impacts of the project. The meaning of these environments and their interrelationships from an Aboriginal perspective begins with a historical overview of Aboriginal land use in the project area.

1.2.1 History of Aboriginal Land Use

Aboriginal people have used the Lac de Gras area for many centuries. Human use of the area may, in fact, extend back several thousand years. Over the centuries, as the climate and position of the treeline changed, and as social, economic and other needs dictated, the area was inhabited intermittently by small nomadic bands. A Paleoeskimo culture, known as the Arctic Small Tool Tradition, may have penetrated the treeline some 3,500 years ago, while ancient ancestors of the modern Dene, known as the Taltheili Tradition, may have first used the region some 2,500 years ago. Throughout recent history, the Lac de Gras area has been utilized by Dene as well as Inuit. Throughout these periods, caribou was the primary focus of land use, although fox trapping assumed greater importance after 1930.

1.2.1.1 Dene Land Use

Dene living east of the Mackenzie River utilized lands in the transitional boreal forest and adjacent barren grounds. Here, they exploited a wide variety of resources, especially fish and caribou. In fact, the society and economy of some Dene groups such as the Dogrib, Yellowknives and Chipewyan were closely tied to the movements of the Barren Ground caribou (Gillispie 1981; Helm 1981). During the early part of the 18th century, small Dene hunting parties occasionally travelled to Fort Churchill on Hudson Bay to acquire trade goods. By the end of this century, trading posts were established near Dogrib and Yellowknives lands. Shortly thereafter, Dene leaders, such as the legendary Akaitcho of the Yellowknives and Edzo of the Dogribs, became middlemen in the fur trade as they manoeuvred to maximize gains for their followers. This soon lead to inter-tribal hostility, resulting in changes to the territories of some groups. Eventually, Akaitcho and Edzo restored peace to the region, establishing a set of unwritten laws by which many Dene elders still live today (Appendix I-A1).

Alterations to traditional land use patterns continued throughout the 19th and 20th centuries owing to the establishment of fur trade posts and the introduction of foreign diseases. By the 1930s, foreign diseases had decimated the Yellowknives to such an extent that they were forced to recombine with their Dogrib and Chipewyan neighbours to form large enough hunting parties to survive.

Many Dene still have extensive ties to the Lac de Gras/MacKay Lake region, which serve to validate their spiritual and physical connection to the land, or "*ndè*":

"My father worked on Ek'ati (Lac de Gras) at one time; all our fathers have worked on Ek'ati at one time. That is where our fathers raised us... Nqdixait (MacKay Lake) was where an old woman died on us while we were trapping... All the land over there is where all the dead bodies are laid. Kak'tei is where grandmother had died and they had to bring her across the lake and over by Kqk'etiba. They carried her there and they buried her. And also my younger brother, Johnny, is buried there... We have a lot of relatives who are buried in the Barren Land. My older sister 'Daali', my uncle 'Eht'akw'q' wife Adele and the person we call 'Wokwekwit'a', his young daughter and many more people. Every year, every summer is how we worked there" (Laiza Koyina, elder, Rae Lakes).

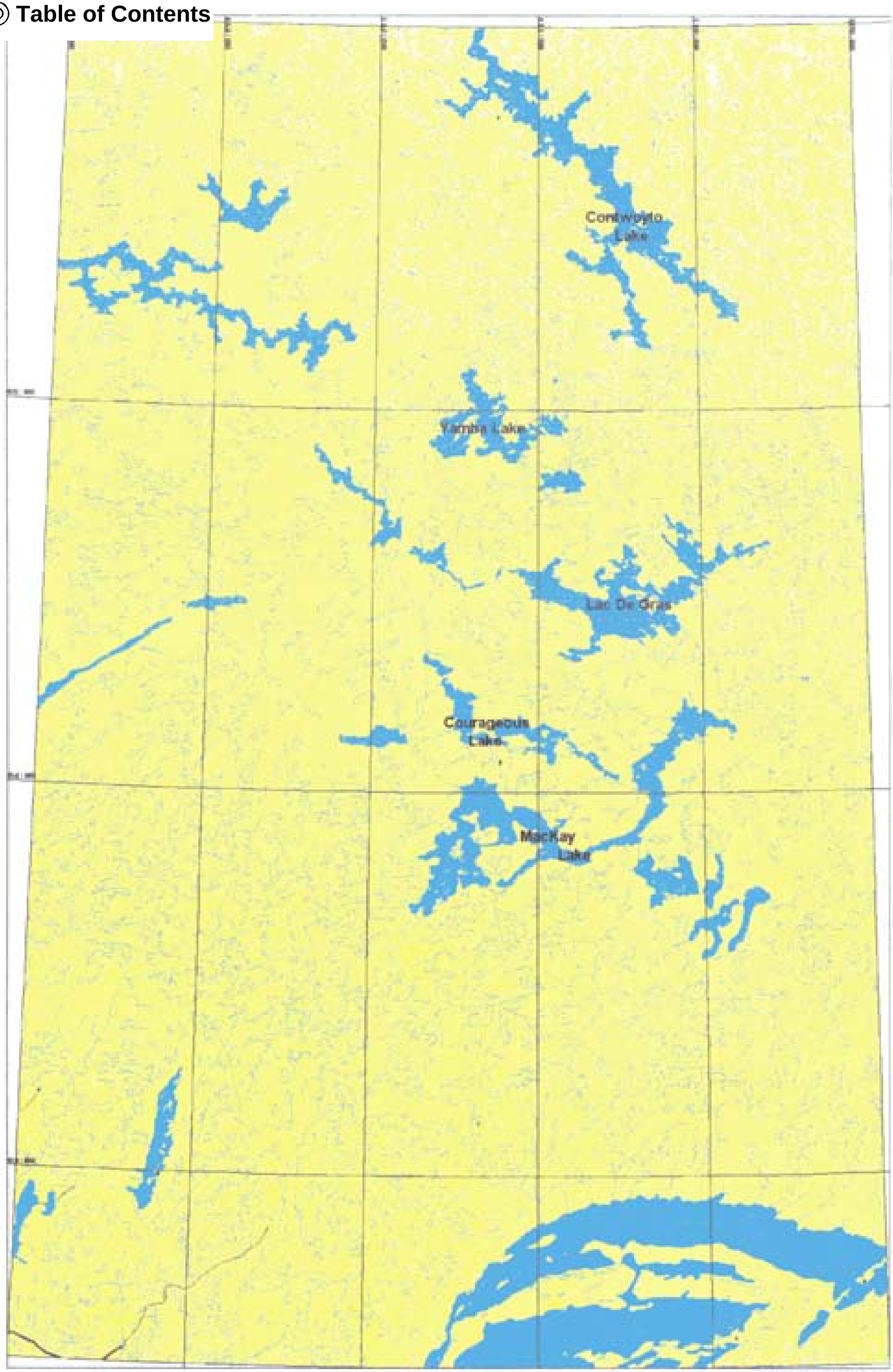
"*the heart of the (Yellowknife Dene Portage Trail)... is MacKay Lake, particularly the places where our best hunters waited each August for the arrival of the caribou. In the past, a good fall hunt meant that our families would have enough meat, fat, tents, and clothing to survive the winter on the land. We still travel to these places every year for a fall hunt. Because we have used these portages and hunting grounds for many generations, much evidence of the Yellowknives Dene presence can be found there. Our Elders speak of the deep significance that this area holds for them; burial sites of their kin and ancestors; former camp sites and gathering places...*" (Yellowknives Dene First Nation 1995).

Cultural sites in the vicinity of and traditional knowledge about the Lac de Gras area are, in fact, viewed by some Dene as playing a central role in preserving their identity as people:

"*...Ek'ati (Lac de Gras) is a place where we work together. So when we say 'our land' it is true because, while we looked for game, we met and worked together*" (Andrew Gon, Rae Lakes).

The extent of Dene land use of the Lac de Gras area is illustrated in the following series of maps (Figures 1.2-1 to 1.2-8). Derived from the Dene Mapping Project data base, and reproduced with the permission of the Dene Nation, these maps depict the land use patterns and activities of Dene and Metis elders and hunter/trappers from Dettah, Yellowknives (N'dilo), Lutsel K'e, Lac la Marte, Rae Lakes and Rae-Edzo (which included land users now residing in Snare Lake). These maps document the travel routes and resource use locations that were used by the inhabitants of these communities in the vicinity of the project area from the early 1900s to 1974. Although these maps were constructed from the traditional knowledge of Dene and Metis elders and land users, as the Dene themselves remind us (Appendix I-A1, p.11), knowing the "land" cannot be derived from

◎ Table of Contents



Source: Dene Nation

Dene Community
Trail Data

Figure 1.2-1

Study Area
109 - 114 Longitude
62.5 - 66 Latitude

◎ Table of Contents

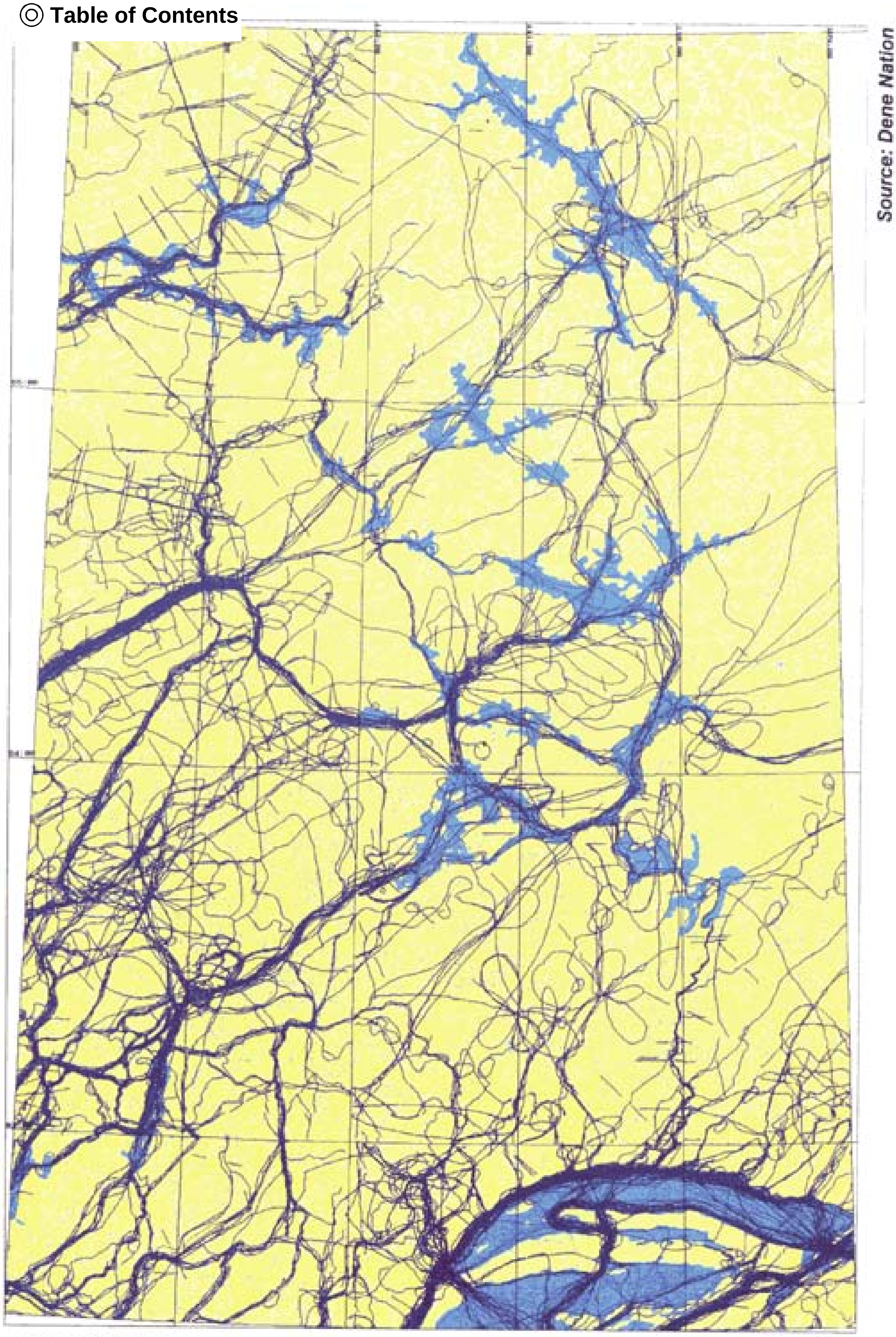


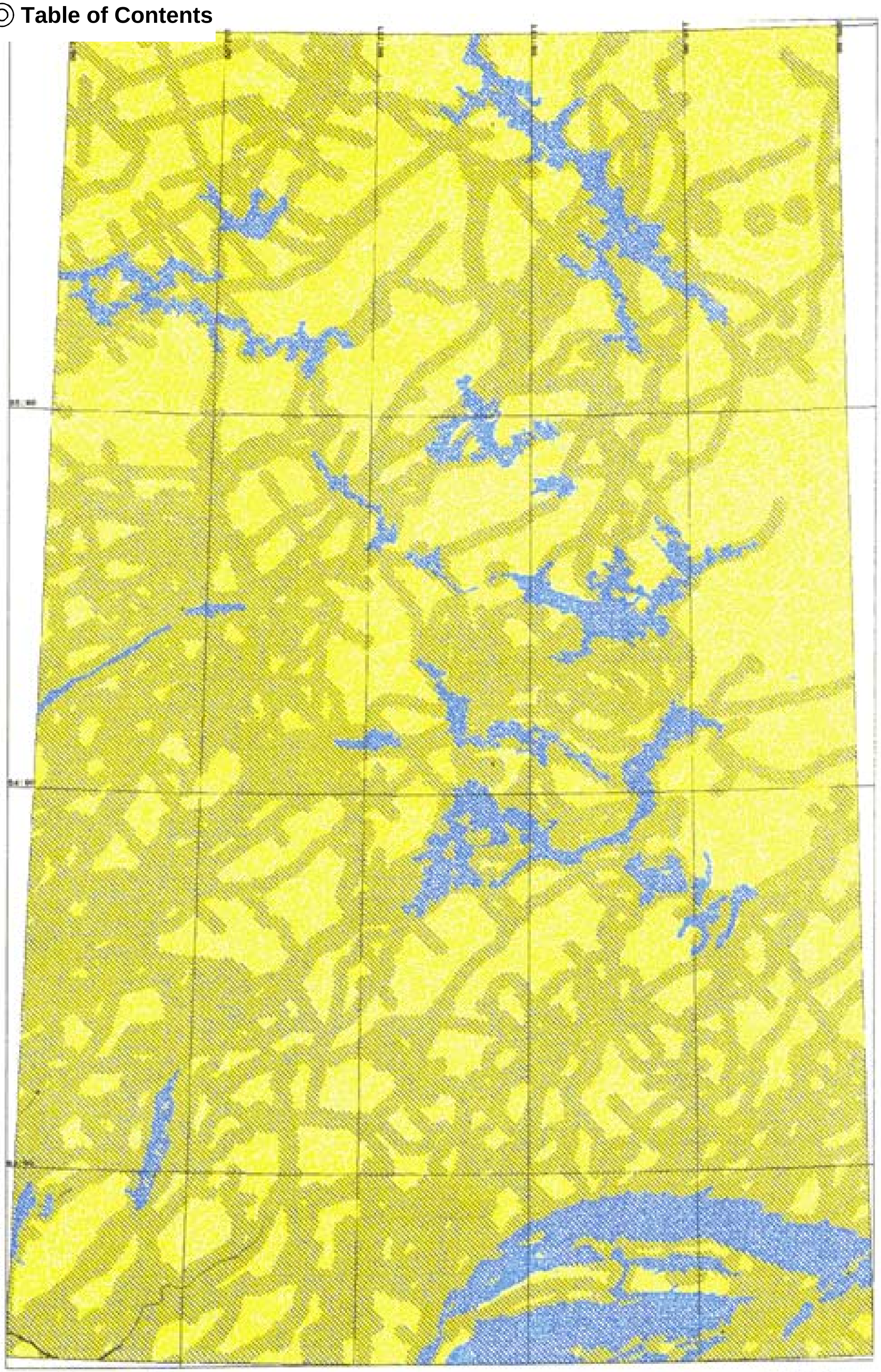
Figure 1.2-2

◎ **Table of Contents**

Dene Community Trail Data

Figure 1.2-3

Non Winter Activity 1



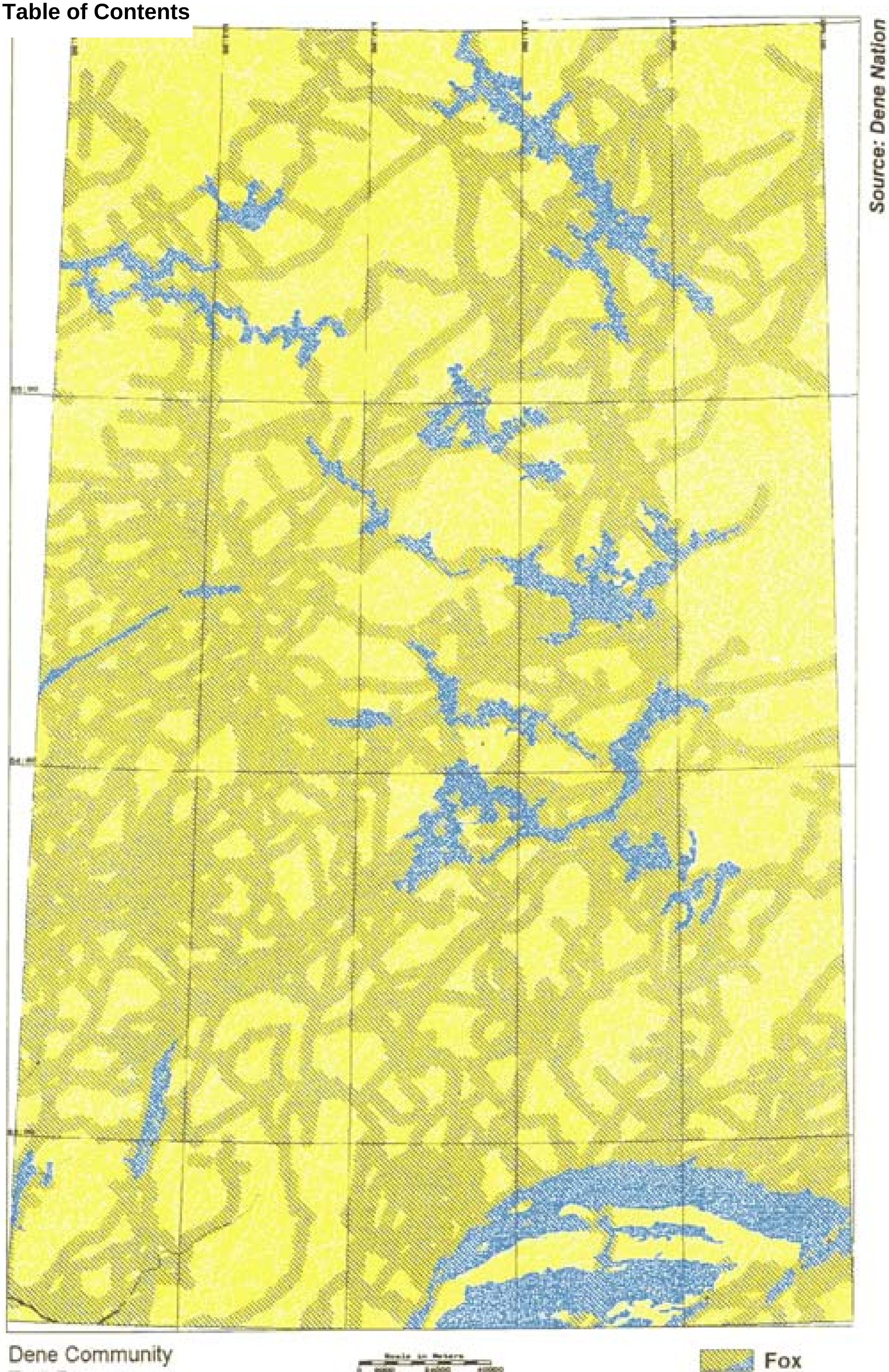
Source: Dene Nation

Dene Community Trail Data

Figure 1.2-4

Winter Activity 1

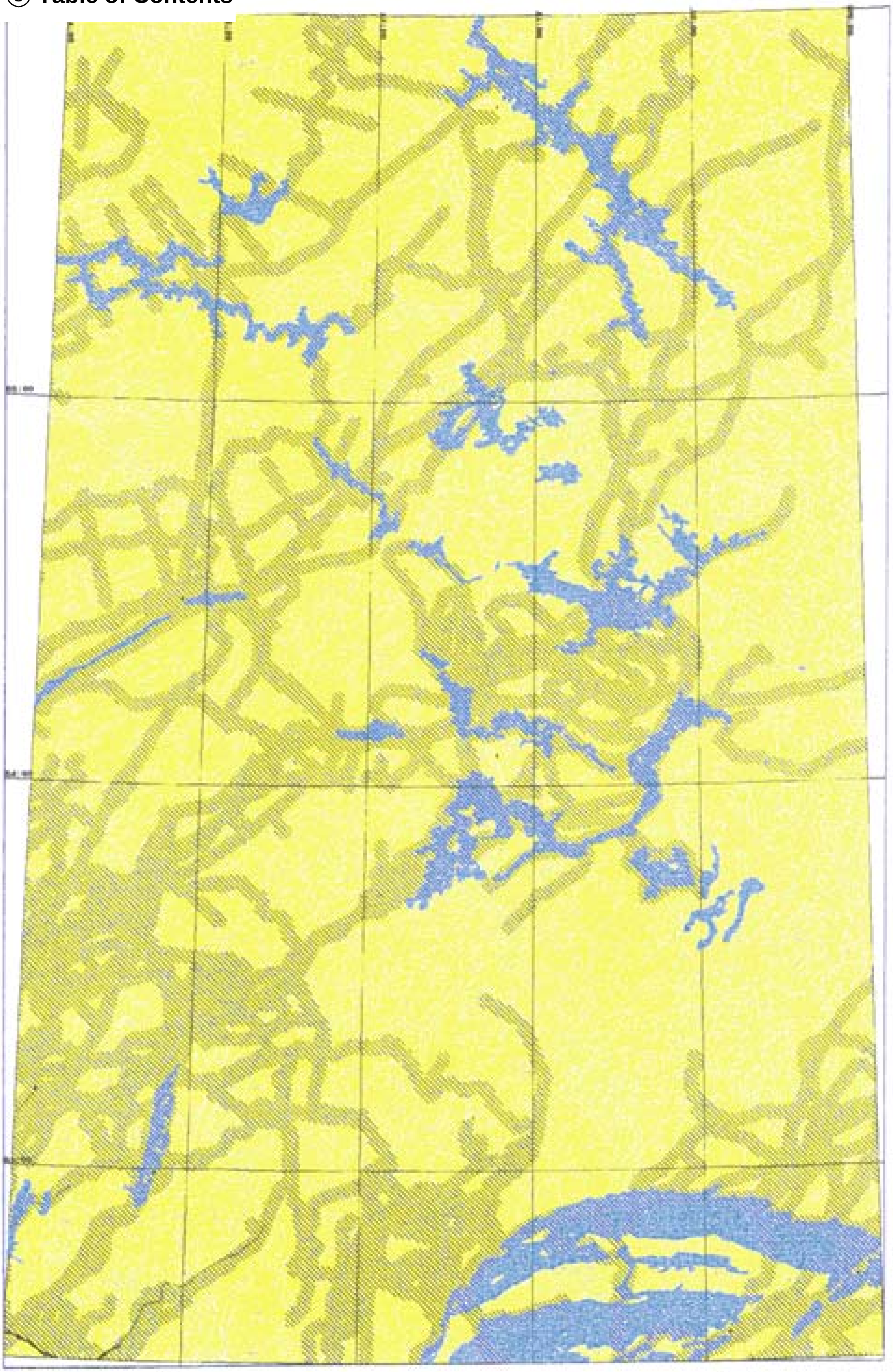
◎ **Table of Contents**



Dene Community
Trail Data

Figure 1.2-5

◎ Table of Contents



Source: Dene Nation

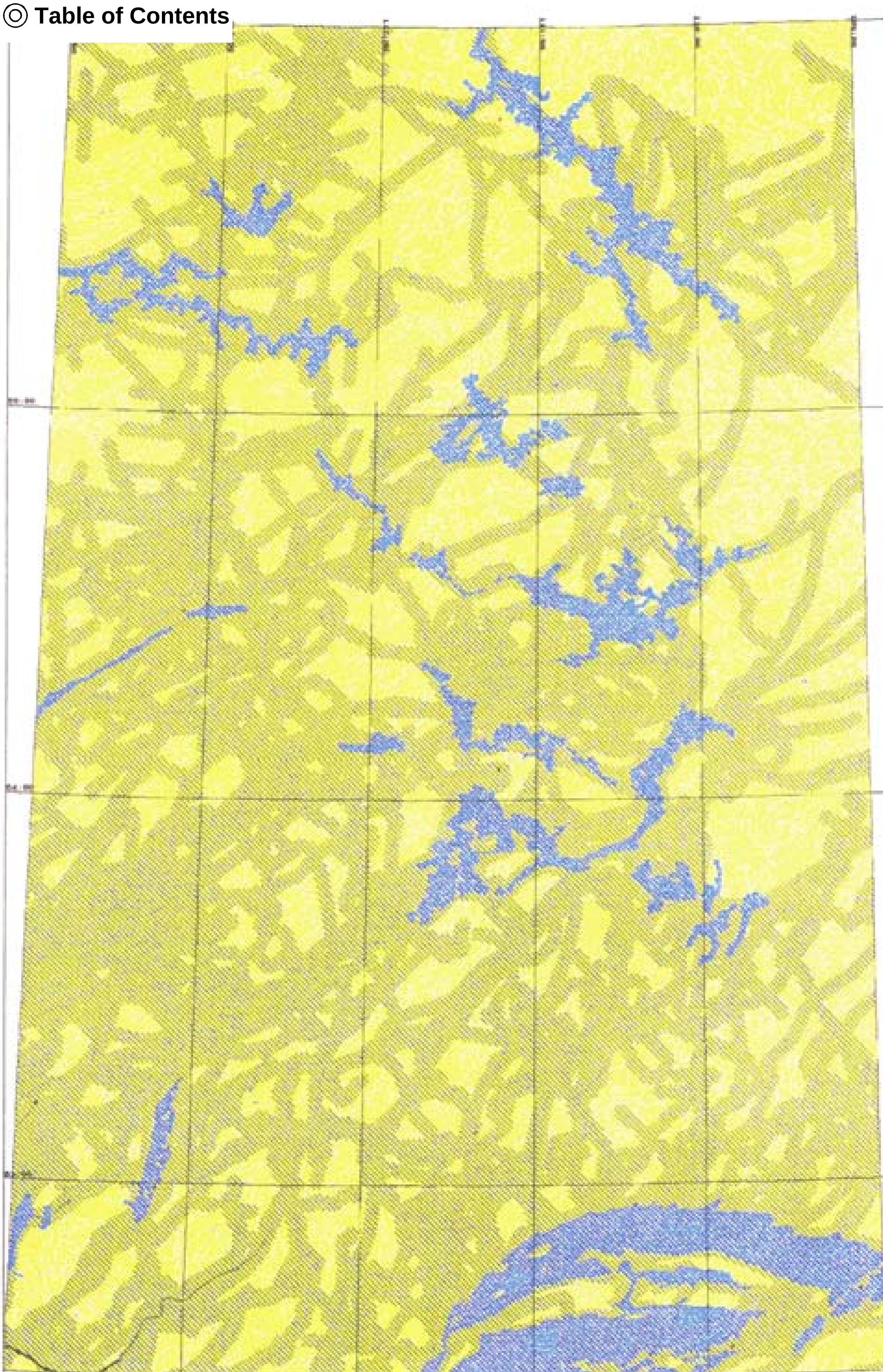
S22: Caribou hunting in winter only.

Dene Community Trail Data

Figure 1.2-6

Caribou S22

◎ Table of Contents



Source: Dene Nation

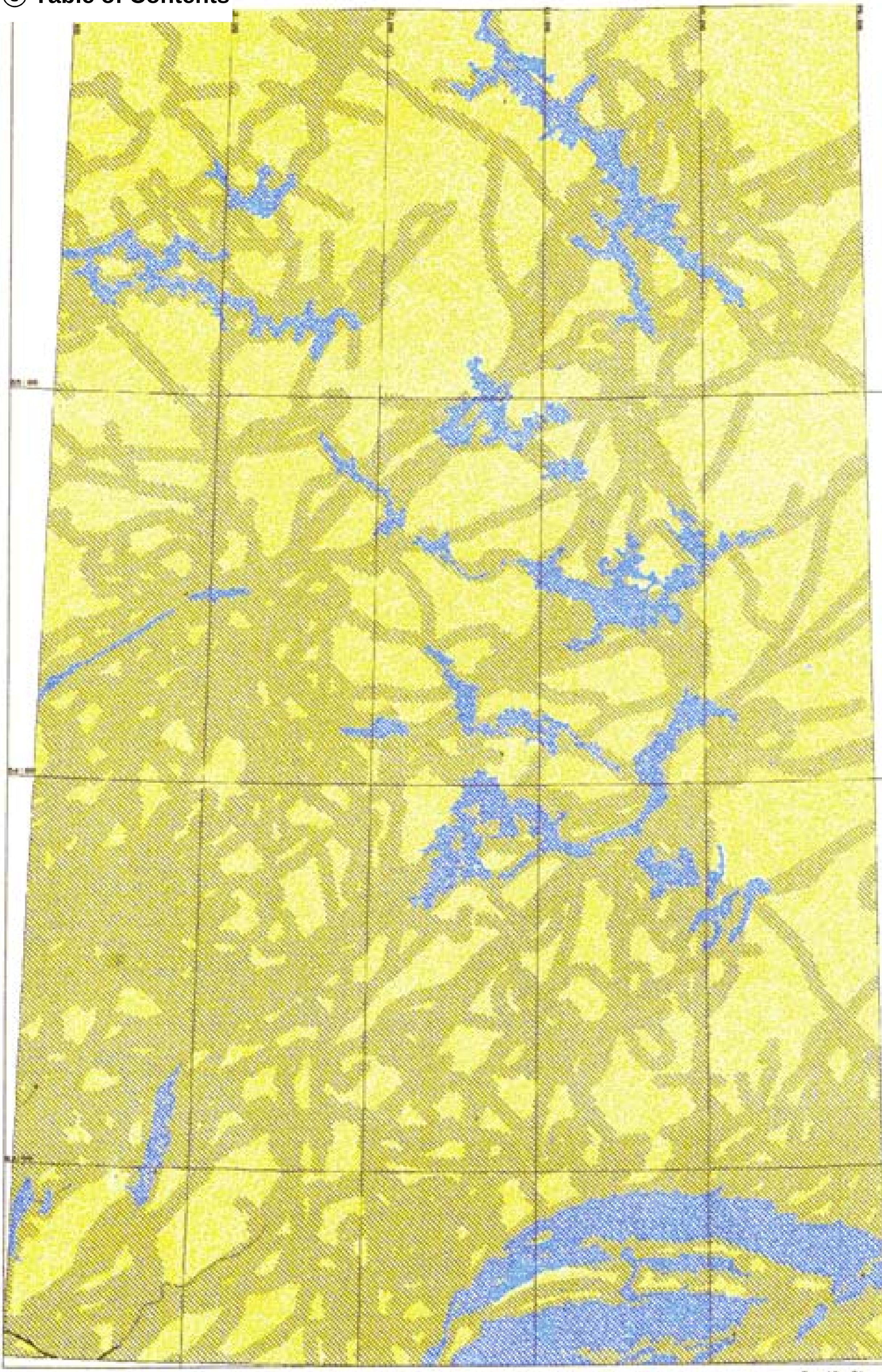
DT < 1960: Activity Zones used before 1960.

Dene Community
Trail Data

Figure 1.2-7

Activity
Zones
DT < 1960

◎ Table of Contents



Dene Community Trail Data

Figure 1.2-8

maps. Knowing *ndè* comes from listening and learning from the elders, and from working and using the land (Appendix I-A1, p. 11).

Figure 1.2-1 depicts the study area for which Dene land use activities and patterns are summarized, with only the English names of major lakes in the project area provided. Figure 1.2-2 illustrates the trails leading from the above communities into the barren lands. Particularly evident in this map is the extent to which the Lac de Gras/MacKay lakes area was used by the Dene. Some insights as to how the land was used, and in what seasons, can be obtained from the following:

"*... Our ancestors loved going to the barren land. Every season they go the barren land. In the old days, there were no white man things. The women made clothes from the caribou hide. The women make caribou pants and caribou skirts. They made clothes out of caribou hides and they used the caribou hides... to make clothes. Our ancestors loved to travel on the barren land and they go there every season. Our ancestors and my father, they travelled on the barren land. My father used to travel to Ek'ati. They used the birch bark canoe on Ek'ati, but I never travelled there in the summertime. I remember living there only in the winter time*" (Laiza Germain, Rae Lakes).

"*From Kq they go to Ek'ati tata (Mao 4, Appendix I-A1) to trap. We travelled with a canoe and we go right beside the eskers. That's where I trap, that place was good for trapping. That's why we have always travelled there...* (Suzie MacKenzie, Rae Lakes).

The extent of traditional land use of the Lac de Gras area by Dene during the summer (June through August) and winter (November through March) can be compared by referring the Figures 1.2-3 and 1.2-4. Evident in these maps is the greater intensity of land use during the winter. Prior to the adoption of fox trapping and the repeating rifle, which made the hunting of caribou easier, Dene travelled to the barrens primarily to hunt caribou, first in the spring during the caribou migration north, and then again in the fall when the caribou returned. Here, they would normally obtain only enough caribou to suit their needs and then return to their settlements:

"*They (Dene) used to go by canoe from Fort Rae, maybe they go for about two or three weeks. They go out there and they kill caribou and come back and that's it, that's the farthest point*" (Archie Mandeville, Yellowknife).

However, as evidenced in the above references to the use of canoes and the following quote, summer use of barrens sometimes extended into the fall as the men waited for the caribou to return:

"*When summer comes the people hunt, the ducks (there), and the people must depend on the caribou. First, men go duck hunting and then they go caribou hunting around Ek'ati* (Suzie MacKenzie, Rae Lakes).

Caribou were again hunted on the edge of the tundra in the fall when furs were in peak condition for clothing and caribou were migrating southwards in large herds towards the treeline. However, after fox trapping was incorporated into the land use activities of the Dene, use of barrens began to extend well into the winter:

"Before I got married, I travelled great distances to other lands. Like Titlita and beyond. After I got married, my husband Zemi had strong naawo *(knowledge). Before Christmas we went to the barren land Ek'ati and Dehzati (Appendix I-A1: Map 3) that is where we lived. We travelled to the barren land going through Gots'okati and Satsoki (Appendix I-A1: Map 2) and over the mountain... From there, there are two big lakes and a third that is called Yahbati (Appendix I-A1: Map 4) and from there, Ek'ati... We had Christmas just before Ek'ati towards the barren land... we lived there (around Ek'ati) a lot... They travelled there in the late fall and lived there. I lived there in the winter time (to trap)* (Laiza Germain, Rae Lakes).

A comparison of Figure 1.2-4 with Figure 1.2-5 demonstrates the close correspondence between winter use of the region and fox trapping. Although the traditional caribou hunting grounds of the Dene extended well into the barrens, with the introduction of the rifle and the fox fur trade, Dene began to travel further into the barrens for longer periods of time. Here, during the late fall/early winter they set traplines (Figure 1.2-5) and hunted caribou to survive the winter (Figure 1.2-6). While the area between Lac de Gras and MacKay Lake was an important area for fur trapping and caribou hunting, these activities were carried out as far north as Contwoyto Lake and east as Aylmer Lake.

With the decline in fur prices in the late 1940s, however, both the intensity and extent of Dene use of the Lac de Gras area declined. Even so, Dene continued to travel to and use the barrens and Lac de Gras area. In fact, a comparison of Dene land use activities before 1960 (Figure 1.2-7) and after 1960 (Figure 1.2-8) reveals that Dene use of the Lac de Gras area declined only marginally after this date. This is a significant finding because the late 1950s and early 1960s was a time of significant change in Dene economy and lifestyles owing to government resettlement programs, increasing opportunities in wage labour (e.g., mining, DEW line, government, etc.), and the introduction of snowmobiles and other forms of mechanized transportation. Yet, Dene continued to depend heavily upon *ndè* and derive sustenance from what it had to offer.

1.2.1.2 Inuit Land Use

Inuit from the Coronation Gulf area traditionally hunted caribou and fished as far south as Contwoyto Lake during the summer and early fall. Occasionally, families overwintered at caribou crossings around this lake, if they had obtained enough meat and fat to supply their food and heating requirements for winter (Farquharson 1976). Mostly though, they descended the Coppermine River in the fall to the coast where they waited for the ocean to freeze before assembling in large sealing villages on the sea ice.

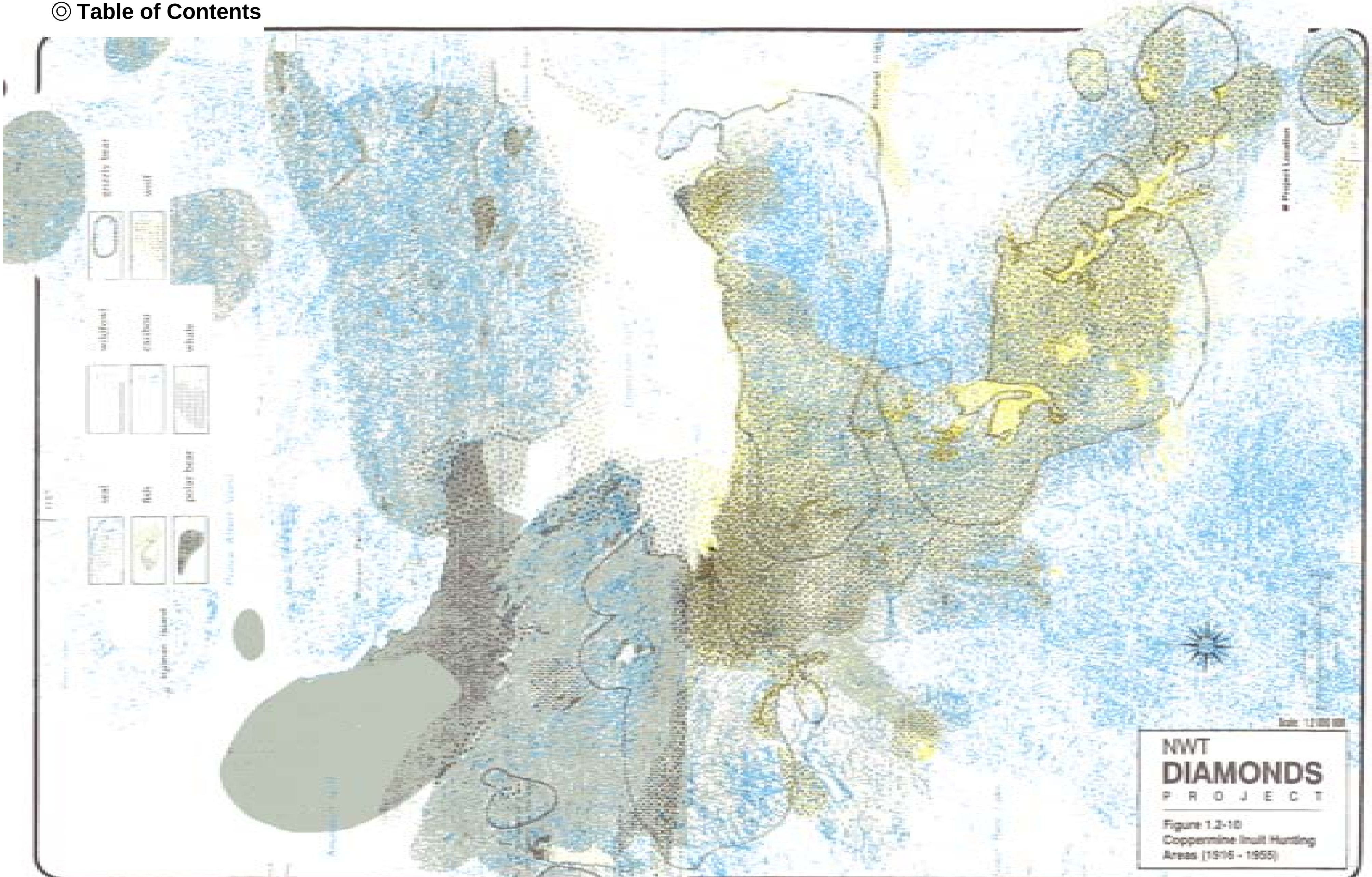
After establishment of trading posts on the Arctic coast during the early part of this century, Inuit began to travel further afield during the winter in search of Arctic fox. With the introduction of the rifle in the 1920s, Contwoyto Lake and its surrounding lakes (Nose, Pellet, Concession) became an important winter fox trapping area and hunting ground. With the acquisition of rifles enough caribou could now be cached to last the winter. Subsequently, winter use intensified. Fishing, mostly with nets in the fall, was also heavily pursued throughout the year.

Campsites were normally established at major caribou crossings, and a large number of traps were set near or around food caches. However, when supplies ran low, Inuit were forced to travel considerable distances in search of food. Frequently, Inuit would travel towards the treeline as far south as Aylmer, Lac de Gras, Point and Itchen lakes for caribou. In comparison with other interior regions exploited by the Copper Inuit, the Contwoyto Lake area was used intensively.

With the building of the DEW line in the 1950s and early 1960s, Inuit land use in the vicinity of the project area once again decreased. Inuit use of the area declined again in late 1960s with the introduction of the snowmobile. Before this, Inuit living at Coppermine and Bathurst Inlet had to maintain seasonal hunting camps and trapping cabins many tens of kilometres to the south near good hunting territory. However, the snowmobile lessened the need to maintain such facilities, as Inuit could now travel farther over shorter periods of time. Today, only a few Inuit hunt and trap near the project area, though Inuit outfitters use the area for sport hunts.

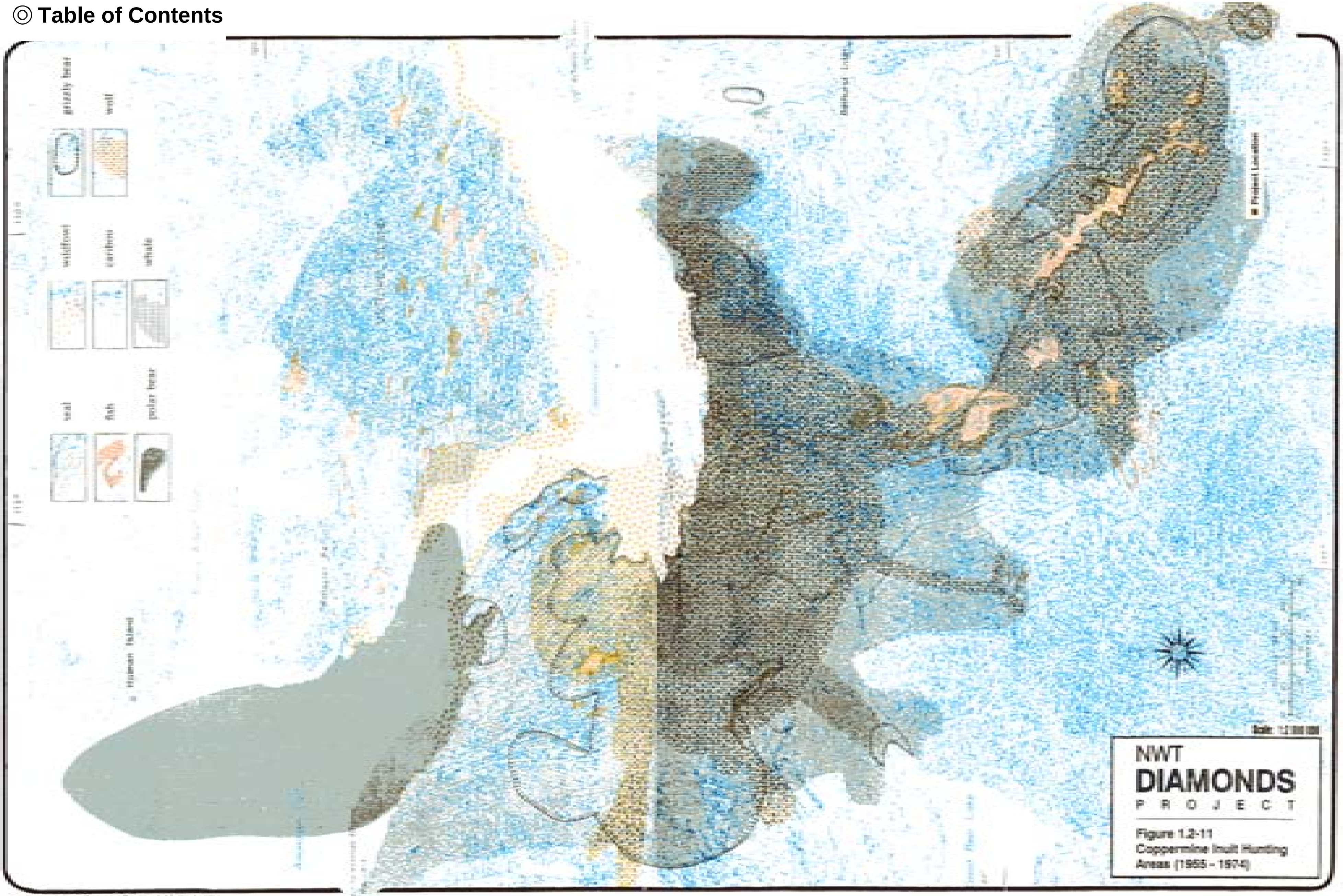
Figures 1.2-9 to 1.2-11, derived from the *Inuit Land Use and Occupancy Project* (Freeman 1976), illustrate Inuit land use activities from Lac de Gras north to the Arctic coast. Traplines for the period from 1916 to 1955 are presented on one map (Figure 1.2-9), while hunting activities for 1916 to 1955 and for 1956 to 1974 periods are rendered on two maps (Figures 1.2-10 and 1.2-11). As shown, Inuit hunted for caribou, wildfowl, grizzly and wolf on all sides of Lac de Gras except the west. Fishing, on the other hand, was restricted to Contwoyto and other lakes to the north. Though less intense than before, the same land use pattern characterizes Inuit use of the area today, with the addition of outfitting/sport hunting.

Source: Milton Freeman Research Limited 1976



Source: Milton Freeman Research Limited 1976

◎ Table of Contents



Source: Milton Freeman Research Limited 1976

1.2.2 Aboriginal Views of Ecosystem Relationships

1.2.2.1 Aboriginal Perspectives on Environment and Society

"*Anything that happens in our territory is not just environmental in nature, it impacts our culture, economy, (and) spiritual relationship with the land*" (Darrell Beaulieu, Yellowknives Dene Band 1995).

For many Aboriginal northerners, environment and society are intimately related. The Dene, for example, object to the separation of biological, physical and socioeconomic environments in efforts to assess the impacts of industry on their lands, because such a distinction "makes it difficult to appreciate how closely they are integrated in the Dene way of life" (Fred Sangris, Presentation to the Environmental Assessment Panel 1995). At the same time, Dene feel that a "holistic view of the ecosystem and its functions and linkages (Fred Sangris, Presentation to the Environmental Assessment Panel 1995), with concentration on the "key linkages and interactions between the biophysical and socioeconomic environments," must be incorporated into environmental impacts assessment (Dogrib Treaty 11 Council Presentation to the Environmental Assessment Panel 1995). Thus, understanding the linkages between and connections among elements, not just the elements themselves, is integral to adequately address the effects of development on Aboriginal people and lifestyles. As one Inuit representative recently stated at the 1992 Inuit Circumpolar Conference in Inuvik:

"*When we think of something or discover a fact, we also think of all the interconnections between that fact and everything else. And so it is going to be connected to everything in our culture.*"

Driving these concerns is the belief that, by separating environment from society, the importance of each and their relationship will be devalued. Aboriginal northerners want all the values they derive from their connection to the land accurately described and represented, including those associated with "physical, economic, mental, emotional, cultural, spiritual" well-being (Fred Sangris Presentation to the Environmental Assessment Panel 1995).

Many Aboriginals perceive themselves as being part of the land. It is who they are and what defines their identities. Being part of the land sustains them in this increasingly changing world emotionally, spiritually, if not physically. Some Dene elders, in an effort to convey their feelings and concepts about the land, offered the following:

"*our riches are our land, the land is our bank*" (Louis Wion, elder, Snare Lake Presentation to Proponent 1995).

"*the land is rich in minerals, (but) animals create riches, not mines*" (Amin Tailbone, elder, Snare Lake Presentation to Proponent 1995).

Thus, Aboriginal concerns about the environmental impacts of industrial development lie not so much in the concern for any one element but for its impact on the entire ecological system, and in the need to maintain complex physical, social, and spiritual interrelationships between humans and the natural world in the face of such impacts.

From this point of view, responsibility lies in actions and behaviours that nurture and enhance ecological relations... that is, the life of other species of animals and plants, and the relationships between humans and animals (Wolfe *et. al.* 1992). The relationship between humans and nature has been described as reciprocal "in which man invests himself in the landscape, and at the same time incorporates the landscape into his own most fundamental experience" (Momaday 1976:880).

The holistic view that northern Aboriginal people still hold towards nature is reflected in the Yellowknives Dene presentation to the Panel (1995):

"*We are taught by our Elders to see the environment as a whole -- to consider the whole food chain, and to see ourselves as part of the environment... environmental reviews should take a more holistic view of both the environment and the project so that we have a more complete picture of what will be happening. We have to view how this proposed diamond mining fits within and affects a functioning ecosystem, of which we are a part. Many of the words commonly used to describe the area -- barren, remote, isolated -- make it seem like there is little to be concerned about. But the area is actually a complex ecosystem where all parts are connected and all parts are important. We are connected to activities in the mining area because, for example, we harvest the wildlife that migrate through there. Other animals and plants we harvest may be affected because they are connected to that area in ways we don't even know yet."*

The concept of harmony has profound implication for the ways in which Aboriginal peoples continue to approach the use of land and resources, as well as for personal and community healing. It is a concept the elders want industry to embrace:

"*We depend on the land...We eat off of it, and it brings us healing. We have travelled this land (Lac de Gras area) and have paddled its waters. We are dependent upon the caribou for meat and clothing...It would be nice if they (Whites) were to show care in how they work the land. If not, it will not be good.*

...We cry out because we love this land...Animals cry. Who cares enough to cry out on their behalf...Let's hope for a change in the future. Not a repeat of yesterday's mistakes" (Andrew Gon, elder, Rae Lakes; for full citation see Appendix I-A1).

1.2.2.2 Importance of Maintaining Ecosystem Relationships

The values that Aboriginal people derive from maintaining their connection to the land relate not just to nutritional benefits, but also to values associated with hunting, fishing, trapping and food collecting activities. These activities relate to the acquisition, processing, distribution and sharing of animals (Freeman *et. al.* 1992). Hunting and the appropriate use of animals sustain the full expression of Aboriginal cultural identity.

Aboriginal northerners have always had a special relationship with the animals upon which they depended for physical, social, cultural, and spiritual sustenance. This relationship demanded great respect, reverence and humility. Showing disrespect for animals by overhunting, not using (underhunting), harassing, not sharing, or thinking badly about them, threatened human survival, for animals would no longer give themselves to humans. The trust would be broken. This is why some Aboriginal people do not look favourably on the "catch and release" practices of sport fishermen:

"*I really disagree with catch and release. If you're gonna go out there to fish, you get what you need and then leave the rest alone... What harm are you bringing on these fish? They're being released (and) you think you feel good about releasing them. You know you released 50 that day (but) that means you've damaged 50 fish that day and how many more are being damaged by other people? I strongly disagree with people that... sport fish, unless you're catching fish to eat for yourself or your animals, or also for other people*" (Ida William Coppermine).

What may seem to be a sound conservation measure to non-aboriginals is felt by some Aboriginal northerners to be an act of disrespect. The fish, having given itself to its procurer, is released, thus devaluing the animal's sacrifice. Anything that threatens to sever the contract between humans and animals, whether it be environmental degradation or the imposition of quotas, jeopardizes human survival. When such threats exist, not only is one's cultural identity undermined, but the cornerstone upon which this cultural identity finds expression and validation is eroded.

Canada's northern Aboriginal peoples have always depended upon partnerships with animals and among themselves to maintain their culture and reproduce their societies. Hunting, fishing and trapping continue to establish and reaffirm productive economic and social alliances. Such activities also serve to validate existing traditional knowledge and acquire new knowledge about the land, as well as to encourage the transmission of this knowledge to younger generations. During communal hunts, the oldest and most experienced men often assume their traditional roles as leaders and decision makers. This tradition is often the reverse of settlement life where younger men have better jobs and more political acumen. Social and economic relations within and between communities are created and maintained through the distribution and exchange of meat and other animals parts. For example, elders are often brought special parts of animals as a sign of respect and affection, thus reaffirming their crucial value to and position in society.

What is so important about hunting, fishing, and trapping – about maintaining a physical and spiritual connection to the land – is that these activities traditionally established, secured and validated the social relationships deemed crucial to Aboriginal survival and existence. Such activities, then, are not merely physical acts, but a set of culturally established rights, responsibilities and obligations that Aboriginal people want the option to continue, if they so choose.

1.3 Ecosystem Characteristics and Linkages

This section describes the manner in which the present volume addresses the characteristics and linkages of ecosystems that are potentially affected by the proposed development of the NWT Diamonds Project. Initially, several key ecological concepts identified by the Environmental Assessment Panel for the NWT Diamonds Project are discussed within the context of environmental impact assessment. The approach used in the actual impact assessment is then rationalized within this conceptual framework. Finally, the general characteristics of the terrestrial and aquatic ecosystems of the study area are briefly described, as are their major linkages with each other and with humans.

1.3.1 Ecological Concepts Identified by the Panel as Important in Environmental Impact Assessment

1.3.1.1 The Ecosystem Approach

The ecosystem approach is a holistic manner of considering the diverse, web-like interconnections among the many components of ecosystems. It does not simplistically view the world as a diverse assemblage of populations, species, communities or environments, but acknowledges that all of these are intrinsically connected, although to varying degrees.

Moreover, the ecosystem approach acknowledges that humans are an integral component of ecosystems. This is particularly true of ecosystems that are directly utilized by humans as sources of sustenance and livelihoods through the harvesting and management of renewable natural resources such as caribou, waterfowl, fish and surface water. However, humans are also connected with species and ecosystems that are not directly utilized, for example, through indirect, non-costed benefits that are attained from such ecosystem services as the provision of clean air, water and soil. Therefore, humans and all other species are affected by any actions that degrade ecosystems.

The ecosystem approach also acknowledges the importance of spatial scale. An important consideration in this respect is that local ecological changes may influence components and processes at larger scales, and the reverse may also be true. Similarly, effects on an individual organism may have an important effect at the level of its population, its community of associated species, and even at the larger scale of landscape.

Temporal dynamics, or changes over time, are also a critical aspect of the ecosystem approach. Change is a pervasive, ecological context – nothing is static in natural, self-organizing ecosystems, or in those that are being actively managed to suit some human purpose.

Acknowledgment of uncertainty is another feature of the ecosystem approach. Since it is not possible to fully measure or understand all of the components and interactions within and among ecosystems, it is also impossible to accurately predict the dynamics of change. There is always a possibility that predictions about ecological changes can be inaccurate, although it is often feasible to estimate the boundaries of the uncertainty in a statistical sense. Therefore, in the context of environmental impact assessment, it must be recognized that complex ecological responses may differ from what was predicted. This is why it is critical to monitor actual ecological responses to undertakings, to ensure that unacceptable impacts are not caused, and if they are, to adaptively change procedures to avoid the impacts or minimize them by appropriate mitigations.

The ecosystem approach is an important, but relatively recent, scientific concept. However, the essence of the ecosystem approach has long been embodied in the world-views of many Aboriginal cultures, particularly in terms of the intrinsic interconnections of humans within the ecosystems that sustain them. This fact is suggested by many testimonies of Aboriginal cultures, as expressed by Darrell Beaulieu, Chief of the Yellowknives Dene Band, which was given during a scoping hearing related to the present undertaking:

"Anything that happens in our territory is not just environmental in nature, it impacts our culture, economy, (and) spiritual relationship with the land."

The notion of the ecosystem approach is clearly relevant to the theory and practice of environmental impact assessment. The ecosystem approach requires consideration of both the direct and indirect consequences of potential changes, at various spatial and temporal scales, as well as attention to implications for both human welfare and that of natural, ecological values.

1.3.1.2 Progress Towards Achieving Sustainable Development

Sustainable development is commonly defined as "development that meets the needs of the present, without compromising the ability of future generations to meet their own needs." This definition of sustainable development focuses on the present and future needs and aspirations of humans.

In this conventional sense, a condition of sustainable development would be represented by an economy that does not deplete its resource base. This can potentially be accomplished by only utilizing renewable resources at or below the rate at which the resources are renewed or regenerated. Non-renewable resources may also be used, but only if their net depletion (which is also influenced by the efficiencies of re-use and recycling) is coupled with an offsetting increase in the stock of a comparable, renewable resource. For example, the use of a fossil fuel may be coupled with a compensating increase in forest biomass somewhere, so there is no net depletion in the global quantity of potential, chemical energy available for use by humans.

However, in accordance with the principle of the ecosystem approach, a somewhat broader definition of sustainable development is required. That definition must accommodate the need to sustain other species and natural ecosystems, in addition to the present and future needs of humans. This latter, more inclusive type of development is referred to as “ecologically sustainable development.”

In this more holistic view, progress towards achieving a condition of ecologically sustainable development requires that proposals to exploit natural resources be designed to realize durable socioeconomic benefits, while respecting the right of future generations of humans to have access to natural resources, and while also maintaining ecological integrity.

Ecological integrity is a notion that cannot be succinctly defined, but is considered to be best represented in ecosystems that, in a relative sense, display the following attributes:

- They have high biodiversity. Biodiversity refers to the total richness of biological variation, including genetic variation within populations and species, the numbers of species in communities and the patterns and dynamics of these over large areas.

- They are resistant to environmental changes and recover quickly after disturbance (the latter is referred to as resilience).

- They are complex in their structure and function (both of these factors generally increase with age of the ecosystem, during succession).

- They have large species and top predators present, because these require relatively large quantities of resources, large areas to sustain their populations, and are long-lived, and therefore integrate the effects of environmental change over an extended time.

- They have efficient and well-controlled nutrient cycling and systems of energy use and transfer. These functions can be damaged if stress or disturbance degrades the balance of the ecosystem, resulting, for example, in the export of dissolved or suspended nutrients in streamwater.

- They can maintain their natural ecological values without interventions by humans through management. For example, if a rare species can only be sustained through vigilant protection, intensive management of its habitat or by a captive-breeding and release program, then its populations and ecosystem are not self-sustaining and are deficient in ecological integrity.

Ecologically sustainable development and ecological integrity are concepts that are clearly relevant to the theory and practice of environmental impact assessment. Consideration must be given to any damages that may potentially be caused to ecological resources required by present and future generations of humans, as well as threats to natural ecological values such as those embodied in the notion of ecological integrity.

1.3.1.3 Cumulative Impacts

Human activities commonly act as environmental stressors, causing various changes in the components and functions of ecosystems. If those ecological changes are judged to be undesirable, they may be avoided by changing the nature of the human activities, or the damages may be repaired through mitigative actions.

Often, however, ecological changes are associated with a complex of environmental stressors, some of which may be associated with human activities, while others are naturally occurring stressors. This complex of stressors and ecological responses may be referred to as cumulative impacts.

For example, certain activities associated with the proposed development of the NWT Diamonds Project may represent environmental stressors, which can potentially cause ecological changes in the study area for this impact assessment. These project-related stressors will, however, be superimposed on an existing regime of environmental stressors. These may be associated with other human activities, such as hunting and fishing, and also with natural environmental stressors such as climate change and natural disturbances associated with wildfire.

In some cases, a particular factor can be acknowledged as a dominant cause of ecological change. For instance, where a small lake must be dewatered in order to mine an underlying, diamondiferous kimberlite pipe, this isolated disturbance will be the overwhelmingly dominant cause of ecological change to the lake ecosystem. In this case, it is not necessary to consider cumulative impacts associated with, for example, climate change or recent fishing effort.

However, cumulative impacts are very important considerations in contexts where the project-related stresses are of a small or moderate intensity. In such cases, additive and more-than-additive effects may be much more consequential than the direct, project-related effects.

1.3.2 Rationalization of the Study Design

In accordance with the EIS Guidelines published by the Environmental Assessment Panel, the ecosystem approach, sustainable development and cumulative impacts have been important considerations in the design and conduct of the environmental impact assessment for the project. The following discussion describes the manner in which these concepts have been integrated into the study design.

Although the ecosystem approach implies a fundamentally holistic view, this does not require that everything be studied, nor that all research be conducted in a fully integrated fashion. Useful and important knowledge can, indeed, be attained by examination of carefully selected components of ecosystems. However, it is critical that the results be interpreted in terms of known or potential connections with other species, with other ecosystems, and with larger-scale, functional attributes such as productivity, nutrient cycling and decomposition. Interpretation must also accommodate the need to understand cumulative impacts and risks to sustainable resource use.

For practical reasons, in virtually all ecological studies, and in all impact assessments, appropriate indicators are selected for study. These indicators are prudently chosen because they are relevant to important aspects of ecological integrity, environmental quality, ecological sustainability or culturally valued attributes. Moreover, changes in those indicators can be interpreted to represent relatively broad, and holistic, ecological changes. (This notion regarding indicator selection is easily understood by considering caribou as a prime object of study in the present impact assessment, as is explained later in this section.)

During the early stages of project planning, the Proponent anticipated potential environmental concerns and discussed the components of a baseline study with community and government representatives. This resulted in the publication of *Baseline Environmental Study Protocols* (BHP 1993). These protocols outlined the focus of the Proponent's work regarding the physical and biological characteristics of the project area.

The specific ecological indicators that have been examined in this impact assessment were selected through analysis of scoping meeting presentations and submissions, and were identified as valued ecosystem components (VECs).

One of the key, ecological indicators that have been examined in this impact assessment is the Bathurst caribou herd. This VEC was universally nominated as being important, because it effectively indicates an important aspect of the sustainability of Aboriginal livelihood and culture in the region potentially affected by the proposed undertaking, while also representing the ecological integrity of the ecosystem.

It is important that the present impact assessment includes studies of those components of the Bathurst caribou herd that pass through places where known, critical habitat is potentially affected by development-related activities. Individual caribou may be affected by direct injuries or mortality (associated, for example, with a vehicular collision), or by disruptions of migration patterns. However, it is also necessary to put those predicted, local effects into an appropriate, ecological context by carefully considering the implications for the health of the entire Bathurst herd, and of the more extensive subspecies *Rangifer tarandus groenlandicus*, and even of the holarctic species *Rangifer tarandus* (which includes all subspecies, including the reindeer of Eurasia). Careful consideration must also be made of potential effects on natural predators and scavengers that rely on caribou, such as wolf, grizzly bear, wolverine, golden eagle and raven. It is also important to examine implications for the sustainability of the harvests by Aboriginal peoples, who hunt caribou as a source of sustenance and for cultural identity, and for sport hunters, who bring economic benefits to the region. Other potential linkages are with other herbivores, such as muskox, hare and lemmings, which may compete with caribou for access to limited food or other habitat components. Larger, functional considerations include implications of changes in caribou abundance for the productivity and species composition of plant communities, and on the closely related processes of decomposition and nutrient cycling. Finally, there must be a consideration of the cumulative effects associated with both project and non-project environmental stressors that affect caribou, including hunting, weather, harassing insects, disease and other factors.

Although the present impact assessment is organized according to a sequential presentation of studies of identified VECs and other aspects of the ecosystem, key ecological concepts identified as important by the project’s Environmental Assessment Panel have been integrated into the study. These include consideration of the larger, interconnected ramifications of changes in VECs for diverse components of the ecosystem, including humans, at various spatial and temporal scales; implications for progress towards sustainable development; and cumulative impacts.

1.3.3 Ecosystem Characteristics and Linkages of the NWT Diamonds Project

This section provides an overview of the areas within the mineral claim block of the NWT Diamonds Project as an ecosystem. Initially, the general characteristics of the terrestrial and aquatic ecosystem types are described. These are then put into broader spatial and temporal contexts, and linkages among components are discussed.

1.3.3.1 General Description of the Ecosystem of the Study Area and its Major Components

The claim block for the NWT Diamonds Project covers an area of about 3,500 km^2 of low-arctic tundra, located about 100 km north of the treeline, roughly between Great Bear and Great Slave lakes. The study area lies in the headwaters of the 520 km long Coppermine River, which has a drainage area of 50,800 km^2 and drains into the Arctic Ocean at Coronation Gulf near the coastal village of Coppermine.

For the purposes of this environmental impact statement, the mineral claim area has been delineated on maps and has been studied as a discrete entity. However, this study area is a component of a much more extensive ecosystem of generally similar character, sometimes referred to as the “central barrens of Keewatin”, which is comprised of a complex of identifiable types of tundra communities as well as rivers, streams, lakes and wetlands.

The study area is extensively underlain by Precambrian bedrock of granitic minerals. Surface exposures of bedrock are relatively uncommon. Most of the landscape is covered by glacial remnants of various types, including extensive boulder fields and sinuous eskers, which provide the most prominent relief feature in the region. The general physiography of the study area is characterized by a low, rolling relief. Surface drainage is correspondingly diffuse, and because of the weak hydraulic gradients, stream and river channels wander extensively.

The natural environmental conditions in the study area are extreme, and are characterized by short cool summers and long, very cold winters. Precipitation is sparse, amounting to only about 37 cm/a. Averaged across the year, the watershed hydrographics consist of about 18 cm/a of surface runoff and 13 cm/a of evapotranspiration. Deep drainage is assumed to be zero because of the extensive development of permafrost, which is complete except under lakes and large rivers. The thickness of the seasonal active layer ranges from several tens of centimetres in organic substrates, to several metres in dark, rocky outcrops. Well-drained terrestrial habitats may become quite dry during the growing season, and small streams may only flow during the brief spring freshet.

About two-thirds of the study area is covered by terrestrial tundra communities and one-third by aquatic communities of lakes, rivers, streams and wetlands. The salient characteristics of the most prominent biophysical types in the study area are briefly described in Table 1.3-1.

Table 1.3-1
General Description of the Most Prominent Community Types in the Claim Block Ecosystem

Community	Description
Aquatic Communities	
Lakes	Lakes are very numerous in the study area and comprise most of the surface water. These lakes have small concentrations of dissolved inorganic substances, are very slightly acidic or circumneutral in pH (that is, about pH 6.3 to 6.6), are well oxygenated throughout the year, and are oligotrophic (that is, biologically unproductive, because of the small supply of phosphate, in addition to constraints associated with the harsh climate). The lakes develop a thick ice cover (2 m to 3 m) during the winter, and are ice-free for about 3 to 4 months of the year.
Littoral Community	The littoral zone of lakes extends from the surface to the greatest depths at which there is a positive net productivity (that is, the rate of photosynthesis exceeds the rate of plant reproduction, so that net primary production exceeds zero). This community type is relatively extensive, because the extreme clarity of the water allows light to penetrate efficiently. Littoral communities are sustained by the primary productivity of algae growing in the water column (the phytoplankton) and on bottom substrates (the periphyton). There are few higher plants in this zone, because of the severe disturbance associated with ice scouring in shallow waters. The primary production is grazed by various species of crustacea and small insects that occur in the water column (the zooplankton), and by insects, crustaceans, molluscs, and other invertebrates occurring in or on the surface sediment (benthic invertebrates). These aquatic herbivores are predated by carnivorous insects and crustaceans, small species of fish (such as slimy sculpin and lake chub), young stages of larger species of fish (such as lake trout and round whitefish), and adults and young of diving ducks (such as scoters and mergansers). The most important top predators in of the littoral community include large fish, and fish-eating mergansers and loons.
Profundal Community	This is a deep-water community, extending beyond the spatial limits of the littoral zone. All primary production in this community is carried out by a diverse assemblage of microscopic algae in the water column. These phytoplankton are grazed by crustacean zooplankton, which are eaten by small fish. Adult lake trout are usually the top predator in this community, along with round whitefish and burbot. Loons and mergansers may eat smaller sizes of fish, and humans may predate on adult fish.

(continued)

Table 1.3-1 (continued)
General Description of the Most Prominent
Community Types in the Claim Block Ecosystem

Community	Description
Streams	Streams of various size are abundant in the study area. Most of their annual flow occurs over a span of less than one month during and just after the melting of snowpack in the early summer. Smaller streams may dry in whole or in part later in the summer, but streams connecting chains of lakes usually have a permanent flow. Except for those connecting relatively large lakes, most of the streams freeze solid for most of their length during the winter. Most streams have moist soil in their vicinity, which is known as the riparian zone, and supports a relatively tall and productive shrub community.
Streams Draining Lakes	Streams draining lakes have a relatively dependable source of water, and tend to flow throughout the summer. These streams segregate into two major habitat types -- pools having relatively deep, slow-moving water and a fine-grained streambed, and riffles with shallower, faster water and a cobble bed. The primary production of these streams is constrained by an oligotrophic nutrient supply and a short growing season, and is almost entirely associated with algae growing on solid substrates (the periphyton). These algae are grazed by various species of benthic insects, and to a lesser degree benthic crustacea and other invertebrates. Grayling is the most important fish in these streams, where it feeds on benthic insects, and usually migrates to a lake to spend the winter.
Headwater Streams Draining into Lakes	Most of these streams are ephemeral, and only run during and soon after the spring freshet, drying up later in the summer, or becoming a disconnected series of shallow pools. The sparse primary productivity is associated with periphyton, and is grazed by benthic insects. Grayling only occur in the largest of these streams, and are the dominant predators.
Rivers	Eventually, the diffuse network of surface drainages on the landscape coalesce to form flowing-water systems large enough to be referred to as rivers. Ultimately, this flowage enters the Coppermine River, and drains to the Arctic Ocean at Coronation Gulf. Water of the upper reaches of the Coppermine River is slightly acidic (pH 6.6) and dilute in dissolved minerals, reflecting the influence of the slowly weathering, granitic bedrock and till. The primary production in rivers is sparse because of the severe limitations of climate and nutrient supply, and is mostly associated with periphyton growing on sediment surfaces. These algae are grazed by benthic insects, which are eaten by grayling, the most important species of resident fish. Anadromous fishes also pass through the river systems.

(continued)

Table 1.3-1 (continued)
General Description of the Most Prominent
Community Types in the Claim Block Ecosystem

Community	Description
Wetlands	In the sense used here, wetlands refer to marshes, bogs, fens, and swamps. None of these are extensively developed in the claim block ecosystem. Marshes occur as shallow-water, fringing communities around some lakes and riparian habitats, but they are not extensive. Seasonally wet meadows of sedges and cottongrass could be considered to be ephemeral fens, but are discussed below under terrestrial communities.
Terrestrial Communities	The terrestrial landscapes of the claim block ecosystem contain a continuum of environmental gradients that influence the development of the tundra vegetation (the development of the regional vegetation, or tundra, being mostly influenced by the severe climate). The most important, community-level influence on plants is the availability of soil and soil moisture. More locally, the persistence of snowbanks is important, as is microclimate, which can be affected by the aspect of slopes, and exposure on ridges of eskers. Disturbance and fertilization in the immediate vicinity of animal dens is another, very local influence on the productivity and distribution of plants. The various communities are mostly defined on the basis of their plant species. In general, the animal components of the communities do not segregate very well by habitat type, particularly the birds and mammals, which tend to use the various communities seasonally.
Sedge Tundra	This community type is an interface between aquatic and terrestrial community types, and is made up of wet meadows dominated by species of cottongrasses (*Eriophorum* spp.), sedges (*Carex* spp.), and grasses (*Poaceae*) that are tolerant of relatively wet growth conditions. However, the various meadows vary in the persistence of their wetness, and their plant-species composition reflects this important environmental variation, because species differ in their tolerance of longer-term submergence of their root systems. Mesic microsites in the wet meadows may support dwarf willows (*Salix* spp.) and dwarf birch (*Betula glandulosa*). Wet meadows are the most productive of the terrestrial communities in the claim block ecosystem. They are seasonally grazed by mammalian herbivores, ranging from small mammals such as lemmings and voles, to caribou.
Tussock Tundra	Tussock tundra occurs in low places with standing water during the earlier part of the growing season, but that drain and become mesic in moisture availability later on. Moister microsites in this community type support sedges and cottongrasses, while more-mesic sites have dwarf shrubs such as Labrador tea (*Ledum palustre*), alpine blueberry (*Vaccinium vitis-idaea*), bilberry (*V. uliginosum*), and dwarf birch (*Betula nana*). This habitat is often used for nesting by Lapland longspur and Smith's longspur.

(continued)

Table 1.3-1 (completed)
General Description of the Most Prominent
Community Types in the Claim Block Ecosystem

Community	Description
Shrub Tundra	This community type develops in the riparian zones of streams, lakes, and rivers, where there are relatively favorable conditions in terms of moisture availability, and often in microclimate. The tallest shrubs are willow (*Salix planifolia*), birch (*Betula glandulosa*) and alder (*Alnus crispa*). Less favourable sites have shorter shrubs species. This habitat is used for nesting by redpolls, yellow warbler, flycatchers, tree sparrow, white-crowned sparrow, and other birds that are more typical of the boreal forest to the south.
Dwarf Shrub Tundra	This mesic-to-dry community type develops on the extensive, well-drained uplands of the claim block ecosystem. The dominant plant species include dwarf birch, crowberry (*Empetrum nigrum*), alpine blueberry, and Labrador tea. This is a relatively unproductive community type. Nesting birds include snow bunting and horned lark.
Herbaceous Tundra	This is a relatively rare community, occurring in relatively warm microsites, often with frequent disturbance, for example, along streambanks and riverbanks, south-facing slopes of eskers and hills, and around animal diggings. Characteristic plants of these places include the river-beauty (*Epilobium latifolia*), tundra wormwood (*Artemisia* spp.), licorice-root (*Hedysarum alpinum*), prickly saxifrage (*Saxifraga tricuspidata*), and variegated horsetail (*Equisetum variegatum*).

1.3.3.2 Spatial and Temporal Contexts

The claim block ecosystem can be considered at a range of integrated, hierarchical scales (Figure 1.3-1). The lowest level of ecological integration is the individual organism, which in the evolutionary sense is an ephemeral, genetic entity. Individuals are assembled into populations, that is, potentially interbreeding aggregations of the same species. Populations are further integrated into communities, or populations of various species that co-exist in space and time within the same habitat and interact with each other. Communities are a spatial mosaic on the landscape, consisting of an array of various types of terrestrial and aquatic communities. At even larger scales, landscapes can be arranged into larger biophysical units, such as ecozones or biomes, which ultimately integrate into the biosphere of Earth.

Of course, the biophysical entities within all of these spatial levels of integration are dynamic and they change over time. These temporal changes occur in response to intrinsic, biological processes (such as aging), and in response to disturbance, ecological succession and longer-term environmental change (e.g., climate). Depending on the lifespan of the organisms that are being considered and the nature of the factor(s) that are forcing change, the temporal dynamic can be short term or longer term.

Therefore, the claim block ecosystem can be considered at a range of spatial and temporal contexts, ranging from small to enormous in extent and short term to longer term in time. All of these contexts are potentially important in impact assessment, depending on the nature and intensity of the stressors that are being considered. Obviously, however, some contexts are more important than others, as will be repeatedly apparent during the discussions of the predicted effects on particular VECs in the impact assessment.

1.3.4 Linkages Among Components and Scales

The terrestrial and aquatic components of the claim block of the NWT Diamonds Project can be considered as comprising a single ecosystem, which is contiguous with the larger ecosystem of the surrounding region. Some of the most prominent linkages among the sub-components of the claim block ecosystem with the larger landscape are discussed below.

1.3.4.1 Linkages Extending Beyond the Claim Block Ecosystem

Many of the linkages of the claim block ecosystem with the larger world are environmental in nature. Hydrologic linkages include the cycle of precipitation by weather systems developing thousands of kilometres away from the study area and the reverse process of evapotranspiration of water from the claim block ecosystem into the global hydrologic cycle (Figure 1.3-2). Similarly, the study

Larger scales, ranging from national, to continental, to global

↑

The Southern Arctic Ecozone, comprising much of the mainland tundra of the NWT, Quebec, and Labrador

↑

A more extensive landscape, defined by the 50,800 km^2 watershed of the Coppermine River

↑

A mosaic of communities within the landscape, defined as the 3500 km^2 of the NWT Diamonds Project claims block

↑

Communities of populations co-existing in the same time and place

↑

Populations of individuals of the same species

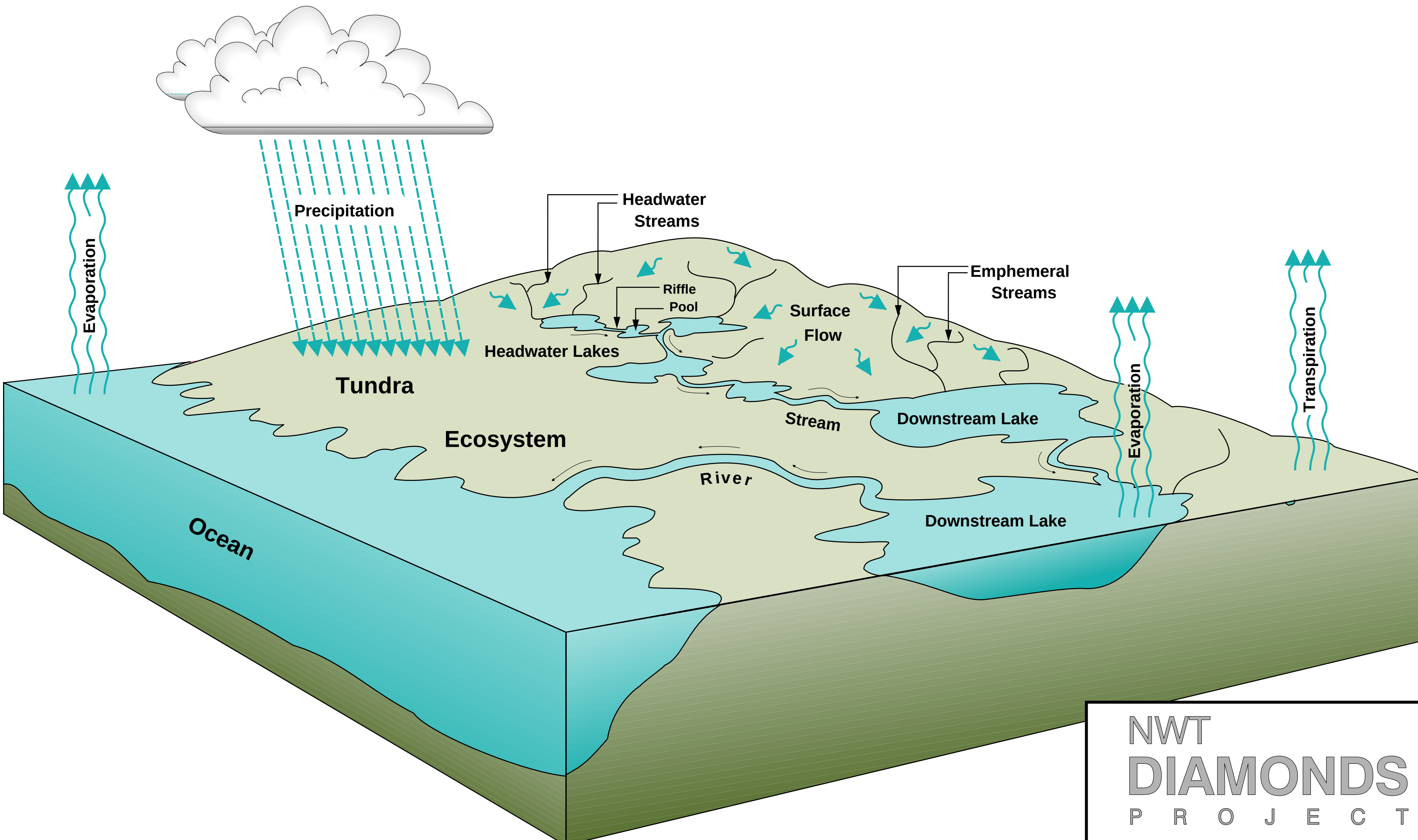
↑

Individual organisms, e.g., a particular caribou or lake trout

NWT DIAMONDS PROJECT

Figure 1.3-1
Hierarchies of Spatial Scale for Claim Block Ecosystem

Source: Rescan



NWT DIAMONDS PROJECT

Figure 1.3-2
Conceptual Hydrologic Cycle in the Claim Block Ecosystem

Source: Rescan

area is a headwater component of the watershed of the Coppermine River. The surface flows eventually join that river and empty into the Arctic Ocean at Coronation Gulf to form another aspect of the global, hydrologic cycle (Figure 1.3-2).

Other inorganic linkages of the claim block ecosystem with global cycles include the uptake of atmospheric carbon dioxide and emission of unused oxygen during plant photosynthesis, and the emission of carbon dioxide during the respiration of plants, animals and microbes. The atmospheric pools of these gases are dynamic and circulate globally; the claim block ecosystem is a small component of that planetary function.

The claim block ecosystem is also linked to far-away places through the migratory movements of some of its animal and bird species. The Bathurst caribou herd, for example, is only a transient component of the claim block ecosystem, migrating during spring and fall between the boreal forest and the calving grounds of the coastal tundra. Most of the breeding birds of the claim block ecosystem are even longer-distance migrants. Tundra swans, for example, winter on estuaries along the southeastern coast of North America, while snow buntings winter mostly in the prairies. The longest-distance migrants are the Arctic terns that breed on some of the larger lakes in the claim block ecosystem – these birds migrate as far south as Antarctica before returning to breed in the arctic area.

In some respects, humans can also be considered to represent a potential, long-distance linkage with the claim block ecosystem. As discussed in Section 1.3.5, human activities result in trace depositions of contaminants and may also be influencing longer-term changes in climate. Of course, the present impact assessment is discussing another, potential human linkage – an industrial development that is intended to mine diamonds and would result in some localized impacts to several of the many lakes and extensive terrestrial habitats in the region.

1.3.4.2 Linkages Within the Claim Block Ecosystem

There is also a plethora of linkages among the environments, species and communities of the claim block ecosystem.

Obviously, all individual organisms, populations, communities and the entire claim block ecosystem are inextricably linked with the non-living components of their environment. They are also linked with each other through various types of biological relationships, such as the social relationships among individuals of the same population, competitive relations among species and by feeding (or trophic) relationships among species, such as herbivores, carnivores and detritivores (that is, feeding or scavenging on dead biomass). Some of these linkages are suggested in Figure 1.3-3.

◎ Table of Contents

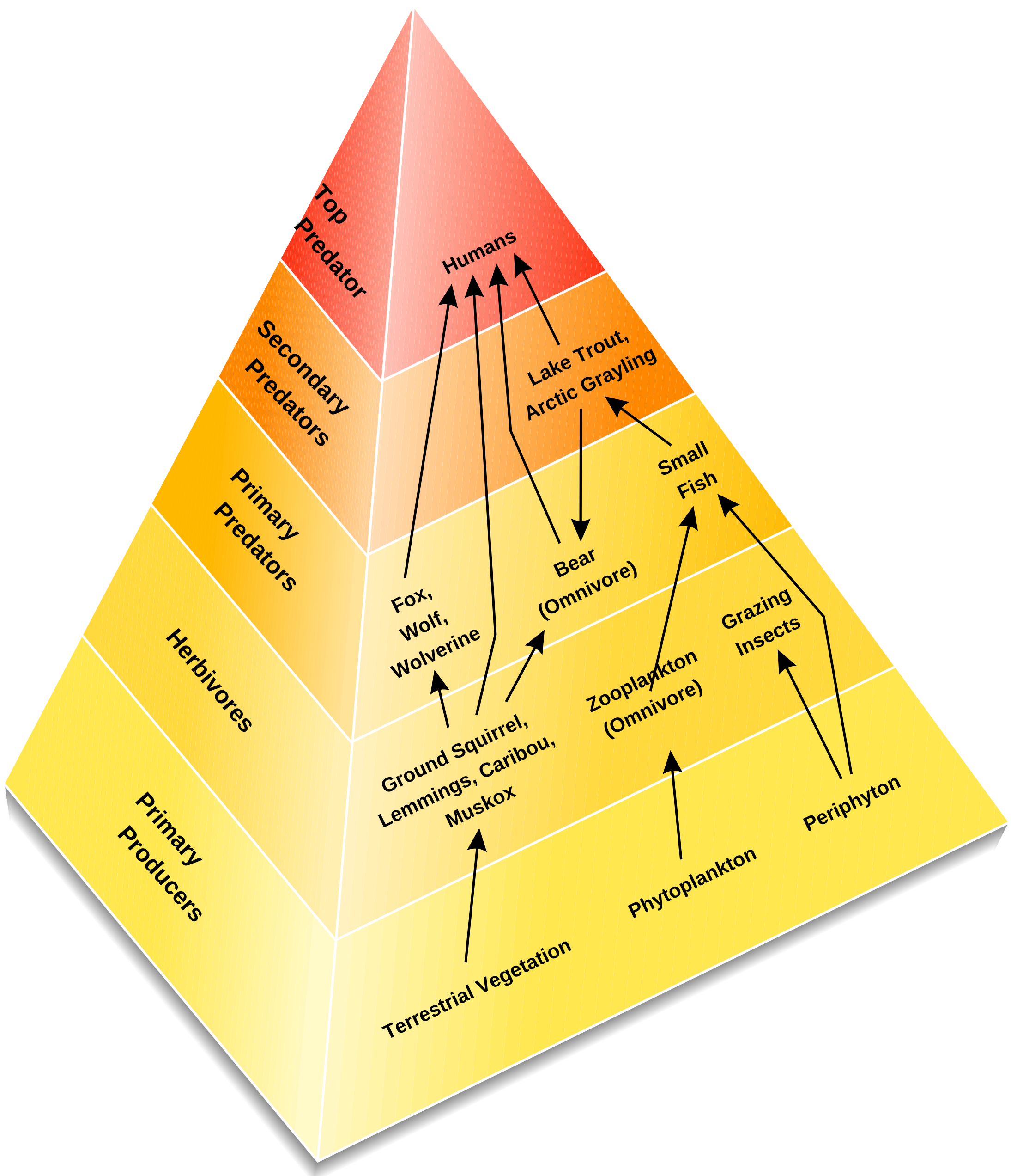


Figure 1.3-3
Food-Web Pyramid of the Claim Block Ecosystem

Source: Rescan

Many of these linkages transpire within the identified communities of the claim block ecosystem. For example, the trophic relationships within lakes largely involve connections among algae, invertebrate herbivores and fish predators. However, some animals are links between the terrestrial and aquatic components of the ecosystem, for example, fish-eating mergansers, loons and Bald eagles and also opportunistic consumers of fish, such as grizzly bears (Figure 1.3-3).

Aboriginals are components of the claim block ecosystem. Although recent occupancy of the study area is not apparent, in the recent past Dene and Inuit have seasonally hunted caribou in the claim block ecosystem and have also fished and trapped.

1.3.5 Ecological Integrity of the Study Area

Ecological integrity in the claim block ecosystem can be judged as being as great as can be achieved, considering the severe climatic limitations on ecological development in the region. The clearest indicators of the great ecological integrity of the study area are the following:

- *The presence of populations of large animals and top carnivores*: In the aquatic components of the ecosystem, the top predators include lake trout and grayling. In terrestrial habitats, these include wolf and peregrine falcon and also grizzly bear and wolverine, although the latter two are more characteristically omnivorous and scavenging, respectively, in their feeding habits. Other than these carnivores, the most prominent large animal in the study area is caribou, which is present in large numbers during its spring and fall migrations. Muskox are also present in a small density, which will likely increase in the near future in parallel with the generally expanding range and populations of this species in the larger region.

- *The presence of clean water, soils and atmosphere*: Soil chemistry and air quality have not been studied for all trace toxics (such as organochlorines), but these units are undoubtedly in a pristine condition.

- *A natural, self-organizing ecosystem*: The study area comprises a dynamic mosaic of communities and a larger ecosystem that is virtually unaffected by substantial human influences. This ecosystem has developed solely under the influence of naturally occurring, environmental factors. Except in situations where recent, natural disturbance has taken place, the self-organizing communities of the study area have attained what amounts to an old-growth condition, characterized by dominance by old individuals of long-lived species, a relatively large ecosystem biomass (within the severe constraints of the climatic and other environmental stresses of the tundra) and intrinsically slow rates of nutrient cycling and productivity. Moreover, the species of the study area, comprising the most easily discussed element of its biodiversity, are entirely natural to the ecosystem, none having been introduced by humans. In addition, there is no evidence that any native species have been extirpated from the region, at least during historical times.

The above discussion should not be interpreted as suggesting that there are no detectable signatures of human influences in the study region. A long and well-documented history of Aboriginal exploitation of the biological resources in the claim block ecosystem exists, particularly of caribou during their spring and autumn migrations and, to a lesser degree, of lake trout, round whitefish and furbearers. However, the indigenous hunters had a cultural ethic of conservation, and they were technologically limited in terms of their weaponry and transportation. Consequently, the hunting effort was undoubtedly sustainable by the natural resource and did not pose a substantial challenge to the integrity of the ecosystem, of which the people are an integral component. More recently, human influences in the area include somewhat greater fishing pressures on some individual lakes periodically associated with guided sport fishing and occasional forays of guided sport hunting in search of trophy animals.

The study area is also affected by several aspects of global environmental changes resulting from human activities. The most notable of these is climatic warming, which is hypothesized to be caused by an anthropogenic enhancement of Earth's naturally occurring greenhouse effect. This influence of humans is mostly associated with emissions of carbon dioxide by the combustion of fossil fuels and the clearing of forests, along with smaller influences associated with emissions of methane, nitrous oxide and chlorofluorocarbons. Modelling of the potential climate warming associated with an enhancement of the greenhouse effect suggests that its intensity will be greatest at higher latitudes, that is, the degree of warming will be most intense in the arctic and subarctic of the Northern Hemisphere and at similar latitudes in the Southern Hemisphere.

These various human influences on the ecosystem of the claim area could be interpreted as suggesting that the region is no longer pristine, in the strictest interpretation of that word. The claim area is a component of a vast wilderness that is almost imperceptibly affected by human activities and has great ecological integrity.

2. Physical Setting

The NWT Diamonds Project lies within the tundra of the Slave Geological Province of the Precambrian Shield, in the central portion of the Northwest Territories about halfway between Great Slave and Great Bear lakes. The area planned for development is approximately 200 km south of the Arctic Circle, near Lac de Gras. The watersheds within the mineral claim block drain into Lac de Gras, which is the headwaters of the Coppermine River. The Coppermine River flows northwest and then north to the Arctic Ocean near the community of Coppermine on Coronation Gulf.

The Northwest Territories contains the largest chain of lakes, pools, rivers, streams and bogs in the world (Moore 1978). This is evident in the area surrounding the NWT Diamonds Project, as approximately one-third of the claim block is covered by oligotrophic water bodies. The low relief of the terrain has resulted in a diffuse drainage pattern. Streams typically meander in braided channels through extensive boulder fields between lakes and ponds following weak hydraulic gradients. Stream flows vary greatly, with high flows recorded during spring freshet, while low flows and dry stream channels are typical in late summer.

The terrain in the project area has been formed as a result of multiple glaciation periods, the most recent being the Late Wisconsinan. The landscape within the claim block consists of relatively diffuse watersheds with numerous near-barren lakes interspersed among boulder fields, eskers and the occasional bedrock outcrop. During the Late Wisconsinan glaciation, till was deposited on bedrock over most of the area in the claim block. Glacial striations indicate that early glacial flows were to the southwest and subsequent flow was to the west and west-northwest.

The climate in the Lac de Gras area is very harsh by southern standards. Summers are generally short and cool, while winters are long and extremely cold. Precipitation is sparse and consists of relatively equal portions of rain and snow. Winds are moderate and are predominately from the northwest.

Each section in this chapter explains what is currently known about each ecosystem component so that potential impacts can be measured or predicted. Current baseline conditions have been compiled through reviews of existing literature as well as extensive field investigations since 1993. Field work was conducted according to NWT Diamonds Baseline Environmental Study Protocols (BHP 1993). Government officials and technical experts have been consulted throughout the evaluation of baseline conditions.

The Proponent has attempted to give full and equal consideration to the incorporation of traditional knowledge, which has been cited as such where applicable.

This chapter will specify valued ecosystem components (VECs) to enable the reader to focus on these particularly important aspects. The VECs identified during the scoping meetings conducted by the EARP Panel during March and April 1995 are summarized in Table 1.1-1. VECs were identified through the analysis of issues and the type or source of the specific concern raised during scoping meetings.

The information presented in this chapter will provide the reader with a reasonable overview of the existing physical conditions in the project area. This portrayal of baseline conditions serves as a basis upon which to predict any potential changes that may occur as a result of the development of the NWT Diamonds Project.

2.1 Terrain and Permafrost

Eskers and permafrost have both been identified as valued ecosystem components (VECs). Eskers have been noted, as they are frequently used for carnivore denning, bird nesting and as travel corridors by caribou and other wildlife. In addition, some eskers have been found to have archaeological significance. Permafrost is significant because of the potential of ecological disturbance (hydrology or soil stability) associated with its degradation within the active layer near the surface.

The NWT Diamonds Project lies within the northwestern Canadian Shield physiographic region where the landscape is bedrock controlled. Surficial, mostly glacial materials are thin and discontinuous, and permafrost is present everywhere except beneath lakes and rivers. Holocene periglacial processes have modified the bedrock surface as well as the younger glacial landforms. Terrain and permafrost conditions are described, first at the regional and then the local scale.

2.1.1 Regional Terrain Conditions

Terrain conditions in the Lac de Gras region of the NWT have been described by Dredge *et al.* (1994) and mapped at a scale of 1:25,000 by Ward (1992). More recently, Rampton (1994) prepared detailed maps of the Quaternary geology of the entire NWT Diamonds Project claim block (Exeter Lake; referred to here as the "claim block"). This was based upon the interpretation of 1:60,000 scale air photos and subsequent field reconnaissance, with map compilation at a scale of 1:50,000. The information in this section has been adapted from the report at Rampton that accompanies the map sheets, and from contributions appearing in Fulton (1989). The areal extent of the Exeter Lake mapping is shown in Figure 2.1-1.

The Lac de Gras region is characteristic of the northwestern Canadian Shield physiographic region (Dike and Dredge 1989), with rolling hills and relief limited to approximately 50 m, all controlled by near-surface, resistant Precambrian bedrock. Numerous lakes fill topographically low areas, which are interconnected by shallow, commonly ephemeral streams.

The region has been subjected to multiple Quaternary glaciations; however, the current landscape can be attributed to the last, or Late Wisconsinan Laurentide Ice Sheet (Dike *et al.* 1989). The claim block was inundated by glaciers flowing in a variety of directions during this period. Glacial striations indicate that the earliest ice flow direction was to the southwest, and subsequent flow was to the west and west-northwest. Varying thicknesses of till were deposited on bedrock over most of the area.

Deglaciation involved retreat in a generally east-northeasterly direction across the NWT and concomitant lowering of the Laurentide Ice Sheet surface elevation. The successively reduced ice mass remained active until very near the end, which was in the Lac de Gras region approximately 9,500 years ago (Dike and Dredge 1989). Penultimate flow directions are somewhat variable, a consequence of local deflections around stagnant lobes. Companion eskers and meltwater corridors trend in the same directions as late glacial striations.

There was an abundant supply of meltwater during the early stages of deglaciation. A complex network of meltwater streams formed, initially on the surface of the ice mass, but quickly passing through the ice to subglacial positions. Erosional and depositional landforms include scallops flanking till uplands, plunge pools and whirlpools filled with boulders, and eskers that in some cases enter and exit plunge pools and whirl pools. A trunk or main esker crosses the claim block in a west-northwest direction from just north of Duchess Lake to south of Yamba Lake. Eskers and glaciofluvial corridors south of the trunk esker (the main development area) primarily have a north-northwest trend, whereas eskers north of the trunk esker have trends ranging from west to southwest (Figures 2.1-1 and 2.1-2).

As the inactive ice mass downwasted, continued meltwater movement caused more areally extensive erosion and deposition. Newly exposed till plains were extensively eroded; in some cases the till was completely removed. Glaciofluvial materials were deposited as irregular hills and knolls, transverse ridges, sheets and bar-like features. Lag concentrations of boulders, and small patches and blankets of sand and gravel, were commonly deposited on the remaining till and bedrock surfaces.

◎ **Table of Contents**

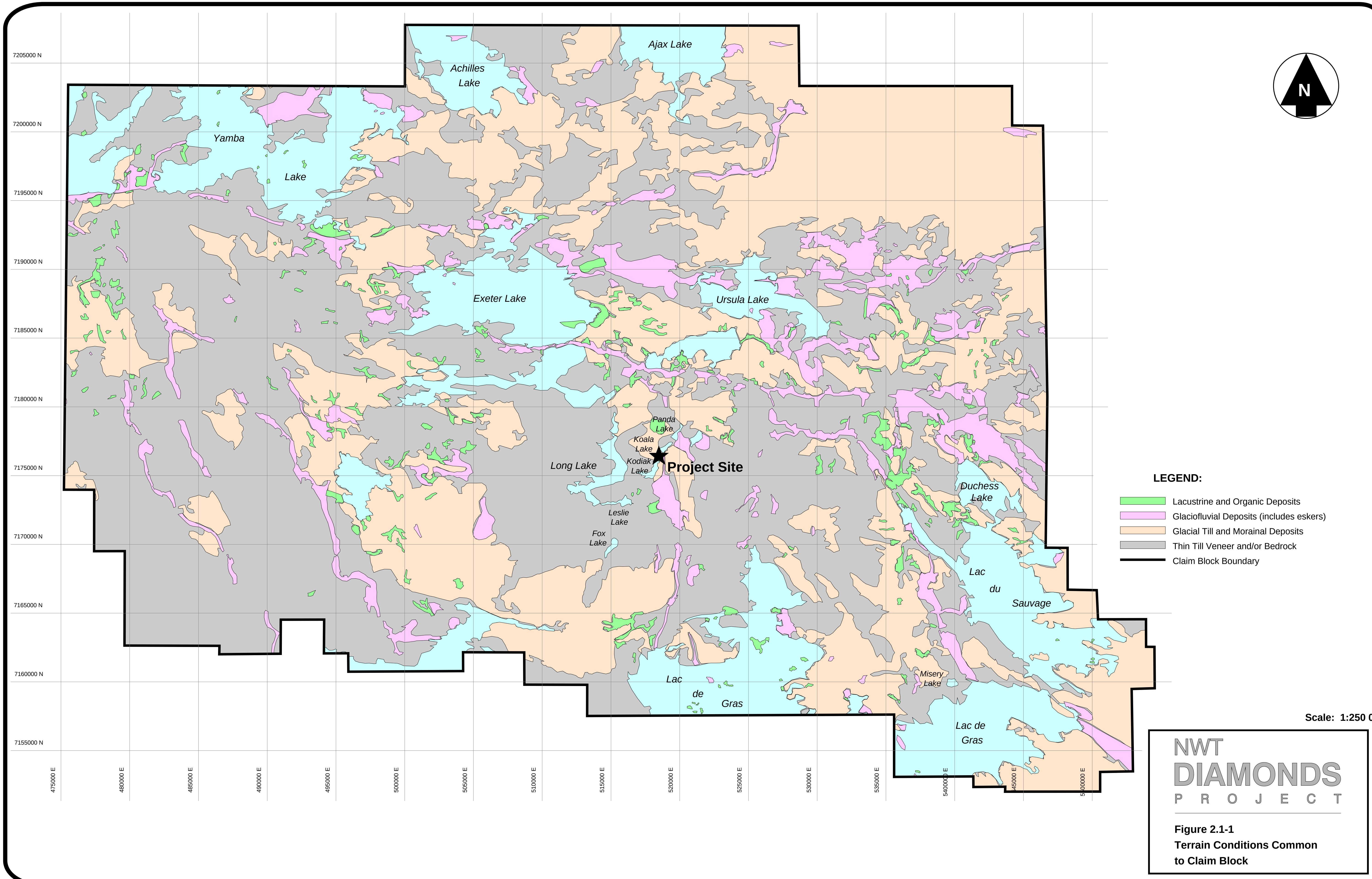


Figure 2.1-1
Terrain Conditions Common to Claim Block

Source: EBA Engineering (Adapted from Rampton 1994)

◎ Table of Contents

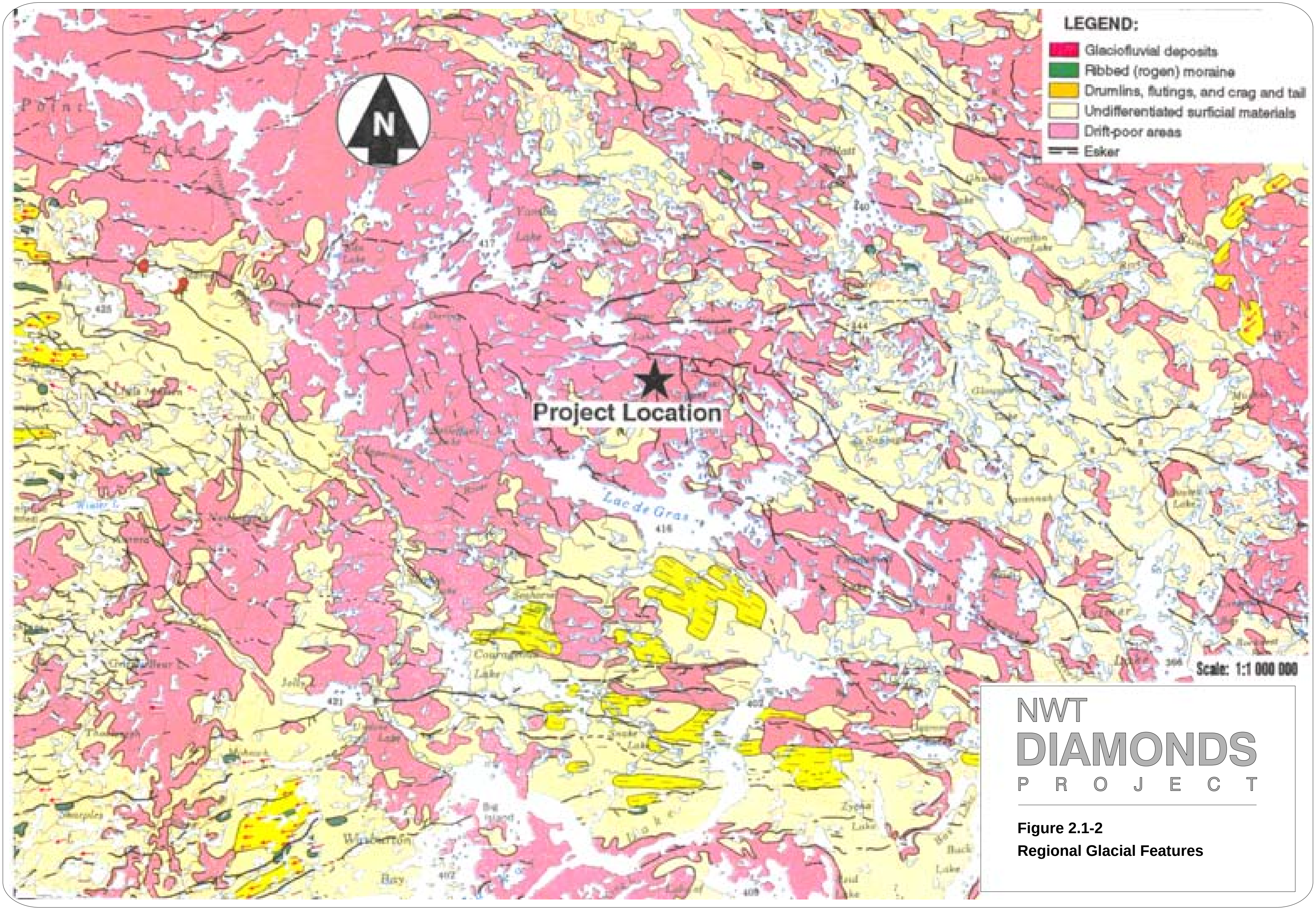


Figure 2.1-2
Regional Glacial Features

Source: Milton Freeman Research Limited 1976

Following deglaciation, the levels of some lakes were higher than at present, as evidenced by strandlines. High lake levels were short-lived, however, as indicated by the lack of deltas and well-developed beaches. There is no evidence that the marine limit extended into the region.

Through the remainder of the Holocene, periglacial processes have caused mechanical breakdown of bedrock and coarse glacial materials and contributed to gravity transport of both glacial soils and products of periglacial comminution. Thin alluvial deposits have formed along some streams, and pond deposits have accumulated in shallow depressions. Organic deposits have also formed on some poorly drained floodplains and low flat areas.

Early isostatic emergence rates reported for the central Keewatin district are believed to be approximately 10 m per century when averaged over the first 1,000 to 2,000 years of record, although rates would have been higher by a factor of two to three times over the approximate 200 years of deglaciation. Late Holocene and ongoing emergence rates are estimated to be somewhat more than 1 m per century (Dike and Dredge 1989).

2.1.1.1 Surficial Materials

Surficial deposits covering the claim block range in age from Late Wisconsinan to Holocene age. Table 2.1-1 lists the deposits from youngest to oldest and includes brief descriptions of their composition, estimated thickness, geomorphology, drainage and origin. A description of each deposit according to the same chronological order follows. Terrain conditions common to the claim block are shown in Plates 2.1-1 to 2.1-5 and Figure 2.1-1.

Postglacial Lacustrine Deposits

Lacustrine deposits owe their existence to proglacial lakes dammed by decaying glacier ice and to postglacial isostatic adjustments. Most deposits lie within a few metres of present lake levels. Their upper limit is occasionally marked by poorly developed strandlines. The brief existence of the postglacial lakes and short fetches resulted in limited long-shore drift. The materials comprising the shorelines are re-worked tills where fines have been removed, in some areas leaving only boulder lags. The lacustrine deposits are primarily silt, silty sands and gravelly sands.

Glaciofluvial Deposits

Glaciofluvial deposits cover a significant portion of the claim block because of ubiquitous meltwater activity. The meltwater appears to have moved as subglacial and interglacial streams and as supraglacial channels, the latter showing increased influence as the deglacial period progressed.

Table 2.1-1
Description of Surficial Deposits

Unit	Composition	Estimated Thickness (m)	Geomorphology and Drainage	Origin
Organic Deposits	Undercomposed organics and muck; may contain lenses of mineral sediment, especially in lower part.	0.5 to 2.0	Cover flat depressions and swells; imperfectly to poorly drained.	Forms from accumulation and decomposition of organic material.
Alluvial Deposits	Silt to gravel size stratified sediment with few lenses and layers of organic detritus; commonly cobbly or bouldery; may have organic cover.	1.0 to 3.0	Floodplains and low alluvial terraces; subject to intermittent flooding; commonly imperfectly drained.	Cobbly, bouldery deposits formed by streams eroding glacial deposits; stratified sediments deposited by streams.
Lacustrine Deposits	Mainly silt and sand with few lenses of organic detritus; sand and pebbly gravel in bars, beaches and spits; locally boulder lags.	0.5 to 3.0	Lacustrine plains; gentle slopes lying immediately above present lakes; bars, beaches and spits; drainage varies from imperfect to good.	Sediments derived by wave erosion and winnowing of fines in former lake beds; erosion and redeposition of glaciofluvial deposits by waves and long-shore drift to form bars, beaches and spits.
Glaciofluvial Deposits (outwash)	Mainly sand and gravel; few beds of silt; locally, mainly cobbles and boulders.	1.0 to 15.0	Glaciofluvial blanket forms flat featureless cover or bar-shaped forms on bedrock or till. Kame and kettle complexes can show rolling topography or sharp hills and ridges. Eskers form sharp continuous linear ridges; well drained.	Glaciofluvial blankets are streambeds from subglacial meltwater sheet flow; the sediments are formed by erosion and winnowing of till; eskers are deposited from major subglacial streams; kames are deposited along subglacial, englacial and proglacial stream channels.

Source: Rampton (1994).

(continued)

Table 2.1-1 (continued)
Description of Surficial Deposits

Unit	Composition	Estimated Thickness (m)	Geomorphology and Drainage	Origin
Till	Compact diamicton (unsorted sediment) with a silty sand matrix; contains pebbles, cobbles and boulders; in places very bouldery; locally may contain lenses and layers of outwash; locally upper part may be loose and contain less silt; patches of outwash and boulders may cover surface; large areas may be covered by boulders; locally bedrock may be exposed, especially in areas of till veneer.	0.5 to 15.0	Till veneers and blankets cover bedrock, and slopes generally reflect bedrock topography. Rolling ground moraine consists of ridges and hills with gentle to moderate slopes that may be a result of primary glacial deposition or may reflect underlying bedrock topography. Generally well drained, although some depressions may be imperfectly drained.	Deposited mainly as lodgement and meltout till at base of glacier. Loose sandy surface layers winnowed of fines by subglacial processes during deposition; extensive boulder lags due to meltwater erosion of till matrix and smaller clasts; patches of outwash from subglacial streams.
Morainal Deposits	Complex of diamicton (till) and glaciofluvial deposits (outwash). Till may be compact to loose. Outwash is commonly silty. Some complexes may be primarily a mixture of sandy and/or silty outwash.	3.0 to 15.0	Hilly terrain with either rolling topography or sharp hills and ridges; short esker segments, kames and rimmed ridges can be common; well drained; isolated depressions may be poorly drained.	Primarily deposited supraglacially or on “dead ice”; much of the till is meltout and has been re-worked by gravity flow in a melting ice surface.
Exposed Bedrock	Granitoids, phyllites, slates, greywackes, schists. Patches of outwash may be present on some surfaces; frost-shattered heaved bedrock blocks on other surfaces.	N/A	Varies from flat plain to rugged hilly terrain; cliffs and steep valley walls.	Exposed bedrock is primarily from glacial erosion and removal of till from surfaces, especially where patches of outwash are present on its surface; heaved bedrock blocks result from frost shatter and heaving.

Source: Rampton (1994).

Plate 2.1-1: *Surface covered with boulder lag of a till deposit (foreground). Lacustrine lowland deposit located beyond the till deposit (beige coloured area).*

Plate 2.1-2: *The most distinct glaciofluvial deposits are the eskers that form sharp continuous linear ridges.*

◎ Table of Contents

Plate 2.1-3: *Bedrock outcrop is exposed, having been stripped of overlying glacial till by subglacial meltwater.*

Plate 2.1-4: *Ground ice exposed at one location during gravel extraction operations.*

Plate 2.1-5: *Natural thermokarst depression resulting from thaw of ice wedge polygons in a peat covered lacustrine lowland.*

Eskers and hummocky kames contain the best sorted glaciofluvial material. The extent of washing and sorting suggests significant transport distance. Kame and kettle complexes, which have gentle to moderate slopes, and glaciofluvial blankets containing moderately and poorly sorted sediments comprise landforms that have been subject to less transport and washing by meltwater.

Eskers, the most distinct glaciofluvial deposit in the claim block, have been identified as a valued ecosystem component. Their overall abundance in the region is clearly illustrated in Figure 2.1-2; however, there are few in the immediate development area. These landforms are composed of well-sorted sand and sandy gravel (Plate 2.1-2). This allows good drainage and limits ground ice formation during annual re-freezing which results in a thick active layer. These conditions enhance habitat opportunities for burrowing animals, hence eskers are frequent denning sites for larger mammals.

"The denning areas for grizzlies, wolves, foxes,... they tend to den in eskers..." (Gerry Atatahak, Coppermine).

Eskers hold special significance for Aboriginal people. Not only are they recognized to be important denning habitat for a variety of burrowing animals, but they are also important routes of travel for both animals and humans. Frequently, campsites and traplines are located on, or in association with eskers:

"From Kq they go to Ek'ati tata (the area between Lac de Gras and MacKay Lake) to trap. We travelled with a canoe and we go right beside the eskers. That's where I trap, that place was good for trapping. That's why we have always travelled there..." (Suzie Mackenzie, elder, Rae Lakes).

Compared to other nearby areas, Ek'ati tata appears to have an abundance of eskers, drumlins and other glacial features (Figure 2.1-2), which made it attractive for human use.

Boulder lags and cobbly bouldery gravels are found in areas where significant thicknesses of till have been removed by meltwater. These materials have almost certainly experienced little transport from where they were eroded out of the till or dislodged from the bedrock.

Glacial Deposits

Glacial deposits, including ablation and lodgement till, cover much of the claim block. These deposits generally have a sandy texture with a minor silt component. The texture is relatively coarser in ablation till, and the fines content (mainly silt) is relatively higher in areas underlain by metasediments than in areas underlain by granitoids. Surface examination indicates that tills in some areas have a higher boulder content, but this may also be due to glaciofluvial erosion and deposition.

Some areas of till veneer and till blanket were formed by erosion of formerly thicker lodgement and ablation till units by meltwater.

Ablation Till

Ablation till represents the accumulation of englacial and supraglacial debris during melting. Deposits are commonly stratified, a reflection of the interaction between ice and meltwater depositional environments that characterize a decaying ice mass. Accordingly, the deposits include complexly interbedded coarse till with glaciofluvial gravels and, occasionally, glaciolacustrine sand and silt deposits.

Basal or Lodgement Till

Most till in the claim block is lodgement till, the product of plastering or smearing of comminuted bedrock material on the surface underlying the glacier. Generally the closer the till is to the underlying bedrock interface, the closer the up-glacier bedrock source of the constituent particles.

Bedrock

Glacial meltwater completely stripped bedrock of its till cover over large areas in meltwater corridors (Plate 2.1-3). Indeed, most bare bedrock throughout the claim block may owe its exposure to meltwater activity. The action of the meltwater has resulted in gaps in eskers where bedrock is exposed and patches of glaciofluvial materials over bedrock in meltwater corridors.

In areas of metasediments where till is thin, frost-shattered and occasionally frost-heaved bedrock blocks are common. Where boulder concentrations have resulted from meltwater erosion, it is frequently difficult to distinguish glacially transported boulders from *in situ*, frost-heaved blocks, although the latter tend to be more angular.

2.1.1.2 Regional Permafrost

A major feature of northern circumpolar regions, and one of considerable ecological and engineering importance, is permafrost. Permafrost underlies approximately 50% of Canada, mostly at higher latitudes but includes polar glaciers, portions of the continental shelf in the Arctic Ocean, and higher elevations as far south as the 49th parallel. Permafrost is defined as soil or rock whose temperature has been below 0°C for at least two years. It is generally broken down into continuous and discontinuous zones (Boyd *et al.* 1981; Brown *et al.* 1981).

The Lac de Gras region lies within the continuous permafrost region (Brown *et al.* 1981; Figure 2.1-3) and is found everywhere except beneath lakes and rivers. The

◎ Table of Contents

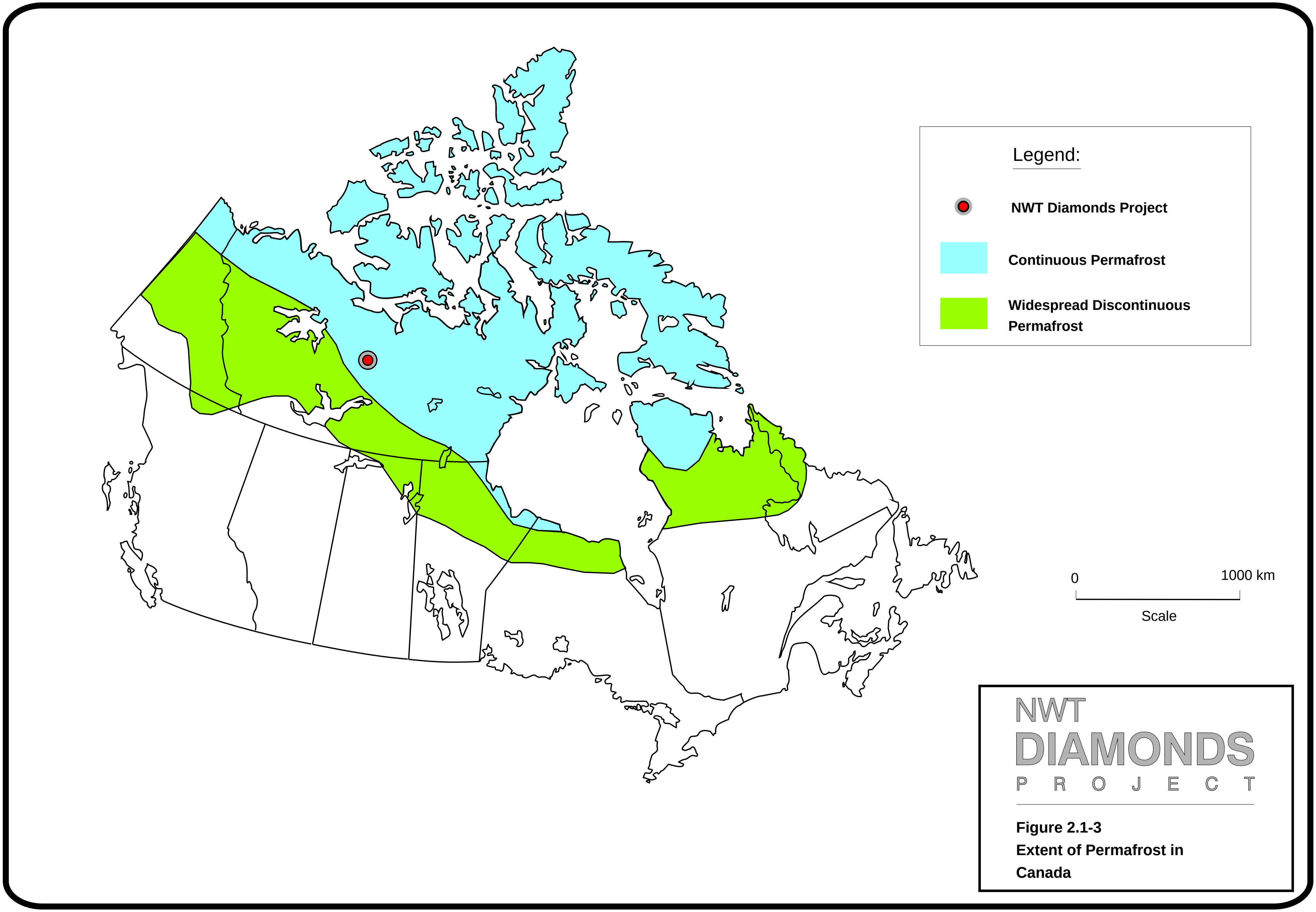


Figure 2.1-3
Extent of Permafrost in Canada

Source: EBA Engineering

mean annual air temperature for the region is variously reported to range from -8.3°C (Brown 1963) to -10.4°C (EBA 1995b). The mean annual ground surface temperature for the region is estimated to range from -4.4°C to -6.5°C based on the work of Brown (1963).

In permafrost areas, a thin zone at the ground surface known as the active layer, thaws and re-freezes annually. The active layer thickness depends upon the nature of the ground surface, i.e., whether it is bedrock, mineral or organic soil. The active layer in the Lac de Gras region ranges from centimetres thick in organic soils to metres thick in areas of exposed rock.

A widely accepted ground ice descriptive system, which is commonly used in the broader sense to describe permafrost, has been developed by the National Research Council (Pihlainen and Johnston 1963; Linell and Kaplar 1966). Although the delineation of permafrost has nothing to do with moisture or ice contents, the importance accorded ground ice in both geomorphology and engineering has given rise to this practice. The fundamental breakdown is based upon visible versus non-visible ground ice and whether the volume of water present is in excess of that which will fill void spaces when the material is thawed. Visible and excess ice is commonly associated with fine sand, silt and clay, and organic soils, but it can also be found in coarse sands and gravels, as well as along discontinuities in rock masses.

2.1.2 Terrain Characteristics in the Main Development Area

The dominant surficial cover over the planned NWT Diamonds Project open pit and waste dump areas is till veneer less than 2 m thick. The till is generally a compact, unsorted mineral soil consisting of a silty-sand matrix with pebbles, cobbles and boulders.

2.1.2.1 Panda and Koala Lakes

At Panda Lake the deposits are predominantly glaciofluvial and comprise sand and gravel eskers. Two small eskers to the southeast have cobbles and boulders on the surface. Patches of outwash and boulders cover the till veneer to the north and south of the lake.

These patches continue southwest to Koala Lake. A concentration of boulders on the south side of Koala Lake has resulted from the removal of fine material by glaciofluvial outwash processes. A northeast trending esker is situated to the southwest of Koala Lake, indicating a slight variation in the late glacial flow.

2.1.2.2 Leslie Lake

The rolling, hilly topography that extends 4 km southwest to Leslie Lake is an expression of the bedrock surface, which is covered by a thin till veneer. Some ablation till deposits cover a small area just north of Leslie Lake.

2.1.2.3 Fox Lake

Fox Lake is surrounded by a lodgement till veneer containing pebbles, cobbles and boulders. The extensive boulder field south of Fox Lake is believed to be a lag deposit, a product of meltwater erosion.

2.1.2.4 Misery Haul Road

The topography of the Misery Lake area is characterized by low to moderate relief with rolling hills and low-lying muskeg areas. Topographic variations correspond to the change in lithology from strongly resistant granitic rocks expressed by positive relief to less resistant biotite schist (greywacke) and low relief. Moraine, kames and eskers are common in the Misery Lake area.

The Misery haul road, which will provide access to the Misery kimberlite pipe, begins north of Larry Lake and continues to the southeast towards Lac de Gras, crossing discontinuous till, bedrock and boulder fields (Figure 2.1-4). A terrain analysis of the proposed road alignment between the pipe and the sample facility was performed by Bruce Geotechnical Consultants Inc. (BGC 1995a). To meet mine production needs, terrain analysis and pad design were assessed by EBA Engineering Consultants Ltd. (EBA pers. comm.). The route traverses surficial materials containing permafrost, and about 3.4 km crosses terrain believed to contain excess ground ice. The remaining 24.9 km is indicated as having low-to-medium permafrost sensitivity. A summary description is provided in Table 2.1-2.

2.1.2.5 Local Permafrost

Data on ground temperature and permafrost in the claim block have been collected and reported by EBA (1994). BGC (1995b) carried out one-dimensional numerical modelling of the geothermal regime in an effort to develop a broader understanding of ground temperatures and permafrost dynamics than the field data provided. The results of EBA's work are described in *Observed Permafrost and Ground Ice Conditions* and of BGC's geothermal modelling study in *Predicted Permafrost Conditions Based on Geothermal Modelling*.

Observed Permafrost and Ground Ice Conditions

The claim block is confirmed to be within the continuous permafrost zone. The mean annual ground surface temperature at Koala Lake is approximately -6°C.

◎ Table of Contents

NWT **DIAMONDS** PROJECT

Figure 2.1-4
Terrain Along Misery Haul Road

Source: Surficial Geology by Terrain Analysis and Mapping Services Ltd.

Table 2.1-2
Misery Haul Road Terrain Analysis

Segment	Start (km)	Length (km)	Terrain Analysis Description	Permafrost Sensitivity
1	0.00	5.90	Sand, gravel, cobbles and boulders (till), ranging from 1 m to 3 m thick overlying bedrock. Local concentration of surface exposed boulders.	Low
2	5.90	2.50	Sand and gravel (till) with some cobbles and boulders, ranging 2 m to 4 m thick. Local concentrations of surface exposed boulders. Excess ground ice present.	High
3	8.40	8.75	Discontinuous sand, gravel, cobbles and boulders (till), ranging up to 2 m thick. Local concentrations of surface exposed boulders ranging from 1 m to 2 m thick.	Low
4	17.15	0.90	Sand with occasional gravel lenses and boulders, ranging from 1 m to 3 m thick; covered by up to 1 m of organic soil. Excess ground ice present.	High
5	18.05	10.25	Sand and gravel (till) with some cobbles and boulders, ranging 2 m to 3 m thick. Local concentrations of surface exposed boulders.	Medium
End	28.30			

The thickness of permafrost is reported to be approximately 280 m (Brown 1967) in a borehole near Koala Lake. The base of permafrost, based on estimates by Terzaghi (1952, cited in SRK 1993) and confirmed during 1994/1995 winter drilling (BHP unpublished data), is approximately 240 m. The permafrost table drops steeply at the shore of deep lakes, and ground temperature data below deep lakes confirm the absence of permafrost. This has been verified in bulk sampling tunnels that encountered thawed zones below the lakes. Deeper than normal thaw has also been recorded below streams at the outlets of lakes. A terrain schematic is given in Figure 2.1-5, which illustrates variations in the permafrost table. The active layer varies in thickness on different soil profiles, ranging from 0.4 m to 2.3 m (EBA 1994). A thin active layer is associated with peat-covered lowlands where abundant soil moisture and the insulating properties of organic soils support a well-developed vegetation cover. A thick active layer is associated with well-drained till uplands that are devoid of vegetation. Ridges of exposed bedrock will have an even deeper summer thaw depth than till; however, few data have been collected on ground temperatures in exposed rock. This variation in active layer thickness for different materials is illustrated in Figure 2.1-3.

Ground ice conditions vary significantly with terrain type. Lodgement tills on upland or sloping terrain are dense and relatively free of excess ice. Where they underlie peat or lacustrine deposits, they are moderately ice-rich with lenses up to

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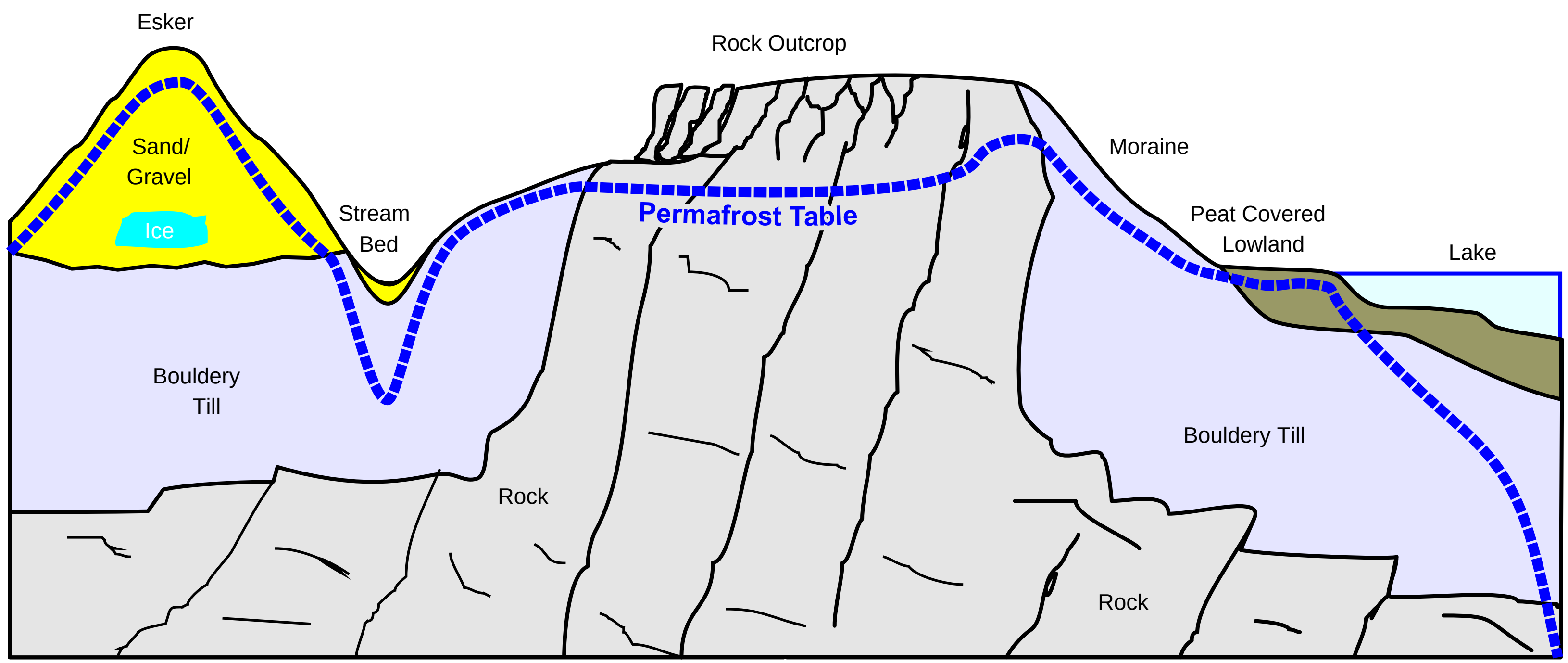


NWT DIAMONDS PROJECT

Figure 2.1-5
Variation in Permafrost Table by Terrain Type

Source: EBA Engineering 1995

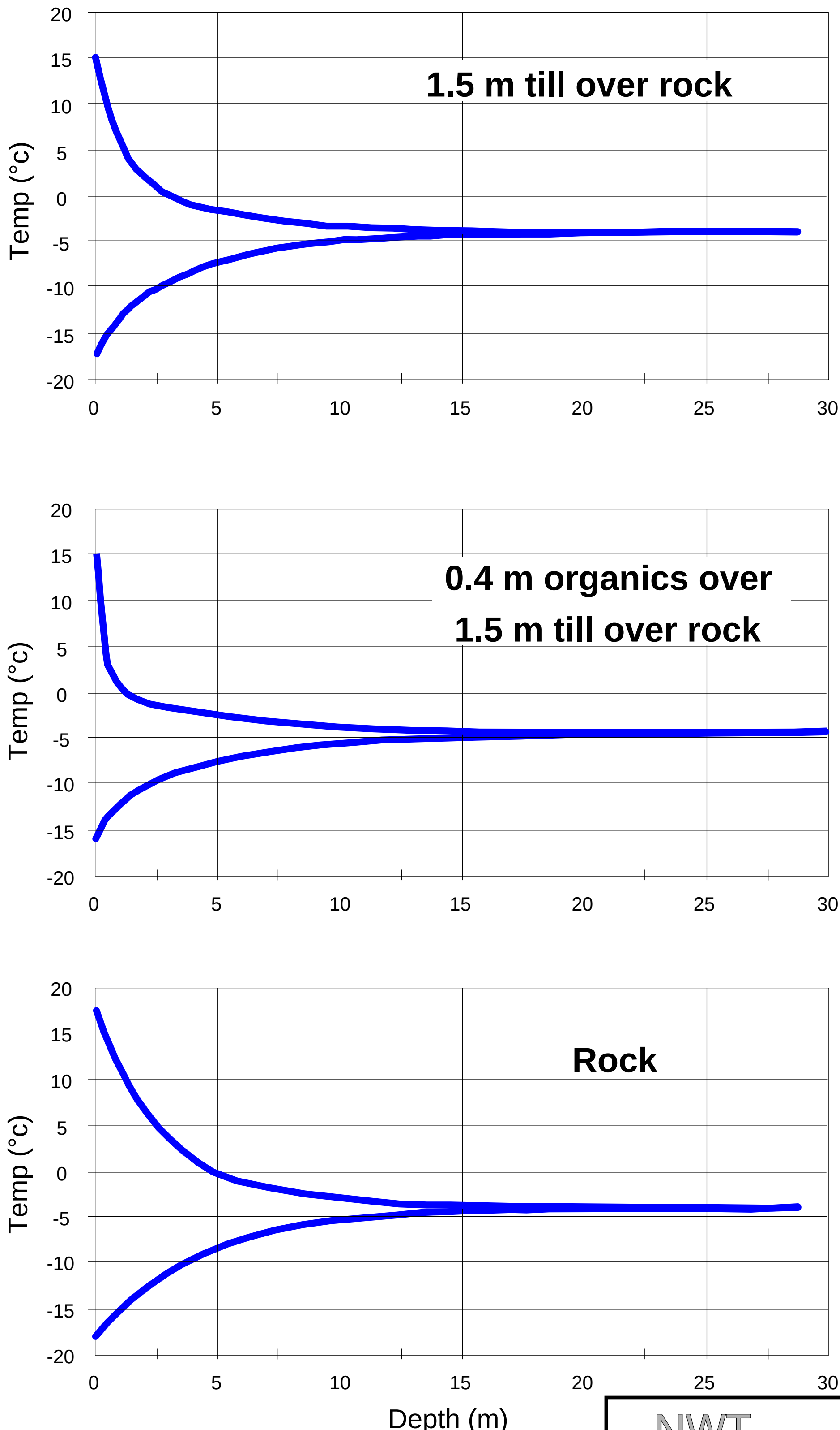
10 mm in thickness being commonplace. Ablation tills are less dense with greater excess ice content. Massive ground ice about 10 m thick was encountered in hummocky moraine sampled at the north end of Long Lake. The thin lacustrine silt and sand deposits that frequently occupy lowlands bordering lakes are commonly ice-rich soils (Plate 2.1-4). The ground ice is stratified in lenses up to 20 mm thick. Eskers have variable ground ice conditions, and interstitial ice bonds the sand and gravel below the permafrost table. Bodies of massive ice occur within most eskers, most frequently near their basal contact with the underlying till. Retrogressive thaw of massive ice near the lower slopes of eskers has resulted in arcuate thermokarst depressions that sometimes give the eskers a scalloped appearance.

Patterned ground, a periglacial landform indicative of permafrost, is not particularly well developed in the project area. Ice wedge polygons have developed on peat covered lacustrine lowlands but are weakly developed on glaciofluvial deposits (Plate 2.1-5). Sorted circles are weakly developed on poorly drained till plains, while frost boils are well developed on hummocky moraines (ablation till). The active layer is very stable throughout the region. Slope forming processes such as solifluction, shallow planar landslides in the active layer and erosion by slopewash are not present to any significant degree.

Predicted Permafrost Conditions Based on Geothermal Modelling

One-dimensional geothermal modelling was undertaken to broaden the understanding of permafrost ground temperatures and permafrost dynamics within the zone of annual temperature change. Details are reported in BGC (1995b). Meteorological data reported by EBA (1995b) and shown in Table 2.1-3 were used as input for the geothermal model. A geothermal gradient of 0.019°C per metre (Brown 1963), mean annual ground surface temperature of -4.6°C and permafrost depth of approximately 240 m provided the best calibration with the meteorological data. Although the ground surface temperature used in the analysis is somewhat less than observed, it is still easily inside the expected range. A summary of the results is provided here.

Thermal Regime: The ground thermal regime determined from the geothermal analysis is illustrated in Figure 2.1-6 for the three generalized terrain types in the area: thin till over rock; thin organics over till over rock; and rock exposed at the ground surface. The predicted thermal regime is compared to actual temperatures measured with the Fox decline thermistors (BHP 1995a and 1995b) in Figure 2.1-7. The measured temperatures show some variation as a result of decline opening versus installation time inconsistencies, drilling and installation disturbance, and the influence of ground warming and/or cooling in response to forced air circulation through the decline. Despite these factors, there is reasonable agreement between the predicted and measured ground temperature regime.



NWT DIAMONDS PROJECT

Figure 2.1-6
Predicted Thermal Regime
for Typical Terrain Types

Source: BGC

◎ Table of Contents

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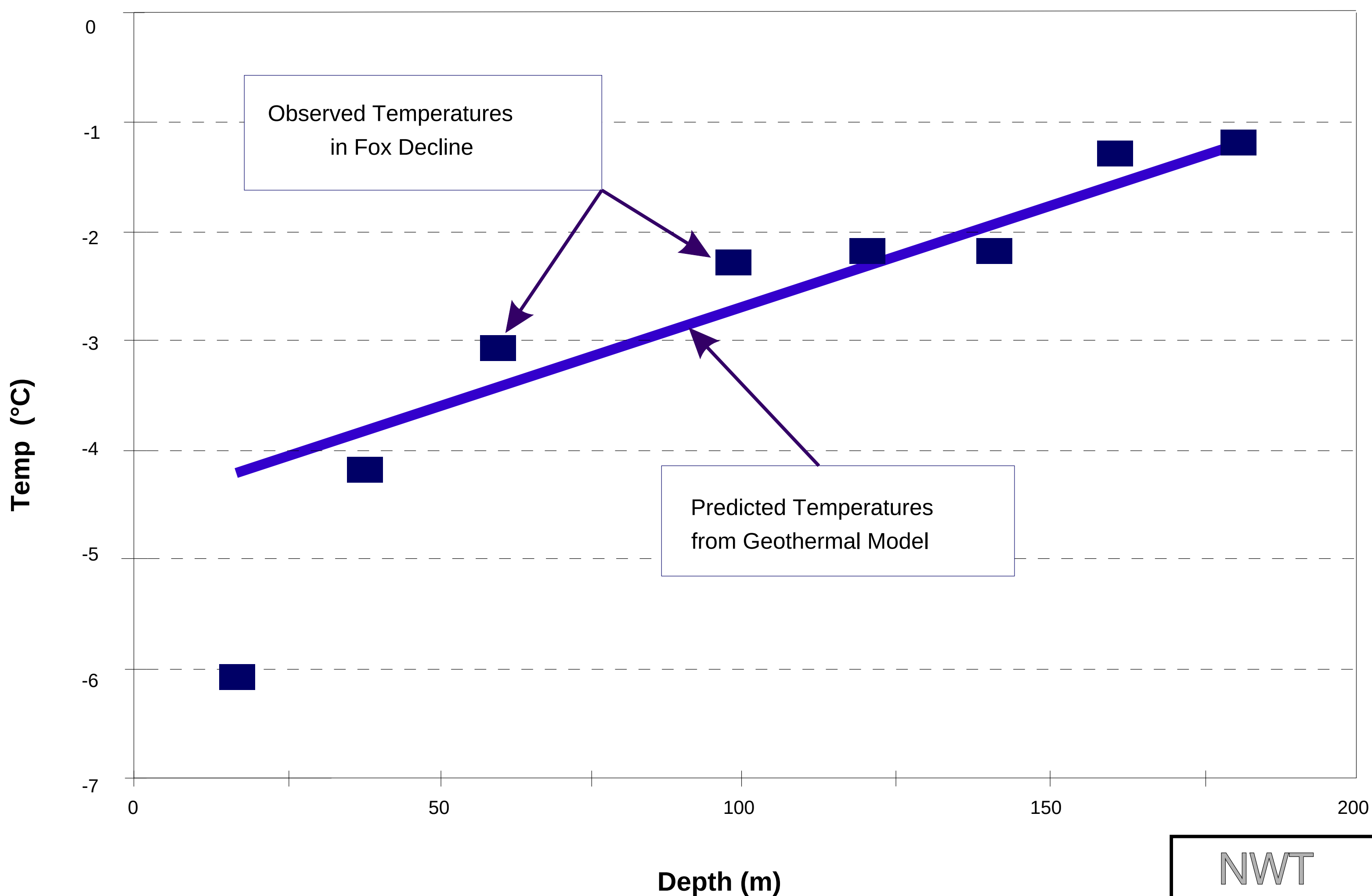


NWT DIAMONDS PROJECT

Figure 2.1-7
Predicted Thermal Regime *vs.* Observed Ground Temperatures

Source: BGC 1995

Table 2.1-3
Meteorological Data Used in
One-Dimensional Geothermal Analysis

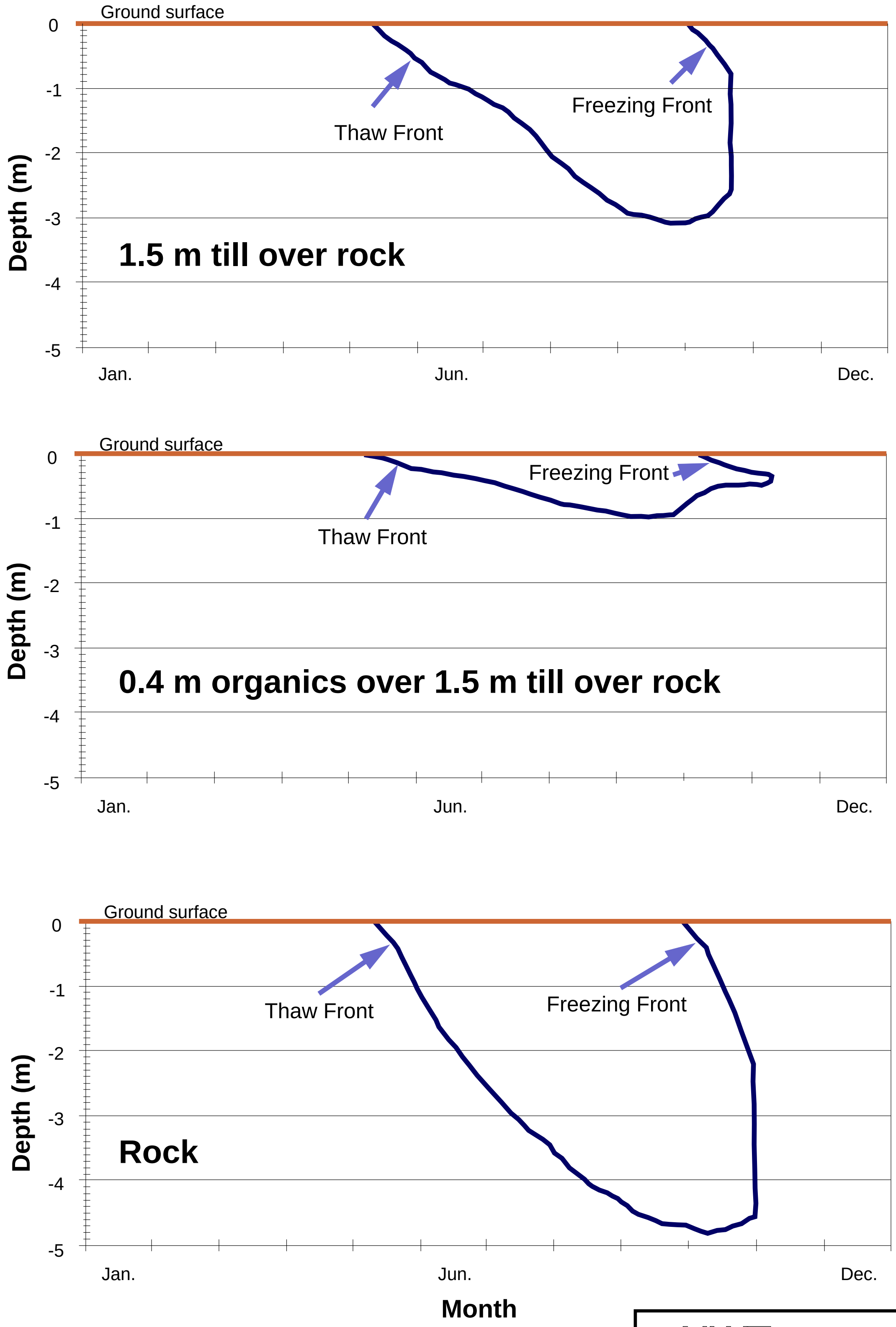
Month	$T(°C)_{Air}$	Wind (km/h)	Snow (cm)	Solar (W/m^2)
January	-30.7	17.7	39.0	9.1
February	-29.5	12.2	47.0	38.7
March	-25.6	12.9	54.0	119.5
April	-15.0	13.5	56.0	206.4
May	-3.2	15.2	38.0	259.7
June	6.2	13.6	0.0	252.0
July	11.1	15.1	0.0	226.4
August	10.1	17.0	0.0	160.8
September	3.2	20.8	0.0	124.9
October	-5.8	19.0	7.0	41.3
November	-18.5	16.3	19.0	14.4
December	-26.5	15.0	31.0	3.7

Depth of Active Layer: As indicated on Figure 2.1-6, the predicted depth of the active layer for the three terrain conditions analyzed ranges from approximately 1 m where an insulating organic soil covers the ground surface profile to nearly 5 m where rock is exposed at the ground surface. This is illustrated in more detail in Figure 2.1-8, which shows the annual development and freeze-back of the active layer.

Depth of Zero Mean Annual Temperature Change: The predicted depth of zero mean annual temperature change ranges from approximately 19 m to 22 m, as illustrated in Figure 2.1-6. Both ice content in the near-surface rock/soil profile and the presence of an insulating organic mat will cause this depth to decrease. A decreasing thickness of mineral soil in the soil profile analyzed will cause the depth to increase slightly.

Temperature Distribution Beneath Lakes: Site observations confirm the absence of permafrost beneath Fox Lake. This is consistent with experience reported by Brown *et al.* (1964). The actual temperature at shallow depths beneath lakes is expected to be within 1°C to 2°C above freezing, decreasing slightly with depth to temperatures only marginally above 0°C. The unfrozen-frozen contact will fall almost vertically below the point along the lake shore where winter ice regularly freezes to the bottom.

Estimated Two-Dimensional Configuration: Predicted two-dimensional configurations, necessary for groundwater modelling, are illustrated in Figures 2.1-9, 2.1-10 and 2.1-11 for the proposed Fox, Koala and Panda pits, respectively.



(Note the region above the thaw front and below the freezing front is above 0°C, hence the active layer)

NWT DIAMONDS PROJECT

Figure 2.1-8
Predicted Position of the Phase Boundary

Source: BGC 1995

◎ Table of Contents

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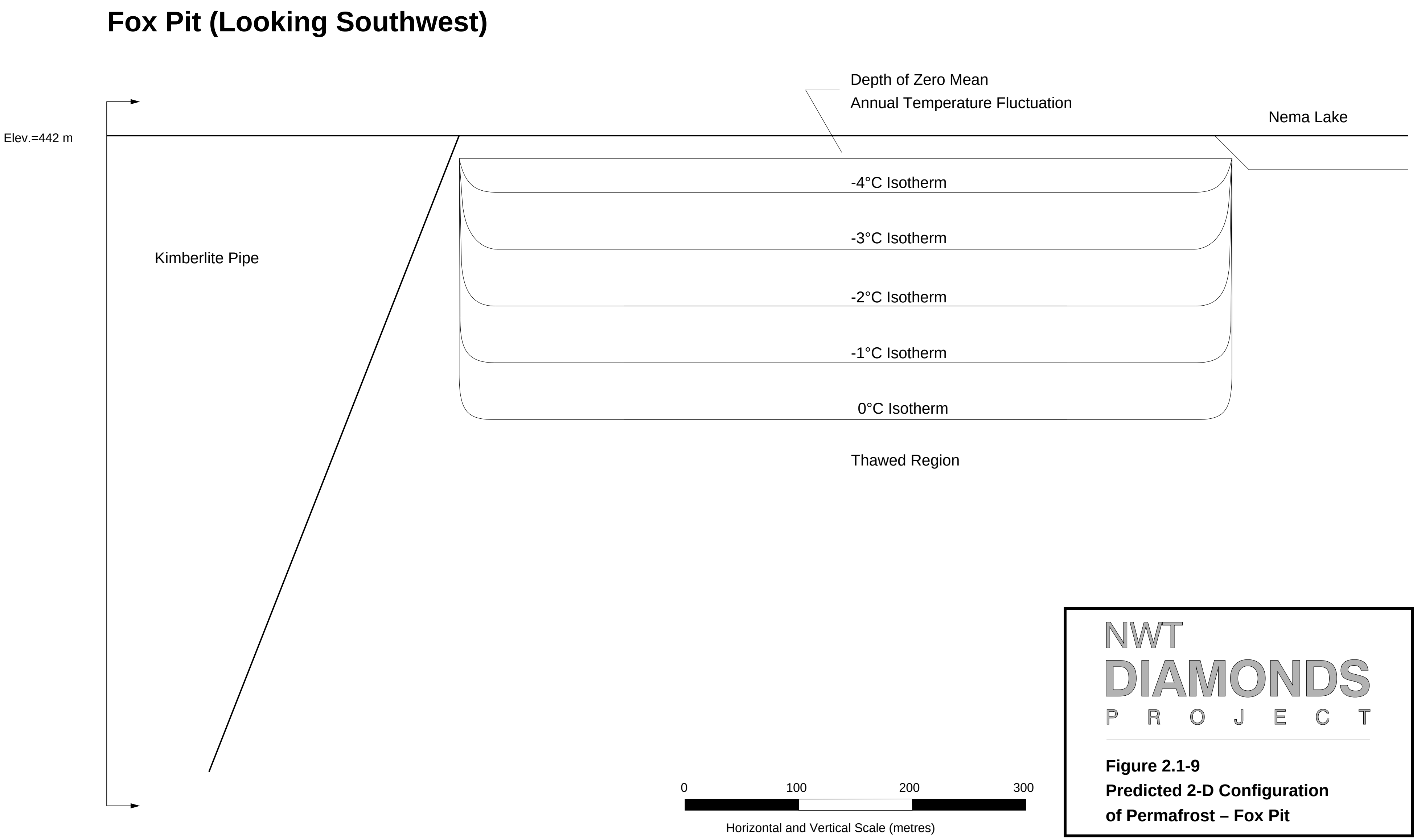


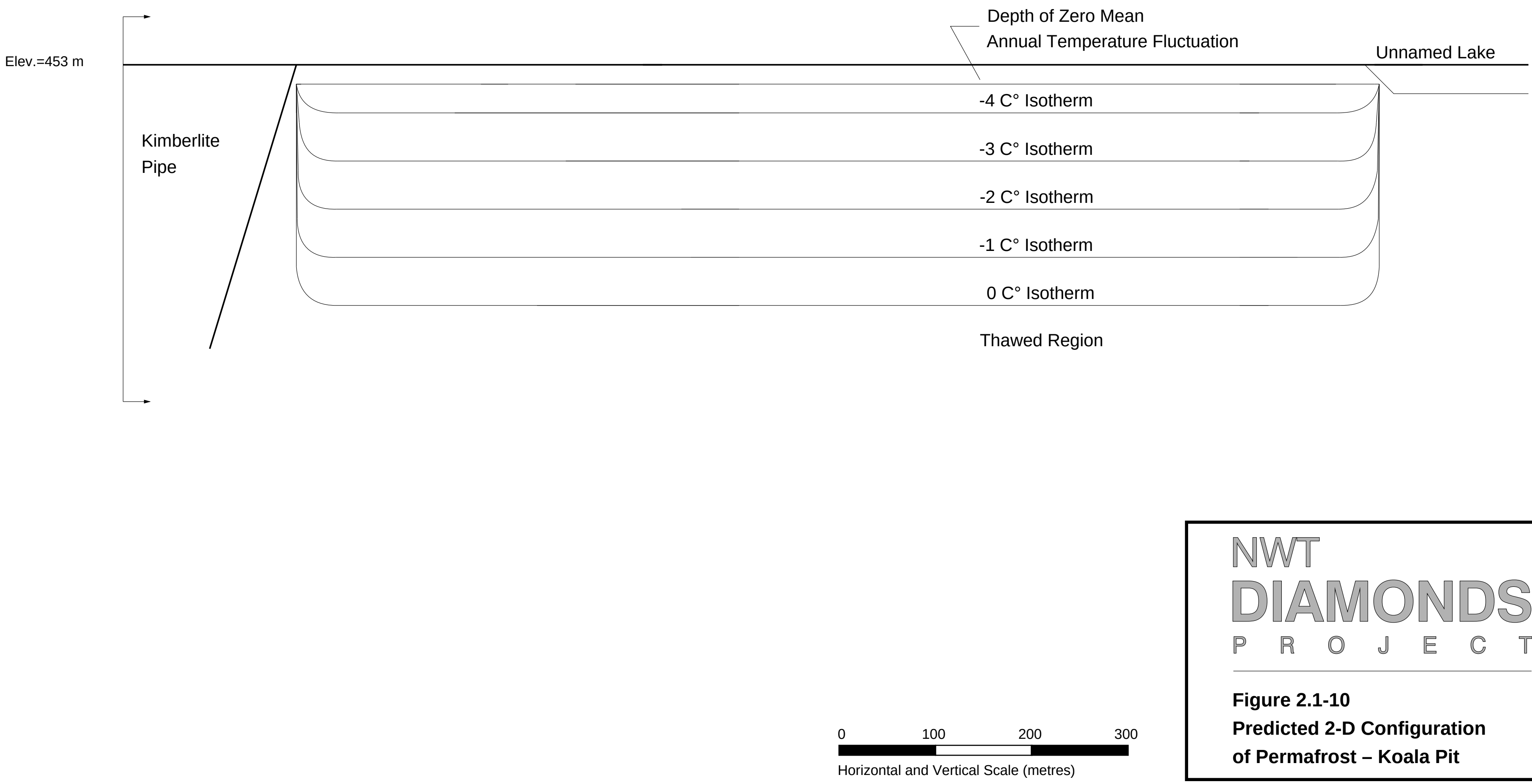
NWT DIAMONDS PROJECT

Figure 2.1-9
Predicted 2-D Configuration of Permafrost – Fox Pit

Source: BGC

◎ Table of Contents

Koala Pit (Looking Southwest)

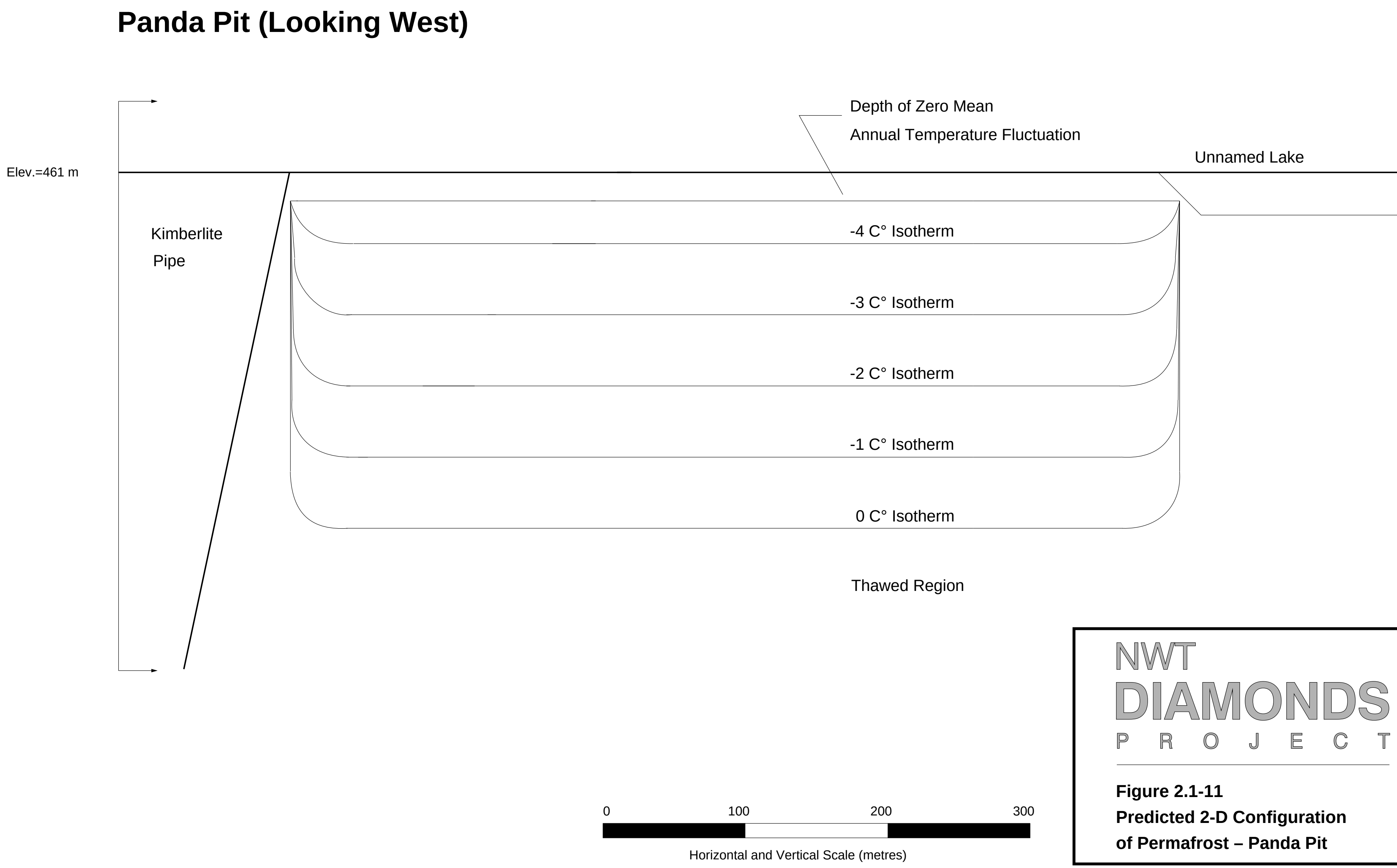


NWT DIAMONDS PROJECT

Figure 2.1-10
Predicted 2-D Configuration of Permafrost – Koala Pit

Source: BGC

◎ Table of Contents



NWT DIAMONDS PROJECT

Figure 2.1-11
Predicted 2-D Configuration of Permafrost – Panda Pit

Source: BGC

These are based on the one-dimensional modelling and experience reported in Brown *et al.* (1964). In each case, the cross-sectional view illustrated extends from the approximate centre of the proposed pit to the nearest lake. These cross-sections form the basis of the two-dimensional groundwater modelling reported in Section 2.3.2.

2.1.3 Summary

The terrain in the claim block was most recently modified by the Late Wisconsinan Laurentide glaciation, during which till was deposited on top of bedrock. A variety of surficial deposits and landforms resulting from glacial and glaciofluvial activities remain, the most distinct being sand eskers. Eskers have been identified as a valued ecosystem component due primarily to their importance to wildlife for denning and as travel corridors.

The claim block lies within a region of continuous permafrost, although the presence of deep lakes or rivers that flow all year round result in deep thaw zones that can extend through the permafrost. The surface active layer, which thaws each summer, varies in thickness depending on terrain conditions.

2.2 Ground Instability

The NWT Diamonds Project lies within the North American tectonic plate on a stable Archean craton, at approximate coordinates 64° 40'N, 110° 35'W. No earthquake of Richter Magnitude M6 or greater has occurred within 1,000 km of the site in recorded history.

A seismic risk calculation for the site was obtained from the Pacific Geoscience Centre, Geological Survey of Canada, and can be found in Appendix II - A1. Predicted peak ground velocities for the 10% and 5% chance of exceedance in 50 years (475- and 1,000-year events, respectively) are shown in Table 2.2-1.

Table 2.2-1
Shaking Level – Chance of Exceedance in 50 Years

	Chance of Exceedance	
	10%	**5%**
Peak Ground Acceleration, gravity units	0.013	0.016
Peak Ground Velocity, m/s	0.039	0.046

Acceleration of 0.01 to 0.02 gravity units is very small and would not cause damage to earth or other structures. The peak velocities of 0.04 to 0.05 m/s are high relative to the acceleration values and indicate that the risk is coming from a distant earthquake rather than a small local earthquake. Velocities in this range would not cause damage to earth or other structures.

Structures that fall within the guidelines of the National Building Code of Canada (NBCC) are designed such that collapse should not occur for the 475-year event (10% chance of exceedance in 50 years). Since both the peak ground acceleration and velocity values are <0.04, this site would fall into Zone 0, a quiescent earthquake zone, and as such no earthquake loads need to be considered in design of buildings under NBCC.

Contours of peak ground acceleration and velocity for Canada, shown in Figure 2.2-1, reinforce the finding that the site is located in a quiescent earthquake zone, where both the peak ground acceleration and velocity values are <0.04.

Based on the Pacific Geoscience data, a 1,000-year event is only marginally more severe than the 475-year event at this site, and would not cause significant damage to even poorly designed structures.

In summary, the site is located in an area of very low seismic activity where conventional buildings that fall under the NBCC guidelines need not be designed to withstand earthquake forces.

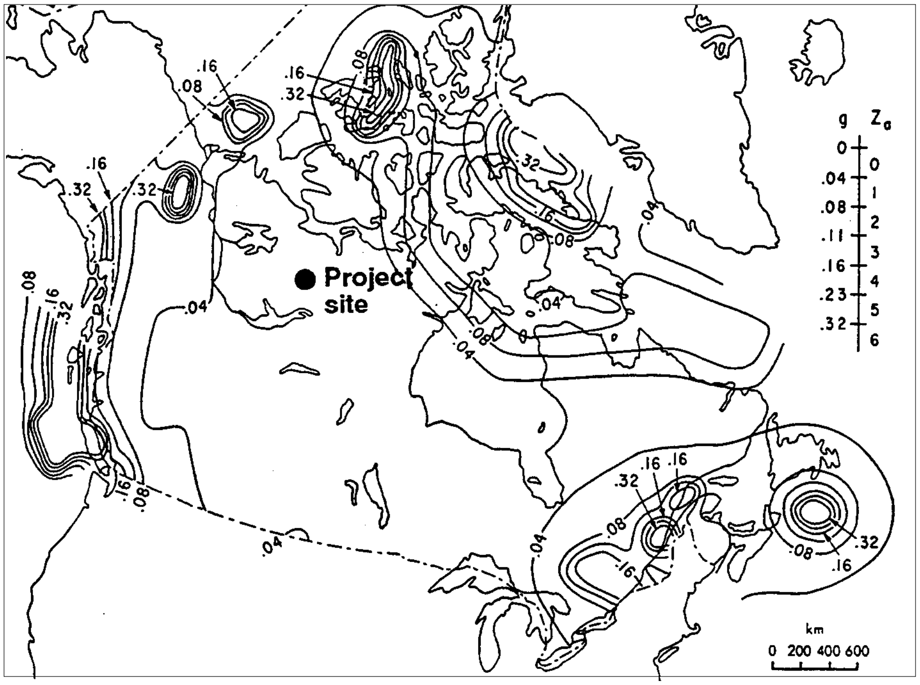
2.3 Hydrology

Hydrology has been identified as a valued ecosystem component. This section will describe the surface hydrology and groundwater flows that are pertinent to this project.

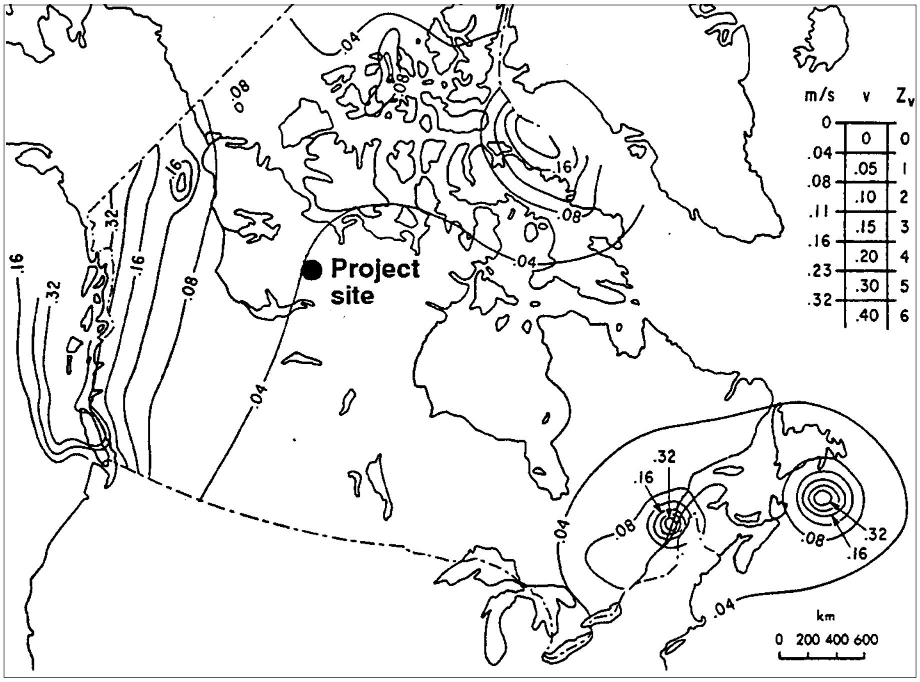
2.3.1 Surface Hydrology

The principal hydrological processes in the Northwest Territories are snow accumulation and snow melt, surface runoff, lake hydrology with a free-water evaporation component, and stream and river flows in drainage basins. The cold climate controls the hydrological cycle, resulting in water being stored as snow and ice for much of the year. Snowfall accumulates over a six to nine month period before melting quickly during the freshet (Woo 1993). In addition, surface stream flow and runoff typically cease during the winter, while river discharge decreases and the lakes freeze. As a result, surface hydrological processes are concentrated in the short period when temperatures rise above freezing.

The NWT Diamonds Project area is located in the Lac de Gras watershed at the headwaters of the Coppermine River Basin. The basin has a length of 520 km and an average width of 98 km, draining an area of 50,800 km^2 (Environment Canada 1988). The Coppermine River has a mean slope of 0.0006 m/m and flows from southeast to northwest, draining into the Arctic Ocean near the community of



Contours of peak horizontal ground accelerations, in units of g, having a probability of exceedance of 10% in 50 years.



Contours of peak horizontal ground velocities, in m/s, having a probability of exceedance of 10% in 50 years.

NWT DIAMONDS PROJECT

Figure 2.2-1
Peak Horizontal Ground Acceleration and Velocity

Source: NRC 1990

Coppermine. The Lac de Gras watershed has an approximate area of 3,980 km^2, constituting 8% of the main basin.

2.3.1.1 Previous Research

Numerous studies have investigated hydrological regimes in arctic and sub-arctic regions. The following is a brief review of existing literature on northern hydrology. The principle sources for defining general hydrological processes were: Environment Canada (1988), providing an overview of the Coppermine River Basin; Prowse and Ommanney (1990), summarizing research in the Arctic; and Woo (1990), with an overview of northern hydrology in the polar regions.

Church (1974) provided a commonly used classification by dividing the North into four distinct regions, based on source and timing of run-off from annual hydrographs. The four regions are: arctic-nival; subarctic-nival; proglacial; and muskeg. A comprehensive classification scheme based on physiographic and vegetational units has been proposed by Wedel (1986).

The hydrometric network in the NWT in 1989, consisted of 116 hydrometric stations providing discharge records, and 95 climate stations (Prowse 1990). Hydrometric station density in the NWT was 1:29,000 km^2, with 58% of the stations located in catchments, less than 10,000 km^2 in size.

Hydrological processes described in previous studies consist of snow hydrology, encompassing snow accumulation, redistribution and snowmelt runoff, permafrost hydrology, which includes lake and wetland hydrology, water balance and evaporation processes, groundwater hydrology, and stream and river hydrology.

The basic processes of snow hydrology were described by Marsh (1990a). Detailed studies on water movement in the snowpack have been presented by Seligman (1936), US Army (1956), Wakahama (1968), Colbeck (1976), Woo and Heron (1981), Marsh and Woo (1984a, 1984b, 1985) and Marsh (1990b). The snowmelt processes depends on the available energy for generating snowmelt runoff. Snowmelt energy balance investigations have been done by Weller and Holmgren (1974), Ward and Orvig (1953), Holmgren (1971), Price and Dunne (1976), Price *et al.* (1976) and Heron and Woo (1978), while soil infiltration and runoff were investigated by Marsh (1988).

Several studies on basin hydrology and water balance have been performed in Arctic and sub-arctic regions. These site-specific studies include: Ohmura (1981, 1982); Woo (1983, 1986, 1988); Woo *et al.* (1981); Roulet and Woo (1986a); Onesti and Walti (1983); Lewkowitz and French (1982). Lake evaporation studies in northern regions include: Louie (1979); Marsh and Bigras (1988); Roulet and Woo (1986b); and Stewart and Rouse (1976b).

Groundwater hydrology in the Arctic is often neglected as permafrost is assumed to be impermeable. This assumption is not always valid as pointed out by van Everdingen (1990) in his review of the properties of frozen ground, permafrost and groundwater hydrology.

Stream and river hydrological processes were reviewed by Wedel (1990), and the hydrology of floating ice was reviewed by Gerard (1990). These studies identify hydrological processes that incorporate hydroclimatological parameters in Arctic environments.

2.3.1.2 Overview of Study Area Hydrology

The majority of the mine development is concentrated in the Koala watershed, while exploration activity is on-going in the other sub-basins as well as in the Pointe de Misère area. The Koala sub-basin contains the Panda, Koala, Leslie and Fox Lake kimberlite pipes. The Misery Lake pipe is located in an isolated minor catchment (1 km^2) draining into Lac de Gras (Figure 2.3-1).

The complex surface hydrology of the project study area is due primarily to the low relief of the terrain, with the resulting diffuse drainage pattern. The lakes are typically connected by boulder-filled streams, which meander in braided channels following weak hydraulic gradients. The overall gradient between Vulture Lake (elevation 475 m) and Lac de Gras (elevation 416 m), via Slipper Creek, is 0.003 m/m.

The Koala drainage basin has an area of 185 km^2, and consists of a system of connected lakes extending from Vulture Lake in the northeast to Slipper Lake in the southwest where the water drains into Lac de Gras. Several sub-catchments (Long, Leslie, Fox, Nora and Mike lakes) supply additional water to the main drainage system. Lake and stream watercourses make up about 16% of the Koala sub-basin.

The Paul Lake catchment comprises an area of 122 km^2, with Paul Lake (approximately 10 km long) dominating the east to west drainage system. Water flows into Paul Lake from both northern and southern areas of the catchment. Surface water comprises approximately 23% of the Paul sub-basin (Figure 2.3-1). The catchment is bounded to the east by a prominent north-south esker system (Lac du Sauvage Esker) that extends to Lac de Gras.

The Ursula Lake watershed lies to the north of the Koala Lake and Paul Lake watersheds, and drains an area of approximately 203 km^2. Approximately 24% of the watershed area is made up of surface waters (Figure 2.3-1).

The South watershed drains an area of approximately 46 km^2 to the east of the Koala watershed. Approximately 13% of the area of the watershed consists of

◎ Table of Contents

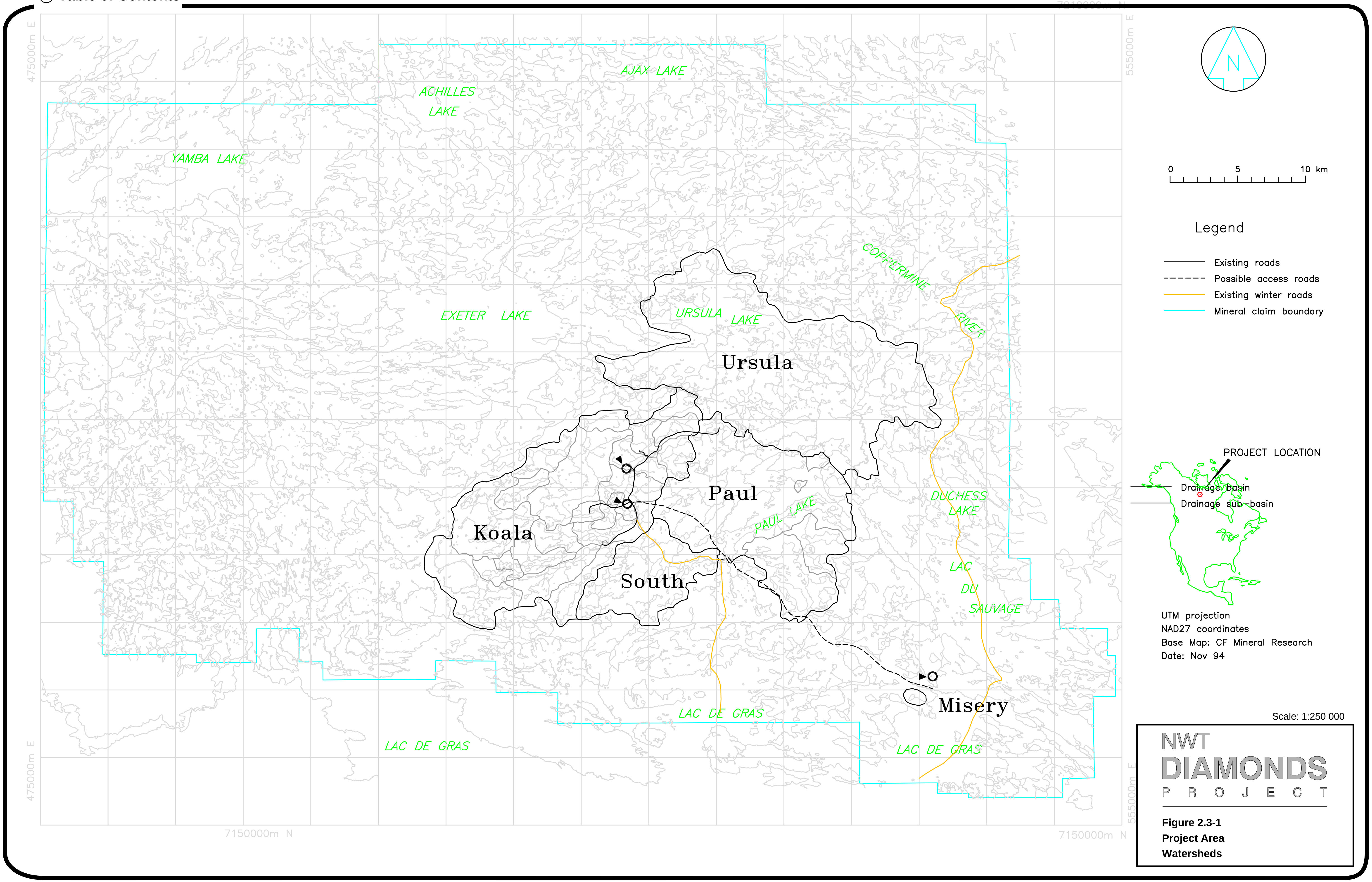


Figure 2.3-1
Project Area
Watersheds

Source: Rescan

surface waters (Figure 2.3-1). Water flows from west to east, draining into Lac de Gras.

2.3.1.3 Methods

Data on lake bathymetry, lake water levels and stream flow were collected to characterize the surface hydrological regime of the project area. These data have been supplemented by regional data from hydrometric stations operated on larger catchments by the Government of Canada, thereby effectively extending the period of record.

Regional Data Sources

Regional hydrological data have been assessed in order to characterize the hydrological regime in the proximity of the NWT Diamonds Project site. Hydrologic data for the Coppermine River Basin were obtained from the Inland Waters Directorate (IWD) of the Water Survey of Canada (WSC), in Yellowknife. The hydrometric monitoring station at Point Lake contained the longest record of discharge data (30 years), while records for Bloody Falls and Copper Creek were only for three years and seven years, respectively. Data for adjacent watersheds encompassing the Burnside-Back River, Yellowknife River and Snare River drainage have been collected. Monitoring sites exist at Burnside and Back Rivers draining Contwoyto Lake, Indin River, Tree River, Thonokeid River, Gordon River, Waldren River and the Hanbury River (Figure 2.3-2).

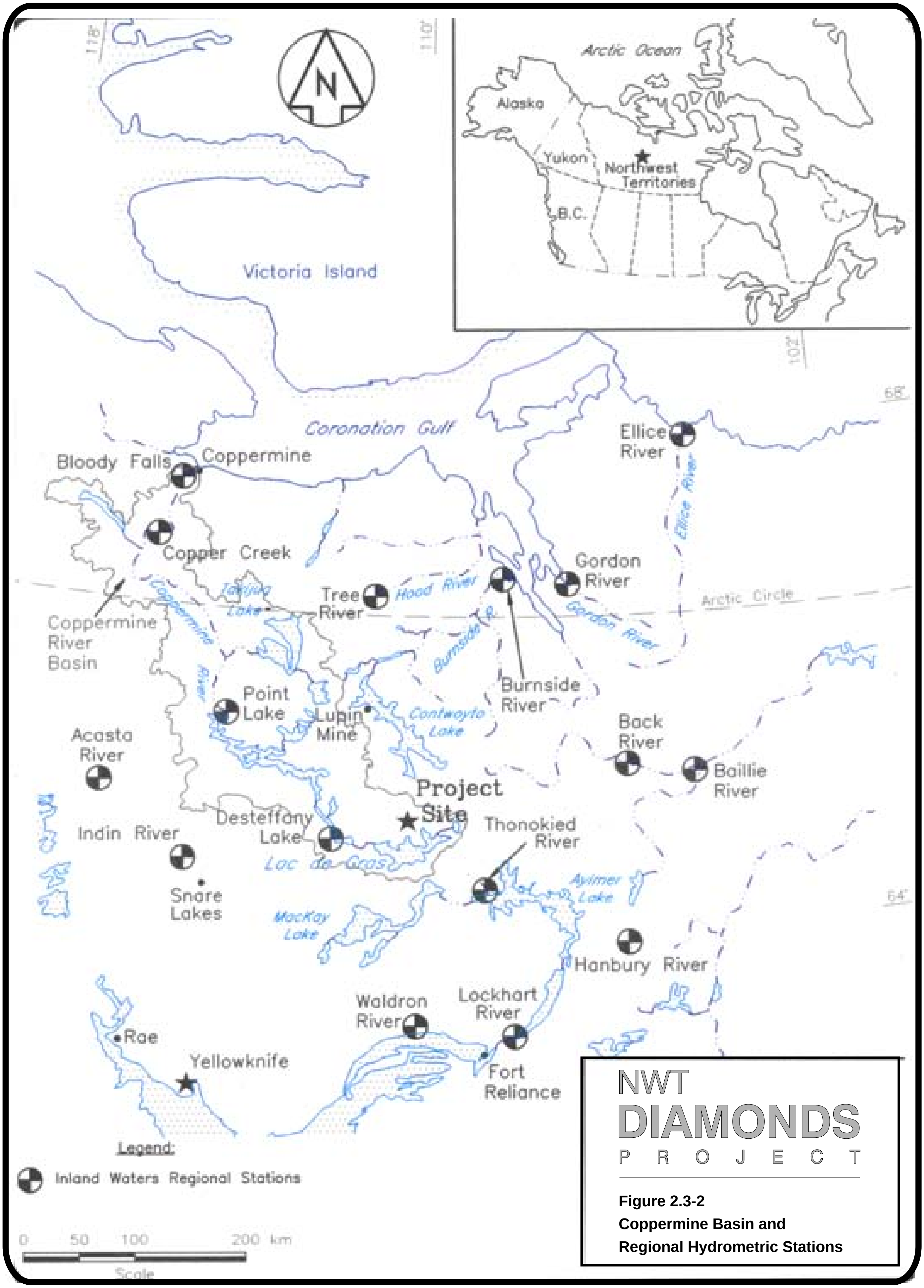
Field Data Collection

A preliminary field program was initiated in the fall of 1992. Detailed bathymetric surveys were conducted on a number of lakes in the project area, and an automated weather station was installed in the vicinity of the exploration camp. This was performed in conjunction with reconnaissance level aquatic and fisheries studies of several lakes and streams. These preliminary studies were documented in *Baseline Environmental Study Protocols* (BHP 1993).

In June 1994, a comprehensive field monitoring program was initiated to assess the hydrological regime in the project area. Twenty-nine hydrometric stations were installed to monitor water levels during the observation period. Staff gauges were placed mainly in lakes, except where suitable stream gauging sites were available. Due to the predominance of boulders in the stream beds, suitable stream gauging sites were rare, although 11 stream sites were monitored. Manual staff gauge readings were taken at all hydrology stations at regular intervals throughout the summer. Ten of these stations were automated to provide hourly water level readings.

The majority of the gauging stations were concentrated in the Koala watershed (Figure 2.3-3). Twenty-three staff gauges were installed in the Koala watershed,

Table of Contents

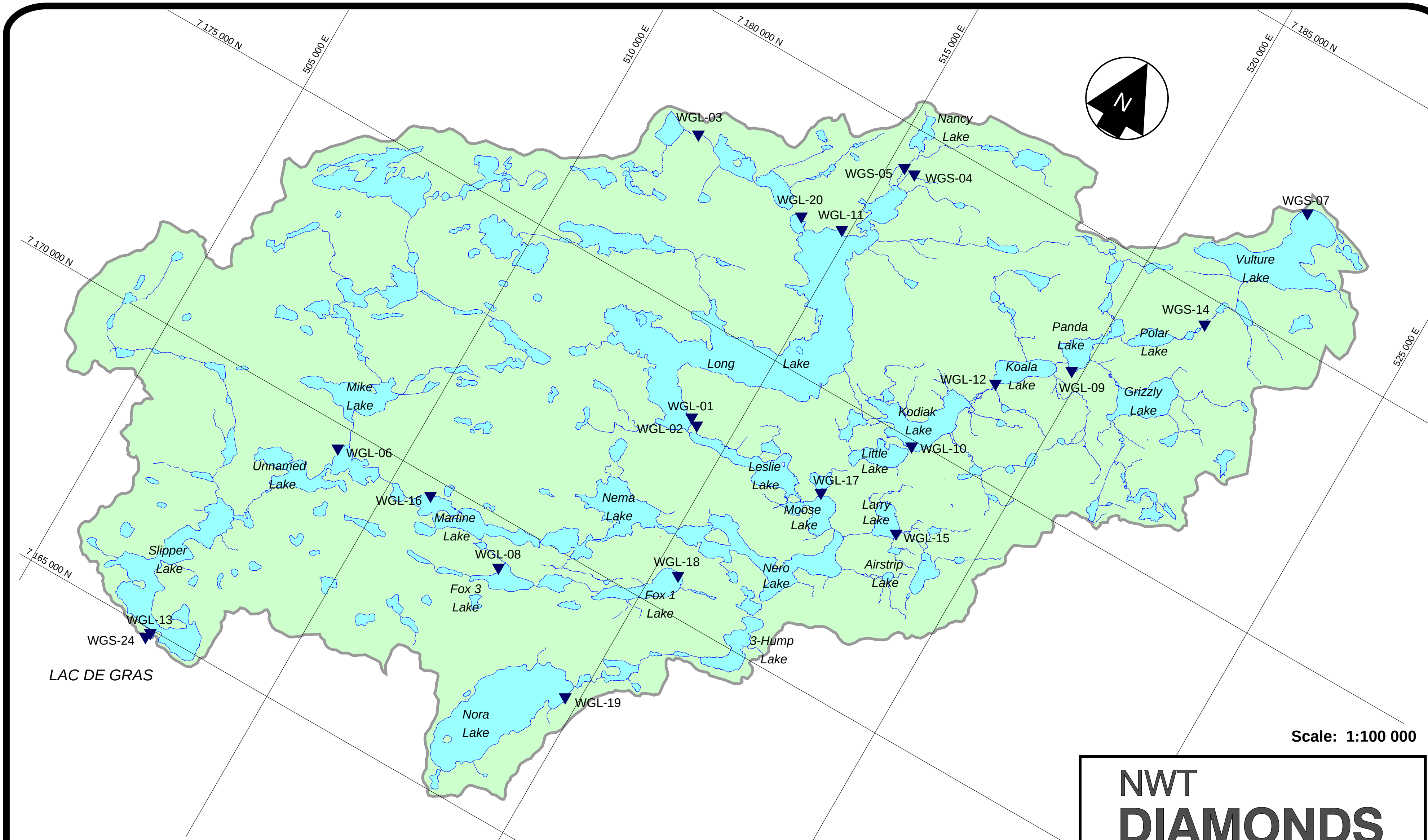


NWT DIAMONDS PROJECT

Figure 2.3-2
Coppermine Basin and Regional Hydrometric Stations

Source: Rescan 1994

◎ Table of Contents



Scale: 1:100 000

LEGEND

WGS-23 ▼ HYDROMETRIC STATION

NWT DIAMONDS PROJECT

Figure 2.3-3
Hydrometric Stations in Koala Watershed

Source: Rescan

with one staff gauge in Lac de Gras, at the outflow of Slipper Creek. Seven staff gauges were placed in streams. Streamflow was estimated at these sites at regular intervals by using a flow meter to measure water depths and flow velocity. Storage-discharge curves were developed to convert staff gauge readings to streamflow.

Nine dataloggers and pressure transducers were installed at Panda, Koala, Kodiak, Long (two stations), Martine and Slipper lakes, and at stream sites connecting Vulture Lake to Panda Lake, and Slipper Lake to Lac de Gras. The dataloggers recorded hourly water levels that were averaged to obtain mean daily water levels. All dataloggers with staff gauges were operational by the end of July 1994.

The Ursula watershed contained a single hydrometric station located along Ursula Creek, near the outlet of the watershed into Duchess Lake. This station was equipped with a staff gauge and a datalogger. Flow measurements were also taken for stage-discharge calculations required to estimate daily discharge.

One staff gauge site was installed at the northwest quadrant of the Paul Lake watershed, to estimate inflow from Bat Lake to the north. Flow measurements were also taken to develop a stage-discharge relationship for estimating discharge.

The South watershed was monitored by a single staff gauge near the outflow of the watershed into Lac de Gras, located within 1 km of the Paul Lake watershed discharge point. A stage-discharge curve was also plotted to estimate daily flows into Lac de Gras.

Misery Lake was monitored by a single staff gauge. Water levels in August 1994 were recorded.

2.3.1.4 Lake Hydrology

Fifteen lakes were monitored for lake elevation and storage from June 1994 to October 1994 in the Koala watershed. Physical dimensions of selected lakes with hydrometric stations are presented in Table 2.3-1. Generally, the minimum lake levels were reached in early August. During the late open water season, there were several rainstorms which resulted in rising lake levels and corresponding reductions in net storage loss.

Table 2.3-2 lists, for each lake monitored, the observation period, maximum change in elevation and corresponding storage loss for the duration of the monitoring period. Maximum storage change varied from 61,000 m^3 for Larry Lake to 2.1×10^6 m^3 for Long Lake. Storage change losses were attributed to combined losses from stream outflow and evaporation. Groundwater flow was assumed to be negligible. This assumption was supported by observations made during drilling at the Long Lake outflow (subsurface consisting of shallow bedrock and permafrost).

Table 2.3-1
Surface Area and Volume of Selected Lake
in the NWT Diamonds Project Area

Lake	Lake Data					
	Breadth (m)	**Length (m)**	**Max. Depth (m)**	**Mean Depth (m)**	**Area (m^2)**	**Volume (m^3)**
Little	288	1,110	20	3.2	319,709	1,009,432
Larry	263	890	8	2.1	233,903	492,228
Nora	863	2,944	17	4.0	2,541,960	10,097,992
Nero	386	3,460	16	2.8	1,336,360	3,731,016
Nema	499	1,552	9	1.9	775,136	1,465,474
Grizzly	420	1,404	43	14.6	589,386	8,578,943
Vulture	659	2,736	43	11.2	1,801,763	20,258,904
Nancy	203	700	5	1.0	141,888	146,582
Airstrip	240	805	3	1.5	193,267	453,104
Fox 1	255	1,712	29	6.9	436,649	3,030,154
Fox 2	193	638	8	2.3	123,015	282,269
Fox 3	233	1,140	7	2.0	265,085	519,683
3 Hump	265	1,545	20	6.0	409,027	2,464,609
1 Hump	197	550	16	4.5	108,187	484,400
Panda	256	1,365	19	3.8	349,925	1,312,921
Koala	304	1,250	20	5.9	380,402	2,254,152
Kodiak	391	2,320	13	2.1	907,213	1,938,277
Long	729	8,430	32	7.4	6,144,067	45,287,370
Leslie	279	2,216	13	2.3	618,427	1,413,350
Slipper	n/a	n/a	n/a	n/a	1,894,891	6,083,299
Misery	226	604	28	7.5	136,650	1,023,560
Martine	n/a	n/a	n/a	n/a	460,919	715,009
Renee	n/a	n/a	n/a	n/a	328,771	356,907

n/a = not available.

2.3.1.5 Mean Flows

Site-specific and regional data have been referenced in order to derive estimates of mean monthly and annual runoff for the project site.

Regional Data

An analysis of regional hydrologic data in the NWT must take into account the sparse data collection network and the limited period of record at many sites. A complicating consideration is that the project catchments for which runoff estimation is required are much smaller than regional gauged catchments. These

◎ Table of Contents

Table 2.3-2
Summary of Lake and Stream Elevation Changes in the NWT Diamonds Project Area for 1994

Station Number	Location	Observation Period	Elevation Change (m)	Maximum Lake Elevation Change (m)	Initial Lake Elevation (m)	Final Lake Elevation (m)	Maximum Lake Storage Change (m^3)
WGL-01	Long Lake - south	Jun 9 to Oct 8	-0.28	-0.334	448.493	448.213	2052118
WGL-06	Renee Lake	Jun 10 to Oct 8	-0.371	-0.499	435.425	435.054	164056
WGL-07	Vulture Lake - dock	Jun 25 to Oct 7	-0.154	-0.174	474.032	473.878	313506
WGL-08	Fox 3 Lake	Jun 24 to Oct 8	-0.112	-0.282	441.029	440.917	74753
WGL-09	Panda Lake	Jun 25 to Oct 9	-0.05	-0.304	460.758	460.708	106377
WGL-10	Kodiak Lake	Jun 25 to Oct 9	-0.04	-0.192	443.742	443.702	174184
WGL-11	Long Lake - north	Jun 27 to Oct 7	-0.254	-0.302	448.441	448.187	1855508
WGL-12	Koala Lake	Jun 28 to Oct 09	-0.128	-0.258	453.800	453.672	98143
WGL-13	Slipper Lake	Jun 28 to Oct 8	-0.082	-0.166	423.953	423.871	314551
WGL-15	Larry Lake	Jun 28 to Oct 6	0.05	-0.262	454.362	454.412	61282
WGL-16	Martine Lake	Jun 29 to Oct 8	-0.226	-0.336	438.339	438.113	154868
WGL-17	Moose Lake	Jun 30 to Sep 25	-0.342	-0.464	444.563	444.221	0
WGL-18	Fox 1 Lake	Jun 30 to Oct 8	-0.186	-0.272	445.482	445.296	118768
WGL-19	Nora Lake	Jun 30 to Oct 8	-0.218	-0.232	463.369	463.151	589734
WGL-26	Isotope Lake	Jul 23 to Oct 7	0.128	-0.068	481	481.058	960
WGL-27	Wolf Lake	Jul 22 to Oct 7	0.194	-0.072	475.725	475.919	0
WGL-28	Lac de Gras	Aug 16 to Oct 8	-0.114	-0.114	415.486	415.372	n/a

factors tend to increase the uncertainty in a regional analysis of surface flows. However, these problems are partially offset by the relative consistency in runoff from place to place in the central NWT. This arises in part from the low spatial variability in long-term precipitation levels and the lack of large terrain features such as mountain ranges, which exert strong localized influences over patterns of rainfall and runoff in much of western Canada.

Daily discharge values for the period of record were obtained from the IWD in Yellowknife at each hydrometric station, and mean monthly discharge values were calculated. A significant portion of the annual discharge occurs in June and July during spring freshet. Approximately 50% of the annual runoff from smaller watersheds is derived from snowmelt, typically resulting in annual flood conditions that are often compounded by spring rainstorms.

Regional stations considered in this analysis are listed in Table 2.3-3. They are spread over a large area of nearly 400,000 km^2 to the north and east of Yellowknife. Catchment areas (Table 2.3-3) vary from 1,500 km^2 to 50,000 km^2, and periods of record from four years to 50 years. Of the fifteen gauges listed in Table 2.3-3, three are on the Coppermine River (a fourth station, Desteffany Lake, has a period of record of less than one year). Runoff at most of the stations is between 150 mm and 190 mm, and generally increases with latitude. This may be due to decreasing catchment losses to evapotranspiration at higher latitudes.

Two stations are considered to be of particular relevance because they combine geographic proximity with reasonably long periods of record. The Point Lake station on the Coppermine River (10PB001) has a period of record of 29 years and a catchment area of 19,300 km^2. Runoff depth averaged 173 mm/a at this station, which is about 200 km northwest of the project site. The Indin River station (07SA004), 200 km west of the project site, is of interest because it has a small catchment, a reasonably lengthy period of record (17 years) and is at approximately the same latitude as the project site. Runoff depth has averaged 159 mm annually at the Indin River station (Table 2.3-3).

Mean monthly discharge for the Indin River station is listed in Table 2.3-4.

Site-Specific Data

As previously discussed, streamflow data were collected at a number of stations in the Koala drainage. Data from two of these stations, Long Lake outflow and Slipper Lake outflow, have been graphed on a unit yield basis along with data collected concurrently at the Indin River station (Figure 2.3-4). For the common period of record (June 9 to October 9, and November 10 to November 23), runoff depth for Long Lake was calculated to be 62.5 mm, while that for Indin River was 54.3 mm. Recognizing the difficulties inherent in accurately measuring streamflow in the small project site watercourses, this provides some indication of higher runoff in the project area than in the Indin River catchment, which could be

Table 2.3-3
Regional Hydrological Stations

Station Name	Station Number	Latitude	Longitude	Drainage Area (km^2)	Period of Record	Years of Record	Runoff (mm)
Acasta River	10JA004	64°52'30"	116°08'19"	2,280	1980 to present	14	160
Back River	10RA001	65°11'34"	106°04'38"	19,600	1978 to present	16	180
Baillie River	10RA002	65°02'39"	104°30'45"	14,500	1978 to present	16	170
Burnside River	10QC001	66°44'10"	108°49'08"	16,800	1976 to present	18	226
Coppermine River at							
- Bloody Falls	10PC003	67°44'25"	115°22'43"	50,700	1983 to 1986	4	211
- Copper Creek	10PC004	67°13'41"	115°53'17"	46,800	1987 to present	7	165
- Point Lake	10PB001	65°24'48"	114°00'14"	19,300	1965 to present	29	173
Ellice River	10QD001	67°42'42"	104°08'27"	16,900	1971 to present	23	154
Hanbury River	06JB001	63°36'07"	105°07'52"	5,770	1971 to present	23	170
Indin River	07SA004	64°23'20"	115°01'16"	1,520	1977 to present	17	159
Lockhart River	07RD001	62°53'48"	108°28'17"	26,600	1844 to present	50	146
Thonokied River	07RC001	64°08'49"	108°55'02"	1,780	1980 to 1990	11	174
Tree River	10QA001	67°38'03"	111°54'32"	5,810	1969 to present	25	189
Waldron River	07SC002	63°02'53"	110°29'15"	1,830	1979 to present	15	119
Gordon River	10QC002	66°48'31"	107°06'13"	1,530	1977 to present	17	190

◎ Table of Contents

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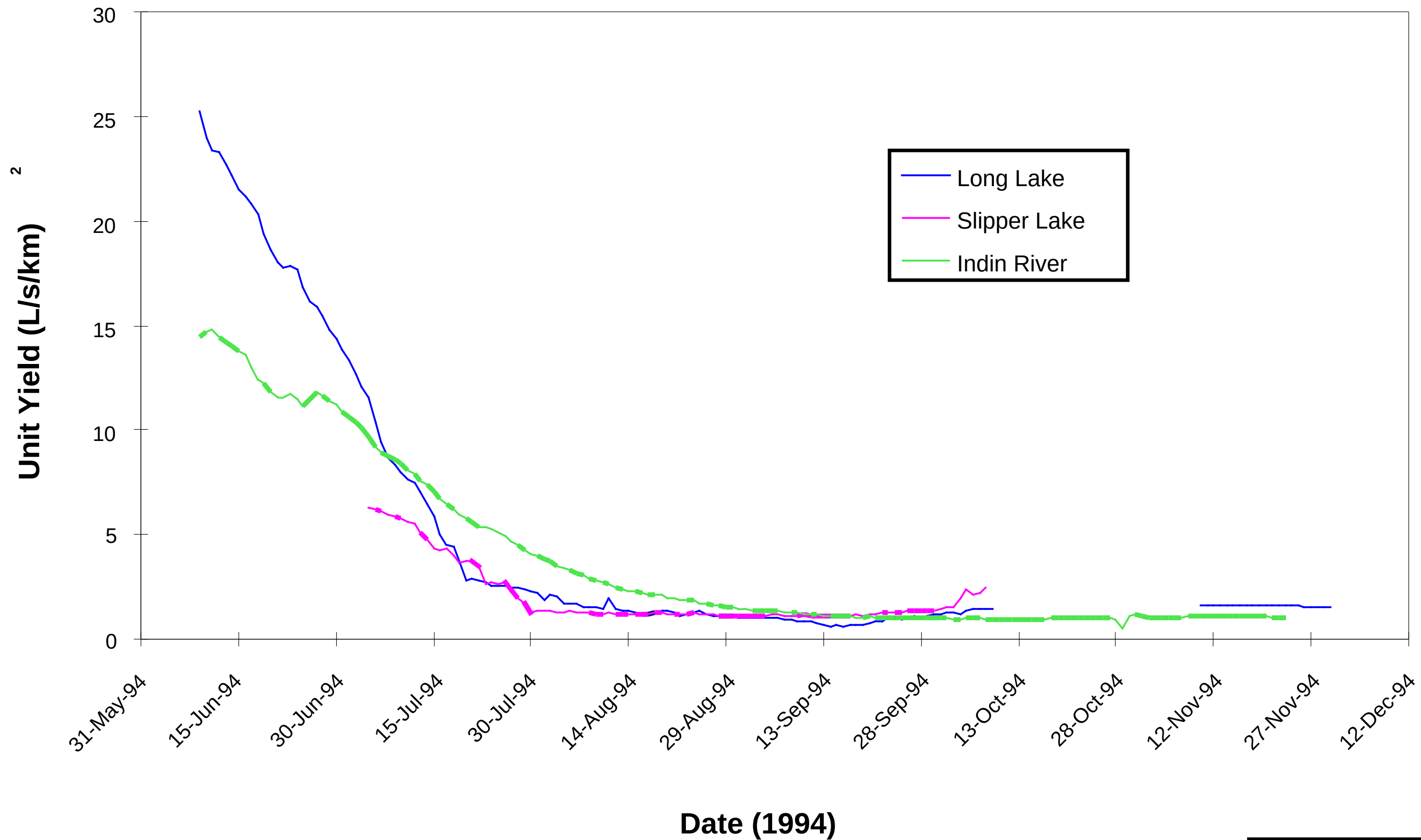


NWT DIAMONDS PROJECT

Figure 2.3-4
Regional and Site Discharge Data, 1994

Source: Rescan, 1994

Table 2.3-4
Mean Monthly Discharges, Indin River
and Project Area Catchments

			Project Area Estimates			
Month	**Indin River Mean Monthly Discharge (m^3/s)**	**% of Annual Discharge**	**Runoff Depth* (mm)**	**Koala (m^3/s)**	**Long (m^3/s)**	**Slipper (m^3/s)**
Jan	1.88	2.0	3.6	0.04	0.06	0.26
Feb	1.38	1.5	2.7	0.03	0.05	0.19
Mar	0.98	1.1	2.0	0.02	0.03	0.14
Apr	0.73	0.8	1.4	0.02	0.02	0.10
May	5.29	5.6	10.1	0.11	0.17	0.72
Jun	34.05	36.3	65.3	0.71	1.11	4.68
Jul	20.23	21.7	39.1	0.42	0.67	2.80
Aug	9.90	10.2	18.4	0.20	0.31	1.32
Sep	5.89	6.4	11.5	0.12	0.20	0.82
Oct	5.25	5.6	10.1	0.11	0.17	0.72
Nov	4.69	5.0	9.0	0.10	0.15	0.65
Dec	3.48	3.8	6.8	0.07	0.12	0.49

* Calculated by applying monthly percentage runoff at Indin River to an estimated annual runoff rate of 180 mm.

due to higher precipitation in the Koala area (Volume II Section 2.6). In addition, headwater catchments are often expected to exhibit higher runoffs than larger regional catchments, since the higher slopes in headwater catchments favour higher runoff coefficients.

At the time these data were analyzed, 1994 streamflow data for the Indin River site were available for the period January 1 to November 23. Total runoff for this period was calculated to be 79 mm. Runoff for the calendar year probably did not exceed 90 mm at Indin River, and therefore was approximately 55% of average. This suggests that average streamflow in the project area is substantially higher than measured streamflow during 1994.

Measurement of Slipper Lake outflow did not commence until early July (Figure 2.3-4). Measured streamflow from July 15 until the end of the field season matches the data for Long Lake and Indin River quite closely. However, data from the first two weeks of monitoring suggest that the peak flows in Slipper Creek were lower on a unit yield basis. This conflicts with data from Long Lake, which is directly upstream. This discrepancy may be due to measurement errors, which appear to have been significant for Slipper Creek. This watercourse is 60 m wide and was extremely difficult to gauge accurately. More data collected during the 1995 field season should resolve this issue.

Runoff Estimation

For the NWT Diamonds Project site, a figure of 180 mm has been used to represent annual average runoff depth. This figure is within the range of runoff depths for all regional stream gauges (Table 2.3-3), but slightly higher than the average figures for the Point Lake and Indin River stations, reflecting the preliminary data discussed above. This also reflects a general desire to make a conservative estimate for the purposes of water management planning.

Insufficient site-specific data have been generated to date for determining monthly average runoff. For the purposes of this document, monthly average runoff at Indin River has been increased to account for the higher estimate of annual runoff in the Koala watershed. The estimated mean monthly discharges for three important project area streams are listed in Table 2.3-4. It is recognized that the annual hydrograph will differ at Koala since the project catchments are much smaller than the Indin River catchment. The smaller size of the Koala watershed results in higher peak flows, and quicker runoff response, than would be typical for the larger Indin River catchment. Therefore flow rates in the Koala catchment derived from regional data, such as those listed in Table 2.3-4, are subject to a degree of uncertainty.

In light of the uncertainties inherent in estimating runoff for project area catchments on the basis of a limited amount of site-specific data combined with regional data from a sparse data collection network, upper and lower bound estimates for the long-term annual average runoff have been made. The upper bound for average runoff is 250 mm and the lower bound is 150 mm. It is considered improbable that the actual long-term average runoff for the project site is greater than the upper bound estimate or less than the lower bound estimate. These figures have been utilized along with similar figures for precipitation (Section 2.6.4) and evaporation (Section 2.6.6) to carry out an analysis of the sensitivity of the Long Lake tailings impoundment water balance to input parameter estimation. This analysis is discussed further in Volume IV, Section 3.

2.3.1.6 Low Flows

Water levels in lakes and streams in the Koala watershed decreased steadily from July onward. Water levels and flow rates reached minimum values for the 1994 study period between mid-August and mid-September. Smaller streams and lakes typically reached their lowest levels in August, while larger lakes (Long Lake) and streams recorded their lowest levels in mid-September.

Regional data (Table 2.3-4) indicate that annual low flows are reached in April. Mean monthly discharge for the Indin River in April is 0.73 m^3/s, which is equivalent to 0.10 m^3/s over the entire Koala catchment. In fact, site studies conducted during April of 1995 suggested that surface flows approach zero by late winter in the watercourses of the Koala basin.

2.3.1.7 High Flows

Maximum annual discharge in Arctic rivers and streams occurs predominantly during the freshet, when approximately 50% of annual runoff occurs. Precipitation stored as snow, melts, generating surface runoff that is directed to lakes, streams and rivers, causing annual flood conditions. In the Koala watershed, freshet usually occurs in late May or June.

The period of record in the Koala watershed was insufficient to make long term flood flow predictions. As a result, concurrent data from long term regional WSC stations at Indin River, and the Coppermine River at Point Lake, were used to determine maximum daily discharge at each station, which were subjected to frequency analyses for 100-year flood flow events. The average maximum daily discharge for the Indin River was 47 m^3/s, while mean maximum daily discharge at the Point Lake station was 269 m^3/s (Table 2.3-5). One hundred year maximum discharges for Indin River and Point Lake were 91 m^3/s and 665 m^3/s, respectively.

Table 2.3-5
Estimated Discharge for Koala Watershed and Regional Hydrometric Stations

Basin	Basin Area (km^2)	Long-term Mean Annual Discharge (m^3/s)	Average Maximum Mean Daily Discharge (m^3/s)	100-Year Estimated Maximum Mean Daily Discharge (m^3/s)
Koala Lake	28	0.16	2.6	3.8
Long Lake	44	0.25	3.6	5.5
Slipper Creek	185	1.06	10	17
Indin River	1,520	7.9	47	90.5
Coppermine R. Point Lake	19,300	105	269	665
Coppermine R. Copper Creek	48,800	255	1,270	2,670
Coppermine R. Bloody Falls	50,700	337	1,412	3,130

One-hundred-year maximum daily discharge values from frequency analysis were plotted against basin area, for Indin River and Coppermine River hydrometric stations (Figure 2.3-5). Extrapolation of the exponential relationship to the Koala basins produced estimates of the 100-year flood events. Estimated 100-year maximum daily flood flows for outflows from Koala Lake, Slipper Lake and Long Lake were 3.8 m^3/s, 17.0 m^3/s, and 5.5 m^3/s, respectively (Table 2.3-5).

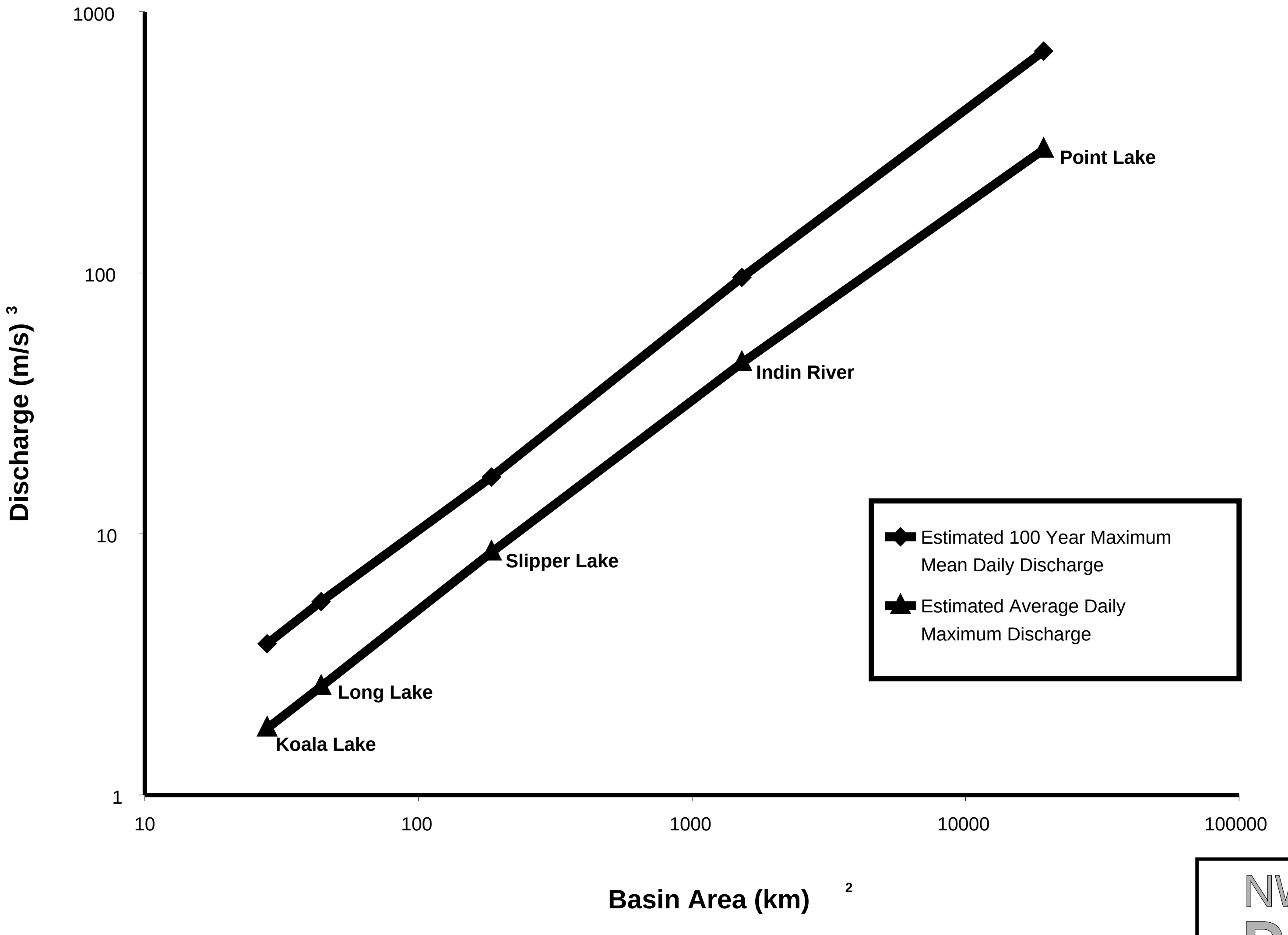
There is evidence that both the maximum daily discharges are underestimated by this calculation method. Field data acquired during the 1995 freshet indicated that maximum flows for 1995 exceeded the calculated 100-year event. For the purposes of this document, this error is of relevance only to the lake dewatering plan and causes the design of the plan to be more conservative than it would otherwise be. Other aspects of water management rely principally on average annual discharge, which has been estimated differently and is not subject to the same error.

Flood flows will be more accurately estimated once data from the 1995 field season is available. The revised estimates will be utilized for purposes such as culvert and spillway design.

2.3.2 Groundwater Flows

The thickness of the active layer, which defines the seasonal, near-surface pore space available for groundwater transport, varies significantly in relation to the nature of the terrain. The active layer begins to develop in May, immediately after snow melt and increases throughout the summer and into the autumn when the advancing freezing front eliminates all seasonal thaw. The likely range for freeze-thaw dynamics is illustrated with three typical near-surface profiles in Section 2.1, Figure 2.1-8. Other variables that influence the development of the active layer include soil thickness, vegetation, slope, aspect, albedo, temperature, precipitation – especially snow cover – and radiant energy.

The thickness of the active layer in the Koala watershed in June 1994 generally varied from 0.25 m in sedge and mossy areas to about 1.0 m along gravel slopes. The sedge/moss areas in stream valleys were typically saturated from snowmelt and low hydraulic conductivities of the muddy soil, whereas gravel slopes and sand eskers were unsaturated. Although hydraulic conductivities were not measured, conductivity values for mud and clay soils typically range from 10^{-6} m/s to 10^{-9} m/s (Freeze and Cherry 1979). Groundwater movement was probably low in the stream valleys, except perhaps in taliks below gravel streambeds, due to the low surface gradient (typically <0.003 m/m) and low hydraulic conductivity of the soil.



NWT DIAMONDS PROJECT

Figure 2.3-5
Maximum Daily Discharge vs. Basin Area

Source: Rescan

In September 1994, active layer thicknesses had increased to approximately 0.7 m in the sedge/moss stream valleys and were greater than 2.0 m thick in the sand and gravel eskers. Soils were unsaturated in the stream valleys due to lowering of the water table, as indicated by the 15 cm to 20 cm drop in nearby stream levels. Unsaturated surface conditions were typical for sand and gravel eskers.

Consequently, negligible groundwater flows are assumed based on the limited active layer thickness (i.e., cross-sectional area for subsurface flow) in tundra environments, low gradients and hydraulic conductivities, which limit the potential for groundwater discharge into lakes and streams during the short period of active layer development. A 1989 study provides confirmation that supra-permafrost groundwater flows can be ignored in the overall surface and subsurface hydrology studies associated with mine development (Wilbur 1989).

2.3.2.1 Groundwater Modelling

Significant seepage flows may be encountered in the proposed pit walls and floors where they intersect open talik and from where the proposed pits extend below the influence of permafrost. Therefore, it is important to predict the seepage into the proposed pits in order to design dewatering systems and to forecast the drawdown and eventual recovery of nearby lakes and potential length of time required to refill the open pits.

Attention herein is focused on conservative estimates of the potential volumes of groundwater seeping into the proposed pits at the point of maximum development (maximum depth). The potential volume of groundwater seepage, potential for drawdown of the neighbouring lakes and length of time required to refill the open pits are considered. The results of thermal modelling were crucial in defining flow boundaries, hence the determination of groundwater volumes.

The following sections detail the groundwater model used and assumptions made during the calculation of seepage into the proposed Fox, Panda, Koala, Misery and Leslie pits. Permafrost conditions and extent largely control the movement of groundwater at this site and help identify potentials for substantial flows. Critical geologic features analyzed in the groundwater modelling include corridors devoid of permafrost between the pit and a surface waterbody, fault zones and the variable hydraulic conductivity of the kimberlite. A groundwater analysis model, SEEP/W3, was used to model and calculate seepage volumes.

Input Parameters for Seep/W3 Analysis (Model Assumptions)

Calculations of inflows into the five pits were developed using boundary conditions established during the development of cross sections from geothermal modelling. The approximate limit of permafrost was established based on three to four deep drill logs. The boreholes were considered to be within permafrost provided the logs indicated the boreholes were dry. This approach was used in Svalbard (Norway) to indicate the permafrost boundary during exploratory drilling for coal mining operations (Brugmans 1989) and was used in this study to develop the baseline permafrost conditions for permafrost boundary conditions. A phase boundary of -0.05°C was used during the geothermal modelling exercise in order to ascertain the depth of permafrost and develop the model cross sections. The chosen phase boundary of -0.05°C assumes that the groundwater chemistry does not contain a high concentration of dissolved salts, the presence of which would mean less extensive permafrost, thus increased seepage. This has not been the case at the site so far.

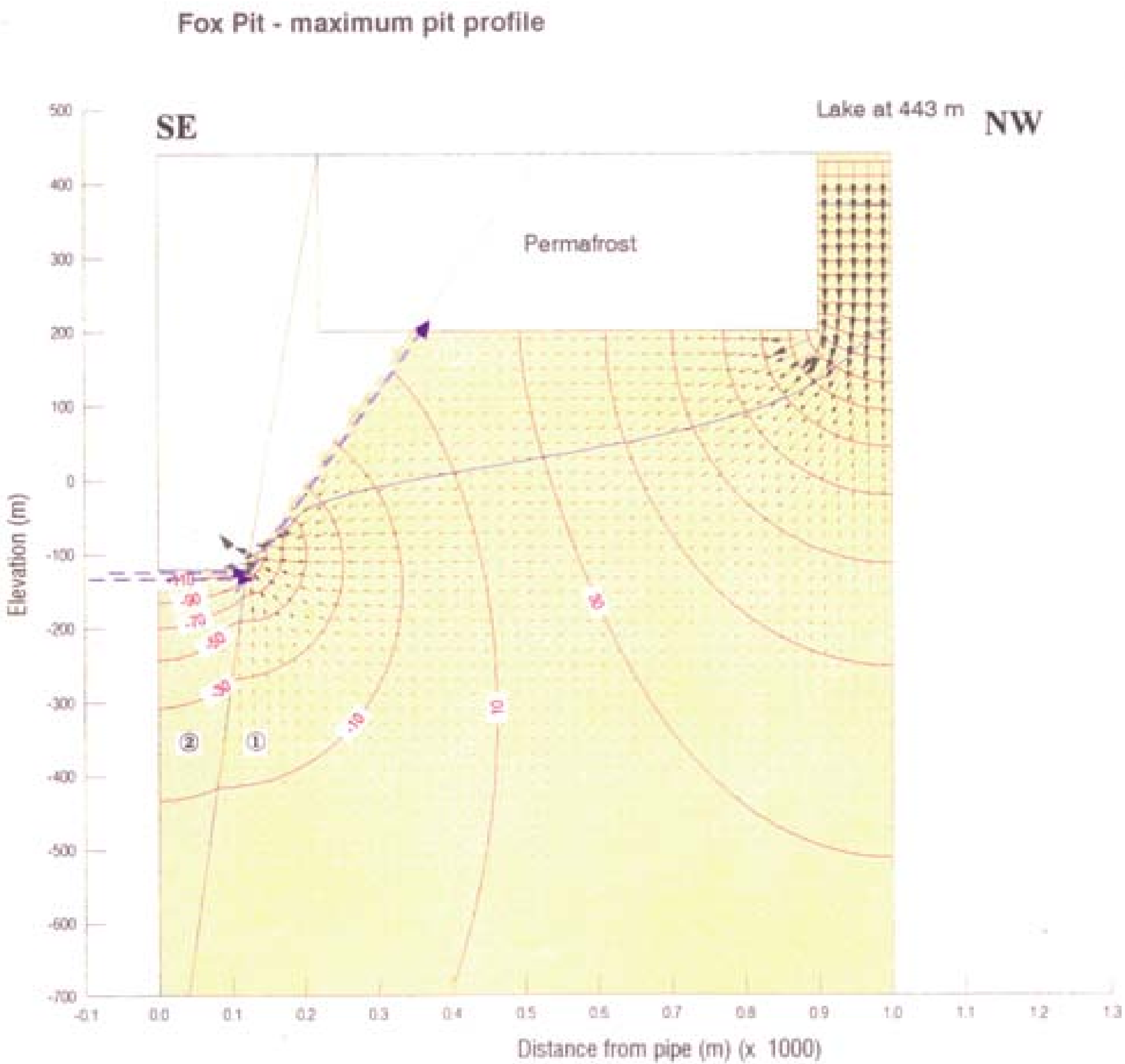
The cross sections were oriented such that they represented the shortest flow paths (hence the highest hydraulic gradients) between the nearest undrained lakes and each of the proposed pits. The cross sections were input into the model rounded to the nearest 10 m for Panda and Misery pits and the nearest 20 m for Koala, Fox and Leslie pits (the respective grid size used for modelling).

For each pit, four models were developed. Each model was comprised of a two-dimensional, steady-state analysis with no flow boundaries located through the centreline of the kimberlite pipe and the centreline of the nearest undrained lake, and with an infinite no flow boundary at the section base (Figures 2.3-6 to 2.3-20). Constant head boundaries were located beneath the lake. Four models were considered in order to test the present condition in relation to the fully developed pits, and the range of rock types and attendant hydraulic conductivities.

Model 1 - Pre-Mining Steady-State Flow Conditions Through Fault Zones

Model 1 for each pit is based on pre-mining conditions. This model was run for calibration and to ensure that the parameters chosen for modelling were reasonable. A full discussion of the pre-mining sections can be found in BGC 1995, Appendix II-A3. Kimberlite pipes and lakes were assumed to be the same size at surface. The kimberlite was assigned a hydraulic conductivity value of 10^{-7} m/s and the other rock types, assumed to be the fault zones, were assigned hydraulic conductivity values of 10^{-6} m/s. Permafrost was assigned a hydraulic conductivity value of 0. Flux sections for Model 1 for each pit were set across the kimberlite pipe at surface.

◎ **Table of Contents**



Flux:

pit bottom=1.1397 x 10^{-5} m/s^{3}

pit face=6.9943 x 10^{-5} m/s^{3}

Legend

Hydraulic Conductivity Values

① Fault Zone:k = 10^{-6} m/s

② Kimberlite:k = 10^{-7} m/s

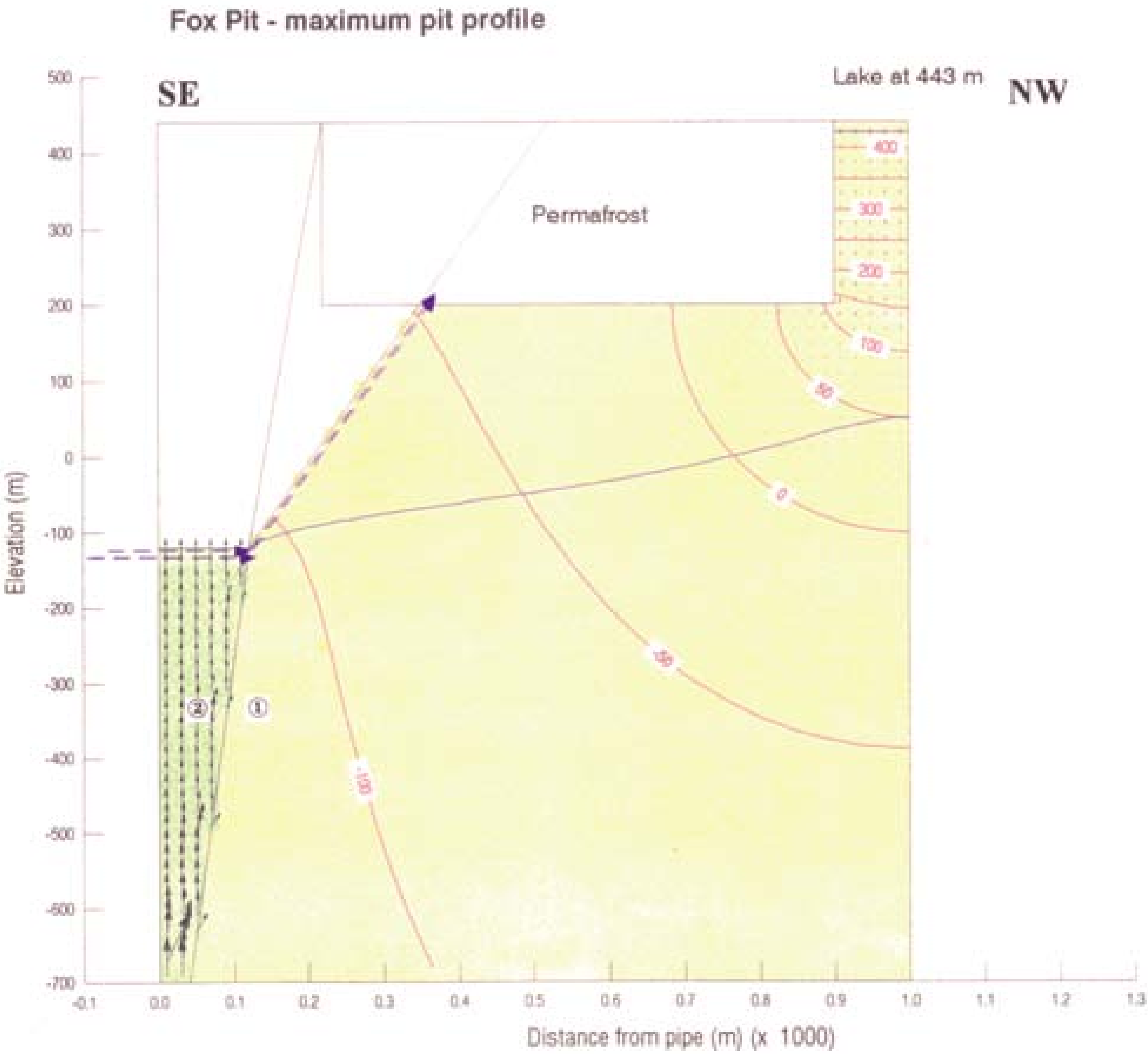
Vector Magnification: 4.8 x 10^{7}

NWT DIAMONDS PROJECT

Figure 2.3-6
Conditions for
Fox Pit Fault Zone

Source: BGC

◎ Table of Contents



Flux:
pit bottom=4.3617 x 10^{-9} m^3/s
pit face=4.9278 x 10^{-10} m^3/s

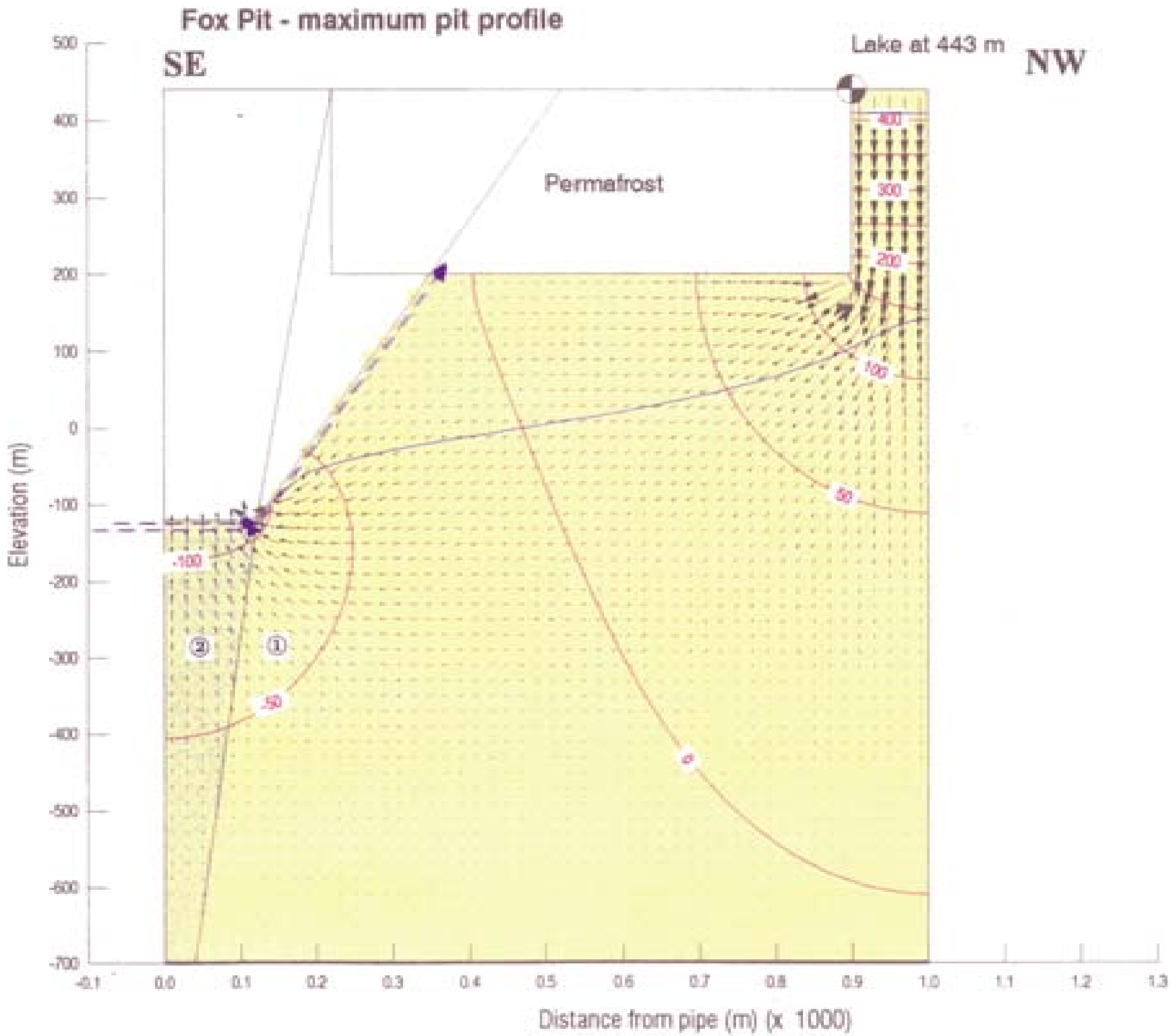
Legend
Hydraulic Conductivity Values
① Granite:k = 10^{-11} m/s
② Kimberlite:k = 10^{-7} m/s
Vector Magnification: 6.4 x 10^{11}

NWT DIAMONDS PROJECT

Figure 2.3-7
Conditions for
Fox Pit Granite

Source: BGC

◎ Table of Contents



Flux:
pit bottom=$5.9018 \times 10^{-5}\ m^3/s$
pit face=$5.5062 \times 10^{-5}\ m^3/s$

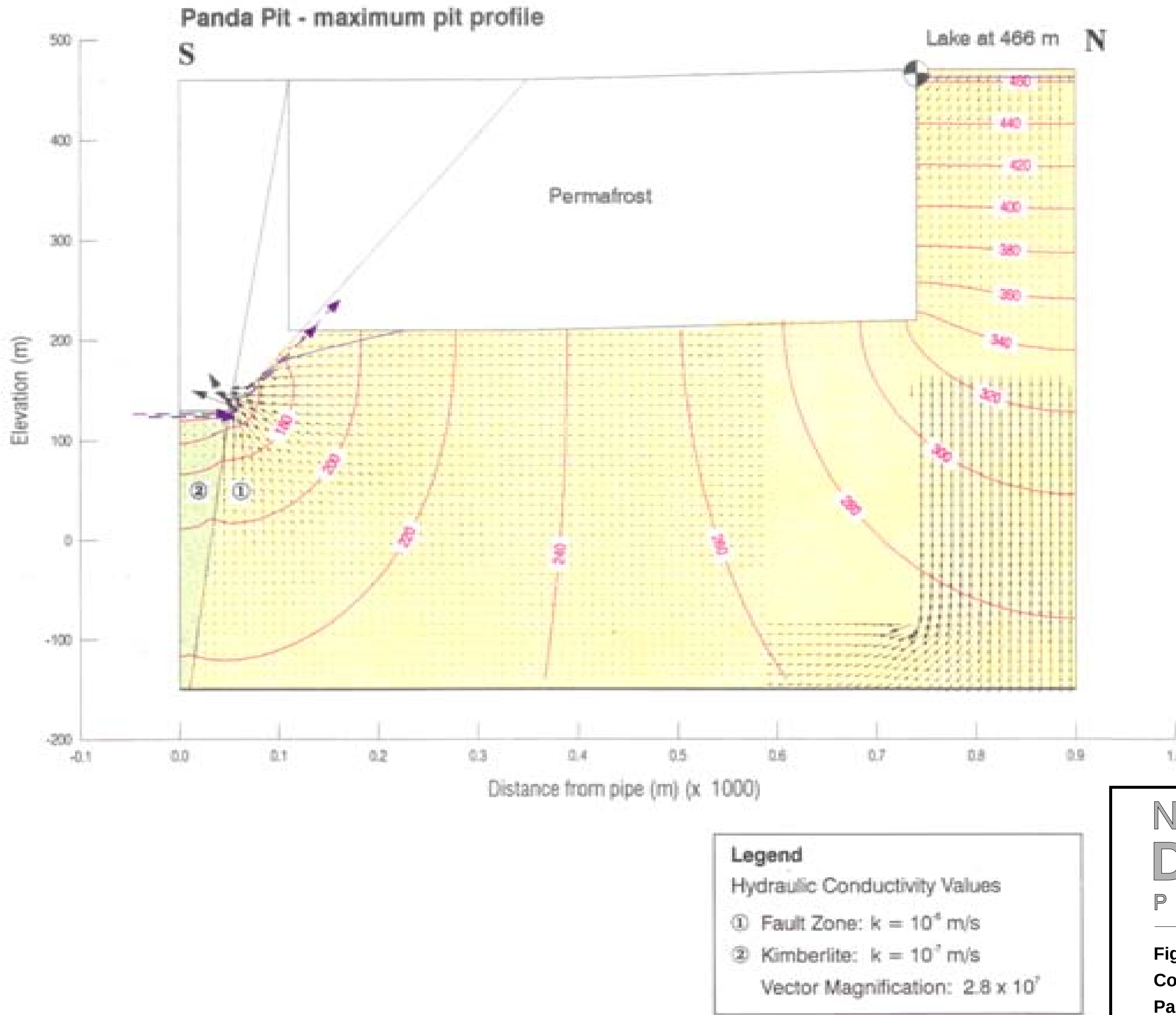
Legend
Hydraulic Conductivity Values
① Fault Zone:$k = 10^{-6}$ m/s
② Kimberlite:$k = 10^{-6}$ m/s
Vector Magnification: 4.9×10^{7}

NWT DIAMONDS PROJECT

Figure 2.3-8
Conditions for Fox Pit Fault Zone (Increased “k” Value)

Source: BGC

◎ **Table of Contents**

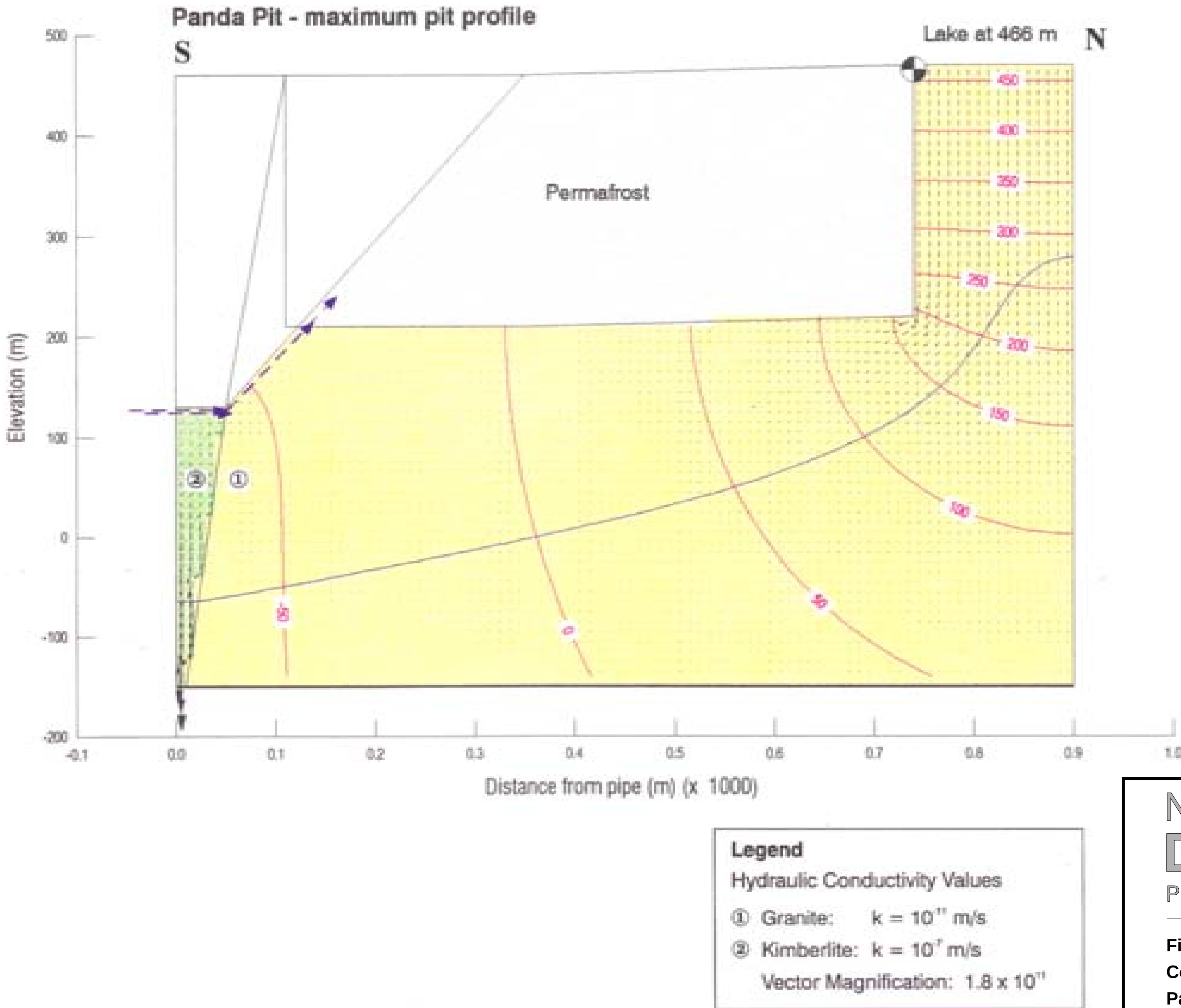


NWT DIAMONDS PROJECT

Figure 2.3-9
Conditions for
Panda Pit Fault Zone

Source: BGC

◎ **Table of Contents**

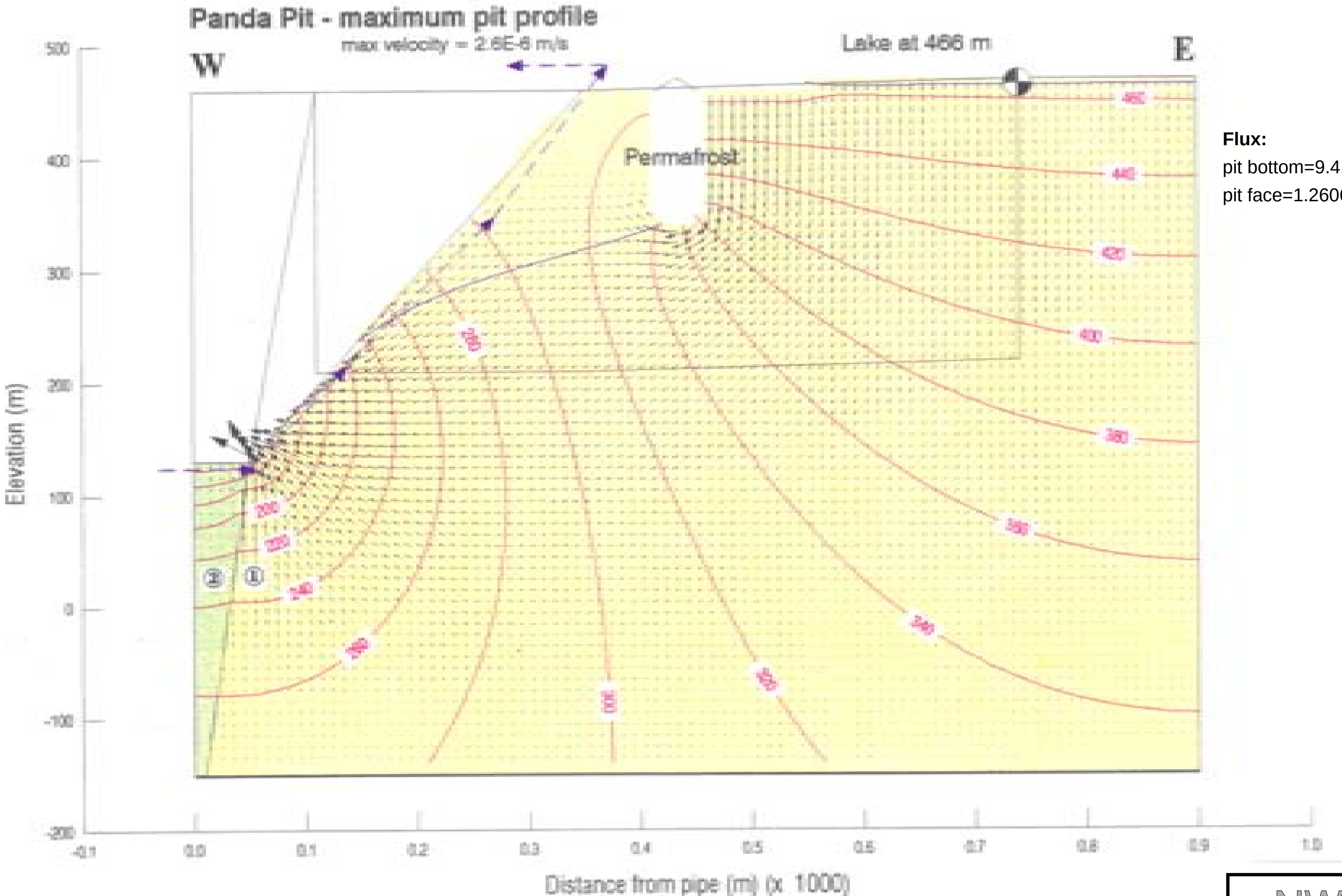


NWT DIAMONDS PROJECT

Figure 2.3-10
Conditions for
Panda Pit Granite

Source: BGC

◎ Table of Contents



Flux:
pit bottom=9.4102 x 10^{-6} m^3/s
pit face=1.2606 x 10^{-4} m^3/s

Legend

Hydraulic Conductivity Values

① Fault Zone:k = 10^{-6} m/s

② Kimberlite:k = 10^{-7} m/s

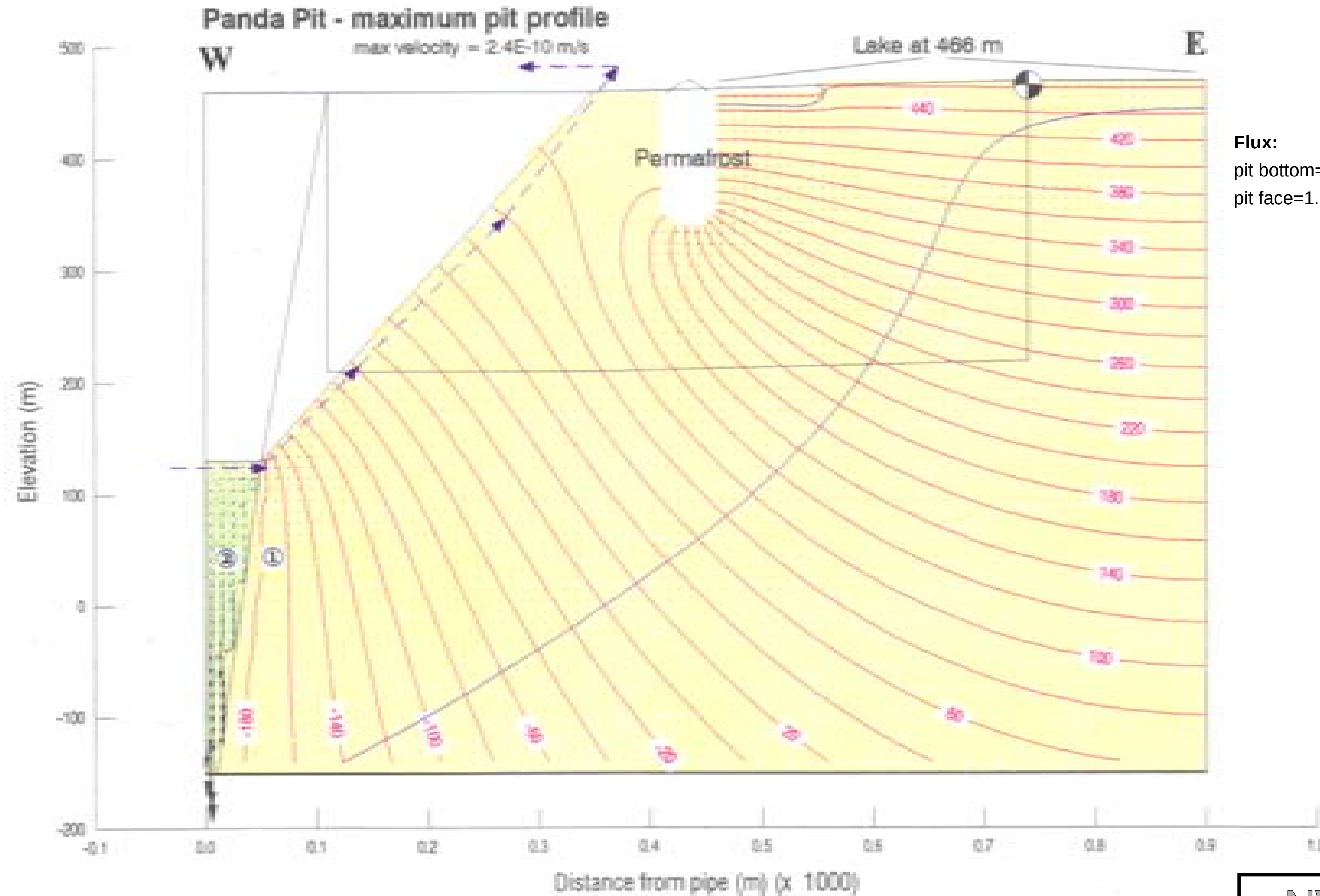
Vector Magnification: 1.96 x 10^{7}

NWT DIAMONDS PROJECT

Figure 2.3-11
Conditions for Fault Zone in Talik between Panda L. and Pit

Source: BGC

◎ **Table of Contents**



Flux:

pit bottom=2.1133 x 10^{-10} m^3/s

pit face=1.1794 x 10^{-10} m^3/s

Legend

Hydraulic Conductivity Values

① Granite:k = 10^{-11} m/s

② Kimberlite:k = 10^{-7} m/s

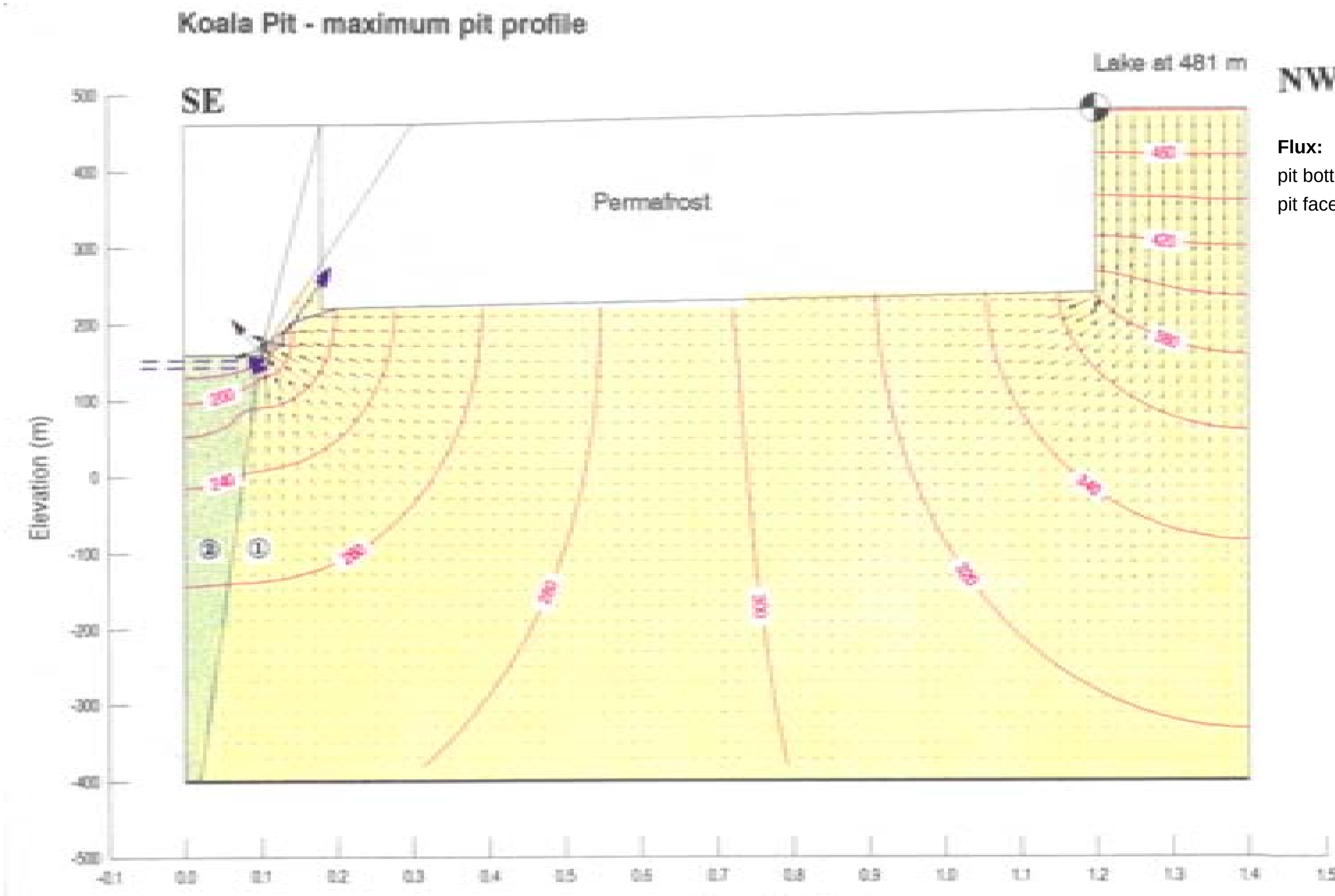
Vector Magnification: 2.1 x 10^{11}

NWT DIAMONDS PROJECT

Figure 2.3-12
Conditions for Granite in Talik between Panda Lake and Pit

Source: BGC

◎ Table of Contents



Flux:

pit bottom=8.9107×10^{-6} m^3/s

pit face=5.2357×10^{-5} m^3/s

Legend

Hydraulic Conductivity Values

① Fault Zone:k = 10^{-6} m/s

② Kimberlite:k = 10^{-7} m/s

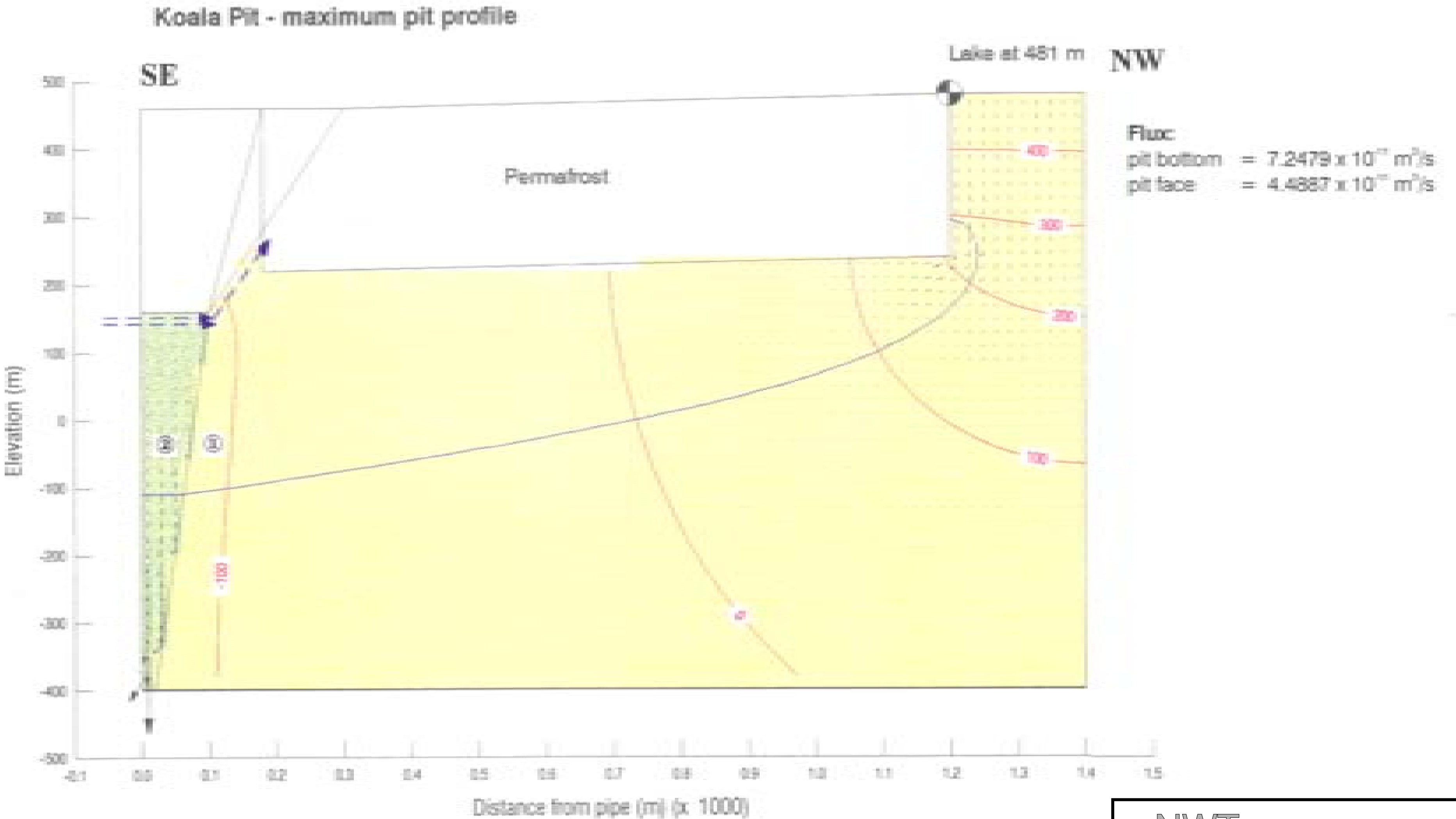
Vector Magnification: 5.7×10^{7}

NWT DIAMONDS PROJECT

Figure 2.3-13
Conditions for
Koala Pit Fault Zone

Source: BGC

◎ Table of Contents



Legend

Hydraulic Conductivity Values

① Granite:k = 10^{-11} m/s

② Kimberlite:k = 10^{-7} m/s

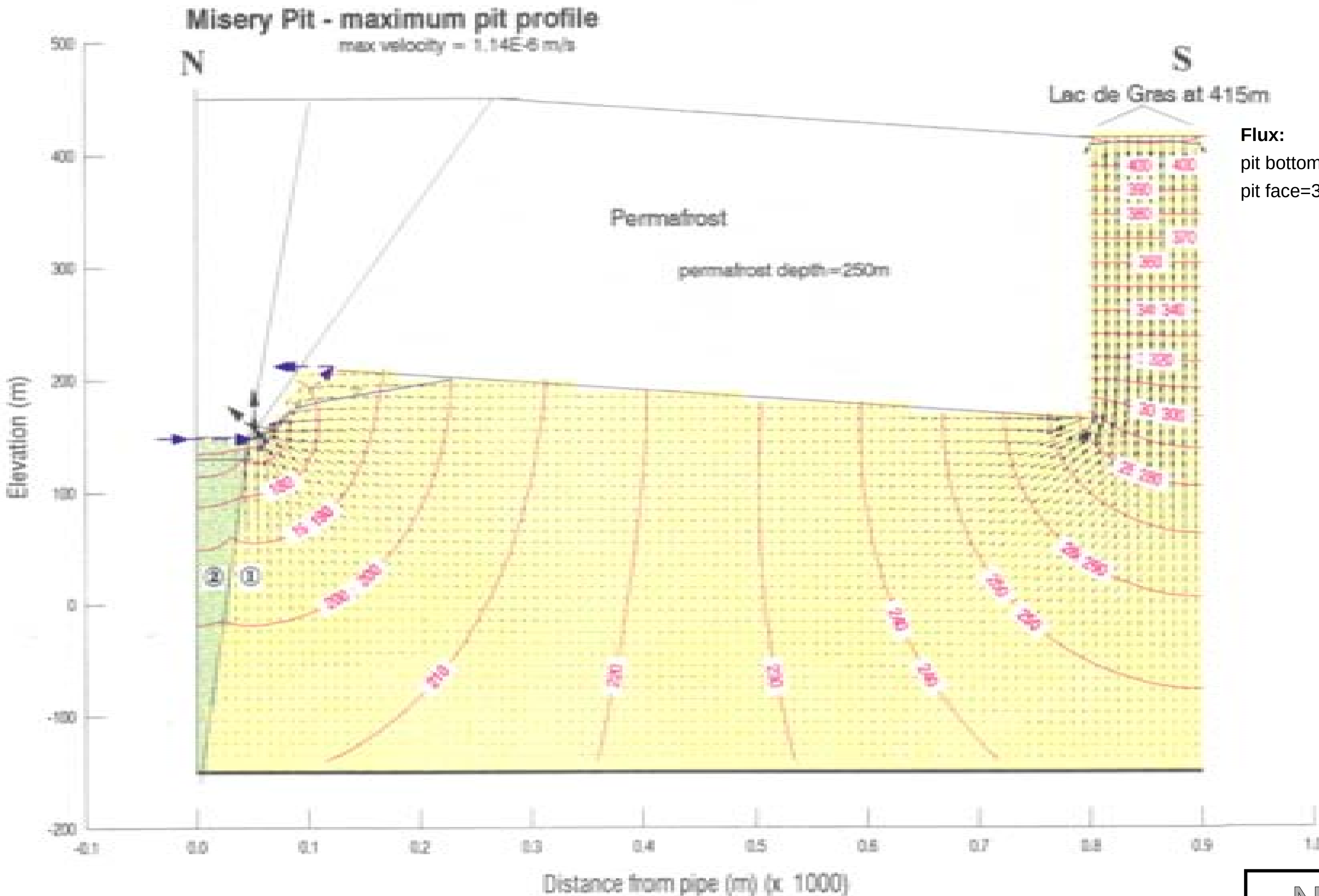
Vector Magnification: 1.0 x 10^{12}

NWT DIAMONDS PROJECT

Figure 2.3-14
Conditions for
Koala Pit Granite

Source: BGC

◎ Table of Contents



Flux:

pit bottom=2.7370 x 10^{-6} m^3/s

pit face=3.2941 x 10^{-5} m^3/s

Legend

Hydraulic Conductivity Values

① Fault Zone:k = 10^{-6} m/s

② Kimberlite:k = 10^{-7} m/s

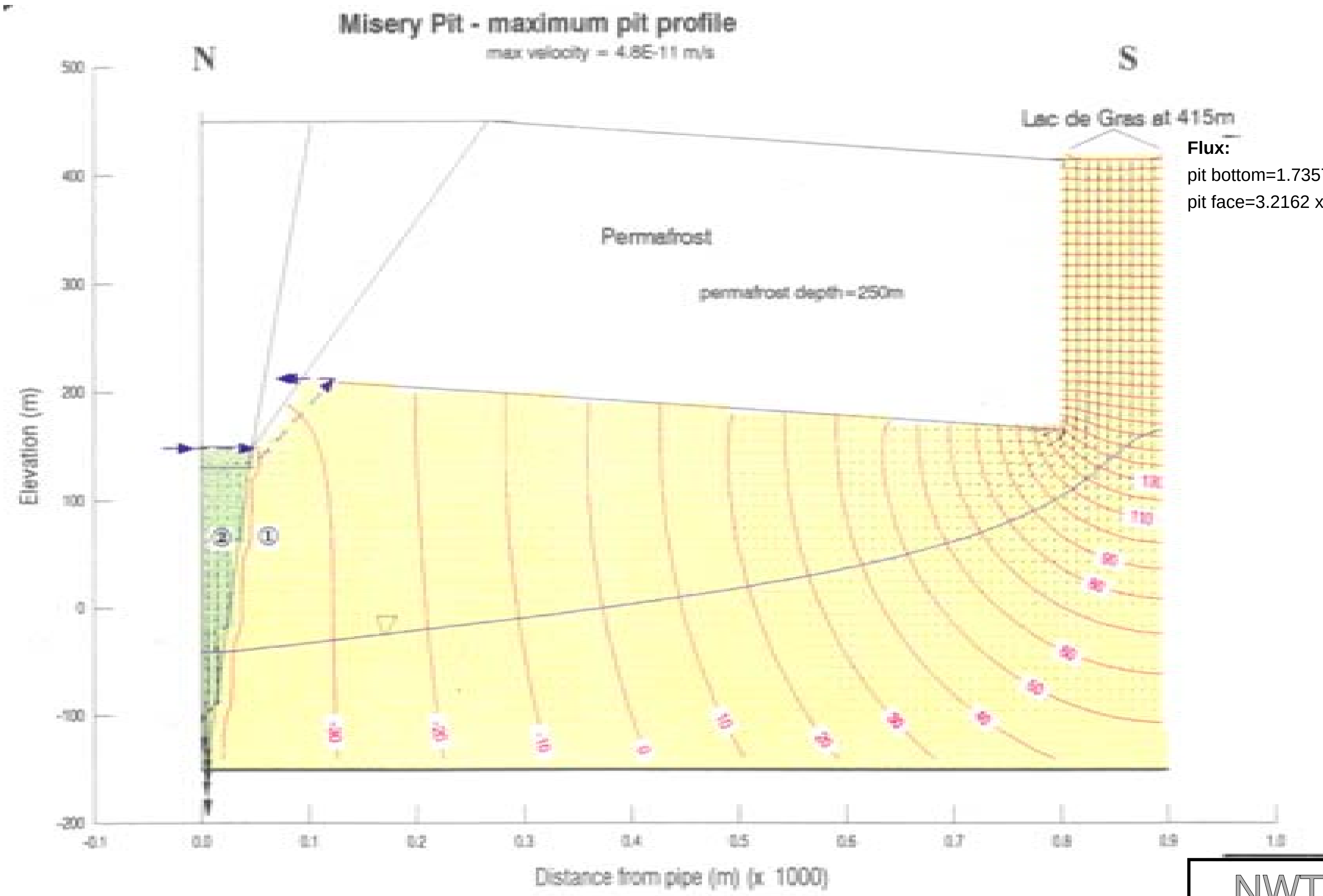
Vector Magnification: 4.38 x 10^{7}

NWT DIAMONDS PROJECT

Figure 2.3-15
Conditions for
Misery Pit Fault Zone

Source: BGC

◎ Table of Contents



Flux:

pit bottom=1.7357 x 10 m/s -11 3

pit face=3.2162 x 10m/s -11 3

Legend

Hydraulic Conductivity Values

① Granite:k = 10m/s -11

② Kimberlite:k = 10 m/s -7

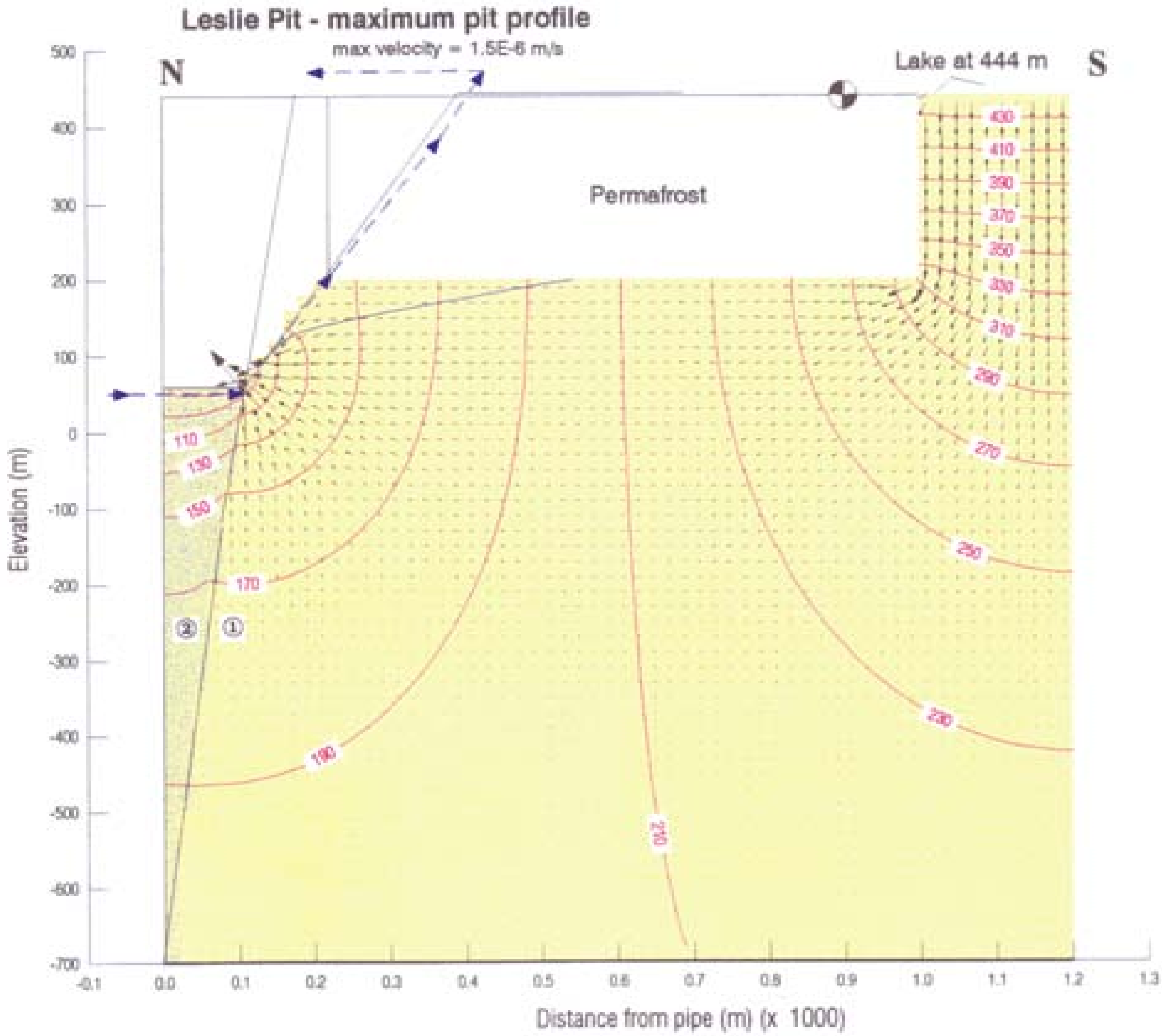
Vector Magnification: 1.04 x 10 12

NWT DIAMONDS PROJECT

Figure 2.3-16
Conditions for
Misery Pit Granite

Source: BGC

◎ Table of Contents



Flux:

pit bottom=9.7464 x 10 m/s -6 3

pit face=5.2473 x 10m/s -5 3

Legend

Hydraulic Conductivity Values

① Fault Zone:k = 10m/s -6

② Kimberlite:k = 10 m/s -7

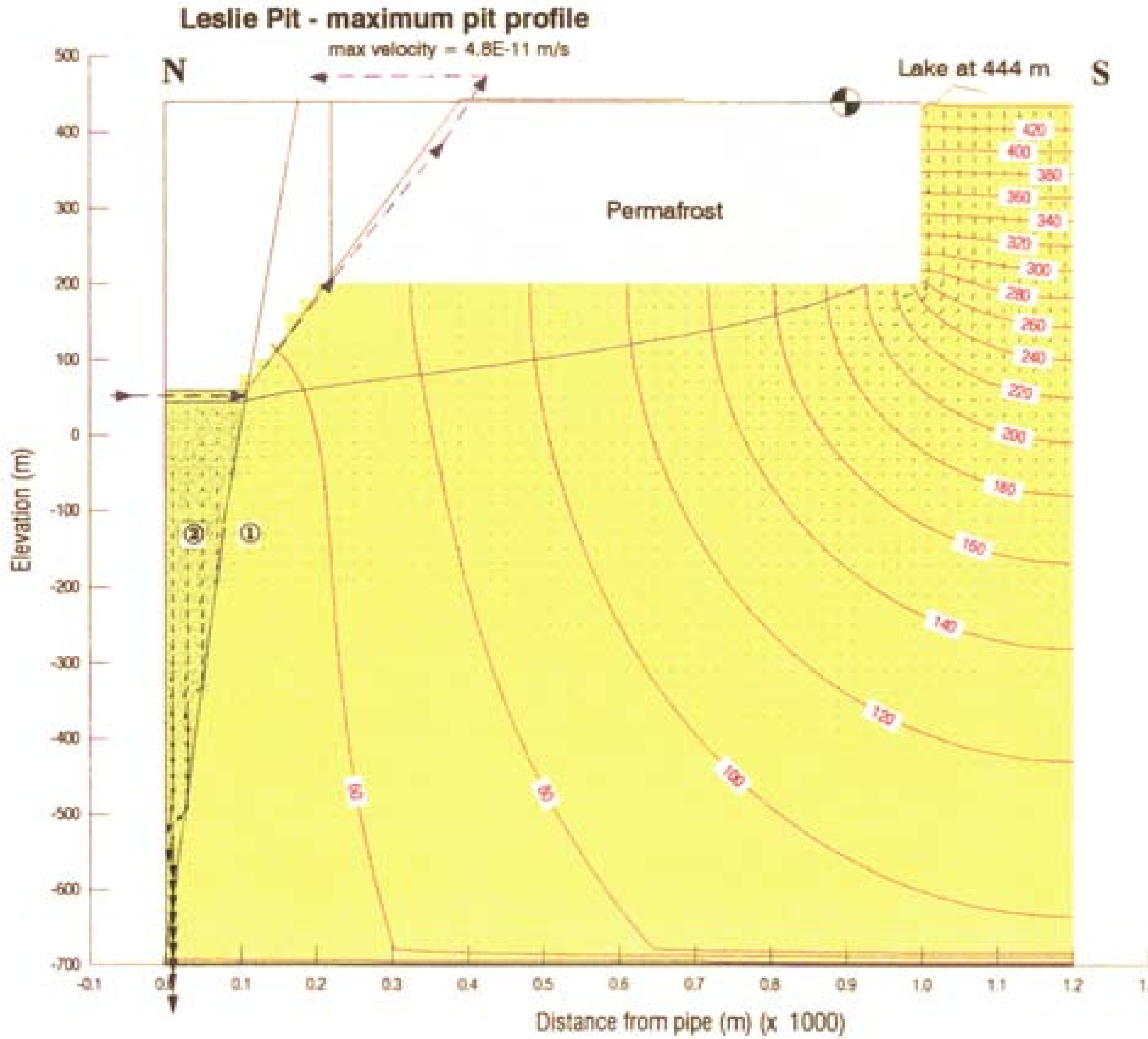
Vector Magnification: 5.00 x 10 7

NWT DIAMONDS PROJECT

Figure 2.3-17
Conditions for
Leslie Pit Fault Zone

Source: BGC

◎ **Table of Contents**



Flux:

pit bottom=7.0 x 10^{-11} m^3/s

pit face=4.7172 x 10^{-11} m^3/s

Legend

Hydraulic Conductivity Values

① Granite:k = 10^{-11} m/s

② Kimberlite:k = 10^{-7} m/s

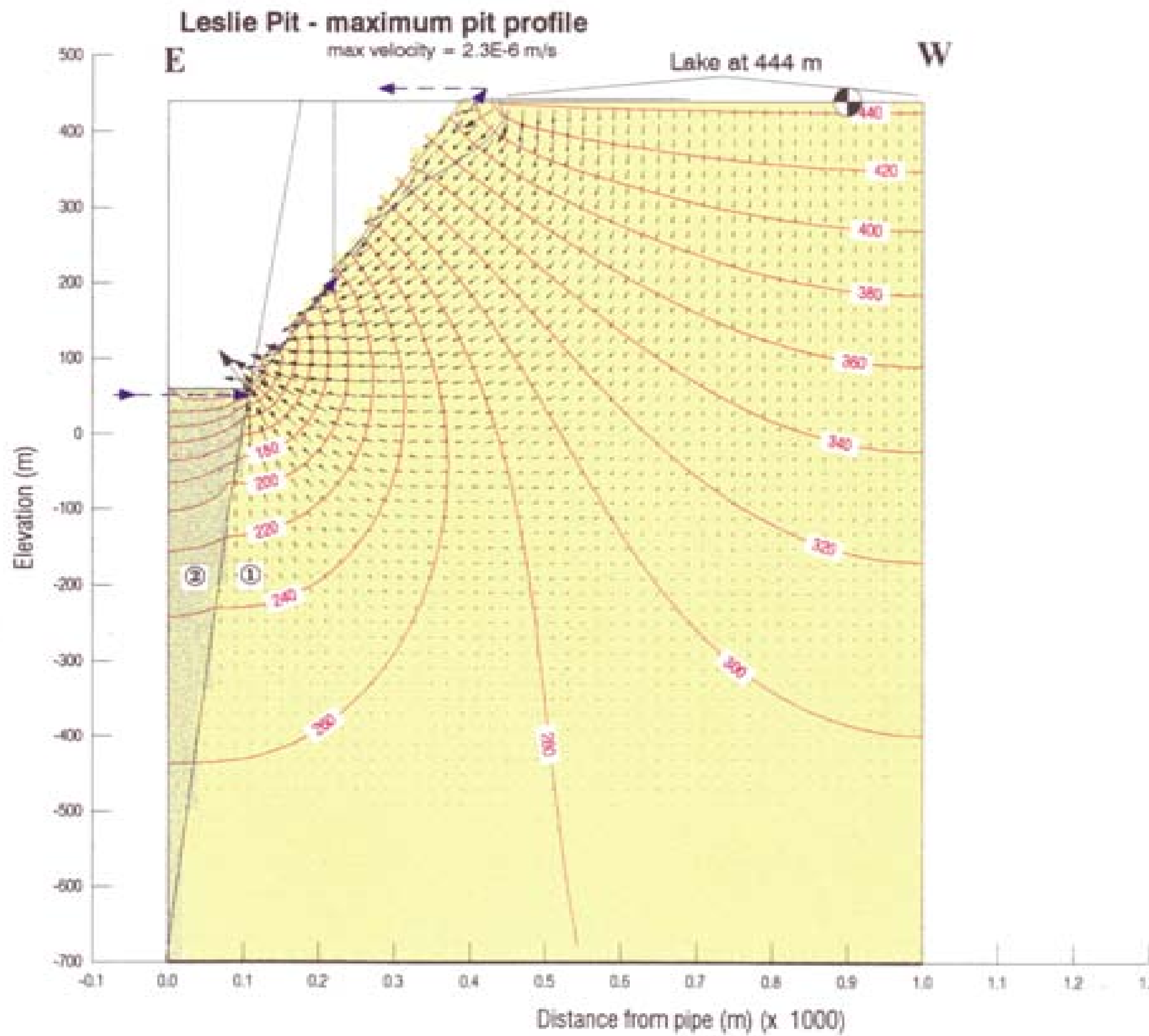
Vector Magnification: 1.54 x 10^{12}

NWT DIAMONDS PROJECT

Figure 2.3-18
Conditions for
Leslie Pit Granite

Source: BGC

◎ Table of Contents



Flux:

pit bottom=1.5093 x 10^{-5} m^3/s

pit face=1.4567 x 10^{-4} m^3/s

Legend

Hydraulic Conductivity Values

① Fault Zone:k = 10^{-6} m/s

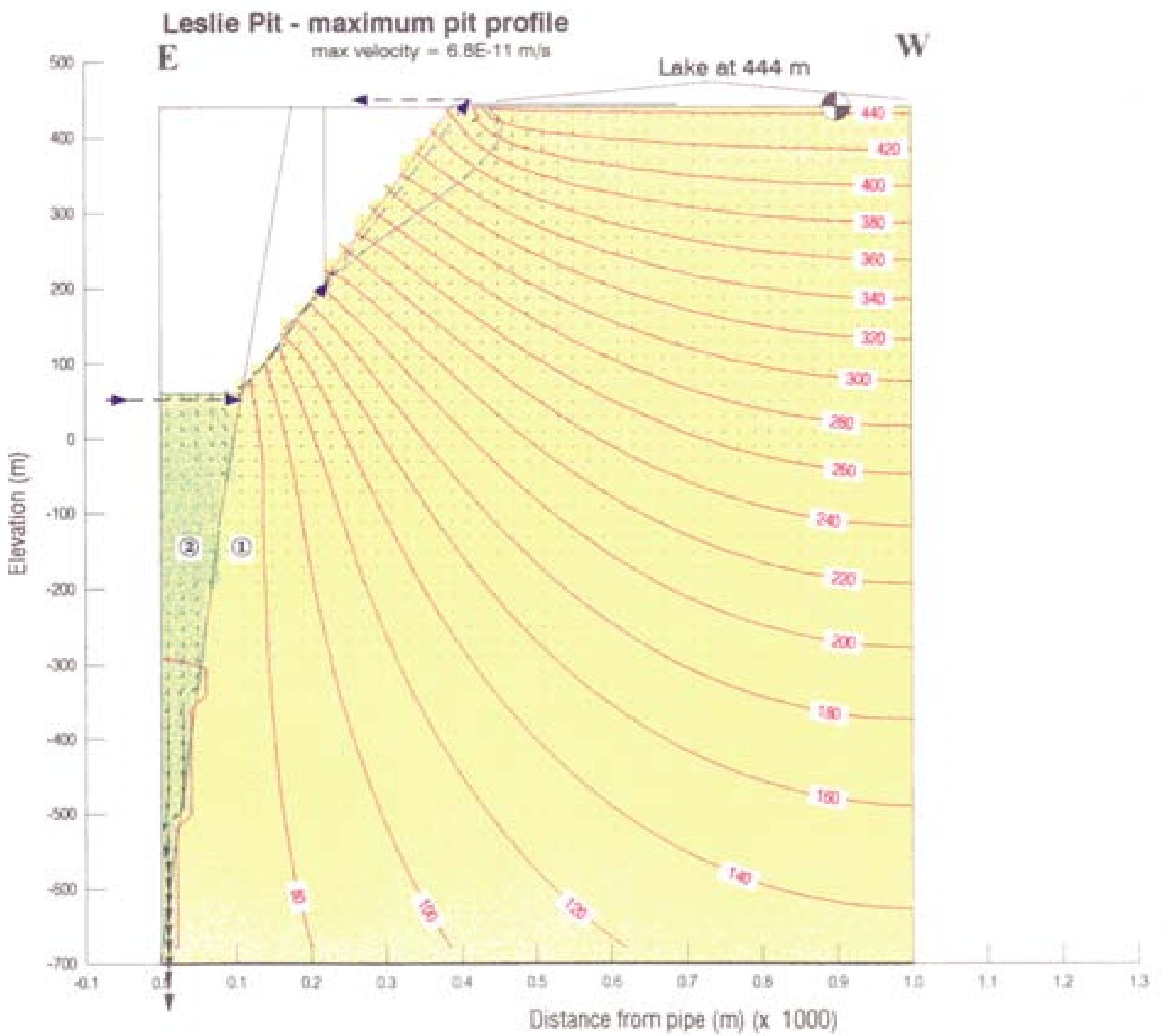
② Kimberlite:k = 10^{-7} m/s

Vector Magnification: 3.32 x 10^7

NWT DIAMONDS PROJECT

Figure 2.3-19
Conditions for Fault Zone in Talik, Moose Lake – Leslie Pit

Source: BGC



Flux:

pit bottom=3.9470 x 10^{-10} m^3/s

pit face=9.3327 x 10^{-10} m^3/s

Legend

Hydraulic Conductivity Values

① Granite:k = 10^{-11} m/s

② Kimberlite:k = 10^{-7} m/s

Vector Magnification: 1.10 x 10^{12}

NWT DIAMONDS PROJECT

Figure 2.3-20
Conditions for Granite in Talik, Moose Lake – Leslie Pit

Source: BGC

Model 2 - Pre-Mining Steady-State Flow Conditions Through Unfractured Granite

Model 2 maintained the same parameters as Model 1 for each proposed pit except granite, with a hydraulic conductivity value of 10^{-11} m/s, replaced the fault zone.

Model 3 - Post-Mining Steady-State Flow Through Fault Zones

Model 3 used the same model parameters as Model 1 including the maximum pit profiles. Seepage from the unfrozen pit walls was solved by the model. No thaw was assumed along pit walls where they intersected permafrost (Figures 2.3-6, -8, -9, -11, -13, -15, -17 and -19). Flux sections in the model were set across the pit floor and parallel to the pit wall, extending from the limit of permafrost to the pit floor.

Model 4 - Post-Mining Steady-State Flow Through Unfractured Granite

Model 4 used the same model parameters as Model 2 including the maximum pit profiles (Figures 2.3-7, -10, -12, -14, -16, -18 and -20).

Flow vectors and head contours were plotted on each model cross section. Note that flow vectors are not to the same scale in all drawings. A vector magnification factor, noted on each figure, was used in order to indicate the flow vectors as the indicated flows were very low.

Model for Fox Pit Using Increased Hydraulic Conductivity

A fifth model was generated for the proposed Fox pit in order to evaluate the sensitivity of the seepage Model 3 to hydraulic conductivity changes of the kimberlite (Figure 2.3-8). The hydraulic conductivity of the kimberlite was increased to 10^{-6} m/s in order to ascertain the potential change to seepage volumes. It was assumed that the hydraulic conductivity of the kimberlite was the most highly variable factor in the flow modelling.

Refined Panda Pit Model

A refined Panda pit model included the modelling of the effects of partial drainage of Panda Lake, specifically, the use of an earth structure to contain the lake 100 m northeast of the proposed pit (Figures 2.3-11 and 2.3-12). The refined model extended the constant head boundary from 100 m east of the pit margin to the centreline of Panda Lake. All other boundary conditions remained the same as the initial models. The additional seepage through the open talik associated with Panda Lake was calculated and added to the initial estimates of seepage.

The analyses assume steady-state conditions. The calculated flux to the pit does not include flow of stored water in the talik and the strata underlying the permafrost as the water table is lowered. The steady-state may take substantial time to become established, especially for the models of groundwater flow through unfractured granite (Figures 2.3-7, -10, -12, -14, -18 and -20). Flux values are given in m^3/linear metre.

Geologic and Geographic Assumptions

Several assumptions have been made in terms of the physical setting (geologic and geographical) for each proposed pit seepage model. Some of these assumptions are listed below.

- Hydraulic conductivities for the granite and fault zones were estimated based on a review of the groundwater and arctic ground condition literature (Ansitratov and Anistratov 1992; Raven *et. al.* 1992; Brugmans 1989; Wilbur 1989; Freeze and Cherry 1979).
- Hydraulic conductivities for the kimberlite were based on available information from the Panda and Fox kimberlite pipes.
- Lakes above the proposed pits are completely drained (except Panda).
- Rock types are homogeneous (competent granite, granite with fault zones and kimberlite).
- No kimberlite pipes outcrop below the neighbouring lakes.
- Fault outcropping on pit walls occurs at the same percentage of outcrop at the pit wall top as it does at depth (7% for Fox pit, 6% for Panda pit, 5% for Koala pit, 5% for Misery pit and 6% for Leslie pit).
- Fault zone width was assumed to be 20 m.
- The pit bottom is the same diameter as the kimberlite pipe.

Based on these assumptions, the resulting estimated inflows into the proposed pits are probably conservative (i.e., high).

Groundwater Derived from Storage

In areas where the open talik is much larger than the proposed pit, saturated granite and fault zones will outcrop in the pit walls from the surface downwards. Saturated wall rock will also prevail once a pit has penetrated below the maximum extent of permafrost. Therefore, as the static water level drops with pit development towards the steady-state condition (indicated by the model), the majority of seepage will be derived from storage. In the cases studied it was assumed that the aquifer conditions are unconfined. Therefore, the potential for seepage due to storage in the wall rock will be related to the specific yield of the aquifer. The specific yield is defined as the ratio of the volume of water that drains by gravity to the volume of rock. Generally, the coarser grained the material, the closer the specific yield will approach the total porosity (Domenico and Schwartz 1990).

Based on the assumption that the granite is of a dense crystalline nature with widely spaced, generally tight discontinuities, maximum total porosity of the non-fractured granite may be approximately 5% and the fault zones may be as high as 10% of the volume (Freeze and Cherry 1979). Following Domenico and Schwartz, the reduced percentage of rock volume that is water yielding pore space is 2% or less for the granite and 5% for the faulted zone. The total potential seepage water derived from storage can be calculated if an estimate of the total volume of unfrozen, drained bedrock is known. For the purposes of this modelling exercise only the storage within secondary porosity (fault zones) has been considered.

The volume of potentially drained wall rock was estimated for all proposed pits assuming all rock above the static water level and below permafrost, including rock above the static water level contained in open talik, were sources of groundwater from storage for each pit. The maximum volume of water that could be derived from storage within the fault zones was calculated based on the pecentage of fault rock material in the pit wall for each pit (stated in the geologic assumptions) and multiplied by 5% (the potential percentage of the rock volume that is considered water yielding pore space). A summary of the potential storage volumes for each pit is contained in Table 2.3-6. The resultant volumes are considered to be conservative estimates of the volume of rock yielding groundwater from storage. No estimate of the length of time for this water to drain has been made.

Steady-State Flux Estimates

Figures 2.3-6 through 2.3-20 illustrate the results of the modelling exercise. The results for each proposed pit are discussed in a general sense in the following sections.

Fox Pit

Figures 2.3-6 and 2.3-7 illustrate the steady-state conditions eatablished once the pit has reached its maximum depth. Figure 2.3-6 illustrates the steady-state conditions within the faulted granite. Seepage is predicted along the bottom 100 m of the pit wall. Estimated volumes from the granite and kimberlite in non-fractured regions is very small (Figure 2.3-7). A summary of the anticipated seepage rates (exclusive of precipitation) is presented in Table 2.3-7.

Table 2.3-6
Potential Stored Water Volume From Fault Zones

Proposed Pit	Volume of Drained Fault Rock (m^3)	Volume of Groundwater in Storage (m^3)
Fox	2.5×10^7	1.3×10^6
Panda	2.0×10^5	1.1×10^4
Koala	2.0×10^6	1.0×10^5
Misery	2.0×10^5	1.0×10^4
Leslie	9.6×10^5	5.0×10^4

Table 2.3-7
Anticipated Seepage Rates into Fox Pit

Flux (m^3/s)	Seepage Rate (m^3/h)
1.1×10^{-5} (floor - fault zone 7% of pit floor)	1
7.0×10^{-5} (wall -fault zone 7% of pit wall)	20
4.4×10^{-9} (floor - kimberlite 93% of pit floor)	0
4.9×10^{-10} (wall - granite 93% of pit wall)	0
Total (m^3/h)	21

Seepage into Fox pit when the hydraulic conductivity of the underlying kimberlite (pit floor) is increased from 10^{-7} m/s to 10^{-6} m/s is illustrated in Figure 2.3-8 and summarized in Table 2.3-8.

Table 2.3-8
Anticipated Seepage Rates into Fox Pit
(Increased Hydraulic Conductivity of Kimberlite)

Flux (m^3/s)	Seepage Rate (m^3/h)
5.9×10^{-5} (wall - fault zone 7% of pit wall)	3
5.5×10^{-5} (floor - fault zone 7% of pit floor)	15
Total (m^3/h)	18

As indicated in the summary of pit seepage (Tables 2.3-6 and 2.3-7), the estimated total seepage rate into the proposed pit is approximately 20 m^3/h. Most of this water will be derived from the fault zones.

Panda Pit

Figures 2.3-9 through 2.3-12 illustrate the same modelling procedures applied to Panda pit. Figure 2.3-9 illustrates the steady-state conditions established within the fault zones once the Panda pit has achieved its maximum depth. The seepage face occurs along the bottom 80 m of the pit and the pit base. Seepage derived from the non-fractured granite is negligible (Figure 2.3-10).

Panda Lake, however, will not be drained to the northeast of the proposed pit. Plans include a dam constructed approximately 100 m northeast of the pit margin where Panda Lake narrows. Field measurements have indicated that permafrost is present below the proposed dam site. The revised model for seepage from Panda Lake includes permafrost to a depth of 120 m below the proposed dam. Assuming that seepage from Panda Lake will be limited to the pit wall beneath the former Panda Lake, the percentage of the entire pit circumference encompassed by the open talik was measured from topographic maps. One fault intersects the pit wall within the 100 m section. The volume of seepage was calculated assuming this fault zone was 20 m in width. Figures 2.3-11 and 2.3-12 illustrate steady-state conditions within the fault zone and granite rock types established at the point of maximum pit development. The majority of seepage into the proposed pit will be associated with this section of the pit wall and, in particular, any faults providing hydraulic connection between the pit wall and remaining portion of Panda Lake. The total seepage into Panda pit indicated by the initial model was refined to account for the increased seepage on the northeast pit wall. Estimates of seepage are summarized in Table 2.3-9.

Table 2.3-9
Anticipated Seepage Rates into Panda Pit

Flux (m^3/s)	Seepage Rate (m^3/h)
4.7×10^{-5} (wall - fault zone 6% of pit wall)	7
6.5×10^{-6} (floor - fault zone 6% of pit floor)	0.2
2.8×10^{-11} (wall - granite 94% of pit wall)	0
5.6×10^{-11} (floor - kimberlite 94% of pit floor)	0
1.3×10^{-4} (wall - fault zone open talik)	9
9.4×10^{-6} (floor - fault zone open talik)	1
1.1×10^{-10} (wall - granite open talik)	0
2.1×10^{-10} (floor - kimberlite open talik)	0
Total (m^3/h)	17

As indicated in Table 2.3-9 the total seepage rate into the proposed pit is estimated to be approximately 17 m^3/h. The net effect of not draining Panda Lake entirely is an increase of the seepage rate into Panda pit from 8 m^3/h to 17 m^3/h.

Koala Pit

Once the proposed Koala pit is established at its maximum depth and steady-state conditions have prevailed, seepage from the fault zones will occur along the base of the excavation (Figure 2.3-13). However, seepage derived from the non-fractured granite wall rock will be negligible (Figure 2.3-14).

As indicated in Table 2.3-10 the total estimated volume of seepage into the proposed pit is 7 m^3/h.

Table 2.3-10
Anticipated Seepage Rates into Koala Pit

Flux (m^3/s)	Seepage Rate (m^3/h)
5.2×10^{-5} (wall - fault zone 5% of pit wall)	7
8.9×10^{-6} (floor - fault zone 5% of pit floor)	0.3
4.5×10^{-11} (wall - granite 95% of pit wall)	0
7.2×10^{-11} (floor - kimberlite 95% of pit wall)	0
Total (m^3/h)	7.3

Misery Pit

Figures 2.3-15 and 2.3-16 illustrate the steady-state conditions established for Misery pit once it is fully developed. As with the other pits, the majority of seepage is associated with the faulted wall rock and is limited to the areas beneath permafrost. Table 2.3-11 summarizes the total estimated seepage rate into the proposed pit.

Table 2.3-11
Anticipated Seepage Rates into Misery Pit

Flux (m^3/s)	Seepage Rate (m^3/h)
3.3×10^{-5} (wall - fault zone 5% of pit wall)	3
2.7×10^{-6} (floor - fault zone 5% of pit floor)	0.1
3.2×10^{-11} (wall - granite 95% of pit wall)	0
1.7×10^{-11} (floor - kimberlite 95% of pit wall)	0
Total (m^3/h)	3.1

Leslie Pit

Figures 2.3-17 to 2.3-20 illustrate steady-state conditions established for Leslie pit. Moose Lake is located on the eastern pit margin of the proposed Leslie pit and an undrained section of Leslie Lake extends west from the western margin of the proposed pit. Therefore, open talik will be associated with the eastern and western pit walls. As in the case of Panda Lake, seepage from the frozen pit walls was modelled (Figures 2.3-19 and 2.3-20) and seepage from the open talik associated with Moose Lake and Leslie Lake was modelled. As in the Panda pit model, it was assumed that one 20 m wide fault intersected the pit wall through the open talik. The combined seepage is presented in Table 2.3-12.

Table 2.3-12
Anticipated Seepage Rates into Leslie Pit

Flux (m^3/s)	**Seepage Rate (m^3/h)**
5.2×10^{-5} (wall - fault zone 6% of pit wall)	8.3
9.7×10^{-6} (floor - fault zone 6% of pit floor)	0.4
4.7×10^{-11} (wall - granite 94% of pit wall)	0
7.0×10^{-11} (floor - kimberlite 94% of pit floor)	0
1.5×10^{-4} (wall - fault zone open talik)	22
1.5×10^{-5} (floor - fault zone open talik)	0.9
9.3×10^{-10} (wall - granite open talik)	0
3.9×10^{-10} (floor - kimberlite open talik)	0
Total (m^3/h)	**32**

Recharge from Neighbouring Lakes

Assuming that the entire volume of water seepage into each of the proposed pits is derived from the surrounding lakes, and based on the anticipated length of time for the granite and faulted rock to yield water from storage, the net affect on water levels in neighbouring lakes (excluding Panda and Moose lakes) is anticipated to be negligible, particularly for the larger lakes such as Lac de Gras. Infiltration from the surrounding lakes will be affected by the thickness of accumulated silt and sediment on each of the lake bottoms which should significantly reduce net infiltration.

2.3.2.2 Summary

Some seepage will occur in all proposed pits due to water contained in the bedrock and the resultant hydraulic gradient established during the development of the open pits. The predicted seepage values derived from the model are considered to be a conservative estimate of the total seepage into the pits once steady-state conditions have been established. Based on the regional geology, it is unlikely that the static condition, as indicated in the seepage models, will be achieved prior to pit abandonment.

Pit development and the resultant lowering of the static water levels in the area surrounding each pit are not expected to affect the nearest lakes to each pit significantly, using the modelled seepage rates. Seepage due to storage from pit walls is expected to be small, based on the specific yield of granite and faulted granite.

2.4 Water Quality

Water quality has been identified as a valued ecosystem component, as the lake and stream waters of the Koala and adjacent watersheds provide fish habitat and are an important source of fresh water. The NWT Diamonds Project is located at the headwaters of the Coppermine River. The water quality within the watersheds at the NWT Diamonds Project site determine much of the ecological integrity of local ecosystems as well as those receiving water flow further downstream.

For the watercourses adjacent to the project site, a detailed and intensive sampling regime was undertaken to characterize the existing conditions and to quantify the natural variability associated with this system. Samples were collected from the Koala watershed and the adjacent Ursula, Paul, South and Misery watersheds (Figures 2.4-1, 2.4-2, 2.4-3 and 2.4-4, respectively). This information was used to establish a baseline upon which potential impacts can be predicted and/or detected. The remainder of this section is dedicated to assessing the baseline water quality of the study area.

2.4.1 Previous Research

An extensive report written by Environment Canada in 1988 presents water quality data collected for sub-catchments in the Coppermine Basin. This document provides useful background information for comparison with the Koala and adjacent watersheds.

Two spatial trends were observed in the Coppermine study. The first trend was that the pH of Coppermine River waters increased as it travelled downstream. While water in the upper basin exhibited a pH of approximately 6.6, water further downstream exhibited pH levels of 7.8 to 8.0 (Figure 2.4-5). This trend can be explained through examination of the geology of the upper and lower basins. The upper portion consists mostly of Canadian Shield granitic material whereas the lower basin is laden with more alkaline dolomitic sediments (Figure 2.4-6).

◎ Table of Contents

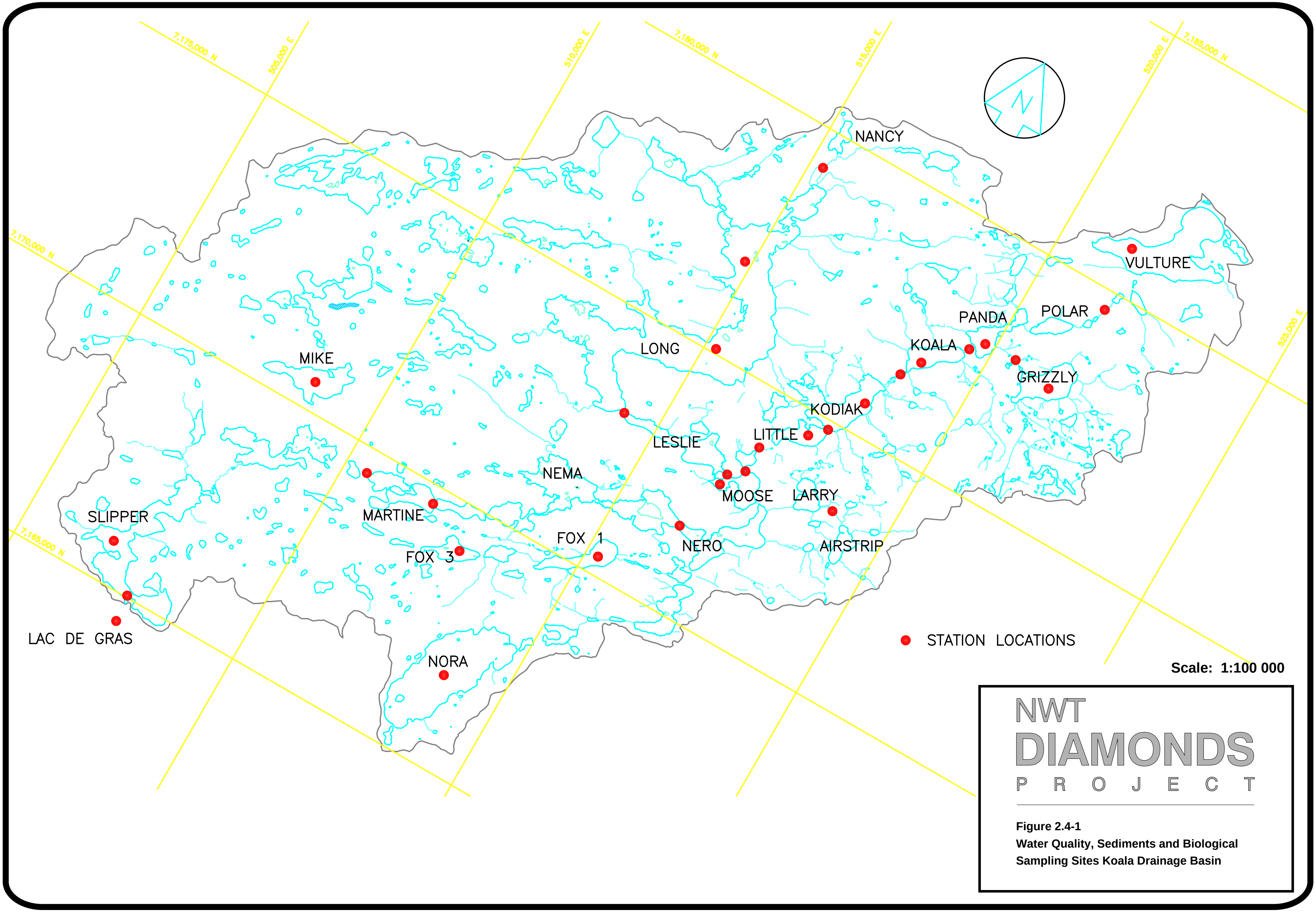


Figure 2.4-1
Water Quality, Sediments and Biological Sampling Sites Koala Drainage Basin

Source: Rescan

◎ **Table of Contents**

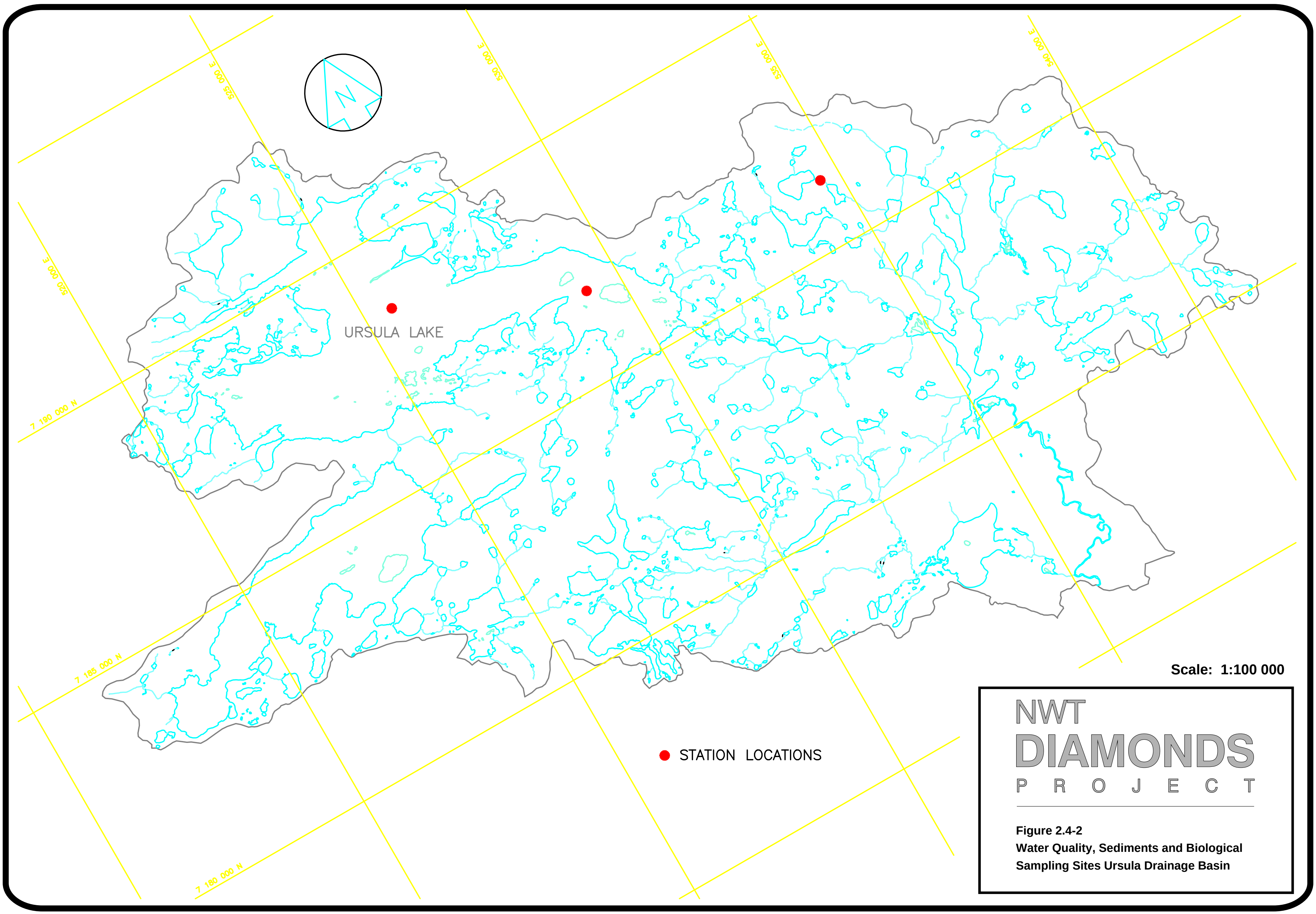


Figure 2.4-2
Water Quality, Sediments and Biological Sampling Sites Ursula Drainage Basin

Source: Rescan

◎ Table of Contents

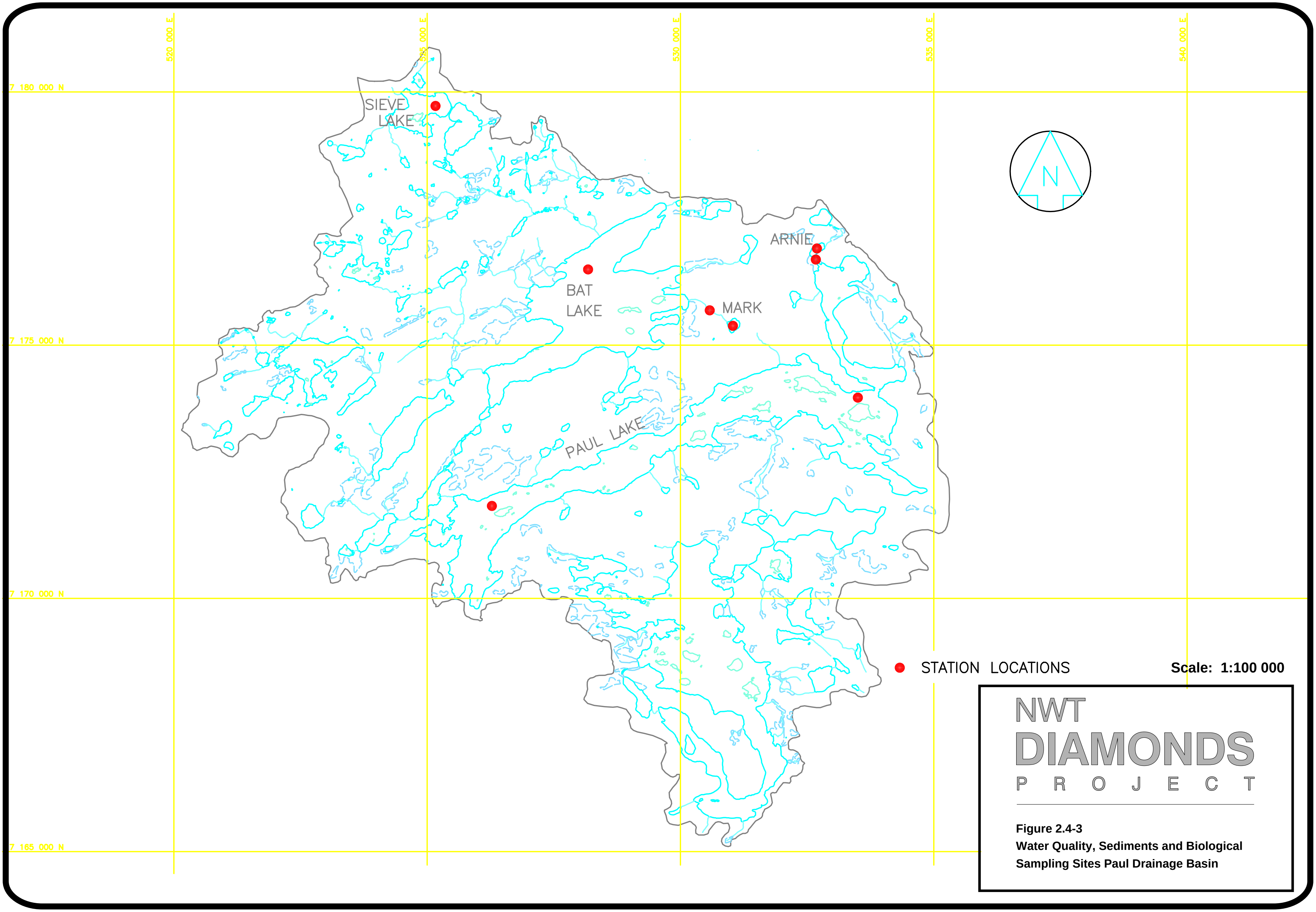


Figure 2.4-3
Water Quality, Sediments and Biological Sampling Sites Paul Drainage Basin

Source: Rescan

◎ **Table of Contents**

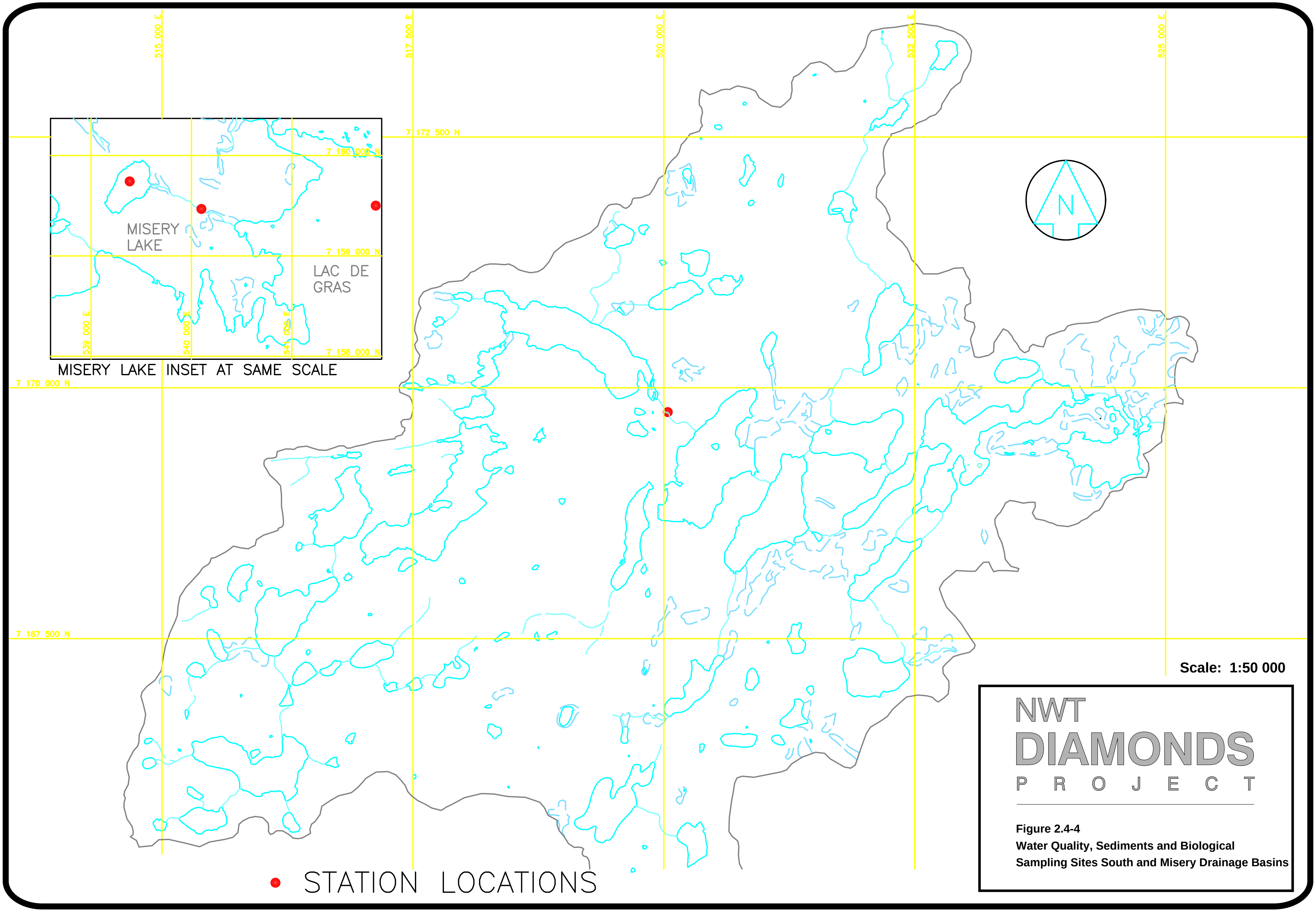
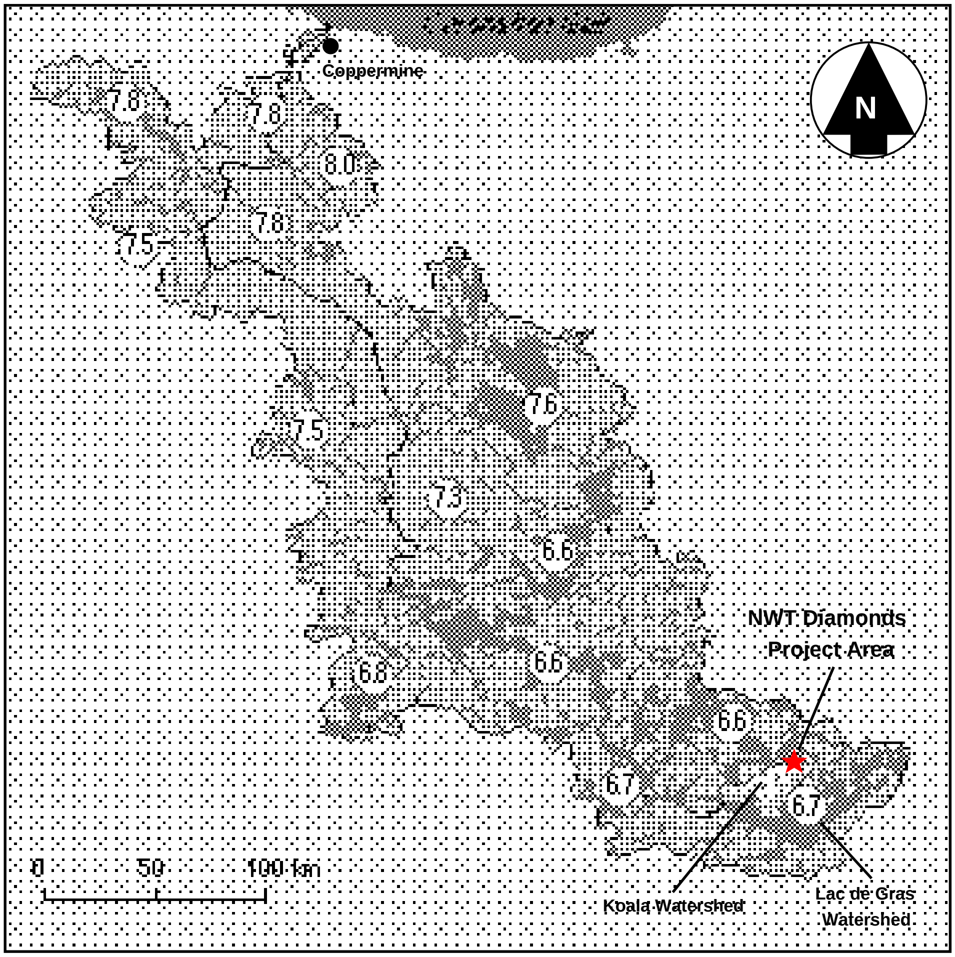


Figure 2.4-4
Water Quality, Sediments and Biological Sampling Sites South and Misery Drainage Basins

Source: Rescan

Coppermine River Drainage Basin



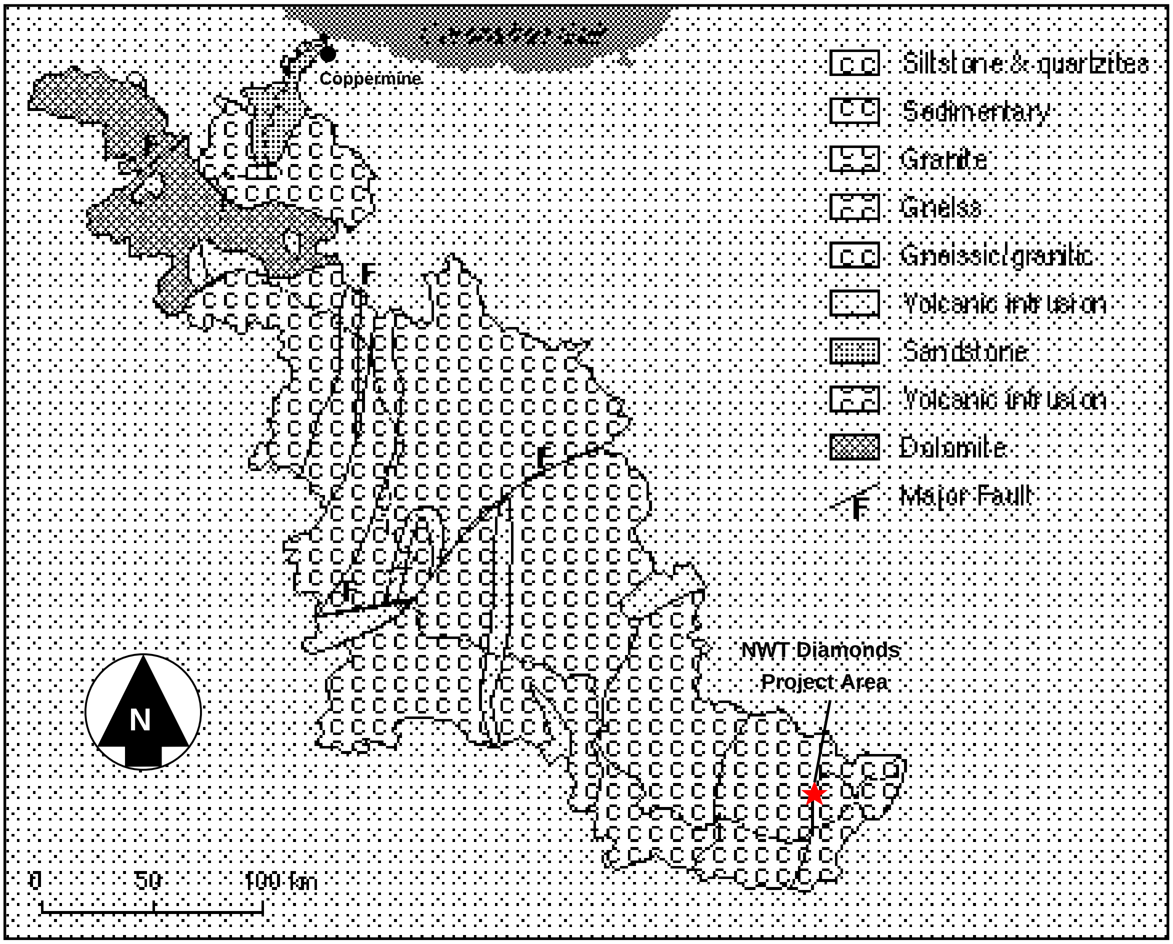
NWT DIAMONDS PROJECT

Figure 2.4-5
Spatial Distribution of pH

Source: Rescan

Table of Contents

Coppermine River Drainage Basin



NWT DIAMONDS PROJECT

Figure 2.4-6
Geologic Features

Source: Rescan

The second spatial trend found in the Coppermine Basin study was an increase in conductivity from the upper basin to the lower portions of the river (Figure 2.4-7). Water in the upper basin showed levels of 10 µmhos/cm and 11 µmhos/cm (Koala Watershed had a similar conductivity of 14). Water in the lower basin had a conductivity of up to 83 µmhos/cm indicating that conductivity increases naturally as the water moves through the basin.

The Coppermine Basin study also included heavy metal concentrations in the Coppermine River below Lac de Gras. All metal concentrations measured were below their detection limits, with the exception of arsenic (0.0002 mg/L) and nickel (0.002 mg/L). Both the arsenic and nickel concentrations reported were extremely close to those detected in baseline studies of the Koala watershed (0.0002 mg/L for arsenic and 0.0025 mg/L for nickel).

Aluminum and lead concentrations were below detection limits in the Coppermine Basin study, although they were slightly elevated in baseline studies of the Koala and surrounding watersheds. As is reflected in the QA/QC data, it islikely that lead levels were superficially high due to contamination (of aerosols from unknown origin) at the time of sampling. Elevated aluminum levels in the Koala watershed have been linked to the presence of alumino-silicates in the kimberlite pipes where exploration drilling has occurred (discussed in greater detail below). Water chemistry in the Koala and surrounding watersheds was compared with other aquatic systems in the Northwest Territories (Schindler *et al.* 1974; Welch and Legault 1986; Cornwell 1992). While potassium and magnesium in the vicinity of the NWT Diamonds Project site were present at concentrations similar to those found in other Northwest Territories watersheds, the concentrations of sodium and calcium were considerably less (Table 2.4-1). This likely results from the proximity of the Koala watershed to the headwaters of the Coppermine drainage basin. Natural waters have not traversed sufficient distances to accumulate major ions, and therefore represent little more than modified rainwater. This premise is supported by the conductivity data of Figure 2.4-7, which indicate increases in ionic strength towards Coronation Bay.

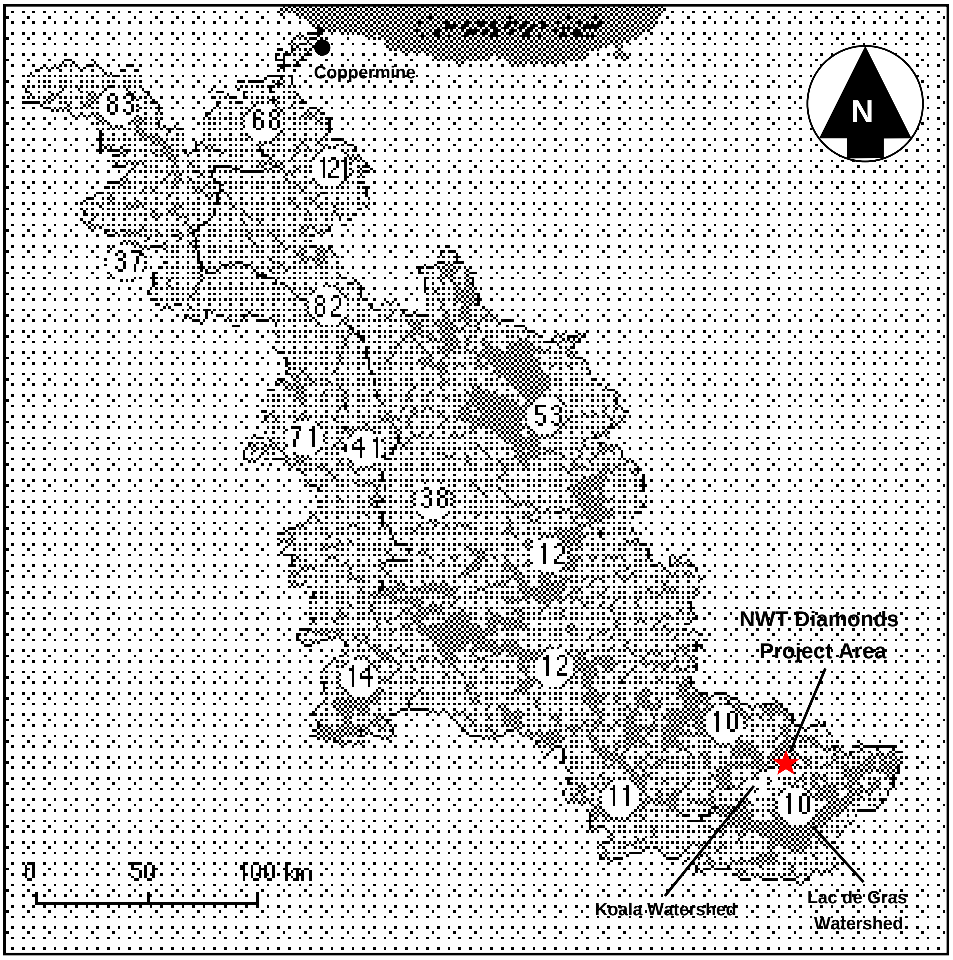
2.4.2 Methods

A number of techniques were used to collect and analyze an extensive suite of water quality parameters for the project area. Sample filtration and preservation were carried out in the field lab. Water quality samples were then shipped to Analytical Services Laboratories (ASL) in Vancouver where they were analyzed for physical parameters, nutrients, total metals and dissolved metals.

2.4.2.1 Field Methods

In August 1993, preliminary water quality studies were conducted on eight lakes (Airstrip, Fox 1, Fox 2, Fox 3, Koala, Kodiak and Long lakes) in the Koala

Coppermine River Drainage Basin



NWT DIAMONDS PROJECT

Figure 2.4-7
Spacial Distribution of Conductivity

Source: Rescan

Table 2.4-1
Major Ion Concentrations from
Snow, Rain and Several High-Latitude Lakes

Lake	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
Char Lake, NWT				
Snow	0.92	0.20	2.08	0.58
Rain	0.80	0.20	19.56	0.73
Stream	8.39	0.90	33.59	6.64
Saqvaqjuac, NWT				
Snow	0.28	<0.04	0.12	0.05
Rain	1.06	<0.04	0.24	0.10
Meadow	3.31	0.74	9.98	1.00
N&N	2.44	0.59	3.17	0.73
Far	2.25	0.35	3.01	0.70
Spring	4.69	0.74	4.25	0.87
Jade	2.32	0.47	4.05	0.68
Saqvaqjuac	1.75	0.39	5.65	0.80
Barrow, AK				
Snow	3.56	0.23	2.40	0.70
Rain	3.13	0.12	1.80	0.34
Toolik, AK				
Snow	0.23	0.06	1.20	0.15
Rain	0.07	0.05	0.24	0.07
Koala Watershed	0.53	0.46	0.85	0.56

Compiled from Schindler *et al.* 1974; Welch Legault 1986; Cornwell 1992.

watershed. In 1994, the study was expanded to include 28 sites in 25 lakes from the Koala, Ursula, Paul and Misery watersheds (Figures 2.4-1 to 2.4-4). Sampling was conducted during the subarctic spring-summer (June 28 to August 5) and summer-fall (August 12 to September 8) seasons. At each lake site, field measurements included pH, conductivity, Secchi disc transparency, temperature and dissolved oxygen profiles with readings taken at 1 m intervals. Water samples were collected for chemical analyses using an acid-washed Go-Flo sampling bottle. In order to collect a discrete sample, the sampling bottle was lowered with both ends open to the desired depth and was triggered shut using a messenger. Five samples were taken: at the surface, mid depth, bottom and at two intermediate depths above and below the thermocline where stratification was evident. Sub-samples were then transferred to labelled plastic bottles, which had been rinsed three times with sample water, for analysis for the following parameters:

- dissolved and total metals (2 x 250 mL)
- nutrients and physical parameters (1 L)
- chlorophyll *a* (1 L).

Samples for dissolved metals were filtered in the field lab using an acid-washed, polycarbonate filtration apparatus and a 0.45 μm mixed-cellulose acetate filter. Preservation of total and filtered dissolved metals involved the addition of concentrated nitric acid (5 mL of HNO_3 per litre of water). All samples were refrigerated immediately after collection and shipped to ASL within two days. Chlorophyll *a* samples were transferred to 1 L foil wrapped plastic bottles to prevent exposure to sunlight and inhibit productivity. These samples were vacuum filtered in the field lab, the filter discs were carefully removed and wrapped in foil, then placed in a labelled petri dish and frozen for transfer to the laboratory for analysis. As chlorophyll *a* is an indirect measure of phytoplankton biomass, chlorophyll *a* is discussed further in Section 3.1.

Five stream sites in the Koala watershed were sampled in August 1993. During three sampling periods in 1994 (subarctic spring, summer, fall), a total of 18 streams were sampled (Figures 2.4-1 to 2.4-4). At stream sites, field measurements included pH, temperature and dissolved oxygen. Samples were collected in plastic bottles, which were rinsed three times before filling, from just below the water surface. Preservation and handling was undertaken as previously described for lake samples.

2.4.2.2 Analytical Methods

Total and dissolved metal concentrations were determined using several methods. Inductively Coupled Argon Plasma Emission Spectrophotometry (ICP-ES), Graphite Furnace Atomic Absorption Spectroscopy (GFAAS) and Hydride Generation Atomic Absorption Spectroscopy (HGAAS), were undertaken according to the American Public Health Association (APHA) Standard Methods, 18th Edition (1992). Anions such as chloride and fluoride (as well as cationic ammonium) were measured with specific ion electrodes, while sulphate was determined by a nephelometric method using barium sulphate precipitation. Nutrients such as nitrogen and phosphorus were measured colourimetrically using a UV/visible spectrophotometer after methods outlined in Parsons *et al.* (1984) and APHA (1992). Table 2.4-2 lists the parameters that were analyzed for each of the samples and, where appropriate, the achievable detection limits.

2.4.2.3 Discussion of QA/QC

As an integral part of the water quality sampling program at the NWT Diamonds Project site, a Quality Assurance – Quality Control program was completed to

Table 2.4-2
Water Quality Monitoring Parameters
and Appropriate Detection Limits

Parameter		Detection Limit (mg/L)
Physical Tests		
pH		N/A
Conductivity		1.0 µmhos/cm
Total Dissolved Solids	(TDS)	1.0
Total Suspended Solids	(TSS)	1.0
Hardness	(as $CaCO_3$)	1.0
Turbidity		0.1 NTU
Alkalinity		1.0
Acidity		1.0
Anions		
Chloride	(Cl^-)	0.5
Fluoride	(F^-)	0.10
Sulphate	(SO4-2)	0.5
Nutrients		
Nitrogen		
Ammonia	(NH_3)	0.005
Nitrate	(NO_3)	0.05
Nitrite	(NO_2)	0.001
Phosphorus		
Total P		0.002
Dissolved P		0.002
Ortho-phosphate		0.002
Total and Dissolved Metals		
Aluminum	(Al)	0.50
Antimony	(Sb)	0.10
Arsenic	(As)	1.00
Barium	(Ba)	1.00
Beryllium	(Be)	0.09
Boron	(B)	1.00
Cadmium	(Cd)	0.10
Calcium	(Ca)	10.00
Chromium	(Cr)	1.00
Cobalt	(Co)	0.06
Copper	(Cu)	0.50

(continued)

Table 2.4-2 (completed)
Water Quality Monitoring Parameters
and Appropriate Detection Limits

Parameter		Detection Limit (µg/L)
Total and Dissolved Metals (cont.)		
Iron	(Fe)	10.00
Lead	(Pb)	1.00
Magnesium	(Mg)	10.00
Manganese	(Mn)	1.00
Mercury	(Hg)	0.05
Molybdenum	(Mo)	0.50
Nickel	(Ni)	0.30
Selenium	(Se)	1.00
Silver	(Ag)	0.03
Uranium	(U)	0.01
Vanadium	(V)	1.00
Zinc	(Zn)	2.00

ensure sampling and analytical integrity. During July, August and September of 1994, the QA/QC program included sampling and analyses for physical parameters, anions/nutrients, total metals and dissolved metals. Data collected from this program has been listed in Appendix II-A6.

2.4.2.4 Blanks

Filter blanks were prepared by collecting a sample of the deionized water after it had been rinsed through the filtration apparatus which was used to prepare the dissolved metal samples. A total of 13 filter blanks were collected and analyzed for total metals. Aluminum, antimony, cadmium, copper, iron, lead, magnesium, silver and zinc showed concentrations above detection limits. Of these, only aluminum and copper exhibited any values which were a degree of magnitude greater than the detection limit.

Three field blanks were taken and analyzed for all water quality parameters. In terms of metals, total aluminum, total copper, total magnesium, total silver, dissolved aluminum and dissolved sodium concentrations were slightly above detection limits. The remaining total and dissolved metals had concentrations either at or below detection limits.

Eleven transport blanks were collected and analyzed for total metals. Of these 11 samples, two showed concentrations higher than detection limits. One sample showed aluminum concentrations three times higher than the detection limit. A second sample had copper concentrations twice as high as the detection limit.

2.4.2.5 Splits

Six sets of split samples were taken from Bat and Arnie lakes and analyzed for all parameters. In order to compare the two samples to one another, the standard deviation of both values was divided by the average to obtain a percentage. For most parameters, concentrations differed by <10%. Parameters which had concentrations varying by >10% included total copper, lead, nickel, silver, uranium and zinc, and dissolved aluminum, arsenic, calcium, copper and uranium. Both pH and TSS showed highly uniform values.

2.4.2.6 Replicates

Replicates provide an excellent indication of sampling validity. Four replicates were taken from Bat Lake and sampled for all parameters. The replicates were compared in the same manner as the splits. For most metal parameters, concentrations differed by <10%. Exceptions generally occurred when sample concentrations existed near the analytical detection limit such that analytical “noise” was a proportionately larger fraction of the actual concentration. Metals which did not follow these general trends included total aluminum, total copper, total lead, dissolved aluminum and dissolved lead. Some of the anion/nutrient parameters showed values which also differed, including total suspended solids, sulphate, free ammonia, ortho-phosphate and total phosphorous.

2.4.3 Water Quality Baseline

The water quality baseline data is compiled from samples collected in the ice-free periods of 1993 and 1994. Since most parameters were below detection limits, emphasis has been placed on characterizing each system and identifying trends both within and between adjacent watersheds.

The baseline assessment was designed to focus on geochemical parameters of water composition to enable the prediction of impacts. The baseline description involves an assessment of the aqueous environment focusing on several key issues:

- general characterization of each watershed and watershed differences
- compositional trends in lakes with water depth
- downstream trends in water quality.

2.4.3.1 Watershed Characterization and Differences

The complete data set for water quality is summarized in Table 2.4-3; this table displays average concentrations for all parameters for each of the five watersheds. Since the entire Lac de Gras area is situated on Precambrian Shield, the surface runoff that accumulates in these lakes contains few particulate or dissolved components. Total dissolved solids (TDS) are low in all watersheds, with watershed averages ranging from 5.5 mg/L to 11.3 mg/L. This is reflected in water conductivity which is also low, ranging from 8 µmhos/cm to 17 µmhos/cm. Major ions rarely exist in quantities more than a few mg/L, and most metals are below analytical detection limits. The pH ranges from 6.3 to 6.7, characteristic of waters flowing over granitic and gneissic terrain.

With two exceptions, aluminum (Al) and lead (Pb), the watershed averages of all measured parameters are below federal CCME (Canadian Council of Ministers of the Environment) water quality guidelines. Using the conservative Al guideline (0.005 mg/L for pH <6.5), the average total Al value exceeds federal guidelines in all five watersheds despite the absence of anthropogenic sources. Even dissolved Al naturally exceeds guidelines in the Koala, Paul and Misery watersheds. The average values for the Koala and Misery watersheds are higher than that for the other three. This difference likely reflects the influence of exploration drilling and the commensurate increase in suspended alumino-silicates rather than representing inter-watershed variability as most other parameters do not display concurrent changes. For waters of pH >6.5, the Al guideline increases twenty-fold to 0.100 mg/L. Under these conditions of slightly higher pH, Al averages for all watersheds are within the CCME guidelines.

As the waters of these lakes are also very soft (<6 mg $CaCO_3$/L), the federal guideline for Pb is 0.001 mg/L. The watershed averages for lead are marginally in excess of federal guidelines for water in all but the South Watershed. It is possible that some of the excursions of lead arise from spurious sample contamination as most values are below the analytical detection limit. This supposition is supported by a lack of geochemical consistency; in other words, variability was dispersed throughout the data set, with no consistent or observable trends.

Table 2.4-4 shows the maximum values of total metals recorded for each of the watersheds studied. From these data, it is evident that most baseline metal concentrations are very low. Where values exceed federal water quality guidelines, they are (with the exception of Al) only slightly in excess. Total Al exceeds water quality guidelines in both the affected and pristine environments. While the largest total Al values are found in the Koala and Misery watersheds where exploration drilling has created suspended solids enriched in Al, the maximum total Al values are not substantially greater that those found in the Paul

Table 2.4-3
Average Concentrations of each Parameter in the Five Watersheds

		Koala Watershed	Ursula Watershed	Paul Watershed	Misery Watershed	South Watershed
Conductivity	(µmhos/cm)	13.91	8.50	14.44	17.46	11.80
Total Dissolved Solids	(mg/L)	9.7	5.5	9.4	11.3	8.0
Hardness	(mg $CaCO_3$/L)	4.5	2.3	4.8	5.9	3.5
pH	(units)	6.3	6.3	6.5	6.6	6.3
Total Suspended Solids	(mg/L)	4.1	1.6	1.5	2.5	4.0
Turbidity	(NTU)	1.3	4.5	7.4	1.6	1.0
Acidity	(mg $CaCO_3$/L)	2.0	1.9	2.0	2.0	1.9
Alkalinity - Total	(mg $CaCO_3$/L)	4.1	2.5	4.7	5.5	3.1
Alkalinity - Bicarbonate	(mg $CaCO_3$/L)	4.1	2.5	4.7	5.5	3.1
Alkalinity - Carbonate	(mg $CaCO_3$/L)	B.D.	B.D.	1.0	1.0	B.D.
Chloride	(mg/L)	0.86	0.56	0.57	0.62	0.76
Fluoride	(mg/L)	0.06	0.03	0.03	0.03	0.03
Sulphate	(mg/L)	1.8	1.1	1.5	1.9	1.4
Free Ammonia	(mg NH_3-N/L)	0.011	0.009	0.01	0.006	0.02
Nitrate	(mg NO_3-N/L)	0.0187	0.1740	0.0053	0.0072	0.0107
Nitrite	(mg NO_2-N/L)	0.0023	0.0018	0.0019	0.0017	0.0017
Ortho-Phosphate	(mg P/L)	0.0046	0.0023	0.0057	0.0047	0.0047
Total Dissolved Phosphate	(mg P/L)	0.0074	0.0041	0.0110	0.0062	0.0087
Total Phosphorus	(mg P/L)	0.0094	0.0049	0.0127	0.0075	0.0127
Total Metals (mg/L)						
Aluminum		**0.0591**	**0.0133**	**0.0361**	**0.0730**	**0.0293**
Antimony		0.0005	B.D.	0.0001	0.0001	B.D.
Arsenic		0.0002	0.0003	0.0003	0.0002	0.0002
Barium		0.0247	B.D.	0.0100	0.0116	B.D.
Beryllium		B.D.	B.D.	0.0030	0.0030	B.D.
Boron		B.D.	B.D.	0.0500	0.0500	B.D.
Cadmium		0.0002	**0.0005**	0.0001	0.0002	B.D.
Calcium		0.9040	0.4300	0.7736	1.223	0.6577
Chromium		0.0014	B.D.	0.0010	0.0010	B.D.
Cobalt		B.D.	B.D.	0.0010	0.0010	B.D.
Copper		0.0011	0.0008	0.0012	0.0008	0.0010
Iron		0.0798	0.0319	0.1125	0.0825	0.1467
Lead		**0.0019**	**0.0016**	**0.0025**	**0.0015**	B.D.
Magnesium		0.6453	0.2891	0.7669	0.8599	0.5023
Manganese		0.0108	0.0120	0.0059	0.0050	0.0080

(continued)

Table 2.4-3 (completed)
Average Concentrations of each Parameter in the Five Watersheds

	Koala Watershed	Ursula Watershed	Paul Watershed	Misery Watershed	South Watershed
Mercury	B.D.	B.D.	0.0000	0.0000	B.D.
Molybdenum	B.D.	B.D.	0.0010	0.0011	B.D.
Nickel	0.0025	0.0010	0.0013	0.0033	B.D.
Selenium	B.D.	B.D.	0.0005	0.0005	B.D.
Silver	B.D.	0.00002	0.00001	0.00001	B.D.
Uranium	B.D.	0.00002	0.00004	0.00002	0.00005
Vanadium	B.D.	B.D.	0.0050	0.0050	B.D.
Zinc	0.0036	0.0020	0.0027	0.0076	0.0040
Dissolved Metals (mg/L)					
Aluminum	**0.0181**	0.0047	**0.0136**	**0.0130**	**0.0080**
Antimony	B.D.	B.D.	0.0001	0.0001	B.D.
Arsenic	0.0001	0.0003	0.0003	0.0002	0.0002
Barium	0.0305	B.D.	0.0100	0.0109	B.D.
Beryllium	B.D.	B.D.	0.0030	0.0030	B.D.
Boron	B.D.	B.D.	0.0500	0.0500	B.D.
Cadmium	0.0002	B.D.	0.0001	0.0001	B.D.
Calcium	0.8518	0.4074	0.7275	1.1510	0.6283
Chromium	B.D.	B.D.	0.0010	0.0010	B.D.
Cobalt	B.D.	B.D.	0.0010	0.0010	B.D.
Copper	0.0009	0.0010	0.0010	0.0006	B.D.
Iron	0.0237	0.0163	0.0713	0.0108	0.0700
Lead	**0.0017**	B.D.	**0.0014**	**0.0016**	B.D.
Magnesium	0.5609	0.2692	0.7336	0.7526	0.4893
Manganese	0.0511	0.0050	0.0050	0.0050	B.D.
Mercury	B.D.	B.D.	0.0000	0.0000	B.D.
Molybdenum	B.D.	B.D.	0.0010	0.0010	B.D.
Nickel	0.0022	B.D.	0.0011	0.0024	B.D.
Potassium	0.4569	0.2366	0.5270	0.5320	0.4867
Selenium	B.D.	B.D.	0.0005	0.0005	B.D.
Silver	B.D.	0.00001	0.00001	0.00001	B.D.
Sodium	0.5285	0.35563	0.47963	0.52700	0.47333
Uranium	B.D.	0.00002	0.00003	0.00001	0.00003
Vanadium	B.D.	B.D.	0.0050	0.0050	B.D.
Zinc	0.0021	0.0013	0.0012	0.0016	0.0030

B.D.: Below Detection.
Bold values are in excess of current CCME water quality guidelines.

Table 2.4-4
Maximum Total Metal Values in each Watershed (mg/L)

	Federal Guidelines	Koala Watershed	Misery Watershed	Ursula Watershed	Paul Watershed	South Watershed
Aluminum	0.005 (pH<6.5) 0 .100 (pH>6.5)	**0.465**	**0.227**	**0.18**	**0.101**	**0.034**
Arsenic	0.05	0.0032	0.0003	0.0005	0.0006	0.004
Cadmium	0.0002	**0.0005**	**0.0008**	0.0017	**0.0003**	0.0001
Chromium	0.002	**0.004**	0.001	0.001	0.001	0.001
Copper	0.002	0.02	0.001	0.002	0.0035	0.001
Iron	0.3	**0.82**	0.21	0.28	**0.39**	0.29
Lead	0.001	**0.01**	**0.006**	**0.002**	**0.01**	0.001
Mercury	0.0001	0.00005	0.00005	0.00005	0.00005	0.00005
Nickel	0.025	0.014	0.006	0.001	0.002	0.001
Silver	0.0001	0.00005	0.00001	0.00003	0.00004	0.00001
Zinc	0.03	0.028	0.03	0.003	**0.041**	0.004

Bold values exceed CCME water quality guidelines.

or Ursula watersheds which appear to be elevated naturally. Differences in water quality between the watersheds are very small and only marginally detectable, as most parameters are below or very near the analytical limits of detection. Where excursions do exist, those resulting from drilling activities are not substantially larger that the natural excursions seen in the pristine watersheds. In general, the lakes in the Ursula watershed support the lowest concentrations of total and dissolved constituents. The lakes of the South watershed support only marginally higher values. The lakes of the Koala and Misery drainage basins are to a limited extent affected by exploration but do not display compositions substantially different from the lakes of the Paul watershed. Thus, the exploration program to date has had only localized impacts on baseline water quality conditions.

2.4.3.2 Water Quality Trends with Depth

The distribution of organic matter, trace metals and other water column components is sensitive to the biogeochemical processes occurring in the water column. The production and consumption of plankton, the vertical distribution of dissolved oxygen and temperature and other physical and chemical processes are capable of profoundly restructuring the chemical composition of the water column. In shallow lakes (<10 m), wind mixing has the effect of homogenizing the water column. However, in deeper lakes, where stratification inhibits mixing below the thermocline (the plane at which water temperature drops most rapidly, i.e., ≥1°C/m), the vertical composition of a lake may not be uniform.

It is important to determine if any of the lakes in the NWT Diamonds Project area display chemical fractionation with depth as the behaviour of the various components (anthropogenic or natural) in a lake, particularly with regard to residence time, are influenced by such distributions.

The effect of summer stratification on water quality was examined for Vulture Lake, Koala Lake and Lac de Gras. All three lakes are relatively deep and support thermal stratification in the summer and represent three discrete stages of potential impact by mining activities. Vulture Lake is upstream of the exploration drilling activities in Panda and Koala lakes, Koala Lake has undergone exploration drilling and Lac de Gras is the water body through which all waters influenced by exploration must flow before entering the rest of the Coppermine drainage basin. As the greatest degree of water column differentiation occurs under conditions of the greatest stratification at the end of the summer, the August sampling data are used to assess the influence of physical limnology on lake chemistry.

Vulture Lake, upstream of the exploration drilling activity in Panda and Koala lakes, is one of the deeper lakes studied (37 m). Samples were collected from several depths in mid-August 1994, under relatively strong stratified conditions (Figure 2.4-8). Surface water temperature in Vulture Lake was 14°C, typical of

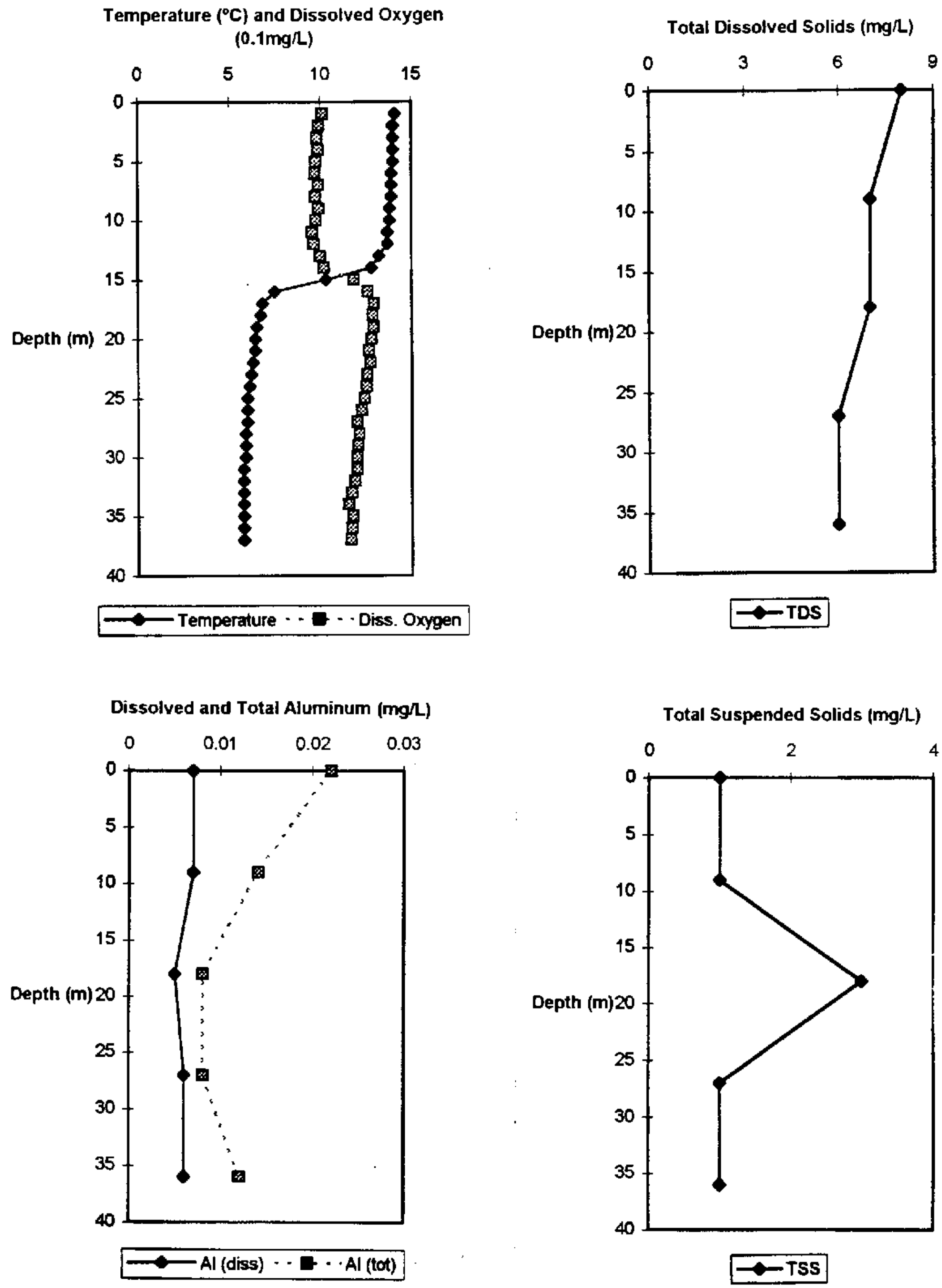


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Figure 2.4-8
Distribution of Parameters in Vulture Lake

Source: Rescan

most of these lakes in mid-August. The mixed surface layer extended to a depth of 10 m. Below this layer the temperature continued to decrease (to 6.5°C) for another 7 m deep. From the base of the thermocline, temperature decreases slowly to a value of 5.8°C near the bottom. Despite relatively strong stratified conditions, lake composition did not alter measurably through the water column (Figure 2.4-8).

The water quality of Koala Lake reflects the fact that it has undergone exploration drilling; Koala Lake had higher concentrations of Al and TSS relative to other undrilled lakes (Figure 2.4-9). When sampled in August 1994, Koala Lake displayed evidence of stratification. Temperatures of 13.6°C at the surface, decreased to 7°C at depth with the thermocline centering at 11 m. Similar to Vulture Lake, the composition of Koala Lake was uniform throughout the water column (Figure 2.4-9). Neither total nor dissolved parameters displayed any changes across the thermocline. Even the non-conservative parameter, oxygen, did not decrease except near the lake floor where it was consumed through the oxidation of sedimentary organic matter.

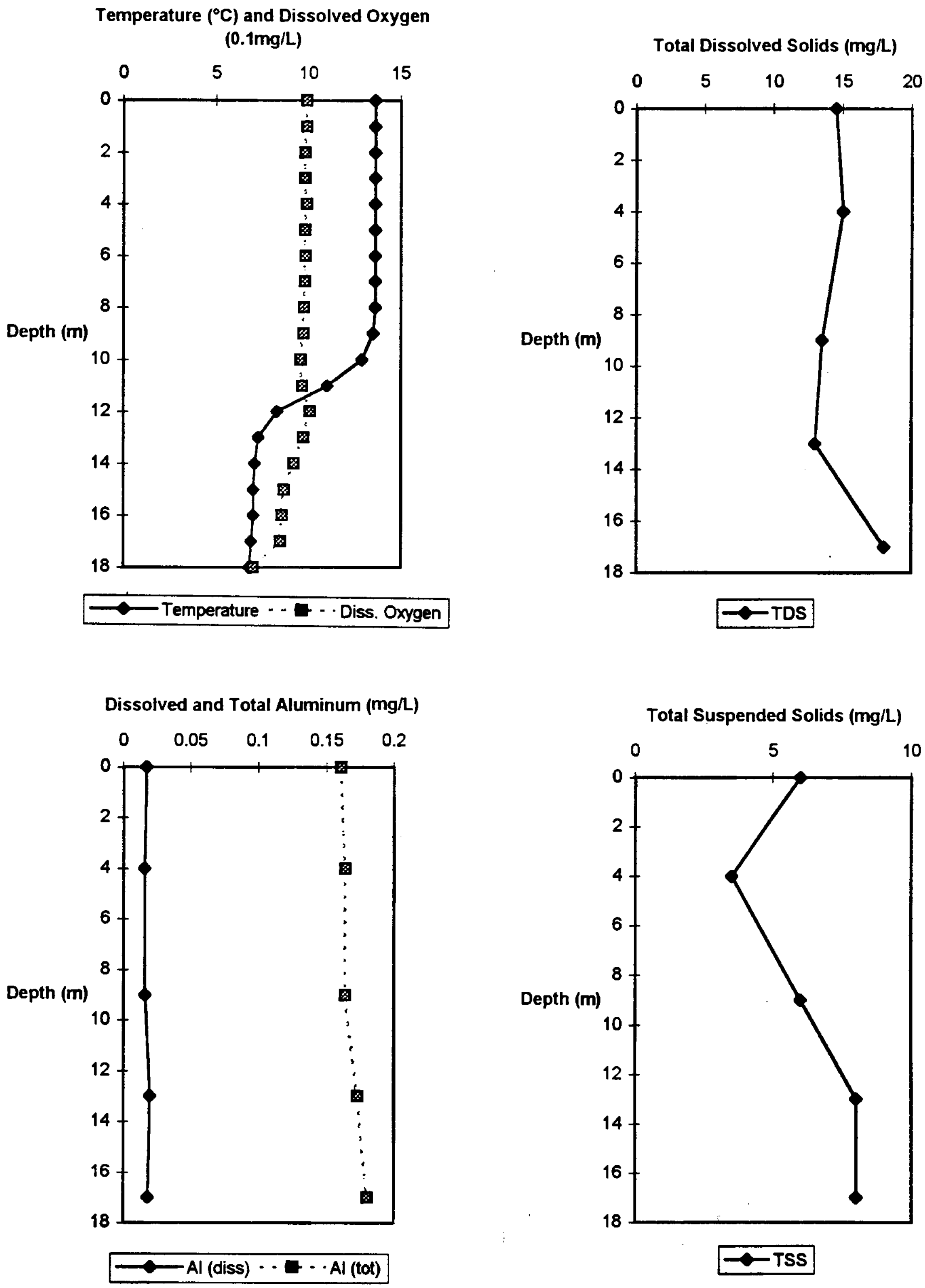
The surface temperature of Lac de Gras, like the previous two lakes, was relatively uniform (13.3°C). However, due to the comparatively large fetch associated with this lake, the thermocline at this site did not begin until 12 m depth, intersecting the lake floor. The coolest temperature at this point was 9.3°C.

Since the water column composition did not change with depth (Figure 2.4-10), waters from the Koala watershed mix completely with the waters of Lac de Gras.

In summary, the absence of compositional differences in the shallow lakes is fairly uniform. Wind mixing is able to penetrate to the lake floor. However, compositional uniformity is evident in all lakes of this study regardless of lake depth or degree of stratification. This situation arises from the combination of several factors. Vertical fractionation in the water column is primarily related to biogenic cycles which occur only during ice-free conditions. Since the ice-free window is brief (approximately four months), there is insufficient time to establish vertical gradients in the water column.

The second factor causing compositional uniformity relates to the fact that the majority of these lakes are oligotrophic. Since primary productivity is low, the intensity of biogenic cycling within the water column is also low. The mechanism driving the majority of fractionation is inherently weak to the extent that insufficient quantities of organic matter, metals and other components are introduced to bottom waters to establish vertical gradients.

Finally, since this watershed lies in the erosion-resistant Precambrian Shield, there is virtually nothing in the water column to fractionate. Even in Koala Lake where particulate and dissolved material is introduced through the winter drilling

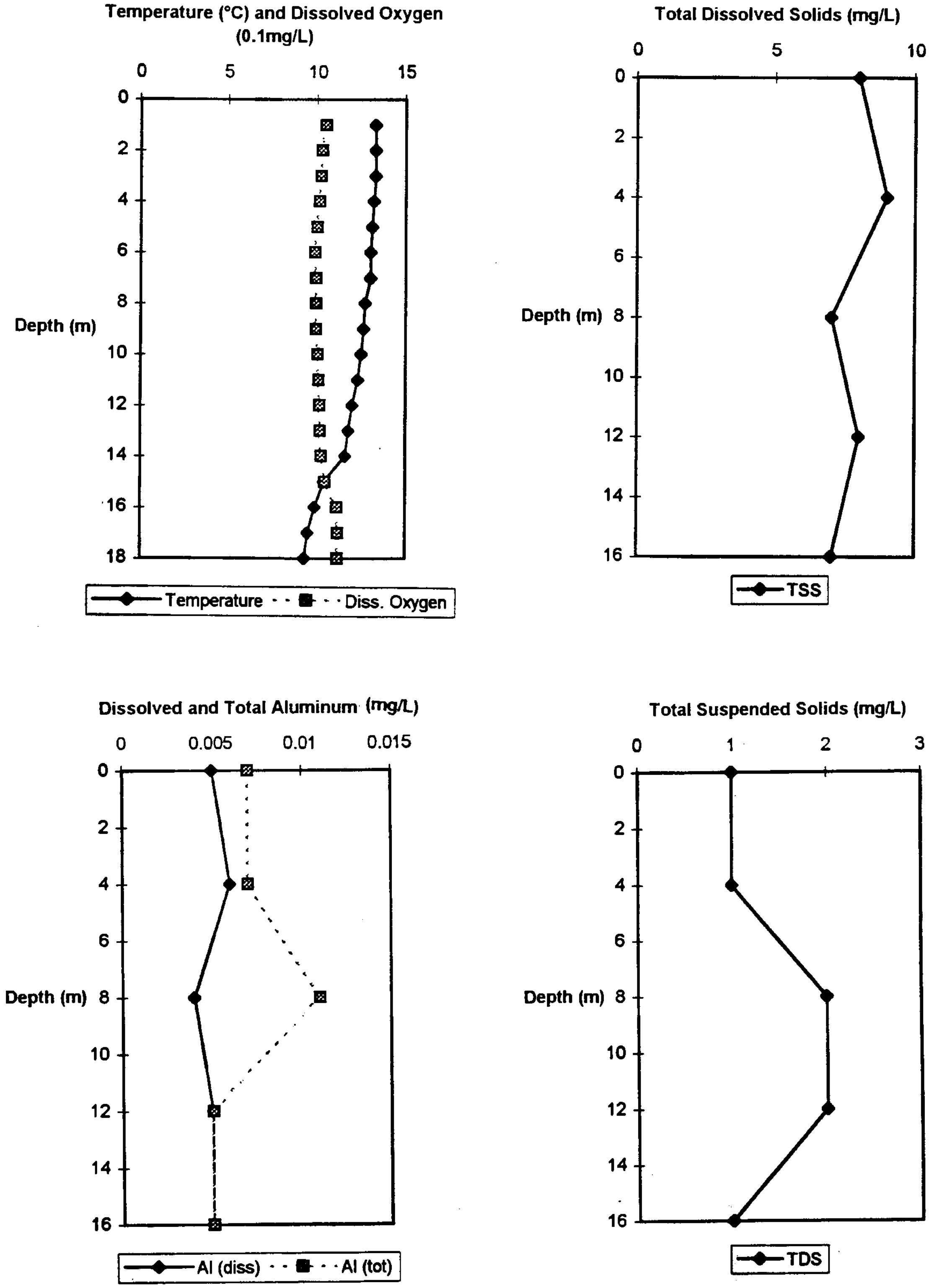


NWT DIAMONDS PROJECT

Figure 2.4-9
Distribution of Parameters in Koala Lake

Source: Rescan

◎ Table of Contents



NWT DIAMONDS PROJECT

Figure 2.4-10
Distribution of Parameters in Lac de Gras

Source: Rescan

program, there is no evidence of structure with depth. Consequently, these lakes can be viewed as chemically homogenous. Outflow composition from each lake is not dependent on thermal (i.e., density) structure. In particular, Lac de Gras is sufficiently large (i.e., large wind fetch) so as to create a mixed layer that extends through the majority of the water column (Lac de Gras, site 54, contains isothermal waters of 10.9°C to the lake floor at 23 m). The implication of this is that surface waters from any potentially affected watersheds will mix through the entire water column of Lac de Gras before entering the remainder of the Coppermine River drainage basin.

2.4.3.3 Downstream Trends in Water Quality

Regional trends in the relatively conservative water quality parameters such as pH and conductivity are evident through the Coppermine River basin (Environment Canada 1988). However, the residence time in the small drainage basins of the study area precludes the presence of detectable changes in the same parameters. Regional trends in water quality on the scale of the project site can only be expected from non-conservative components such as suspended solids or dissolved constituents having relatively high chemical reactivities (i.e., dissolved trace metals).

As the natural waters within all five watersheds are devoid of most of the components and are of similar composition, downstream trends are virtually non-existent. One exception is total and dissolved Al in the Koala watershed. In two instances (discussed in greater detail in Volume IV, Section 2.4), Al was introduced into the Koala watershed. Winter drilling through the ice into Koala and Panda lakes elevated suspended solids enriched in Al (presumably as aluminosilicate minerals).

2.4.4 Summary

Baseline water quality data have been collected for the five catchments adjacent to the mine site above Lac de Gras and include the Koala, Paul, Misery, Ursula and South watersheds. Natural water composition is typical of headwaters of high latitude watersheds and can be described as soft, of low ionic strength and of circum-neutral pH.

Despite exploration drilling activities, average water quality from the Koala and Misery watersheds does not differ substantially from that of the remaining three. The data indicate that the vertical distribution of components in each lake is approximately uniform regardless of lake depth and significant annual thermal stratification. Downstream composition is also uniform except where exploration activities have influenced local water quality. In such cases, natural settling and dilution return water quality to baseline conditions relatively quickly.

2.5 Sediments

Water quality in the vicinity of the project site may be affected by sediment arising from construction activities. Though sediments were not specifically defined as a VEC, in the context of water quality, its importance is presented here.

Lake sediment samples (typically from the upper 2 cm) were collected from the Koala, Ursula, Paul, South and Misery watersheds (Figures 2.4-1 to 2.4-4) using an Ekman grab sampler. The samples were analyzed for metal content and in some cases organic parameters and grain-size. Natural cycling of trace metals and other water column constituents is intimately tied to sediment composition. Changes in water chemistry as a result of natural and/or anthropogenic processes are generally reflected in sediment geochemistry. It is therefore important to establish baseline conditions to facilitate predictions of the potential impact of mining on the lacustrine deposits. As lake bottom sediments are planned for rehabilitating waste dump areas, it is necessary to determine the suitability of these sediments for reclamation success, through planned research programs. As interfacial sediments are the most compositionally variable (due to intense post-depositional, geochemical restructuring), metal inventories and trends must be evaluated from a diagenetic framework in order to delineate their ultimate source. Such considerations are particularly important to identify correctly sediment impacts over the natural enrichments common to all lakes (i.e., Tessier *et al*. 1985; Carignan and Nriagu 1985; Bryon and Langston 1992).

Stream sediments were also collected. Their composition depends more on local hydrological conditions than steady state deposition. Stream sediment data were used to supplement lake sediment data.

2.5.1 Previous Research

A limited set of data for the project area was compiled from a geochemical reconnaissance survey performed by the Geological Survey of Canada (1992) in the Lac de Gras area. Ten to 15 of the government's stations were located within the project area. Unfortunately, the area resolution is low and, given the high degree of small-scale compositional variability found within lake sediments, these data are of limited use. Further, the samples were collected from the shallows at the edge of the lake and are not representative of sediment composition. However, several studies of other high latitude, hydrologically similar lakes are useful for comparison. Also, studies of typical diagenetic processes common to all freshwater sediments provide relevant data.

Natural sediments typically contain components ranging from eroded rocks to soils of local origin. Additionally, they are subject to a host of post-depositional, physical and chemical processes that dramatically alter their bulk composition. Collectively, these processes are referred to as diagenesis. Previous studies on high latitude (and other) lakes have shown that the concentration of trace metals, organic matter and other components of lake sediments result in part from the steady-state accumulation of material "raining" from above. However, natural, post-depositional enrichments and not anthropogenic inputs have caused elevated levels of Ba, Co, Cu, Mo, Ni, Fe and Mn in the surface sediments of similar arctic lakes (Cornwell 1986). The alteration of metal inventories in natural sediments is common to all lacustrine and marine sediments (Carignan and Nriagu 1985; Falkner *et al.* 1991; Balistrieri and Murray 1992). Accordingly, sedimentary metal concentrations can vary considerable over small distances.

Of all the components found in natural sediments, organic matter is perhaps the most important. It is considered to be the fuel for almost all chemical reactions that occur after deposition. This is because organic matter is unstable in the presence of oxygen, decomposing into its constituent elements. This reaction is accelerated by a host of bacterial species, which catalyze the reaction to derive energy for their own metabolism (Frenchel and Blackburn 1979). Since the concentration of oxygen in natural waters is low, it is often rapidly depleted within the surface layers of sediments. When oxygen is no longer available to react with the organic matter, secondary oxidants are utilized in its place by the bacterial community. The order in which secondary oxidants are utilized is as follows: nitrate, Mn-oxide, Fe-oxide, sulphate and carbon dioxide. That is to say, once the nitrate is consumed, the Mn-oxide will be consumed. This process will continue until all oxidants are consumed (Froelich *et al.* 1979). Of particular importance is the consumption of Mn and Fe oxides, since the by-product of the reaction between these solid oxides and organic matter (in the absence of more favourable oxidants) is dissolved Mn and Fe. The significance of this transformation arises from the natural cycling of these metals and trace metals and their associated scavenging properties (Stumm and Morgan 1981).

Where dissolved oxygen is present, Fe and Mn oxides exist as solids whose surfaces strongly adsorb many trace metals. When they are utilized in subsurface sediments as secondary oxidants in the absence of oxygen, they revert to dissolved Fe and Mn creating concentration gradients (Froelich *et al.* 1979). As dissolved Fe and Mn diffuse upward toward the sediment-water interface, they eventually encounter dissolved oxygen and revert back to their original solid, oxide form. Iron and manganese oxides are both efficient in adsorbing a broad range of dissolved metal ions. Thus, their continuous formation in the near-surface sediments results in surface enrichment of the oxides themselves, as well as a host of other metals such as As, Cu, Co, Zn (Tessier *et al.* 1985; Fuller *et al.* 1993; Hamilton-Taylor and Davison *in press*).

An additional consideration in many lakes is the tendency for fine-grained material to resuspend, settle and focus in more tranquil waters (Bengtsson *et al.* 1990; James and Barko 1993). Since metal oxides and organic matter are fine-grained, they are susceptible to resuspension and redeposition in the deeper areas of lakes. Wind and wave activity create turbulence in the water column, which scours the sediments of the shallows. The fine-grained fraction remains in suspension until it enters calm waters such as those found in a deep basin (James and Barko 1993). Consequently, sediment composition of many lakes is dependent on the water depth.

Collectively, the above processes of oxide cycling, organic matter oxidation and settling of fine-grained sediments are used to interpret the trends seen in the baseline data.

2.5.2 Methods

Sediment samples were shipped from the field directly to laboratories for analysis. Water content was determined gravimetrically by drying sediment samples to obtain a constant weight at 103°C. Solid metals were analyzed by acid digestion (hydrochloric and nitric acid hot plate digestion) followed by a combination of inductively coupled plasma emission spectrometry (ICP-ES), flame atomic absorption spectroscopy (FAA), hydride generation atomic absorption spectroscopy (HGAAS) and graphite furnace atomic absorption spectroscopy (GFAAS). Total carbon and carbonate carbon were determined by gas chromatography and carbon dioxide analysis, respectively, after selective conversion of each fraction to carbon dioxide. Organic carbon was determined by subtracting the amount of carbon dioxide from total carbon. Total Kjeldahl nitrogen (TKN) was determined colourmetrically after acid digestion. Grain size analysis was by using sieves after the samples were oven-dried.

2.5.3 Sediment Characterization

This section focuses on lake sediments (rather than riverine deposits), as they represent the most accurate pre-mining record of sediment accumulation. Rivers and streams are highly variable in deposition. They accumulate material whose composition depends more on localized hydrodynamic conditions than on steady-state deposition. Consequently, it is difficult to discuss the geochemical conditions of these environments. Data from stream sediment analysis will be used when necessary.

Each lake within the Koala watershed is described in a general geochemical context. The other watersheds are described for comparative purposes. However, because sediments are highly susceptible to sorting before and after deposition, and because surface sediments are subject to post-depositional diagenetic alterations, the data will be discussed generally. The discussion will focus on only those metals that may be of concern to the project in the future.

Sediment samples were collected throughout the summer of 1994. The fact that samples were taken throughout the season is not a concern, as sediment samples will only change slightly throughout the season. Temporal variability in bulk composition of sediments integrated over the upper few centimetres can be assumed to be negligible.

Sediment bulk composition and grain size data for all samples can be found in Appendix II-A4.

2.5.3.1 Koala Watershed

The sediments of the various lakes of the Koala watershed are described as they move downstream, beginning with Vulture and Grizzly lakes and ending with Lac de Gras (Figure 2.4-1).

Vulture and Grizzly Lakes

The sediments of Vulture and Grizzly lakes were sampled at several depths during two field trips in 1994. Vulture and Grizzly lakes are the two deepest lakes of the survey with a depth of ~45 m. The sediments of each lake are compositionally indistinguishable and are discussed concurrently.

There were no obvious anomalies in the deposits of either lake. As expected, sediment composition varied with depth, suggesting that accumulation is dependent more on the hydrologic regime than the depositional conditions due to proximity to specific terrestrial sources. The sediments are expected to be relatively enriched in organic carbon, originating from primary productivity within the lake. This premise is based on the low organic carbon to nitrogen (C_{org}/N) weight ratio of sediments collected from the relatively fine-grained deposits of Vulture-Polar stream (C_{org} = 1.35 wt.%; C_{org}/N weight ratio = 8.4). Low C_{org}/N weight ratios indicate dominance by comparatively nitrogenous lacustrine organic matter (Henrichs and Farrington 1987). It is likely that the two deepest stations contained the highest values of most metals (As, Fe, Mn, Cd, Ag and others; Table 2.5-1), as deep basins preferentially accumulate organic carbon and other fine-grained material. Metals are introduced in part through their association with organic matter in addition to the accumulation of authigenic mineral phases.

Table 2.5-1
Grizzly Lake Sediment Composition for Three Depths

Water Depth (m)	As (µg/g)	Co (µg/g)	Fe (µg/g)	Mn (µg/g)	Cd (µg/g)	Ag (µg/g)
1	1.65	5.5	8,440	122	<0.10	<0.10
5	9.04	20.7	18,800	874	<0.10	<0.10
43	26.60	23.7	57,300	546	0.51	0.46

The surface sediments in the deepest basin are enriched in Fe and Mn, suggesting that the interfacial sediments are oxic despite the implication of the predominance of fine-grained, organic-rich material. The elevated Fe suggests that oxides precipitated in the water column or in shallower sediments preferentially accumulate in the deep areas. Further, diagenetic oxide cycling rather than sulphide precipitation likely accounts for much of the metal enrichment, as the water column contains little sulphate to create authigenic sulphides. The well-known natural recycling of Fe and Mn within near-surface sediments (Froelich *et al*. 1979) is commonly observed to create enrichments of many other trace metals through mechanisms of coprecipitation. Support for the dominance of authigenic oxides in the surface sediments comes from the commensurate enrichment of As and Co, which are known to associate very strongly with such solid phases (Murray and Dillard 1979; Hem *et al*. 1985; Fuller *et al*. 1993).

Panda, Koala, Kodiak, Little and Moose Lakes

Kodiak, Little and Moose lakes are located downstream from Panda and Koala, yet are found before the confluence with the outflow from Nancy, Long and Leslie lakes (Figure 2.4-1). All of the lakes in this series have a maximum depth of 18 m except for Moose Lake, which is half that depth. These five lakes are discussed concurrently, as they form an uninterrupted series of depositional environments useful for comparative purposes.

Kodiak and Little lakes are physiographically similar to Panda and Koala lakes. While Kodiak Lake is not quite as deep as Little Lake (maximum depth 14 m), its sediments are nonetheless compositionally similar. Kodiak Lake is floored by organic-rich sediments that have undergone more hydrodynamic sorting than other lakes. Hydrodynamic sorting is reflected by changes in grain-size and organic content (Table 2.5-2). The variables are affected by the depth from which samples are taken. The shallows (2 m) are devoid of fine-grained material, consisting primarily of coarse sands and gravels. As organic matter is hydrodynamically equivalent to fine silts and clays (Calvert 1987), it does not exist in sizeable quantities within this coarse matrix. Rather, organic carbon is seen to accumulate in the deeper areas of the lake where the waters are calmer and fine-grained material can settle (Table 2.5-2). Consequently, the bulk composition of the interfacial sediments is controlled in part by grain-size (gravels and sands are mineralogically distinct from sands and silts) but, more importantly, by the presence of organic matter and the post-depositional chemistry that it fuels.

The presence of organic matter in the deeper deposits of Kodiak and other lakes fuels post-depositional diagenetic reactions that dramatically alter the bulk composition of surface sediments. The organic matter in Kodiak Lake results from primary productivity within the water column rather than from the terrestrial environment. This observation is supported by a low C_{org}/N weight ratio ranging

Table 2.5-2
Select Sediment Parameters in Kodiak Lake

Water	Grain Size Distribution (%)				Sediment Components (wt. %)		Sediment Components (µg/g)	
Depth	Gravel	Sand	Silt	Clay	C_{org}	Fe	As	Co
2 m	1.21	92.1	5.42	2.49	0.75	1.02	3.44	6.50
7 m	0.00	19.7	52.3	28.0	4.65	2.37	4.58	12.2
9 m	0.00	-	-	-	4.70	2.18	5.11	11.1
14 m	0.00	-	-	-	-	2.97	13.5	19.1

from eight to 15, which reflects the fact that aquatic plants are more nitrogenous than terrestrial ones (Stumm and Morgan 1981). Consequently, organic matter in the sediments is labile and capable of actively consuming oxidants, promoting diagenesis and facilitating the formation of authigenic minerals within the sediments. As seen in Table 2.5-2, the content of Fe increases with water depth as a result of increased diagenetic activity in conjunction with hydrodynamic sorting and accumulation of amorphous oxides. Enrichments of authigenic Fe oxides often correspond to elevated distributions of certain trace metals. In Kodiak Lake, commensurate increases in As and Co (trace metals) with Fe are further evidence of oxide cycling, as both metals are known to associate strongly with oxides of Fe and Mn (Murray and Dillard 1979; Hem *et al.* 1985; Fuller *et al.* 1993).

Little Lake is approximately 18 m deep, with fine-grained, organic-rich material (4 to 8 wt.% carbon). However, unlike Kodiak Lake, Little Lake sediments host substantial quantities of organic matter even in the shallows (i.e., 2 m water depth; Table 2.5-3). The C_{org}/N weight ratio is relatively low, ranging from ten to 15, suggesting that the majority of organic material is derived from primary productivity within the lake. The surface sediments at an intermediate depth (5 m) in Little Lake are enriched with Fe and Mn. These sediments contain As, Cu and Co suggesting that authigenic oxides exist within the interfacial sediments. However, the deep deposits do not display the same chemical composition. It is possible that the elevated levels of organic matter in the deep basin (8 wt.% at 17 m depth) foster reducing conditions within the upper few centimetres of sediment, preventing Fe and Mn oxides from accumulating. This is evident from the relatively elevated values of Cd, Ag and Hg compared to the shallower Fe-rich sediments at 5 m depth. The former metals are known to associate strongly with authigenic sulphides rather than with oxides (Stumm and Morgan 1981). Thus, it is more likely that authigenic sulphides, and not metal oxides, are the dominant, stable authigenic phase in the deep basin despite the low concentrations of lake sulphate.

Table 2.5-3
Select Sediment Parameters in Little and Moose Lakes

Water Depth (m)	C_{org} (wt.%)	TKN (wt.%)	Fe (wt.%)	Mn (µg/g)	As (µg/g)	Co (µg/g)	Ag (µg/g)	Cd (µg/g)	Hg (µg/g)
2	4.1	0.41	2.48	420	9.03	19.5	<0.1	<0.1	0.030
5	4.95	0.41	8.11	1,300	80.4	96.8	<0.1	<0.1	0.048
8	–	–	4.82	1,700	6.3	34.4	<0.1	<0.1	0.021
17	7.95	0.54	2.79	317	11.4	21.0	0.22	0.37	0.075
20	–	–	2.70	332	4.88	19.9	0.25	0.41	0.044
Moose Lake	0.12	–	0.77	151	0.62	4.40	<0.1	<0.2	<0.005

The depositional environment of Moose Lake (Figure 2.4-1) differs dramatically from both Kodiak and Little lakes. The waters are shallower (approximately 9 m), benthic sediments consist of sands and gravels containing virtually no organic carbon (approximately 0.1 wt.%), and most metal levels are low, as is typical of Fe-containing detrital minerals (Turekian and Wedepohl 1969) (Table 2.5-3). The reasons for the compositional disparity between Moose Lake and adjacent water bodies is not immediately evident. However, the geologic terrain near this water body differs dramatically from that of surrounding lakes. Moose Lake is adjacent to an angular to sub-rounded boulder field, while most other lakes are flanked by less dramatic terrain. Sediment composition likely reflects those geologic differences. Additionally, the bottom of Moose Lake is devoid of any fine-grained material, suggesting that the hydrographic regime precludes accumulation of fines. For comparative purposes with Panda and Koala lakes, the conditions of Little Lake are more appropriate than those of Moose Lake.

Fundamentally, the depositional environments of Panda and Koala lakes are very similar to Kodiak and Little lakes. Each lake is ~18 m deep and tends to accumulate finer-grained sediments in the deeper areas. The composition of the sediments in both lakes is similar (Table 2.5-3). However, sediment composition displays a change from the 1993 sampling to that of 1994. The 1993 sampling of Koala Lake (6 m water depth) indicated sediments strongly enriched in organic matter (~6.5 wt.%) and authigenic oxides of Fe and Mn. Elevated values of Co, As and Zn (70, 110 and 210 µg/g, respectively) support the presence of metal oxides, while elevated Cd and Hg (0.7 and 0.6 µg/g, respectively) suggest that the sample may also have contained authigenic sulphides. The upper few centimetres of sediments contained oxides and sulphides along with elevated concentrations of organic matter. This observation suggests that the sediments of Koala Lake underwent intense diagenic alteration. This alteration resulted in several metals appearing in the surficial sediment. Organic carbon decreased by one order of magnitude (0.65 wt.%) along with decreases in the metal content observed previously (Table 2.5-4). Surface sediment diagenetic reactivity probably decreased similarly.

Table 2.5-4
Select Parameters from the Sediments of Koala and Panda Lakes

	Metal Concentrations at Water Depth (µg/g)						
	Koala (1993)	Koala Lake (1994)			Panda Lake (1994)		
	6 m	2 m	9 m	18 m	1.5 m	10 m	18 m
As	111	7.96	4.52	5.93	1.06	20.5	17.6
Co	76.1	11.2	17.2	24.1	3.9	60.9	64.2
Fe	66,600	14,200	14,700	21,000	7,100	60,600	64,000
Mn	4,400	219	235	286	81.6	2390	838
Cu	111	21.8	109	48.5	4.5	63.2	77.7
Cd	0.72	<0.1	0.58	0.21	<0.1	0.32	0.22

The sediments of Koala and Panda lakes show trends similar to those evident in the other lakes. Hydrodynamic sorting creates coarse-grained deposits in the shallows while the deeper zones accumulate the fines including amorphous oxides and organic matter. Iron, cobalt, arsenic, copper and cadmium concentrations increased with water depth (Table 2.5-4), suggesting that despite dilution of the natural sediments described above, the geochemical processes are virtually unaltered.

Long and Leslie Lakes

Since Long Lake is the largest and one of the deepest lakes in the Koala watershed, it is expected to display the greatest degree of depth-dependent trends. As with other lakes of this study, there is a strong tendency toward elevated Fe with increased water depth in both the north and south basins, resulting from the preferential accumulation of fine-grained material in the comparatively calm, deep waters (Table 2.5-5). The 5 m depth site (and presumably deeper sites) predominantly contains silt-clay sized sediments along with substantial quantities of organic carbon (2.4 wt.%). Further, the increases in Co, Cu and As with Fe and Mn suggests that the bulk composition of the surface deposits is dominated by Fe and Mn oxides.

Leslie Lake is much smaller and shallower (12 m) than Long Lake but shares many of the depositional trends of the other lakes. In particular, Leslie Lake displays the hydrodynamic trends reflected by grain-size. Fine-grained material

Table 2.5-5
Select Geochemical Parameters from Long Lake

Water Depth (m)	Fe (µg/g)	Mn (µg/g)	As (µg/g)	Co (µg/g)	Cu (µg/g)
3 (N)	25,500	342	3.95	17.2	40.8
5 (N)	25,600	288	4.25	14.6	57.9
22 (N)	124,000	9,310	248	106	110
3 (S)	30,100	364	6.45	17.4	709
6 (S)	26,400	278	6.07	17.4	68.1
32 (S)	85,400	3,220	34	69.3	106

N = north basin, S = south basin.

(i.e., organic carbon) tends to accumulate in the deep basin. Elevated concentrations of organic carbon were observed at the 11 m mark (5.9 wt %). This concentration was higher than samples taken from a depth of 5 m (2.6 wt %); (Table 2.5-6). Grain-size analysis indicate that the sediments throughout much of the lake are dominated by the silt-sized fraction and are mixed with sand and clay. Grain-size data are consistent with the presence of organic carbon. Aside from the preferential accumulation of organic carbon in the deep basin, there are no obvious enrichments of metals at any depth, nor is the enrichment of Fe seen in many of the other lakes. However, minor enrichments in Cu and Co at the 11 m site allude to the preferential accumulation of authigenic Fe oxides in the deep basin.

Table 2.5-6
Select Parameters from the Sediments of Leslie Lake

Water Depth (m)	C_{org} (wt.%)	Fe (µg/g)	Mn (µg/g)	Co (µg/g)	Cu (µg/g)
3	2.35	20,800	249	11.5	15
5	2.6	22,400	271	12.5	16.4
11	5.9	22,400	263	14.5	44.4

Airstrip and Larry Lakes

The sediments of the comparatively shallow Airstrip and Larry lakes (7.5 m and 7 m, respectively) were relatively fine-grained (dominated by sands and silts) hosting organic carbon concentrations of ~7 wt.% in their deepest basins. As with the other lakes described above, marginal enrichments in Fe, Cd and Hg along with high concentrations of organic matter (having a low C_{org}/N weight ratio between ten and 15) indicate that the sediments of these two lakes may host oxic interfacial sediments. However, conditions suggest a reducing environment at relatively shallow depths below the sediment-water interface. This can be seen from the absence of either oxide-like or sulphide-like associations within the surface sediments (Table 2.5-7).

Table 2.5-7
Select Parameters from the
Sediments of Airstrip and Larry Lakes

Water Depth (m)	C_{org} (wt.%)	Fe (µg/g)	Cd (µg/g)	Hg (µg/g)
Airstrip Lake				
7.5	6.8	9,760	<0.2	0.020
Larry Lake				
1	0.7	9,960	<0.1	<0.005
Larry Lake				
7	7.4	19,800	0.18	0.059

Nora and Nero Lakes

Nora and Nero lakes are both of intermediate depth and host sediments with substantial concentrations of organic carbon (11 and 4.5 wt.%, respectively). Nora Lake contains higher concentrations of organic carbon than the other lakes observed, but displays no composition anomalies. The trends seen in other lakes occur in both Nora and Nero lakes. As would be expected, the concentrations of metal oxides increased with depth (Table 2.5-8).

Table 2.5-8
Select Parameters from
the Sediments of Nora and Nema Lakes

Water Depth (m)	C_{org} (wt.%)	Fe (µg/g)	Mn (µg/g)	As (µg/g)	Co (µg/g)
Nora Lake					
4	11.2	33000	414	34.5	25
5	11	29700	322	23.9	27
14.5	7.45	67600	653	87.5	33
Nero Lake					
4	4.85	28400	327	5.14	17.5
5	4.35	41400	740	13.60	26.1
13	5.05	109000	3930	99.50	48.1

Fox and Martine Lakes

Fox 1 Lake is the deepest of the two Fox lakes (Fox 1 and Fox 3) and Martine Lake. A deep sediment sample was collected at 21 m. By comparison, Fox 3 and Martine lakes are shallow with deep basin depths of approximately 7 m. These differences are reflected somewhat in the bulk sediment composition. The trend towards elevated accumulations of organic matter, metal oxides and associated elements is clearly visible in Fox 1 Lake, while evidence of the same trends in Fox 3 and Martine lakes is unclear (Table 2.5-9).

Table 2.5-9
Select Parameters from the Sediments
of Fox 1, Fox 3 and Martine Lakes

Water Depth (m)	C_{org} (wt.%)	Fe (µg/g)	Mn (µg/g)	As (µg/g)	Co (µg/g)
Fox 1 Lake					
2	1.65	16,000	196	1.84	7.6
6	3.1	33,500	382	20.7	12.1
21	5.8	12,600	15,500	127	87
Fox 3 Lake					
4	8.9	35,100	218	19.2	16
7	10.4	29,100	217	14.9	17
Martine Lake					
2.5	9.0	22,000	315	4.4	13.8
6.5	6.7	33,200	330	8.6	22.7
Fox 1 Lake					
2	1.65	16,000	196	1.84	7.6
6	3.1	33,500	382	20.7	12.1
21	5.8	12,600	15,500	127	87
Fox 3 Lake					
4	8.9	35,100	218	19.2	16
7	10.4	29,100	217	14.9	17
Martine Lake					
2.5	9.0	22,000	315	4.4	13.8
6.5	6.7	33,200	330	8.6	22.7

Mike Lake, Slipper Lake and Lac de Gras

The sediments of Mike Lake, Slipper Lake and Lac de Gras were all collected from similar depths. As indicated by the data presented in Table 2.5-10, all three lakes follow the recurring trend of elevated accumulations of metal oxides with increasing water depth typical of almost every lake studied within this watershed.

Table 2.5-10
Select Parameters from the Sediments of
Mike Lake, Slipper Lake and Lac de Gras

Water Depth (m)	Fe (µg/g)	Mn (µg/g)	As (µg/g)	Co (µg/g)	Cu (µg/g)
Mike Lake					
2	29,600	421	3.73	19.7	54.3
9	92,800	969	189	45.2	74
16	246,000	11,400	172	103	198
Slipper Lake					
2	39,700	281	18	18.9	84.2
6	23,100	218	6.73	14.3	57.7
16	46,200	451	11.4	25.8	139
Lac de Gras					
3	30,500	418	12.6	27.8	51.4
8	32,200	3,050	20.6	41.7	60.7
16	202,000	20,200	250	377	107

As discussed above, evidence for the dominance of bulk composition by authigenic metal oxides arises through the corresponding increases in Co, As and Cu along with those of Fe and Mn.

Paul, South, Misery and Ursula Watersheds

The Paul, South, Misery and Ursula watersheds are considered for comparative purposes with the Koala watershed. Therefore, analysis of the data is not as extensive.

Sieve, Mark and Bat Lakes

The sediments of Sieve, Bat and Mark lakes are covered by relatively shallow water and consequently do not display the hydrodynamic sorting observed in many of the other lakes studied. While correlations exist between Fe, Mn, Co, As (and Cu and Zn to some extent), the typical trends associated with water depth are not highly evident (Table 2.5-11). The shallows appear to be enriched in organic matter more than the deeper regions.

Arnie and Paul Lakes

While both Arnie and Paul lakes are of shallow to intermediate depths, they do not display the trends with depth observed in many of the other lake deposits (Table 2.5-12). Organic carbon contents are sufficient to fuel the requisite diagenetic chemistry. Correlations were observed between Fe, Co and As. However, the sites enriched in metal oxides are not the deepest basins.

Table 2.5-11
Select Parameters from the
Sediments of Sieve, Bat and Mark Lakes

Water Depth (m)	C_{org} (wt.%)	Fe (µg/g)	Mn (µg/g)	As (µg/g)	Co (µg/g)
Sieve Lake					
2	–	19,000	353	4.07	8.7
7.5	0.6	39,500	238	22.2	18.9
Bat Lake					
3	6.8	25,700	243	11.2	12.1
4	–	26,300	229	13.6	17.3
Mark Lake					
3	11.8	55,600	757	50.7	41
8	0.6	76,100	368	50.3	34.2

Table 2.5-12
Select Parameters from the
Sediments of Arnie and Paul Lakes

Water Depth (m)	C_{org} (wt.%)	Fe (µg/g)	Mn (µg/g)	As (µg/g)	Co (µg/g)
Arnie Lake					
3	3.75	37,000	400	5.44	24.5
4	3.4	31,400	347	5.34	16.5
Paul Lake					
2.5	1.4	30,600	428	7.63	16.4
5	–	35,900	976	39.5	38
12	1.5	30,700	355	7.96	14.7

Ursula Lake

Ursula Lake was the only lake sampled for sediment within the Ursula watershed. While Ursula Lake sediments lie under relatively deep waters (>17 m), they do not display the typical trends in sorting with depth, nor do they appear to be dominated by oxides (As and Co do not correlate with Fe and Mn as well as in other lakes; Table 2.5-13). It is likely that the elevated concentrations of organic matter in these deposits (~ 8 wt% to 9 wt.%) are sufficient to reduce the redox potential of the surface sediments to a degree that inhibits the formation and accumulation of metal oxide. Consequently, metal oxides are not thermodynamically stable.

Table 2.5-13
Select Parameters from the Sediments of Ursula Lake

Water Depth (m)	C_{org} (wt.%)	Fe (µg/g)	Mn (µg/g)	As (µg/g)	Co (µg/g)
3	–	18,700	317	10.9	8.8
7	8.05	24,100	258	3.54	12.8
17.5	8.55	27,000	272	4.66	15.0

Misery Lake and Lac de Gras

Misery Lake is relatively deep (>28 m) and displays the compositional trends observed in the sediments of virtually all of the lakes of the Koala watershed. The organic carbon content increases marginally with depths from 1.2 wt.% at 4 m to 3.7 wt.% at 22 m depth (Table 2.5-14). The C_{org}/N weight ratio ranges from 10 to 15, indicating that the organic matter is derived from primary productivity in the lake. Iron and manganese concentrations increase with depth, suggesting that not only does the oxide fraction accumulate in the deep basin, but that the sediments are sufficiently oxic to allow their preservation within the upper few centimetres. Both As and Co are enriched at 22 m at a level similar to Fe and confirming the dominance of the oxide fraction with regard to bulk composition.

Table 2.5-14
Select Parameters from the Sediments of Misery Lake

Water Depth	C_{org} (wt.%)	Fe (µg/g)	Mn (µg/g)	As (µg/g)	Co (µg/g)
4 m	1.2	33,100	429	46.7	23.2
5 m	2.45	36,500	470	36.1	24.1
22 m	3.7	104,000	3,970	274	69.8

Sediment samples were collected from Lac de Gras to a depth of 31 m (Table 2.5-15). The organic carbon content of Lac de Gras sediments ranged from 0.6 to 1.8 wt.% in the deeper sites. Sediments were dominated by the sand-silt size fraction. As with the majority of lakes discussed, and with the area of Lac de Gras adjacent to the Koala watershed outflow, oxides and associated metals were seen to increase with depth.

Table 2.5-15
Select Parameters from the Sediments of Lac de Gras

Water Depth	C_{org} (wt.%)	Fe (µg/g)	Mn (µg/g)	As (µg/g)	Co (µg/g)
2 m	1.2	14,500	170	6.38	6.4
5 m	0.6	16,100	532	6.94	10.9
22 m	1.75	34,000	16,400	23.5	33.2

2.5.4 Summary

The distribution and composition of sediments in the Koala watershed (and others in the vicinity of the NWT Diamonds Project) can be ascribed to the combined effect of several depositional parameters. The first relates to the presence of substantial quantities of organic matter in the lake sediments. The C_{org}/N weight ratio at all sites is low (typically 10 to 15), suggesting that the organic matter is almost exclusively derived from primary productivity within the lakes themselves. Despite the oligotrophic nature of most of the lakes in the area, their sediments can (and do) host relatively high concentrations of organic matter. Such a situation arises when the sedimentation rate is low and the inputs of organic matter are not diluted by other solid phases. The appearance of sizeable quantities of organic matter in sediments is the result of a well understood series of diagenetic alterations and accumulation of biogenically-associated trace metals.

The second influence on the distribution and composition of sediments is the abundance of amorphous, labile Fe and Mn in the sediment system. Fe and Mn are sensitive to redox conditions. They form solid oxides in oxic regimes and dissolved species under reducing conditions. Fe and Mn have a tendency to accumulate and become enriched in the oxic surface sediments. Due to the affinity of many trace metals toward oxide surfaces, there is often a corresponding enrichment in several other trace metals such as As, Co, Cu, Zn. Finally, the effect of hydrodynamic sorting and deposition of fine-grained material to the calm regions of the lake preferentially transporting these components from the shallows to the deep regions. The net effect is the accumulation of coarse-grained lag deposits in the shallows, while the basins host fine-grained sediments enriched in organic matter, metal oxides and associated trace metals. Consequently, while intra-lake variability is high, the trends between lakes are relatively consistent and predictable, resulting from the combined effect of all post-depositional chemical and physical processes. The sediments of the lakes in the Koala watershed do not differ substantially from the adjacent watershed or from other lakes of similar morphology.

2.6 Climate

The severe climate of the North affects both ecosystem and human development and is considered a valued ecosystem component. Characterization of the climate of the project area is necessary both for impact assessment and project planning purposes. This section presents site-specific and regional data in order to predict trends in air temperature, precipitation, winds and evaporation. In addition, the issue of climate change is briefly discussed.

The NWT Diamonds Project site is located in the Low Arctic Ecoclimatic region of northern Canada (Ecoregions Working Group 1989). Summers are generally short and cool, while winters are long and extremely cold. Precipitation in the region is commonly between 250 mm and 300 mm/a, divided almost evenly between rain and snowfall water equivalent.

2.6.1 Previous Research

The main features of climates in tundra environments have been described by Barry *et al.* (1981) during the International Biological Program. Northern climatological characteristics have been summarized by Rouse (1990, 1993). Studies of climate in arctic and subarctic regions requires the collection of weather information at local or regional scales. The mandate for collecting weather data in Canada lies with the Atmospheric Environment Service (AES) branch of Environment Canada, which has approximately 95 climate stations operating in the Northwest Territories (Prowse 1990). A review of NWT climate stations (Acres 1982) indicated that their distribution and density was poor due to the large area and remoteness of the region, particularly in the central Keewatin where the NWT Diamonds Project is located. The nearest operational station is located at the Lupin Mine approximately 100 km north of the project site.

The Canadian Climate Atlas (Environment Canada 1986) indicates that mean annual precipitation for the NWT from the 60°N parallel to the arctic coast is between 200 mm to 400 mm. Rainfall accounts for 100 mm to 200 mm of total precipitation. Due to cold winter temperatures, snow accounts for the remainder which accumulates for six to nine months. The total mean annual snowfall is between 100 cm to 150 cm (Environment Canada 1986), but snowfall is often redistributed by wind producing variations in snow depth related to terrain type (Woo *et al.* 1993). Snow catch in weather gauges is typically underestimated (Goodison 1978), due to the inherent errors in obtaining accurate gauge measurements caused by wind, residual container wetting and trace amounts of precipitation that are currently assigned a value of zero in the precipitation archive but may contribute a significant amount to total snowfall (Metcalfe *et al.* 1994). Site-specific snow measurements in the NWT indicate that snow catch may be underestimated by 100% to 300% (Woo *et al.* 1983).

A corrected precipitation archive for AES stations in the NWT (Metcalfe and Ishida 1994; Metcalfe *et al*. 1994) is currently undergoing verification. Preliminary results indicate that the nearest AES station to the NWT Diamonds Project at Lupin, with mean annual precipitation of 285 mm, has a corrected annual precipitation of approximately 315 mm (Metcalfe *et al.* 1994).

The snow survey network in the NWT is small, with only 20 snow surveys reported in a recent summary report (Prowse 1990). The annual mean maximum depth of snow accumulation for the Coppermine River basin is between 50 cm and 70 cm (Findlay 1978), whereas recent satellite snow survey maps from 1979 to 1990 indicate an average snow water equivalent of 80 mm to 110 mm (DIAND 1994).

Numerous site-specific studies in the Arctic required detailed climatological data for evaluating energy balance and evaporation that commonly involve the installation and monitoring of survey equipment. The first microclimatological field experiment for energy balance in the arctic was done by Bryson (1956) at Barrow, Alaska. Further detailed work was conducted by Mather and Thornthwaite (1956, 1958), Abrosbrak (1968), Clebsch and Shanks (1968), Weller *et al.* (1972), Maykut and Church (1973), Weller and Holmgren (1974) and Dingman *et al.* (1980). A similar approach of installing micrometeorological equipment to monitor climate variables for estimating evaporation was also adopted at the NWT Diamonds Project site.

Heat and energy balance experiments on arctic tundra were also conducted beginning in the 1960s at a research site on Axel Heiberg Island in the high arctic by Andrews (1964) and Havens (1964). This site was also used in classic studies of heat and energy balance of an upland tundra site vegetated with hummocky grasses by Ohmura (1981; 1982) and Ohmura and Muller (1976). Radiation balance in the arctic and the Hudson Bay Lowlands has also been studied by Rouse and Bello (1983; 1985), Vowinckel and Orvig (1984), Rouse *et al.* (1987) and Rouse (1991).

Mean annual lake evaporation in the NWT from national climate maps ranges from 250 mm to 400 mm at 60°N to 100 mm along the Arctic coast (Ferguson *et al.* 1970; den Hartog and Ferguson 1978a). The values are based on Class A evaporation pan data and calculated lake evaporation estimates from climatological data (Prowse 1990). However, the Class A pan network consisted of only five stations that usually indicated pan evaporation was greater than precipitation (Lathan 1988). Comparison of mean annual precipitation and lake evaporation maps shows that lake evaporation is ≥50% of precipitation (Prowse 1990). Canadian evapotranspiration maps indicate mean annual evapotranspiration in the NWT ranges from 200 mm to 300 mm at 60°N to 100 mm at the Arctic coast (den Hartog and Ferguson 1978b). However, the sparse data network limits the usefulness of national maps to site-specific studies.

Wetlands and lake evaporation as well as evapotranspiration in arctic regions has been examined in numerous site-specific investigations using a variety of energy and water balance methods. Wetland and lake evaporation has been studied by Rouse and Stewart (1972), Stewart and Rouse (1976a, b), Rouse *et al.* (1977) and Roulet and Woo (1986). Evaporation studies have also been conducted by DIAND at the Salmita tailings pond located 50 km south of the project site from 1992 to 1994 (Reid 1993, 1994).

Studies on lakes and tailings ponds at the Lupin Mine have been conducted using a stable isotope mass balance method to estimate evaporation (Whidden 1994). Mean evaporation from small lakes at Lupin for 1992 and 1993 were 3.2 mm and 2.6 mm/d respectively (Gibson *et al.* 1994b).

2.6.2 Methods

Data collection from regional weather stations and on-site monitoring provided the basis for long-term climate assessment for the NWT Diamonds Project. On-site weather monitoring at the exploration camp began in August 1993 for direct comparison of local weather parameters to regional data. Since an extensive weather database was not available at the project site, climate data from regional weather stations were collected for estimating long-term average climatological parameters as such average temperature and precipitation.

2.6.2.1 Regional Climatological Stations

Data were collected from AES weather stations at Coppermine and Yellowknife located about 300 km from the NWT Diamonds Project site. Additional daily meteorological data were gathered from the nearest AES station at the Lupin Mine approximately 100 km north of NWT Diamonds Project exploration camp. Data were also collected from a former AES station located at the southern end of Contwoyto Lake about 80 km north of the project site. The Contwoyto Lake station began recording weather data in 1956, but was dismantled and moved to the Lupin Mine site in 1981. Combined Contwoyto Lake and Lupin Mine weather data were available, providing 34 years of record for long-term weather variations near the NWT Diamonds Project area.

Monthly temperature and precipitation data were collected from each AES station for the available period of record and compared with data collected at Koala Camp. In addition, daily temperature, precipitation and wind speed and direction for 1993 and 1994 were collected from the Lupin station for direct comparison to daily Koala camp values. Data analysis showed that the Lupin AES weather stations had the best correlation of temperature and precipitation to Koala camp data.

2.6.2.2 Koala Project Area Data

A 10 m weather tower was initially installed at Exeter Lake in August 1992, but relocated to the exploration camp site in August 1993 due to the closure of the Exeter camp. This weather station (at UTM coordinates 7173759 N, 518744 E), is at an elevation of 476 m, approximately 0.5 km southeast of camp. A Nipher shielded snow gauge was added to the station in October 1993 to measure snowfall water equivalent at the site.

An additional automated station was installed at Pointe de Misère (7159300 N, 540200 E) approximately 30 km southeast of the NWT Diamonds exploration camp on a ridge overlooking Lac de Gras in July 1994 to determine possible climatic variability due to a lake effect. Aside from brief periods of instrument failure, a continuous record of wind speed and direction at 10 m height, temperature, relative humidity, and rainfall was gathered from both the Pointe de Misère and Koala sites. Snowfall was monitored only at the Koala weather station.

A third automated micrometeorological station was installed along the shore of Long Lake in July 1994. The 2 m high station was designed to measure physical and meteorological parameters required to estimate lake evaporation based on Penman’s combination method involving both an energy balance and an atmospheric transport component (Penman 1948; Chow *et al.* 1982).

All weather stations were programmed in general agreement with Atmospheric Environment Service standards (AES 1992). Climate variables were sampled every 5 seconds with data summaries written to a storage module hourly and daily. Hourly summaries for Koala and Pointe de Misère weather stations include the following information:

- date and time
- wind speed, direction and standard deviation of direction, averaged over the last two minutes of the hour at 10 m elevation
- hourly average wind speed, direction and standard deviation of direction (15 minute sub-sampling for standard deviation calculation) at 10 m elevation
- hourly average temperature and relative humidity
- total rainfall during the previous hour.

The daily summaries calculated at midnight include the following climate data in addition to diagnostic information:

- daily maximum wind speed, time of maximum wind speed and wind direction at that instant
- maximum and minimum daily temperatures.

The Long Lake weather station measured the above parameters at 2 m and 0.9 m above the water surface, in addition to:

- hourly average net radiation
- hourly average solar radiation
- hourly average water temperature at surface, 0.5 m and 1.5 m depths.

A summary of all mean daily data recorded for automated weather stations at Koala, Long Lake and Pointe de Misère is presented in Appendix II-A5.

An additional weather station operated by Braden-Burry Expediting Ltd. at the NWT Diamonds Project airstrip began recording instantaneous weather parameters in April 1994. Climatological parameters monitored daily at 07:00 include air temperature (high, low and current), ceiling, visibility, wind speed and direction, wind-chill, altimeter and associated physical observations.

2.6.3 Air Temperature

Air temperatures at the NWT Diamonds exploration camp were compared with temperatures from regional AES stations at Coppermine, Lupin and Yellowknife. Mean monthly temperatures at Koala weather station were similar to air temperatures at both Lupin and Coppermine for the 1993 to 1994 study period, while Yellowknife air temperatures were consistently higher (Table 2.6-1 and Figure 2.6-1). The best correlation of Koala air temperatures was with data from the Lupin weather station.

Due to the close correlation of Koala and Lupin data, Contwoyto Lake air temperatures from the Canadian Climate Normals were used to estimate long term average temperature at Koala. The mean annual dry bulb temperature at Contwoyto Lake was -11.8°C (Environment Canada 1993). The extreme maximum and minimum temperatures for Contwoyto Lake were 27.2°C and -53.9°C, respectively. Estimated monthly temperatures for Koala are listed in Table 2.6-2.

2.6.4 Precipitation

Precipitation levels are usually highest during the late summer to early winter period, although some precipitation usually falls in all months of the year. Half or

Table 2.6-1
Average Monthly Temperatures at NWT Diamonds Project, Lupin, Coppermine and Yellowknife for August 1993 to December 1994

Month	Koala (°C)	Lupin (°C)	Coppermine (°C)	Yellowknife (°C)
Aug 1993	9.8	9.2	9.9	14.2
Sep	1.1	0.1	1.6	6.0
Oct	-8.2	-8.9	-5.0	-1.3
Nov	-21.1	-21.7	-19.2	-13.7
Dec	-28.5	-29.0	-27.6	-22.2
Jan 1994	-34.3	-34.4	-30.5	-33.0
Feb	-34.4	-33.6	-29.6	-30.2
Mar	-20.6	-21.7	-23.4	-14.0
Apr	data missing*	-17.5	-18.4	-6.7
May	data missing*	-2.4	-1.2	7.3
Jun	data missing*	7.3	6.0	14.4
Jul	data missing*	13.9	14.6	19.3
Aug	11.6	10.2	11.0	16.1
Sep	3.9	2.2	3.6	8.6
Oct	-3.8	-4.8	-3.1	1.3
Nov	-17.6	-18.5	-18.1	-12.4
Dec	-22.5	-23.4	-23.6	-20.8
1994 mean	**n.a.**	**-10.2**	**-9.4**	**-4.2**

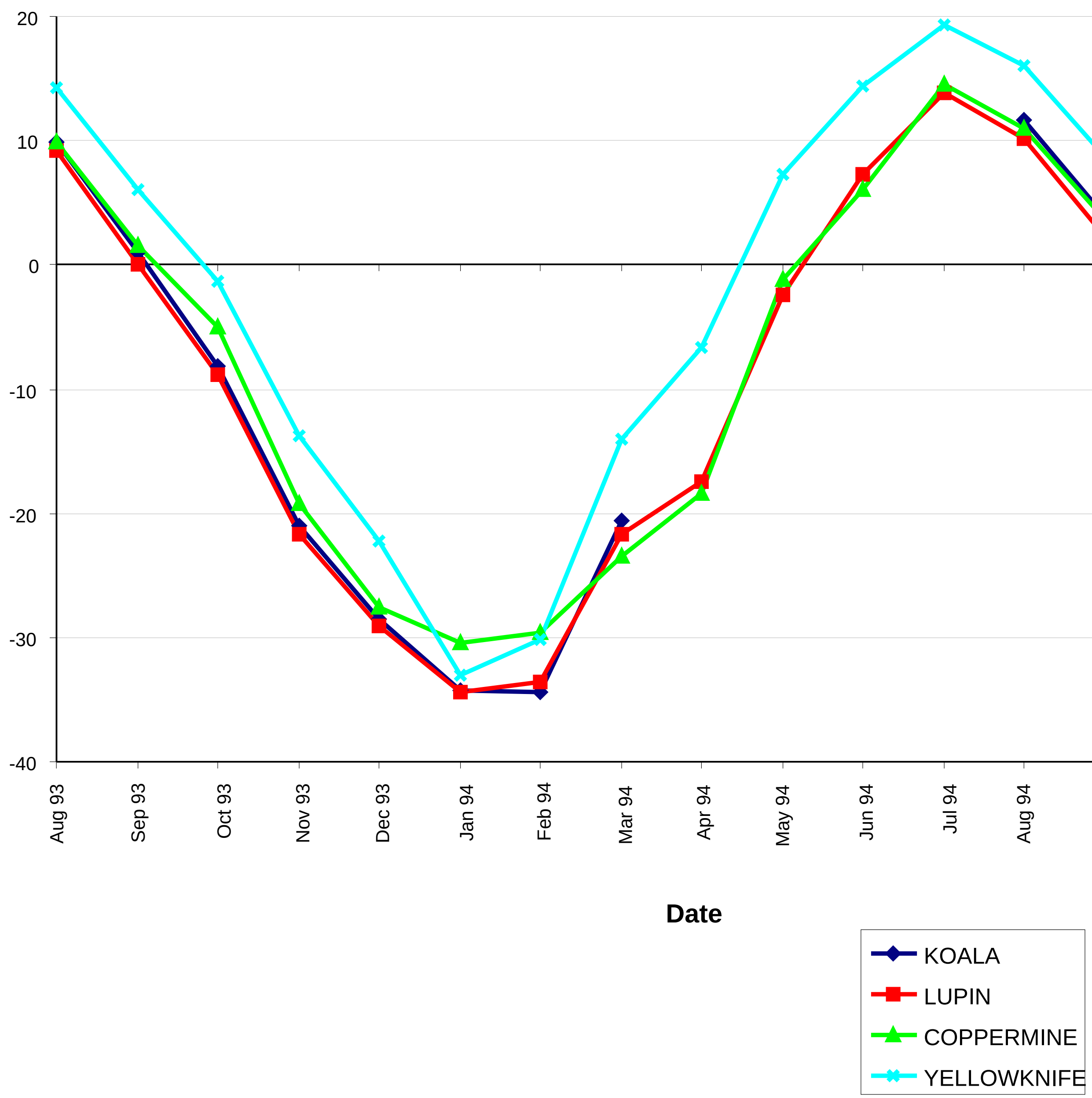
* Data missing due to probe malfunction.

more of the annual precipitation may fall as snow, generally between October and April.

Snowfall is difficult to measure accurately, particularly in the arctic where snow redistribution by wind is significant. As mentioned previously, Canadian research has indicated that snowfall may be significantly under-reported in the north, due to systematic measurement errors. This has been recognized in project planning and every effort has been made to develop an operational plan which is sufficiently flexible to accommodate uncertainties in parameter estimation.

Precipitation rates have been measured at the project site, as part of the baseline study program. These data have been used to estimate the hydrological cycle at the project site, and to quantify inputs to the water balance model for the site (Volume III, Section 3). Long-term variability in climatic conditions precludes a simple extrapolation of precipitation data from a short period of record, for the derivation of a long-term average annual precipitation rate. Therefore, in order to estimate the average annual precipitation at the project site, a correction factor

◎ **Table of Contents**



Note: Data missing at Koala for April to July 1994

NWT DIAMONDS PROJECT

Figure 2.6-1
Temperature Comparison at Koala and Regional Stations

Source: Rescan

Table 2.6-2
Estimated Monthly Air Temperature
for NWT Diamonds Project Site

	Estimated Air Temperature (°C)		
Month	**Mean**	**Maximum**	**Minimum**
Jan	-31.4	-27.9	-35.1
Feb	-30.6	-26.9	-34.4
Mar	-27.2	-22.6	-32.1
Apr	-17.2	-11.9	-22.7
May	-5.2	-0.9	-9.6
Jun	4.8	9.5	0.0
Jul	9.9	14.9	4.8
Aug	9.0	12.8	5.2
Sep	2.0	4.7	-0.8
Oct	-7.5	-4.9	-10.2
Nov	-20.1	-16.4	-23.9
Dec	-27.5	-24.1	-31.0
Annual	**-11.8**	**-7.8**	**-15.8**

Source: Canadian Climate Normals 1961 to 1990, Contwoyto Lake (Environment Canada 1993).

was derived by comparing precipitation rates measured at Koala with those measured at the nearest regional station (Lupin). This correction factor was then applied to the archived, long-term average annual precipitation rate for the region (Contwoyto/Lupin) to derive an estimate of average annual precipitation for the project site.

2.6.4.1 Regional Data

Archived regional data from Yellowknife, Contwoyto Lake (pre-1982), Lupin (1982 to present) and Coppermine AES stations have been used to assist with the estimation of average annual precipitation for the BHP NWT Diamonds project area. Table 2.6-3 lists the mean monthly precipitation (rain, snowfall water equivalent and total) for Yellowknife, Contwoyto Lake and Coppermine. These data are from the archived 1961 to 1990 climate normals (Environment Canada 1993; Metcalfe *et al.* 1994). The data indicate that precipitation decreases slightly from south to north. Snowfall water equivalent comprises 42% of total precipitation at Yellowknife, 48% at Contwoyto Lake and 50% at Coppermine. Although over two decades of data are available from Contwoyto Lake, this station is no longer operational. It was dismantled in 1981 and data collection started at the nearby Lupin site in 1982. The average precipitation measured at Lupin during the period 1982 to 1992 (288.5 mm) was higher than the 1961 to

Table 2.6-3
Monthly Average Precipitation for
Yellowknife, Contwoyto Lake and Coppermine
1961 to 1990

	Yellowknife			**Contwoyto Lake**			**Coppermine**		
Month	**Rain (mm)**	**Snow Water Equivalent* (mm)**	**Total (mm)**	**Rain (mm)**	**Snow Water Equivalent* (mm)**	**Total (mm)**	**Rain (mm)**	**Snow Water Equivalent* (mm)**	**Total (mm)**
Jan	0.0	14.9	14.9	0.0	7.0	7.0	0.0	11.3	11.3
Feb	0.0	12.6	12.6	0.0	7.8	7.8	0.0	8.7	8.7
Mar	0.0	10.6	10.6	0.0	10.2	10.2	0.0	10.4	10.4
Apr	1.6	8.7	10.3	0.5	10.7	11.2	0.4	15.2	15.6
May	12.2	4.4	16.6	6.2	12.1	18.3	5.0	11.6	16.6
Jun	23.0	0.3	23.3	22.2	2.9	25.1	15.0	1.7	16.7
Jul	35.2	0.0	35.2	36.2	0.0	36.2	29.7	0.1	29.8
Aug	41.6	0.1	41.7	40.1	1.0	41.1	38.7	0.6	39.3
Sep	24.8	4.0	28.8	21.5	11.2	32.7	24.0	7.0	31.0
Oct	14.6	19.4	34.8	2.0	28.6	30.6	4.2	24.2	28.4
Nov	0.6	23.3	23.9	0.0	15.7	15.7	0.0	14.2	14.2
Dec	0.2	14.5	14.7	0.0	10.6	10.6	0.0	11.5	11.5
Total	**154.0**	**113.3**	**267.3**	**128.6**	**118.0**	**246.6**	**117.0**	**116.4**	**223.4**

Source: Environment Canada 1993, Metcalf *et al*. 1994.
* Calculated as the difference between rain and total precipitation.

1990 annual precipitation normal for Contwoyto Lake (246.6 mm). From an examination of these numbers, it is not immediately apparent whether the period 1982 to 1992 period was wetter than the 1961 to 1990 period, or whether the Lupin site is wetter than the Contwoyto Lake site.

To resolve this issue, the 1961 to 1990 precipitation normals for Yellowknife and Coppermine were compared with average annual precipitation data for the 1982 to 1992 period (see Table 2.6-4). This comparison indicates that precipitation during the period 1982 to 1992 was higher than during the period 1961 to 1990. It was concluded that there is no strong indication that the Lupin site is wetter than the Contwoyto Lake site. Therefore, precipitation data for Lupin have been combined with those for Contwoyto Lake into a single data set. The mean annual precipitation for the combined data set is 265 mm.

Table 2.6-4
Regional Precipitation Data 1982 to 1990
Climate Normals and 1982 to 1992 Period

Station	1961 to 1990 Precipitation Normal (mm)	1982 to 1992 Average Annual Precipitation (mm)
Yellowknife A	267.3	296.5
Contwoyto	246.6	—
Lupin	—	288.5
Coppermine	233.4	255.2

As noted in the preamble to this section, previous studies have indicated that precipitation is systematically underestimated in the north. A recent effort was made by Metcalfe *et al.* (1994) to correct rainfall and snowfall measurements in the north for gauge measurement errors such as wind effects, “trace” precipitation events and losses due to wetting of the gauge surfaces. Archived precipitation normals for Yellowknife were revised upward from an annual precipitation of 267.3 mm to 336.1 mm, an increase of 26%. For Coppermine, annual precipitation of 233.4 mm was corrected to 323.2 mm, an increase of 38%. Although the precipitation normals for Contwoyto Lake were not corrected, annual precipitation totals for the period 1982 to 1992 at the nearby Lupin site were corrected from 288.5 mm to 316.9 mm, an increase of 10%.

These results suggest that the average annual precipitation at Contwoyto/Lupin is higher than 265 mm. The authors of the study recommend that the results must be interpreted with caution because further refinements to the correction methods are being investigated. For this reason, corrections to regional and site-specific data following the methods outlined in the study report have not been implemented in this EIS.

2.6.4.2 Site-Specific Data

Site-specific precipitation data were collected during the summer months by a tipping bucket rain gauge connected to the Koala weather station, and during the winter months by a Nipher shielded snow gauge which was installed adjacent to the Koala station. The rain gauge provided hourly and daily total rainfall information which was collected and stored by the Koala weather station datalogger. The Nipher gauge measured snowfall water equivalent and was monitored by camp personnel on a daily basis (weather permitting). Precipitation information was compared with data from the three regional stations for the period August 1993 to December 1994. The results of this comparison are listed in Table 2.6-5.

Table 2.6-5
Precipitation at Koala Camp and Regional Stations
August 1993 to December 1994

		Precipitation (mm)			
Month		**Koala**	**Lupin**	**Coppermine**	**Yellowknife**
August	1993	7.1	19.2	39.8	16.1
September		17.0	29.9	26.2	42.1
October		19.2	19.4	21.6	20.6
November		23.0	14.8	11.9	15.5
December		38.5	12.0	2.8	27.6
January	1994	6.7	3.4	5.9	7.4
February		1.9	2.2	1.5	8.4
March		37.6	22.0	11.0	20.4
April		21.6	8.2	1.0	3.2
May		3.6	15.4	19.3	14.2
June		32.3	39.2	38.1	20.5
July		2.0	13.8	3.6	28.0
August		46.7	47.2	62.6	4.0
September		47.0	43.4	22.0	20.8
October		68.7	29.2	33.3	28.9
November		30.3	11.0	21.5	39.3
December		30.3	14.8	26.6	18.4
Total (October 1993 to September 1994)		**280.1**	**241.0**	**201.3**	**190.6**

Considerable variation in monthly precipitation existed between Koala and the other stations. Overall precipitation levels were higher at Koala than at Lupin, Coppermine and Yellowknife. This was due mainly to higher snowfall during the winter; summer precipitation levels were, generally, similar at all four sites. As discussed below, there is uncertainty with respect to whether snowfall is actually higher at the project site than at Lupin, or whether the observed difference results from a systematic measurement error.

In order to derive an estimate of average annual precipitation at the project site, precipitation data collected at Lupin and Koala for the water year October 1993 to September 1994 were compared. The total recorded precipitation during this period was 16% greater at Koala than at Lupin (280.1 mm and 241.0 mm, respectively). Annual average precipitation at Lupin/Contwoyto Lake is 265 mm (see above). Applying a correction factor of 16% yields a figure of 307 mm, which has been rounded up to 310 mm to provide an estimate of average annual precipitation at the project site.

There are two principal sources of error associated with this estimate. First, blowing snow may constitute a significant fraction of measured snowfall at Koala.

The Nipher snow gauge at Lupin is monitored each six hours regardless of weather conditions, and data are corrected for accumulation of blowing snow.

At Koala, the gauge is located several hundred metres from the exploration camp and cannot, therefore, be monitored frequently during blizzard conditions. No attempt was made to correct for accumulation of blowing snow at this site. This suggests that the greater recorded snowfall at Koala may be a result of systematic measurement error. If this is the case, then the average annual precipitation at the project site may be closer to 265 mm.

A second potential source of error is the fact that neither the Contwoyto/Lupin data nor the site-specific data were corrected for other systematic measurement errors following the methods of Metcalfe *et al.* (1994).

These two errors tend to offset one another: correcting the site-specific data for overcatch of blown snow will reduce the estimate of average annual precipitation at the project site, while correcting the site-specific and regional data for other systematic measurement errors will increase the estimate. For the purposes of this document, it is not warranted to revise the estimate of 310 mm until more information is gathered. However, project planning needs to account for potential errors in precipitation estimation.

The sensitivity of the project site water balance to uncertainties in the estimation of average annual precipitation was assessed as part of project planning. For annual precipitation, a range of 250 mm to 350 mm annually has been used. These figures represent upper and lower bounds, respectively, for the estimate of average annual precipitation and were derived on the basis of a qualitative assessment of regional precipitation data and known measurement errors. The implications of potential errors in parameter estimation with respect to water management are discussed in Volume III, Section 3.

A frequency analysis was performed on archived Contwoyto Lake/Lupin precipitation data, maintaining the 1.16 correction factor to derive annual precipitation for various return periods at Koala. The results of this analysis are listed in Table 2.6-6.

Table 2.6-6
Annual Precipitation for Various Return Periods
Contwoyto, Lupin and Koala

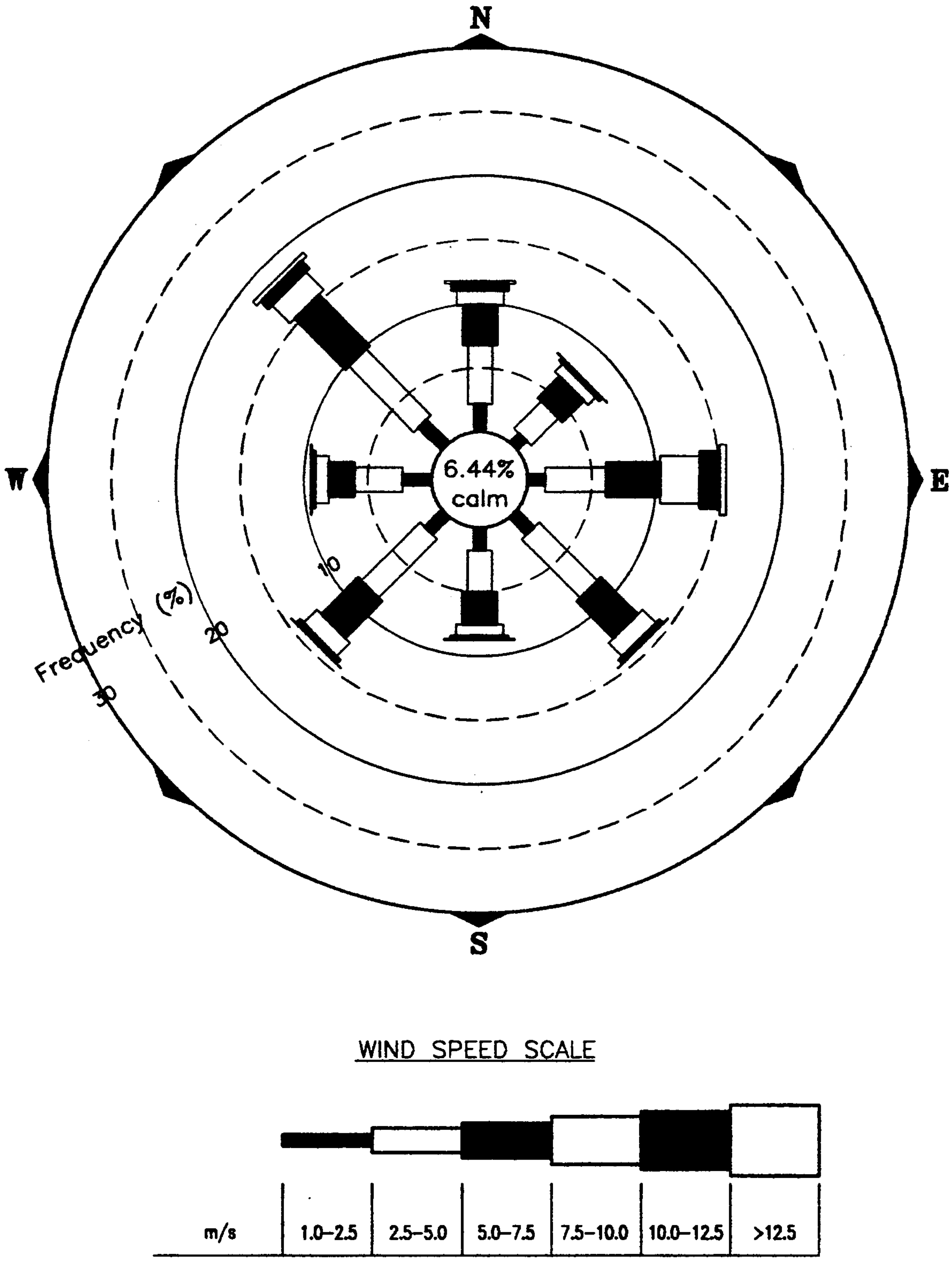
Return Period (Years)	Annual Precipitation Contwoyto / Lupin (mm)	Annual Precipitation Koala (mm)
Mean	265	307
5	300	348
10	319	370
25	337	391
50	349	405
100	359	416
500	378	438
1,000	385	447

2.6.5 Wind Speed and Direction

Wind speed and direction data were collected from the three automated NWT Diamonds Project area weather stations with the Koala station having the longest local period of record from August 1993 to January 1995. The predominant wind direction for the Koala weather station is from the northwest (19%) (Figure 2.6-2). Wind speeds were generally in the 2.5 m/s to 5.0 m/s range (36%), with calm winds (<1 m/s) prevalent 6% of the time. Winds exceeding 10 m/s occurred in all directions less than 5.8% of the time.

2.6.6 Evaporation and Evapotranspiration

Evaporation of water from a lake surface occurs mainly during the ice-free season, which generally extends for approximately four to five months between June and October. Evapotranspiration measures overall water vapour losses from a catchment, reflecting a combination of direct evaporation from lakes, rivers and land surfaces, in addition to transpiration by plants. The combined losses from lake evaporation and evapotranspiration are substantial components of the water balance of a catchment. For this reason, baseline studies have included a component to provide site-specific data on evaporation and estimates of annual



Notes: Data available from August 14, 1993 to January 3, 1995.
All data collected during icing events and when the sensor was removed for repair has been excluded from these calculations.

NWT DIAMONDS PROJECT

Figure 2.6-2
Koala Weather Station
Wind Rose

Source: Rescan

evaporation and evapotranspiration, for the purposes of project planning and impact assessment.

2.6.6.1 Lake Evaporation

From a water balance perspective, the most important water body on the project site is Long Lake, which will receive process plant tailings for a twenty year period. Two methods were employed during 1994 to estimate evaporation from Long Lake during the open water season: Penman's combined method and Class A pan measurements.

Long Lake was ice free on approximately June 19, 1994, although shore leads (water corridors) were evident at the end of May. On-site measurements began in July, precluding full open water season monitoring. The data collected were referenced to regional data collected concurrently, in order to provide the basis for accurate estimates of average annual evaporation and evapotranspiration.

Penman's Method

A micrometeorological station was established on July 19, 1994, on a dock along the southeast shore of Long Lake. The station monitored air temperature and relative humidity at two levels above the lake surface (0.9 m and 2.0 m), wind speed and direction, incident shortwave and net all-wave radiation, and lake water temperature at surface, 0.5 m and 1.5 m depth. The data collected were averaged daily and used to estimate open water evaporation with the Penman combination model (Chow *et al*. 1982). Data synthesis and evaporation calculations were performed in accordance with the methods reported in recent studies by Indian and Northern Affairs personnel in the NWT (Reid 1994).

Estimated lake evaporation for the period July 19 to October 9, when the station was dismantled, was 147 mm. Daily evaporation rates ranged from 4 mm to 7 mm during July and August, and decreased to less than 1 mm in late September. Mean daily evaporation was 1.8 mm. Extrapolating this daily average rate over an assumed ice-free period from June 19 to October 20 yields an estimated total lake evaporation of 220 mm during 1994.

Pan Evaporation

A Class A evaporation pan was installed on land adjacent to the Long Lake micrometeorological station in July 1994. The pan was monitored daily for evaporative depletion or rainwater additions to maintain constant volume. Total pan evaporation was between July 28 and September 19, when ice entirely covered the pan, was 157 mm. Mean daily pan evaporation was 2.9 mm, which corresponds to a total pan evaporation of approximately 360 mm over the assumed ice-free period of June 19 to October 20.

Due to radiation and boundary effects, pan evaporation is almost always higher than lake evaporation. Generally, a pan coefficient is applied to Class A pan evaporation to yield an estimate of lake evaporation. Pan coefficients vary widely (Linacre 1994) about an average value of 0.77. A "typical" value is 0.75, which when applied to a seasonal total of 360 mm yields an estimated lake evaporation for 1994 of 270 mm.

Estimated Annual Evaporation

The period of record of site-specific data is insufficient to derive estimates of annual average evaporation. Regional data were referenced to site-specific data in order to extend the effective period of record.

A comparison of daily pan evaporation rates at Long Lake and Yellowknife Airport was made for the common days of record during 1994 (July 28 to September 19). The pan evaporation during this period at Long Lake averaged 67% of the pan evaporation at Yellowknife Airport (157 mm and 233 mm, respectively).

Annual average lake evaporation at Yellowknife has been estimated on the basis of corrected pan evaporation rates to be 481 mm (AES 1984), for an open water period of June 1 to September 30. The estimated mean monthly evaporation rates at Yellowknife are listed in the second column of Table 2.6-7. Mean monthly estimates for project area lakes were derived from these figures by first calculating a daily average rate at Yellowknife for each month, applying a correction figure of 0.67 to these values to derive an estimated daily average rate for each month at the project site, and then converting these daily rates to monthly totals based on the number of days of open water in each month. It was assumed for this purpose that the open water period at the project site will, on average, extend from June 19 until the end of September.

Table 2.6-7
Annual Average Lake Evaporation
Yellowknife and Long Lake

	Estimated Evaporation (mm)			
	Yellowknife Airport		**Long Lake**	
Month	**Daily Rate**	**Monthly Total**	**Daily Rate**	**Monthly Total**
June	5.5	164	3.7	44
July	5.1	158	3.4	106
August	3.5	109	2.4	73
September	1.7	50	1.1	34
Total	—	**481**	—	**257**

Note: Daily rate applied for an assumed open water period of 12 days during June.

The estimated annual average lake evaporation calculated in this manner is 257 mm. This is equivalent to an average evaporation rate of 2.4 mm/d during the open water season, between mid-June and the end of September. This value is higher than the average rate estimated by the Penman formulation from Long Lake data (1.8 mm/d). This results at least in part from the fact that the average rate of 1.8 mm/d for Long Lake included the end of the open water season, when evaporation rates are low, but missed the first month of open water, during which period daily evaporation rates are higher.

For the purposes of this EIS, annual open water evaporation is estimated as 250 mm. This value is slightly higher than, but in general agreement with, Reid's (1994) estimate of evaporation from the nearby Salmita tailings pond, and presently represents the best estimate of average annual lake evaporation in the project area. This figure has been used for the purposes of project planning and impact assessment in predicting water balances for the tailings pond, natural lakes and pit lakes in the project area.

Recognizing the uncertainties in estimating lake evaporation, planning for tailings management and water management has included an analysis of the sensitivity of water balances to changes in average values of evaporation (and runoff and precipitation; Sections 2.3 and 2.6.4). For annual evaporation, a range of 200 mm to 350 mm annually has been used. These figures represent upper and lower bounds, respectively, for the estimate of average annual lake evaporation. In other words, whatever the uncertainties are in estimating lake evaporation, it is considered improbable that average annual lake evaporation is less than 200 mm, or greater than 350 mm.

The effects of variability in evaporation and other water balance inputs on the water balance of the Long Lake tailings impoundment are discussed further in Volume IV, Section 3.

It is recognized that sublimation (i.e., direct vapour loss from snow and ice) occurs. However, its contribution to the water balance is relatively small and, for the purposes of this EIS, is assumed to be negligible.

2.6.6.2 Evapotranspiration

Basin losses due to evapotranspiration cannot easily be measured and hence must be estimated using a simplified water balance equation for a catchment with no net change in storage:

$$ET = P - R$$

where ET represents combined losses due to open water evaporation and evapotranspiration, P is the total precipitation falling on the catchment and R is the outflow or runoff from the catchment. Inherent in this equation is the assumption that losses to groundwater are negligible.

In order to estimate average annual ET for the project area, a crude balance was performed on a regional scale, for two large catchments. Discharge data were obtained for the Water Survey of Canada (WSC) hydrometric stations at Indin River and Coppermine River at Point Lake, for the years 1978 to 1993. Total annual discharge was calculated at each station for a water year of October 1 to September 30, to ensure that thaw season runoff was attributed to a single winter snow accumulation. Precipitation data for water years 1978 to 1993 were obtained from the AES for the Contwoyto Lake and Lupin stations. The assumption was made that these precipitation data were reasonably representative of precipitation over the entire catchments.

The average annual archived precipitation for 14 years of common data was 265 mm. The average water year runoff for both basins was approximately 160 mm. Average losses to evapotranspiration were calculated as the difference, 105 mm annually. Although this is a crude analysis, it correlates well with estimates of combined evaporative losses provided in the *Canadian Climate Atlas* (Environment Canada 1986).

Significant uncertainty is associated with physical measurements of precipitation and runoff. In particular there is evidence to suggest that precipitation in the Arctic has been under-reported due to systematic measurement errors (Section 2.6.4). If this is so, then actual ET losses would be higher than 105 mm on a regional scale. With average annual precipitation at the project site estimated at 310 mm (Section 2.6.4), and with runoff estimated at 180 mm (Section 2.3), average annual ET losses for the project area are estimated at 130 mm.

2.6.7 Climate Change

The question of climate change from global warming is controversial. The best that one can describe at present is that, first, there is a historical data set that indicates some global warming; second, there are some computer simulation models that predict what to expect in the future; and, third, recent satellite data tend to contradict the warming theory.

2.6.7.1 The Historical Record

Those people with the longest and most enduring connection to the land are often in an excellent position to assess climate changes at both the local and regional levels. Aboriginal elders, who have spent much of their lives on the land, frequently possess the richest and most detailed knowledge of the region’s climate. For example, in the area south of MacKay Lake, one Metis elder observed recent and significant changes in water levels:

"I have never seen the water so low in all my travels out where I have been trapping, Duncan Lake and all through there. Those creeks are just bone dry. Just bone dry. I think it is going to be worse again" (Stan Laroque, Yellowknife).

As the above quote reveals, the elders and land users may be especially cognizant of climatic changes at the local level and of the significance of these changes on wildlife. For instance, a decrease in lake and stream levels forecasts a poor trapping year for beaver and muskrat, while freezing rains in the fall may prove devastating to both caribou and the Aboriginal people that depend upon this animal to sustain their cultures, economies and social relations. Thus, short-term climatic fluctuations may have important implications for both wildlife and Aboriginal communities.

Aboriginal elders may also possess the wisdom and knowledge to ascertain whether short-term changes in temperature, precipitation, wind directions, length of seasons, etc., are minor perturbations in an otherwise stable climatic episode, or the harbinger of significant climatic change, which may necessitate alterations in human adaptions.

The historical record for four time periods of global warming and cooling is shown in Figure 2.6-3. These data show that average global temperatures have varied by about 10°C over the past 100,000 years, and that even within the last 10,000 years global temperatures have ranged from 2°C warmer to 5°C colder than they are today. In the past 100 years, the average surface temperature of the Earth has warmed by about 0.5°C. However, not everyone may have experienced this effect, and local conditions can often be very different from the global average.

For example, at Rankin Inlet, Mr. Ollie Ittinuer, President of the Inuit Cultural Institute, was quoted as saying:

"This summer (1992) it was not hot all summer — no vegetation grew, both ice and snow really didn't melt. I have read that it is getting warmer. When is this going to become a reality?"

Although subjective, Mr. Ittinuer may be correct in implying that arctic temperatures have not increased greatly in the past four decades, as 10-year running seasonal mean temperatures in arctic tundra regions show no significant warming trends in any season (Figure 2.6-4; Skinner and Maxwell 1994).

At present, it is believed that the current global warming has been partly induced by the release of industrial gases, particularly carbon dioxide, methane and nitrous oxide (the greenhouse gases), which tend to trap solar radiation. Because the rate of release of these gases is increasing with increased industrialization in the world, the rate of global temperature increase could be as much as 0.2°C to 0.5°C per decade. This rate is much faster than in any period in the past 10,000 years.

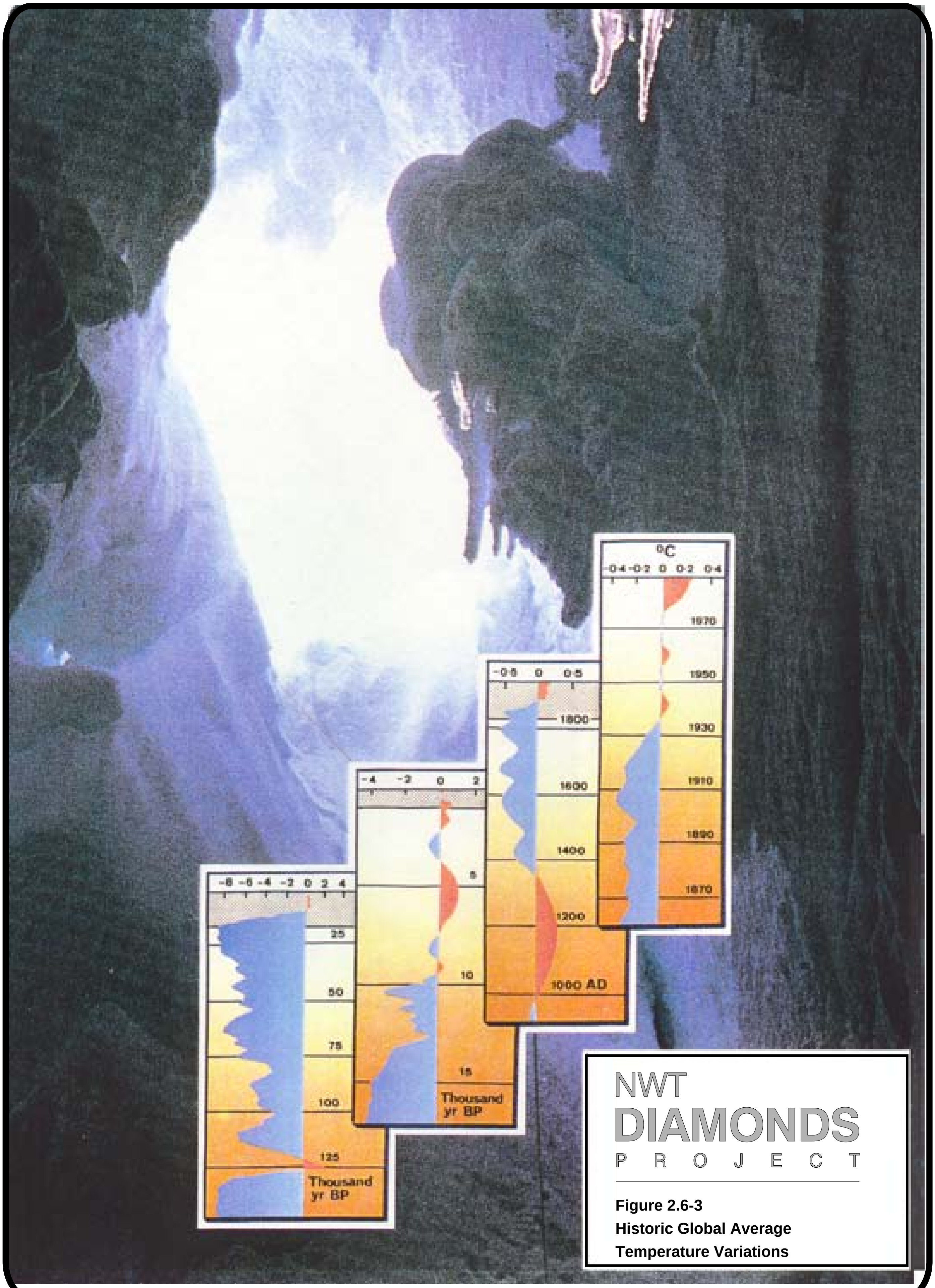


Figure 2.6-3
Historic Global Average Temperature Variations

Source: The Royal Swedish Academy of Sciences, 1992

◎ Table of Contents

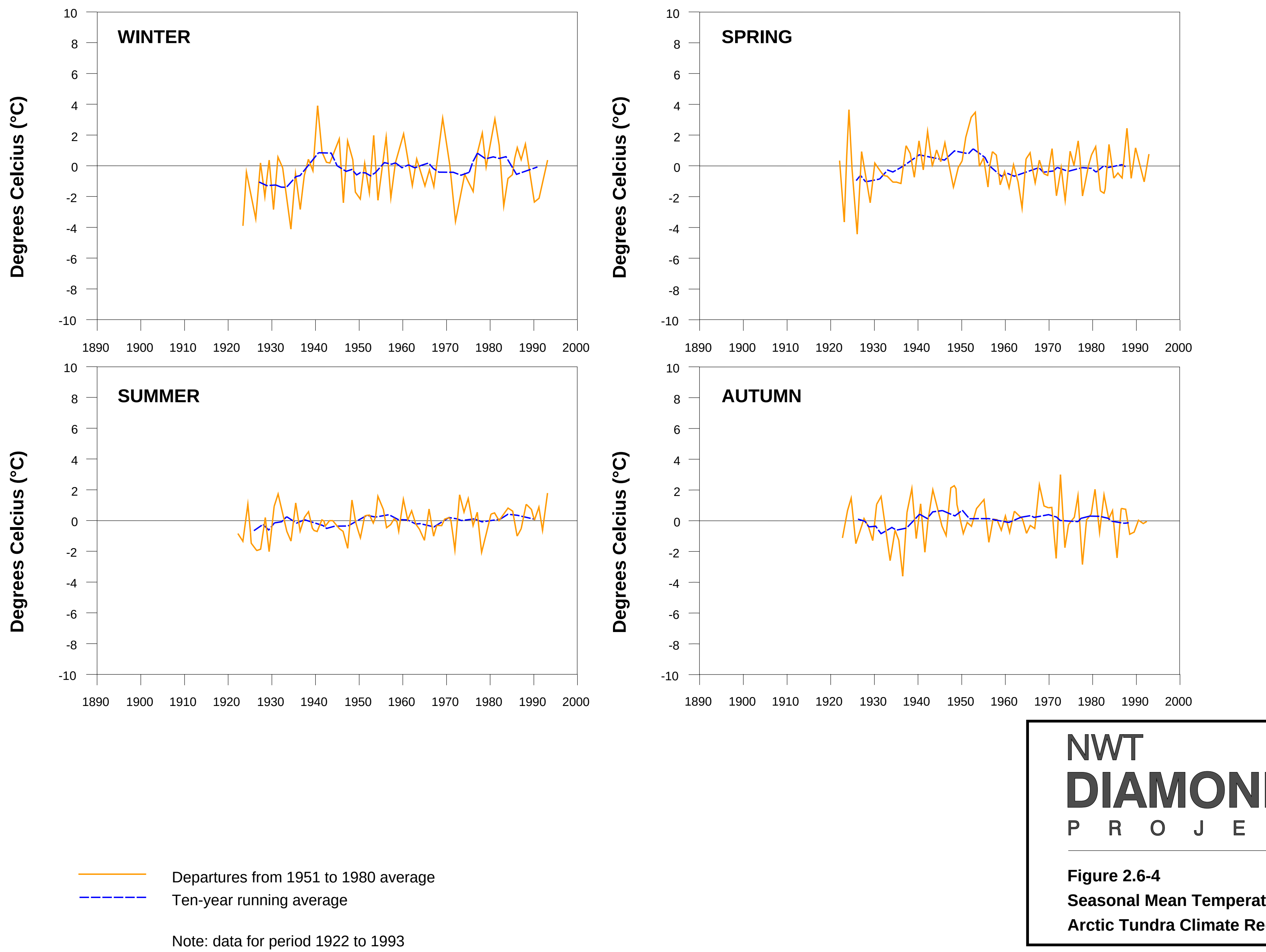


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Figure 2.6-4
Seasonal Mean Temperatures - Arctic Tundra Climate Region

Source: HCCD, Environment Canada

The phenomenon is generally referred to as “global warming”, and it is this event that is of primary concern to scientists.

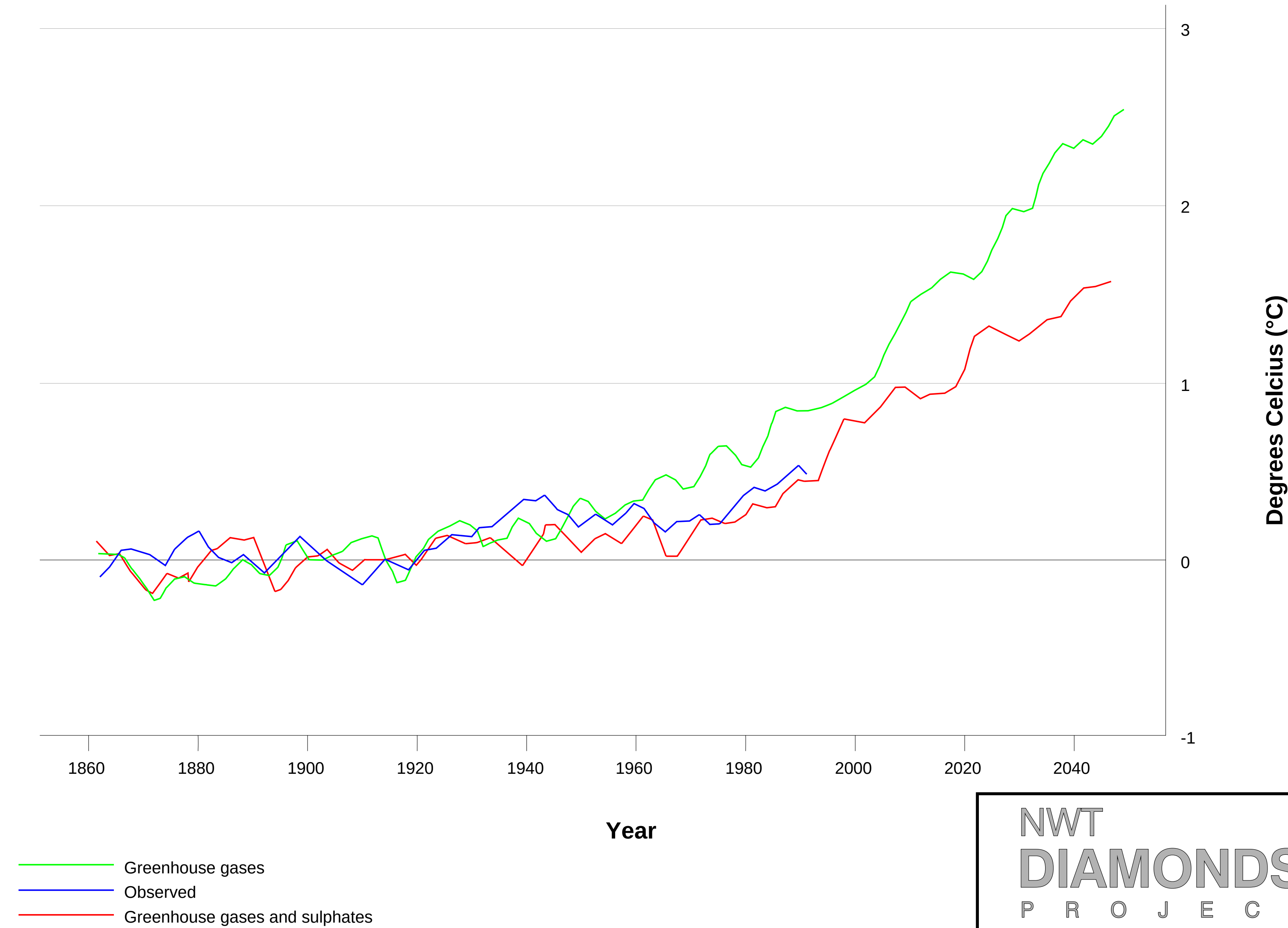
2.6.7.2 Computer Simulation Models

Many computer models estimating the effect of greenhouse gases on global climate have been constructed, and they are continually being modified to better match observations. Models based on CO_2 accumulation alone have generally shown that the global temperatures should be at least 0.5°C warmer than actually being recorded. Some scientists have suggested that particulate sulphates formed from SO_2 emissions have had a cooling effect on the planet by reflecting solar radiation away from the Earth’s surface, thus counter-balancing the greenhouse effect. The results of two models, one excluding sulphate but including CO_2 and the other including sulphates, are shown in Figure 2.6-5. The model that includes sulphates obviously tracks the global temperature better that the model that uses only CO_2.

If the computer model results in Figure 2.6-5 are more or less correct, then further projections of regional differences in the temperature and rainfall over the Earth’s surface can be made. If these are then also assumed correct, changes in the ecology of large areas of Canada can be predicted. A simulation of such a prediction is shown in Figure 2.6-6. In this prediction, much of the western area north of 60° North latitude and east of the Rocky Mountains would change from a tundra/boreal ecosystem to a temperate grassland ecosystem – a change that would take several decades to become established. Even in this prediction, however, the project area remains in the tundra region of continuous permafrost.

2.6.7.3 An Alternative View from Satellite Data

The NASA/University of Alabama satellite-measured temperature record is now in its 16th year of recording, and the data generated by this record do not match the temperature trend as measured from meteorological stations at the Earth’s surface. One reason for this may be that many meteorological stations, are near cities and urban sprawl may have encompassed some of the stations, thus producing higher (local) temperature readings than are found by satellites. In fact, satellite data over 16 years of observations show a decrease in average global surface temperature of about 0.2°C, despite the fact that some seasonal local temperatures have been reported as large increases and decreases (e.g., May 1994 readings were 4°C over Antarctica). In addition, there is now some doubt regarding the theory that sulphates partially reflect back radiation. This effect would be minimal in the southern hemisphere, where heating should consequently be expected to be greatest. However, cloud cover in this region appears to play the same role as a reflectant in the absence of sulphates.

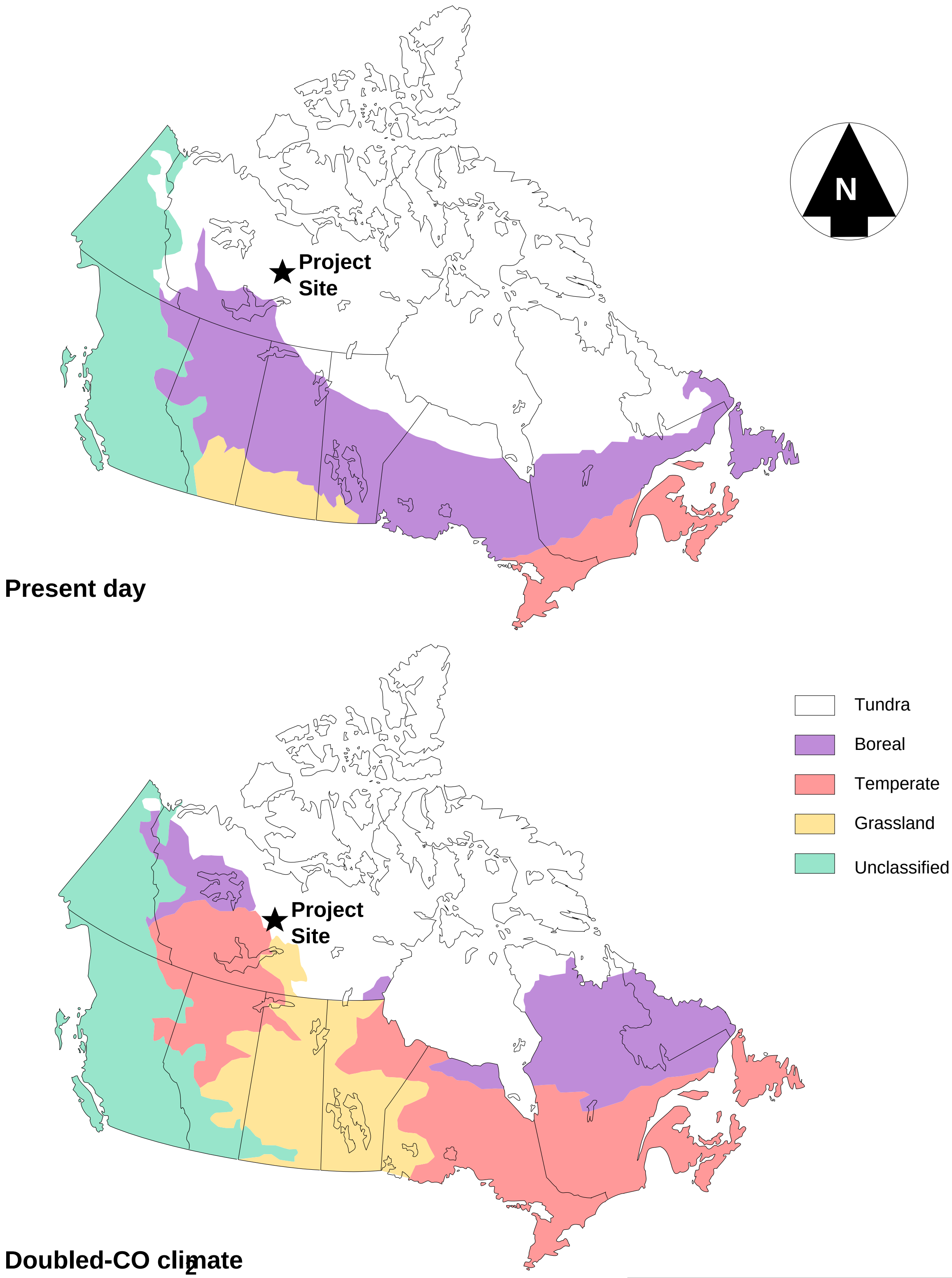


NWT DIAMONDS PROJECT

Figure 2.6-5
Models of Global Warming Compared with Observations

Source: The Economist

Table of Contents



NWT DIAMONDS PROJECT

Figure 2.6-6
Projected Ecoclimatic Zone Changes

Source: Environment Canada 1994

2.6.7.4 Possible Impact of Climate Change in the General Area of 65°N/110°W

From a rather short satellite data record, it appears that although anomalous temperatures may be reported annually for the general area of the Mackenzie Valley, west to the Rockies, the longer-term record indicates little overall change in climate for this region.

Ground observational temperature data and computer model projections give a prognosis for the area that is quite different from the satellite data. An ongoing study of the Mackenzie Basin (Mackenzie Basin Impact Study 1994) suggests that over a protracted period, an overall warming trend of about 4°C could occur together with an approximate 10% increase in precipitation. Such a temperature is unlikely to be noticed during the winter months when seasonal temperatures are less than -15°C, but during the spring and summer, an early spring and warmer summer are likely to increase the abundance of both plants and animals.

While the above climate scenarios are very different, none of the predicted changes can at present be suggested as having significant impact on mining activities within the near future.

2.6.7.5 Summary

Ongoing climate monitoring programs are managed by the Atmospheric Environment Service (AES) of Environment Canada. The nearest AES station is Lupin Mine, 100 km north of the project. Meteorological data from Lupin Mine and other regional AES stations provided verification for the on-site data collection program. The major parameters used to describe the climate near the NWT Diamonds Project are ambient air temperature, wind speed and direction, and evaporation.

On-site data collection consists of a year-round meteorological station located near the Koala exploration camp and two temporary stations: one at Pointe de Misère (30 km southeast of the exploration camp) and the other at Long Lake.

Close correlation of Koala and Lupin data and the Contwoyto Lake air temperatures from the Canadian climate normals were used to estimate long-term average temperature at the project site of -11.8ºC.

Precipitation falls during all months of the year but is highest during the late summer and early winter. Generally half of the total annual precipitation falls as snow between October and April. Mean annual precipitation for the NWT Diamonds site is estimated to be 310 mm based on data collected on site and at Lupin and Contwoyto Lake. Due to the difficulty of measuring snowfall when there are strong winds, and other systematic measurement errors, the mean annual precipitation in the range of 250 mm to 350 mm is considered more appropriate and has been used for engineering design purposes.

Wind speed and direction data have been collected at the on-site weather station since August 1993. Winds generally blow from the northwest, although winds from the east and southeast are common. The wind speeds are generally moderate (between 2.5 and 5.0 m/s) and calm conditions are uncommon (6% of time wind speeds are less than 1.0 m/s).

Evaporation occurs mainly from June to October when the lakes are ice-free. Using meteorological data collected at Long Lake for July 19 to October 9, 1994, the estimated total lake evaporation is 250 mm. A range of 200 mm to 350 mm has been used for engineering design purposes.

The issue of climate change driven by global warming is a public concern. However, the long-term records indicate little climate change for the region.

2.7 Air Quality

Air quality is considered a valued ecosystem component (VEC) because of its intrinsic importance and aesthetic value in terms of visibility, odour, effects on worker health and safety and importance to wildlife and vegetation. Generally, the air quality in the Lac de Gras region is free of any anthropogenic contamination, as there are no major emitting sources of gaseous pollutants in the region.

The assessment of current ambient particulate levels within the mineral claim boundary, as illustrated in Figure 2.7-1, is an important step in establishing data on baseline air quality for the NWT Diamonds Project site. Prior to August 1994, there was very little existing site-specific air quality information. In August 1994, a field study was conducted to quantify the levels of ambient particulate matter.

For the purposes of this assessment, the mineral claim block is defined as the air quality spatial boundary for the project. The use of diesel and gasoline powered equipment for mineral and diamond exploration will cause an increase in gaseous and particulate air emissions in the area. Due to the extremely cold climatic conditions (mean annual temperature of -11.8^{o}C at Koala Camp), persistent winds (wind speeds of <1 m/s only occur approximately 6.4% of the time), buoyant emissions and turbulent mixing, any air emissions will likely be quickly dispersed and carried away from the source.

2.7.1 Previous Research

Environment Canada, Atmospheric Environment Service (AES), completed studies covering many aspects of the northern contaminants issue, including atmospheric emissions of toxic substances and transport of persistent organic pollutants. The objective of one study, Atmospheric Emissions of Toxic Substances, is to determine sources of atmospheric emissions containing

Table of Contents

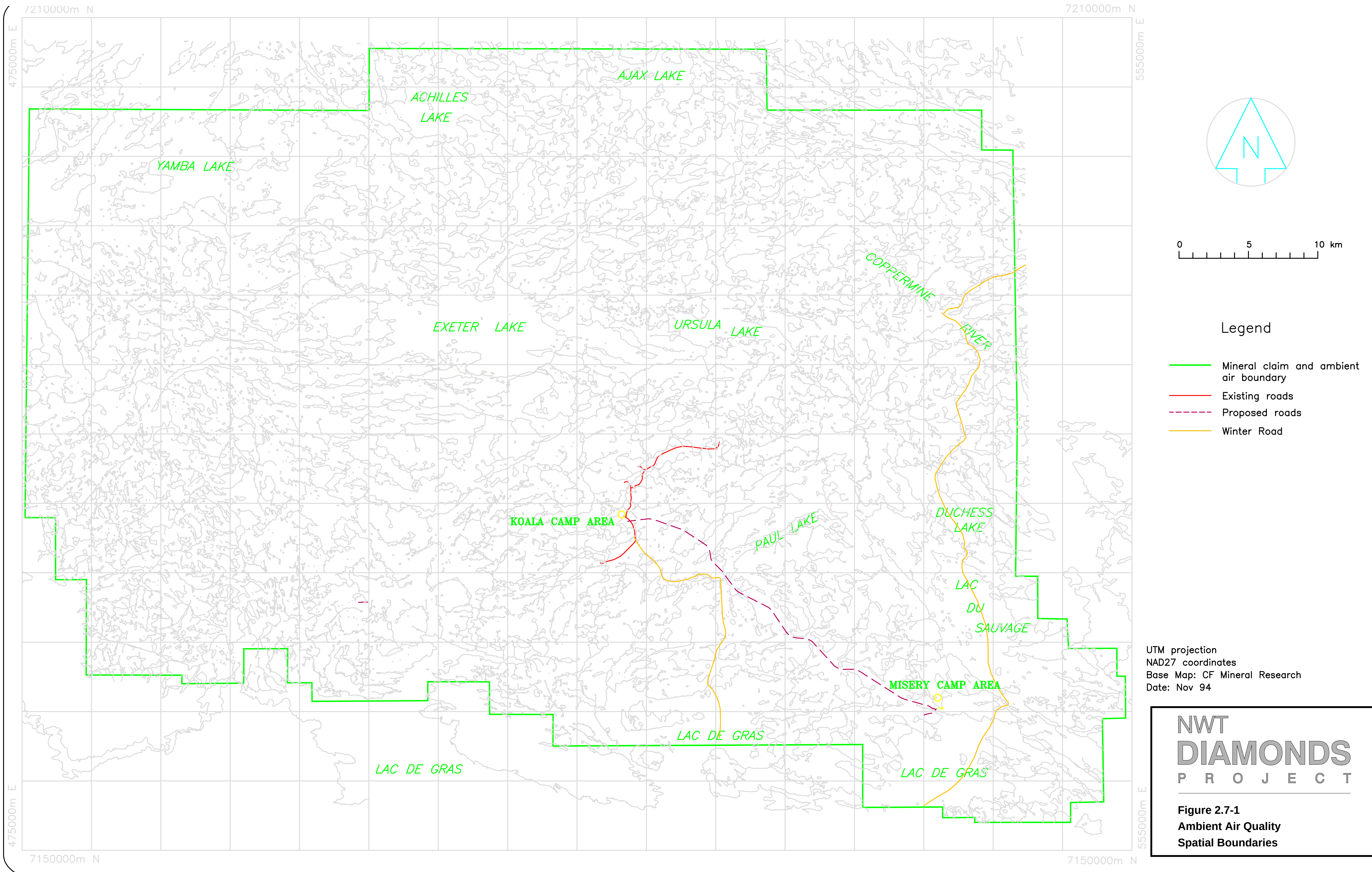


Figure 2.7-1
Ambient Air Quality
Spatial Boundaries

acidifying and toxic pollutants such as sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOC), metals and pesticides. The source information will be used as the basis for modelling activities, interpretation of measurements, assessment and international action. In 1991/1992 the basic information was compiled for further development of an air/soil exchange model. Data for SO_x, NO_x, VOC, and Pb for various regions were compiled and first estimates of annual emission inventories were prepared. In 1992/1993 the work was discontinued due to changing priorities and insufficient support of the Northern Contaminants Program.

Arctic air chemistry has been monitored since 1979 through the Canadian Arctic Aerosol Sampling Network (CAASN), with stations at Mould Bay, Igloolik and Alert. The objective is to investigate the occurrence, nature, origin and effects of air pollutants resulting from human activity. The program endeavored to maintain a routine aerosol sampling network to determine long-term trends in air quality. Weekly aerosol samples are collected on 20 x 25 cm filters using high volume air samplers. Filters were subsequently analyzed for major ions by ion chromatography (IC); pH after extraction with distilled water; trace metals soluble in concentrated nitric acid by inductively-coupled plasma emissions spectroscopy (ICP); and total trace elements by neutron activation analysis (NAA). Results of the CAASN studies conducted between 1979 and 1994 concluded that there is a strong seasonal variation in anthropogenic aerosol concentrations; winter average SO_4^{2-} concentrations in Canada are slightly lower than in the Norwegian Arctic; during winter 20% to 90% of airborne sulphur exists as SO_2 (concentrations range from 0.2 to 1.5 ppb(v)); and concentrations of total nitrate (HNO_3^- plus particulate NO_3^-) during December to February are much lower than that of SO_4^{2-} particulate (Barrie *et al.*, 1985 and Barrie 1985). The nearest CAASN sample sites (Mould Bay and Igloolik) are 1,300 km from the project site.

Air quality in other regions of the Northwest Territories is affected by operations such as mining and power generation. The three nearest operations to the NWT Diamonds Project are the Echo Bay Lupin underground mine (approximately 80 km north), Royal Oak Colomac open pit gold mine (approximately 155 km southwest) and the Royal Oak Giant Yellowknife underground mine (approximately 295 km southwest). No ambient air quality monitoring has been performed at the Colomac mine. Ambient air monitoring is performed in Yellowknife to determine the impact of emissions from the Giant Yellowknife Mine roaster stack. Stack sampling is carried out once per year for the arsenic roaster stack, and a dispersion modelling study is currently in progress for air emissions from the baghouse and stack system. The air emissions from the Yellowknife mine are not representative of the air emissions that will result from the NWT Diamonds Project, as diamond ore processing does not include roasting and the subsequent emission of large quantities of arsenic and sulphur dioxide.

Air emissions monitoring at the Lupin mine consists of monthly NO_x sampling from the diesel power plant stacks (six in total). While dust monitoring has been done using low volume samplers, no ambient (high volume air sampler) data have been collected.

The NWT Power Corporation supplies Yellowknife with all of its electrical power from diesel power generators, some of similar capacity to those planned to be used at the NWT Diamonds Project. The Jackfish Lake Power plant uses a variety of diesel engines (13 in total) ranging in size from 680 kW to 5180 kW. The original diesel generator was installed in 1969, and additional units have been added to meet the increase in demand for power. The engines operate on P40 type fuel during winter months and P20 during summer. The total fuel consumption for all diesel engines during 1992/1993 and 1993/1994 was roughly 18.4 and 20.0 million litres, respectively (NWT Power Corporation 1995). The expected annual fuel consumption rate for the power generation facilities at the NWT Diamonds Project is approximately 21.9 million litres (based upon the consumption of 60,000 L/d, 365 d/a (Rescan 1994). With the expected growth of the Jackfish Lake power plant, the levels of air emissions from the NWT Diamonds Project will be equal to or less than the Jackfish Lake power plant (Rescan 1994).

The Jackfish Lake power plant is not currently monitored on a regular basis for air emissions. However, an air quality computer modelling study is underway to assess potential impacts to a proposed subdivision to be located nearby. The study has been commissioned by the City of Yellowknife and is expected to be completed by the end of June 1995. The study will include stack testing for the diesel engines (to determine air contaminant emission rates) and ambient monitoring.

2.7.2 Methods

An ambient air particulate sampling program was carried out at the NWT Diamonds Project site in August of 1994. High volume (HV) samples were taken over a total of 11 days to assess the baseline levels of ambient total suspended particulate (TSP) for comparison with the Canadian Ambient Air Quality Objectives (CAAQO). For the purposes of this study we have chosen the acceptable range of quality from the CAAQO. The acceptable range of quality is intended to provide protection against effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well-being. The other ranges of quality are desirable and tolerable. The desirable ranges are long-term goals and provide a basis for antidegradation unpolluted parts of the country. The tolerable ranges are time-based concentrations of air contaminants above which, due to a diminishing margin of safety, appropriate action is required to protect the health of the general population.

A high volume air sampler draws a known volume of ambient air at a flowrate of $1.13 \pm 0.11\ m^3$/min through an inlet and through one or more filters, which trap particulate matter. The concentration of TSP or respirable dust is computed as the total mass of collected particles divided by the measured volume of air sampled, and is expressed as micrograms per standard (or normal) cubic metre of air (µg/Nm³).

A PM10 sampler differs from a TSP sampler primarily in that it incorporates a size selective inlet that directs only the -10 µm fraction of the particulate matter to the filter. The PM10 method measures the mass concentration of particulate matter with an aerodynamic diameter of less than or equal to a nominal 10 µm in ambient air over a period of 24 hours. These particles are representative of the respirable dust that is of human health concern.

A total of three TSP HV samplers and one respirable particulate (PM10) sampler were used. Four HV air sampling sites were used in the study (Figure 2.7-2). The sampling sites were selected in accordance with the U.S. EPA General Aspects of Quality Assurance for Ambient Air Monitoring Systems in the *Quality Assurance Handbook for Air Pollutant Measurement System* (U.S. EPA 1984). The sites were selected to determine baseline concentrations of particulate and, with one exception, were therefore located in the undisturbed tundra. A PM10 sampler was installed at the exploration camp to determine respirable dust concentrations near the sleeping quarters and other camp facilities. Selection of the sample sites also considered such factors as the availability of power, adequate elevation of the sampler inlet, predominant wind direction and accessibility. These objectives provided the rationale for selecting the following four ambient air sampling sites:

- *Koala Camp area*: A PM10 sampler was installed on top of one of the sleeping trailers in the exploration camp. This location was selected to prevent tampering/vandalism.

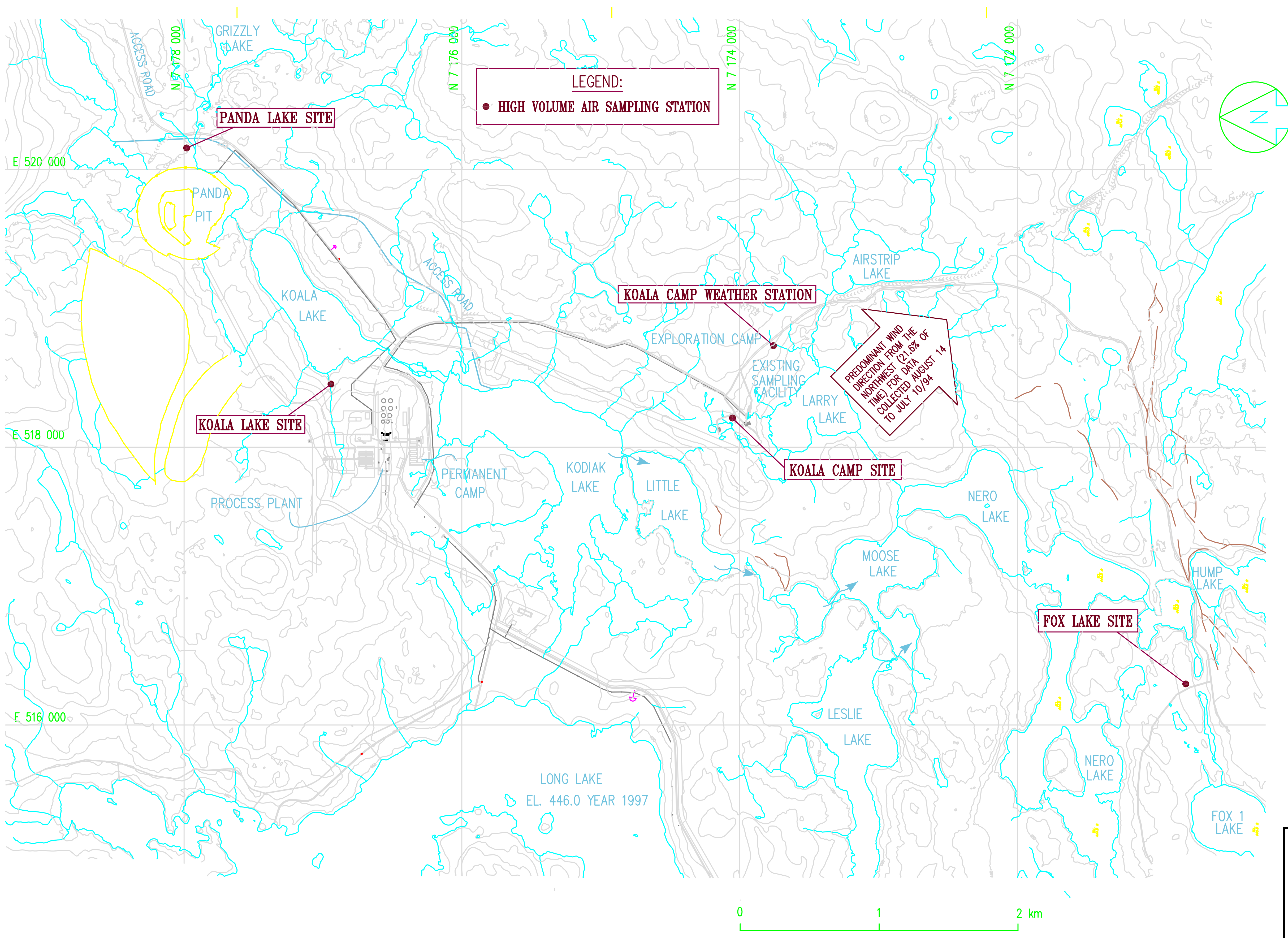
- *Fox Lake area*: A TSP sampler was installed 600 m northeast of the future site for Fox Lake area, 150 m northwest of the portal and 200 m northwest of a waste rock dump.

- *Panda Lake area*: A TSP sampler was installed 500 m northeast of Panda Lake.

- *Koala Lake area*: A TSP sampler was installed approximately 500 m north of the rock quarry and 500 m west of Koala Lake.

Data from the nearest automated weather station, in the Koala camp area, indicate that the predominant wind direction is from the northwest, recorded as occurring 21.6% of the time for the period of August 14, 1993, to July 10, 1994. To determine baseline ambient particulate concentrations, the sample sites were located northwest of potential fugitive dust sources.

◎ Table of Contents



Scale: 1:30 000

NWT DIAMONDS PROJECT

Figure 2.7-2
High Volume Air Sampling Sites

Source: Rescan

The only continuous sources of air emissions near the Fox Lake area sample site were the diesel power generating station and air being exhausted from underground at the portal. The Fox Lake area TSP air sampler was positioned approximately 200 m to the west of the portal and generator. These sources were expected to have minimal effect on the air quality at this sampler location. There was also intermittent fugitive dust from wheeled vehicles in the vicinity of the portal.

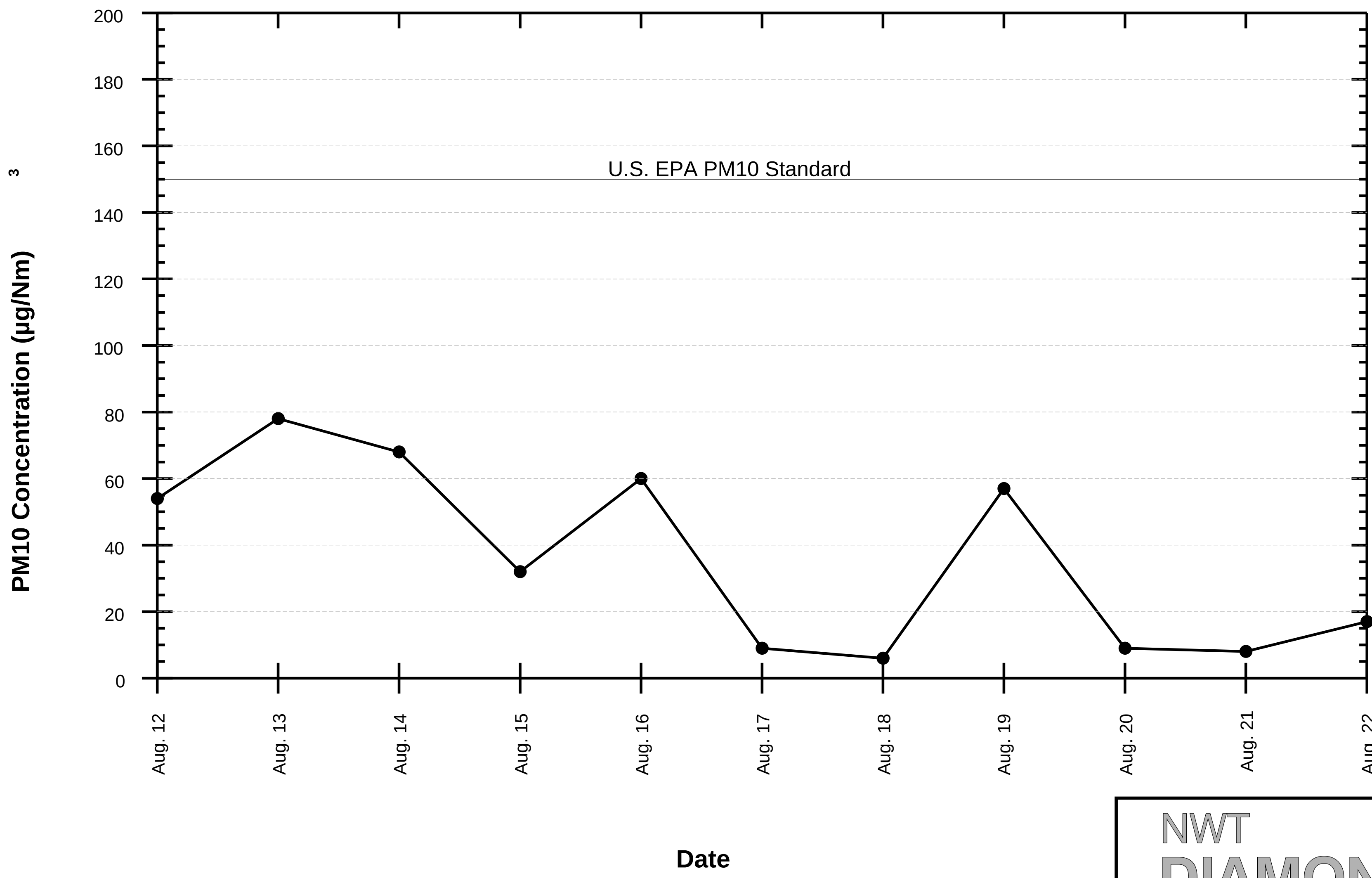
Although exploration activities (blasting and aggregate crushing at the quarry) were underway in the vicinity of the Koala Lake area sampler, it was believed to be positioned far enough away from these activities so as not to be affected.

The Panda Lake area sample site was occasionally affected by road and/or diversion channel construction activities. Haul trucks used the road several times per day. The Panda Lake area TSP sampler was located 700 m upwind and northwest of the road to minimize the effects from fugitive dust. According to data from the exploration camp weather station, the wind occasionally blew from the south, southeast and east during baseline monitoring 10.2%, 14.3% and 2.7% of the time, respectively, for August 12 to 22, 1994.

During the sample collection at the exploration camp several types of activities were taking place that influenced the results. Forest/tundra fire smoke was often blowing towards the camp, carried by southerly winds. During several of the days of the sampling program, visibility was decreased to less than 2 km by forest/tundra fire smoke. The highest concentrations of forest/tundra fire smoke were observed during August 13 and 14, 1994. The high levels of smoke from fires indicate that short periods with excessive ambient particulate levels occur naturally in this area. It is also important to recognize that due to the relatively short time for this sampling program, and the high levels of forest fire smoke, the results may indicate higher levels of long-term ambient air particulate than may be the case.

The most notable source of fugitive dust near the exploration camp was the airstrip, which is not paved. Fugitive dust was dispersed from the runway during aircraft take-off and landing and when the wind was blowing from the west or northwest, thus potentially affecting the PM10 results. The results from the PM10 sampling program are summarized in Table 2.7-1.

In the absence of Canadian Ambient Air Quality Objectives for PM10, U.S. EPA criteria for 24 h PM10 concentrations (150 µg/Nm^3) serve as a basis for comparison. The highest PM10 concentration recorded was 78 µg/Nm^3 (Figure 2.7-3). The average PM10 concentration was 36 µg/Nm^3, well below the U.S. EPA criteria.



NWT DIAMONDS PROJECT

Figure 2.7-3
PM10 Concentrations at Koala Exploration Camp - August 1994

Source: Rescan

Table 2.7-1
PM10 Air Sampling Results

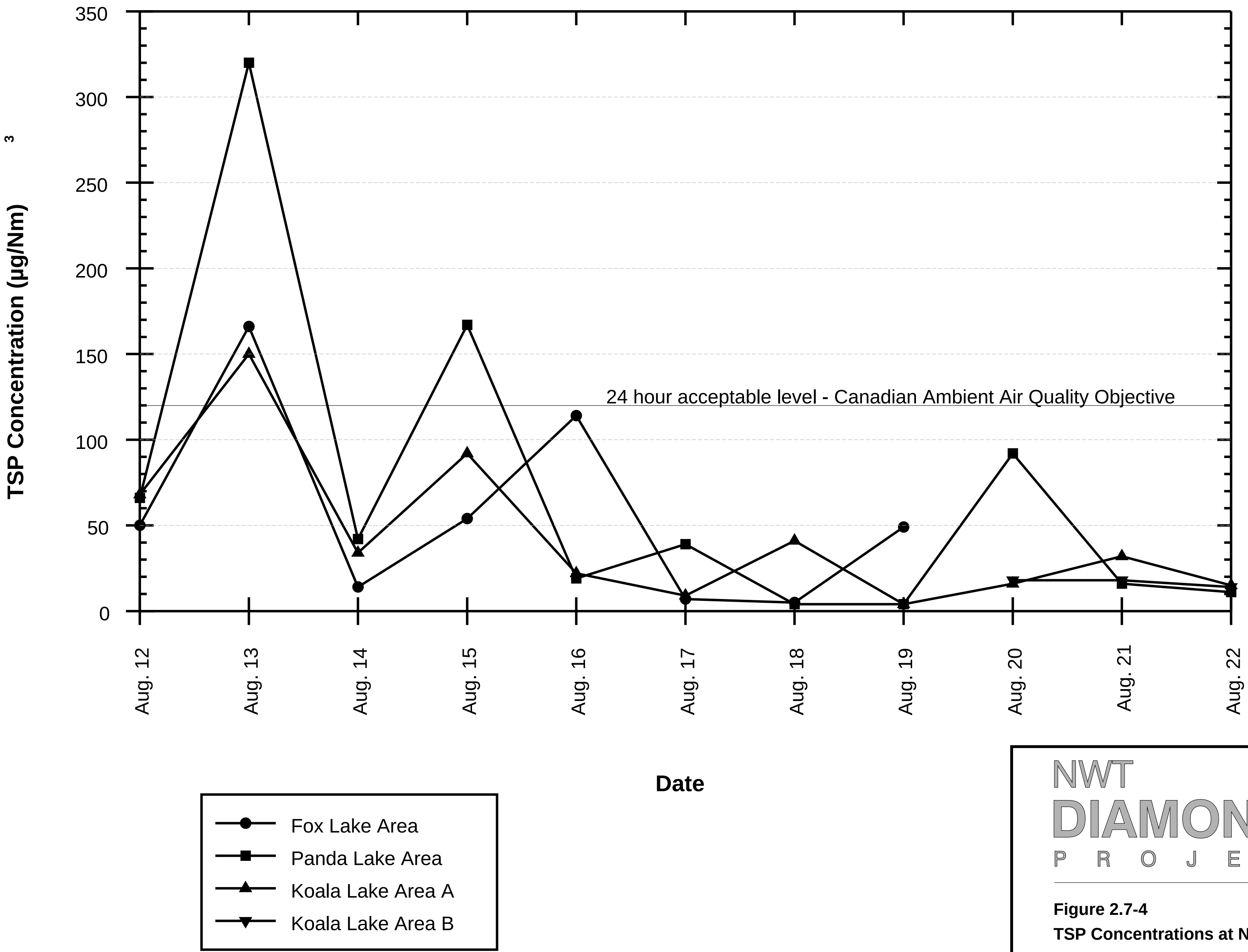
Sample Site	Type of Sample	Concentration (µg/Nm^3)	Predominant Wind Direction	Comments
Koala Camp Area				
12 Aug	PM10	54	W	
13 Aug	PM10	78	SW	Poor visibility due to forest fire smoke
14 Aug	PM10	68	SE	1.5 mm of rain
15 Aug	PM10	32	S	
16 Aug	PM10	60	S	Forest fire smoke, 11 mm of rain in the afternoon
17 Aug	PM10	9	SW	6 mm of rain
18 Aug	PM10	6	W	4 mm of rain
19 Aug	PM10	57	NW	Daily maximum wind speed 17 m/s (62 km/h)
20 Aug	PM10	9	SW	
21 Aug	PM10	8	SE	Daily maximum wind speed 14.5 m/s (52 km/h)
22 Aug	PM10	17	SE	9 mm of rain
Average	**PM10**	**36**		

The results of the high volume air sampling program are summarized in Table 2.7-2, including the date, concentration, prevailing wind direction and notes about the sampling period. Figure 2.7-4 illustrates the various sampling results in comparison with the CAAQO 24-hour acceptable level of 120 µg/Nm^3 for TSP.

Winds from the south, southeast and east occasionally transported fugitive dust directly from the road toward the Panda Lake area sampler. The moisture content of the road surface material was also a determining factor in the amount of fugitive dust created. The days on which road construction traffic was the highest and there was rainfall corresponded to the highest TSP concentrations measured at the Panda Lake area sample site. Days with rainfall (August 14, 17, 18 and 22) corresponded to the lowest measured particulate concentrations at this site. It is evident from these results that the Panda Lake ambient air sampling program has been affected by the site activities and may not be representative of the true ambient baseline levels.

Of the 44 high volume air samples taken, four exceeded the 24-hour acceptable Canadian Ambient Air Quality Objective for TSP concentrations (120 µg/Nm^3).

◎ Table of Contents



NWT DIAMONDS PROJECT

Figure 2.7-4
TSP Concentrations at NWT Diamonds Project - August 1994

Source: Rescan

Table 2.7-2
Total Suspended Particulate Concentrations

Sample Site	Type of Sample	Concentration ($\mu g/Nm^3$)	Predominant Wind Direction	Comments
Fox Lake Area				
12 Aug	TSP	50	W	
13 Aug	TSP	166	SW	Poor visibility due to forest fire smoke
14 Aug	TSP	14	SE	1.5 mm of rain
15 Aug	TSP	54	SW	
16 Aug	TSP	114	S	Forest fire smoke, 11 mm of rain the afternoon
17 Aug	TSP	7	W	6 mm of rain
18 Aug	TSP	5	NW	4 mm of rain
19 Aug	TSP	49	NW	Daily maximum wind speed 17 m/s (62 km/h)
Average	**TSP**	**57**		
Panda Lake Area				
12 Aug	TSP	66	W	
13 Aug	TSP	320	SW	Poor visibility due to forest fire smoke
14 Aug	TSP	42	E	1.5 mm of rain
15 Aug	TSP	167	SW	Heavy road traffic
16 Aug	TSP	19	S	Forest fire smoke, 11 mm of rain in the afternoon
17 Aug	TSP	39	W	6 mm of rain
18 Aug	TSP	4	NW	4 mm of rain
19 Aug	TSP	4	NW	Daily maximum wind speed 17 m/s (62 km/h)
20 Aug	TSP	92	S	
21 Aug	TSP	16	SE	Daily maximum wind speed 14.5 m/s (52 km/h)
22 Aug	TSP	11	E	9 mm of rain
Average	**TSP**	**71**		
Koala Lake Area				
12 Aug	TSP	68	W	
13 Aug	TSP	150	SW	Poor visibility due to forest fire smoke
14 Aug	TSP	34	E	1.5 mm of rain
15 Aug	TSP	92	SW	

(continued)

Table 2.7-2 (completed)
Total Suspended Particulate Concentrations

Sample Site	Type of Sample	Concentration ($\mu g/Nm^3$)	Predominant Wind Direction	Comments
16 Aug	TSP	22	S	Forest fire smoke, 11 mm of rain in the afternoon
17 Aug	TSP	9	W	6 mm of rain
18 Aug	TSP	41	W	4 mm of rain
19 Aug	TSP	4	NW	Daily maximum wind speed 17 m/s (62 km/h)
20 Aug	TSP	16	S	Two TSP samplers at this sample site
20 Aug	TSP	18	S	
21 Aug	TSP	18	SE	Daily maximum wind speed 14.5 m/s (52 km/h)
21 Aug	TSP	32	SE	Two TSP samplers at this site
22 Aug	TSP	15	E	9 mm of rain
22 Aug	TSP	14	E	Two TSP samplers at this site
Average	**TSP**	**38**		

Three of the four samples that exceeded the standard were collected on August 13, 1994 (Panda, Koala and Fox Lake areas), when forest/tundra fire smoke was at its heaviest during the 11-day sampling. The fourth sample, which surpassed the standard, was collected at the Panda Lake area on August 15, 1994, a day during which no precipitation was recorded and road traffic was higher than normal.

It is apparent that even with a variety of site activities as described, the average ambient particulate concentration did not exceed 120 $\mu g/m^3$, the 24-hour acceptable Canadian Ambient Air Quality Objectives for suspended particulate matter.

As a background study, it is reasonable to analyze the particulate collected for trace metals. Four of the ambient particulate samples collected were analyzed for concentration of trace metals in ambient dust, as this may be a human health concern. The analytical results were expressed in micrograms per filter.

To calculate an ambient concentration of trace metals in airborne particulate ($\mu g/Nm^3$), the total weight of each metal on each filter was divided by the volume of air drawn through the filter. To account for the metals contained in the Teflon filter, a field blank was submitted to the laboratory. To calculate the average ambient metal concentration, the metal content of the filter (field blank) was subtracted from the average total (sample and filter) of the metal measured. The average ambient metal concentrations are given in Table 2.7-3, along with occupational safety and health criteria. Canadian Ambient Air Quality Objectives do not exist for trace metals in particulate. However, the American Conference of Governmental Industrial Hygienists (ACGIH) provides work place criteria for comparison. None of the measured concentrations of trace metals in the particulate exceeded ACGIH standards. Aluminum was the most abundant metal in the particulate and was three orders of magnitude below the established criteria. Mercury was the least abundant metal and was more than four orders of magnitude below the criteria (Table 2.7-4).

Particulate size classification helps identify whether there may be problems with the size of the particulate collected. In order to assess the particle size of the ambient dust, a cascade impactor was used during the HV air sampling program to determine the particle size distribution for the TSP. The cascade impactor is a size selective inlet for a HV air sampler that separates particulate into six size classes: >7.2 µm, 7.2 to 3.0 µm, 3.0 to 1.5 µm, 1.5 to 0.95 µm, 0.95 to 0.45 µm and <0.45 µm. A total of three cascade impactor samples were collected at each site and used to generate average particle size distributions. The data are presented graphically in terms of a cumulative size distribution showing the percent of particle mass finer than (or greater than) the particle diameter (in microns) in Figure 2.7-5.

The Fox Lake area sample site had the finest ambient air average particle size distribution, with almost 75% of the particles finer than 0.49 µm. Koala Lake area had the coarsest average size distribution, with approximately 50% of the particles <0.49 µm. The particle size distributions for Fox and Panda Lake area sample sites were very similar except for the finest size classification, 0.49 µm. The Fox Lake area samples contained a larger portion of these finer particles.

Since the ambient air TSP concentrations were quite low, and the presence of forest/tundra fire smoke affected the TSP concentration, there was considerable variation in the particle size distributions at each site. It is evident that the Koala Lake area cascade impactor samples may have been influenced by the site preparation activities (blasting and aggregate crushing at the quarry) taking place at the time of the study. These activities may be responsible for the coarser particle size distribution at this site. Hence, the baseline particle size distribution is most likely similar to the results obtained for Fox and Panda Lake area sample sites.

2.7.3 Summary

The ambient air sampling program conducted in August 1994 at the NWT Diamonds Project provides baseline ambient data on the air quality in the Lac de Gras region. The analytical results indicate that baseline ambient particulate

◎ Table of Contents

Table 2.7-3
Concentration of Metals in Ambient Dust

Date	Sample Location	Sample Type	Volume of Air Sampled (m^3)	Total Metals ($\mu g/Nm^3$) Aluminum	Antimony	Arsenic	Cadmium	Copper	Iron	Lead	Mercury	Zinc
Aug. 13	Koala Camp Area	PM10	1,393	2.0	0.014	0.001	0.0001	0.13	0.68	0.01	$<3.6 \times 10^{-5}$	0.12
Aug. 13	Panda Lake Area	TSP	1,682	N.D.	0.003	0.004	0.00006	0.02	7.4	0.005	$<3.0 \times 10^{-5}$	N.D.
Aug. 15	Fox Lake Area	TSP	1,859	3.4	0.003	0.0005	N.D..	0.003	0.13	0.001	$<2.7 \times 10^{-5}$	0.096
Aug. 15	Fox Lake Area (replicate)	TSP	1,859	N.D.	0.0004	0.0003	N.D.	0.009	0.02	0.0005	$<2.7 \times 10^{-5}$	0.060
Aug. 16	Koala Lake Area	TSP	1,869	2.6	0.02	0.0006	0.009	0.01	0.19	0.0016	$<2.7 \times 10^{-5}$	0.067
	ACGIH TLV/TWA[a]			10,000	500	10	10	1,000	N/A	150	25	N/A
	NWT TLV/TWA[b]			10,000	500	200	50	1,000	N/A	150	100	N/A

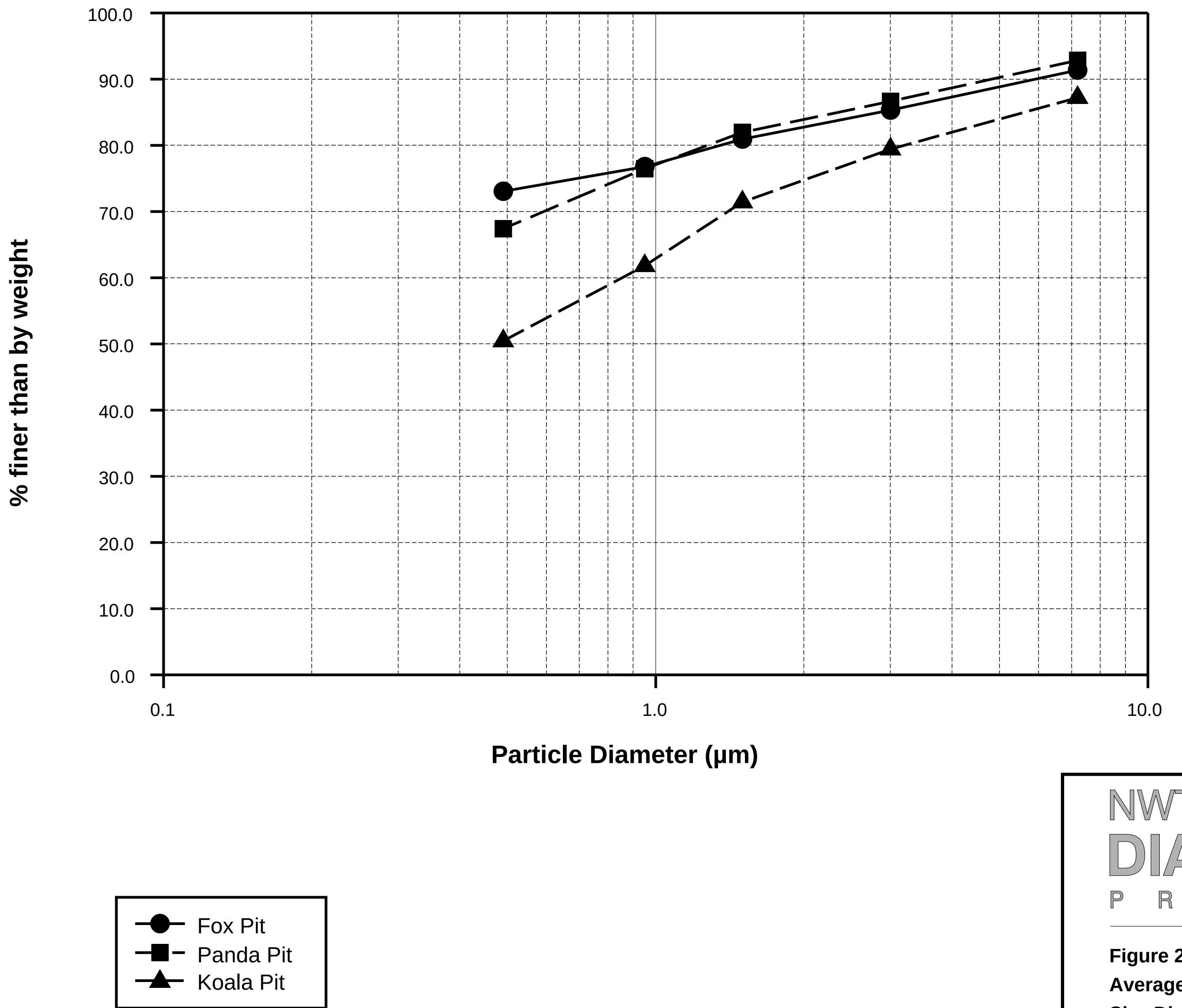
Notes:
N.D. = Not Detectable. The measured concentration of metals was equal to or less than the concentration of metals for a blank filter.
N/A = Not Available.

a) ACGIH TLV/TWA = American Conference of Governmental Industrial Hygienists - Threshold Limit Value Time Weighted Average 1994-95.
b) NWT Mining Safety Act - Mining Safety Regulations, Chapter M-16.

Table 2.7-4
Metals in Ambient Dust

Date	Sample Location	Sample Type	Concentration of PM10/TSP (μg/Nm^3)	Total Metals (% of total collected particulate) Aluminum	Antimony	Arsenic	Cadmium	Copper	Iron	Lead	Mercury	Zinc	Other Silicious Material
Aug. 13	Koala Camp Area	PM10	78	24	0.03	0.002	0.0004	0.18	1.5	0.018	$<4.6 \times 10^{-5}$	0.48	73.7896
Aug. 13	Panda Lake Area	TSP	320	3	0.004	0.0013	0.0001	0.010	2.4	0.0022	$<9.3 \times 10^{-6}$	0.06	94.8224
Aug. 15	Fox Lake Area	TSP	54	29	0.074	0.0068	0.0007	0.082	3.1	0.017	$<4.9 \times 10^{-5}$	1.8	65.9195
Aug. 15	Fox Lake Area (replicate)	TSP	54	20	0.089	0.0081	<0.0002	0.18	3.6	0.020	$<4.9 \times 10^{-5}$	2.4	73.7027
Aug. 16	Koala Lake Area	TSP	22	67	0.14	0.0053	0.0043	0.087	2.5	0.014	$<1.2 \times 10^{-4}$	1.1	29.1493

◎ Table of Contents



NWT DIAMONDS PROJECT

Figure 2.7-5
Average Particle Size Distributions

Source: Rescan

measurements were affected by both naturally occurring events, such as forest/tundra fire smoke, and on-site exploration activities such as the heavy traffic on August 15, 1994 at the Panda Lake area.

Naturally-occurring events can cause this region's ambient air particulate concentrations to exceed acceptable levels of the Canadian Ambient Air Quality Objectives. If the concentrations measured during short-term events, such as the forest/tundra fire smoke, are included in the average baseline data, then the average ambient air particulate levels approach the acceptable levels set out in the Canadian Ambient Air Quality Objectives.

To estimate the average long-term baseline ambient particulate levels, it is reasonable to exclude short-term events from this limited ambient particulate data set. If short-term events are excluded, such as the fire smoke and the heavy traffic dust events, the average baseline particulate concentrations from this sampling program approach 30 $\mu g/m^3$, one-quarter of the 24-hour acceptable level set out in the Canadian Ambient Air Quality Objectives.

In order to assess both local short-term impacts, as well as regional long-term impacts, it is recommended that another ambient air quality monitoring program be executed. The details of the monitoring program are discussed in Volume III, Section 10.5.

2.8 Noise

The NWT Diamonds Project lies in a relatively pristine wilderness area where few anthropogenic sources of noise existed prior to commencement of the project. Although noise from aircraft, snowmobiles and hunters' guns may have been present occasionally at any given location, ambient noise levels would generally have been established by natural sources such as wind, thunder, wildlife and insects.

No data are available on ambient noise levels prior to any project activity commencing, but natural sounds measured elsewhere in rural and wilderness areas have generally ranged between 25 and 40 dBA, with no wind (Broderson and Edwards 1976; Barron Kennedy Lyzun 1995). Considerably higher levels can occur in the presence of wind and/or rain, but this effect is most pronounced in treed areas. Since the NWT Diamonds Project is situated in a tundra region, increases in ambient noise due to wind and rain will be significant but less dramatic than would be expected in forested regions.

Ambient noise levels as low as 25 dBA are unlikely to persist for an entire day, even in wilderness areas, thus 24-hour average sound levels would almost always exceed 30 dBA. Propagation of sound from distant sources such as snowmobiles and hunters guns will be enhanced during temperature inversions, which take place most often during the winter season. However, seasonal changes in temperature, humidity and ground cover would not significantly affect the level of ambient noise generated by local sources such as insects or wind.