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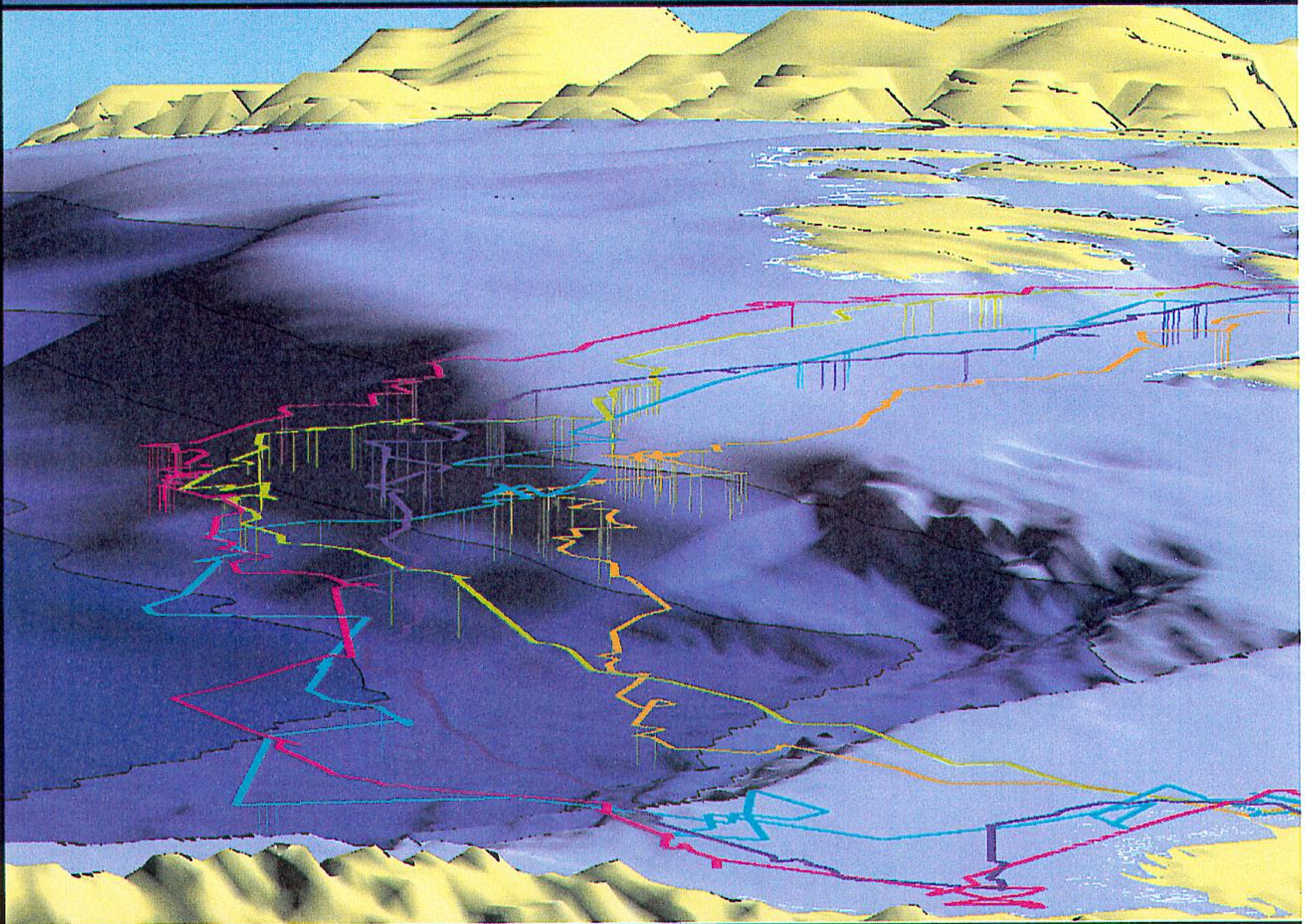
Knowledge Gaps Associated With Exploration and Development of Natural Gas in the Mackenzie Delta Region



The Environmental Studies Research Funds

PREPARED BY

KAVIK-AXYS Inc.

IN ASSOCIATION WITH

LGL Limited Environmental Research Associates

North/South Consultants Inc.

Salmo Consulting Inc.

McGill University

The National Hydrology Research Institute

KAVIK-AXYS Inc.

Summer 2002

KA031

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To All Participants in the Inuvik ESRF Workshop 10 July 2002

Review of Draft Report

Knowledge Gaps Associated with Exploration and Development of Natural Gas in the Mackenzie Delta Region

I have attached a draft of the ESRF report for your review and consideration. This draft includes a summary of the workshop in Inuvik in January 2002.

You are invited to comment on the rough material in this draft. I am particularly interested in any comments you may have about the specific chapter(s) which cover the Working Group session which you personally attended. Your comments will be carefully considered in the preparation of the final report. The Project Advisory Team will make the final calls about the wording of the knowledge gaps and recommendations for the final report.

The final report on this project may influence the long-term planning of the federal government, the NWT government, ESRF, the co-management boards and the non-government organizations.

I would like to thank you in advance for the time and energy that you may put into reviewing this document. This report will be a useful milestone along the highway towards the future of the Mackenzie Delta Region. Arrangements will be made to provide you with a hard copy of the final report.

Please send your comments by Friday August 2nd to:

Ms. Kim Gormley
Kavik-AXYS Environmental Consulting
Suite 600, 555 Fourth Avenue SW
Calgary, AB
T2P 3E7

If you need an electronic copy of this report, please email Kim at kgormley@axys.net.

Sincerely yours,

Kevin A. Lloyd
for

Ricki Hurst
Chair, ESRF Project Advisory Team

and

Manager of Pipeline Preparedness,
Indian and Northern Affairs Canada

cc. Bob McLeod, Deputy Minister, Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories, Yellowknife, NT

Bonnie Gray, Chair, ESRF Board of Directors

Bobby Overvold, Regional Director General, Indian and Northern Affairs Canada, Yellowknife, NT

Duane Smith, Chair, Inuvialuit Game Council, Inuvik

Norm Snow, Executive Director, Joint Secretariat

Al Kennedy, Imperial Oil and ESRF Board

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Marty Bergmann, Fisheries and Oceans Canada

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The Project Advisory Team and the authors of this report would like to gratefully acknowledge the capable assistance of all of the delegates to the workshop in Inuvik. Particular thanks go the following individuals:

- Dr. Michael Lawrence of North/South Consultants Inc. who stepped into the project on short notice to cheerfully handle the Fisheries and Aquatics discipline.
- Dr. Wayne Pollard of McGill University who rearranged his schedule to provide senior authorship of the chapter on Permafrost, Soils, Surface Water and Groundwater.
- Mr. Michael Fabijan and Ms. Liz Swift who did all manner of things for all kinds of people.
- Mr. Billy Day, Inuvialuit elder, who gave the opening prayer, provided wise counsel to the whole group and gave closing remarks.
- Dr. Fred Roots, Emeritus Science Advisor to Environment Canada who took time out from his other recurring journeys to the Antarctic and Arctic to come to Inuvik. Fred provided invaluable material from his archives.
- Dr. Tom Beck, past-Chair of the Environmental Impact Screening Committee who took time away from working on his barn to make a post-retirement trip back to see his many friends in the Mackenzie Delta and bring good wishes from Dr. Ian McTaggart-Cowan.
- Mr. Hans Maurer of the Green Briar Dining Room who went out of his way to provide a fine banquet for workshop delegates.
- Mr. Roger Connelly and the Honourable Nellie J. Cournoyea who made special arrangements so that Nellie could welcome delegates to the Mackenzie Delta. Nellie is past-Member of the Legislative Assembly for Nunakput, past-Premier of the Northwest Territories and the President and CEO of the Inuvialuit Regional Corporation. Nellie said that any of the delegates who had not been working in Inuvik 30 years ago missed a good party!

Acronym List

2-D	two-dimensional
3-D	three-dimensional
BEMP	Beaufort Environmental Monitoring Project
BREAM	Beaufort Regional Environmental Assessment Program
CAPP	Canadian Association of Petroleum Producers
CCP	Community Conservation Plans
EC	ecosystem component
EIRB	Environmental Impact Review Board
EISC	Environmental Impact Screening Committee
ELC	ecological land classification
ESRF	Environmental Studies Research Fund
GHG	greenhouse gas
GSC	Geological Survey of Canada
IFA	Inuvialuit Final Agreement
IPCC	Intergovernmental Panel on Climate Change
ISR	Inuvialuit Settlement Region
MAGS	Mackenzie GEWEX Study
MBIS	Mackenzie Basin Impact Study
MEMP	Mackenzie Valley Environmental Monitoring Program
NHRI	National Hydrologic Research Institute
NOGAP	Northern Oil and Gas Action Program
NPS	inches in diameter
psu	practical saline units
SC	social component
TCF	trillion cubic feet
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

The current level of activity associated with the natural gas reserves of the Mackenzie Delta region is unprecedented. As much as 7000 km of 2-D seismic and 1000 km^2 of 3-D seismic was planned for the winter of 2000/2001 and more for 2001/2002 (KAVIK-AXYS and LGL 2001). The number and extent of seismic surveys has put pressure on Hunters' and Trappers' Committees and environmental review groups and raised concerns over potential cumulative environmental effects.

The delineation of existing discoveries will further increase activity, as will the drive to develop reserves on the Delta (e.g., the Parson's Lake, Taglu, Devon, Kurk and Niglintgak leases) and construct a pipeline to transport natural gas and natural gas liquids via Norman Wells to northern Alberta. All concerned parties, including local people, industry, federal and territorial government agencies, co-management boards, environmental non-governmental organizations and regional governments have been increasing their levels of preparedness to deal with the possibility of formal proposals for development.

If formal proposals are tabled, then regulatory authorities need to be confident they adequately understand the nature of both the proposed projects and the residual impacts after mitigation. There is, therefore, a need to forecast scenarios for development and anticipate the questions that environmental impact assessments (EIAs) will need to answer. The gaps in knowledge needed to evaluate these assessments must be filled now. These gaps include not just aspects of the ecology of the region but also gaps with respect to the availability and effectiveness of mitigation measures.

The specific objectives of this review as stated in the Request for Proposals from ESRF are to:

1. *document past and ongoing research in relation to the potential environmental impacts of natural gas exploration, development and gathering systems in the Canadian Mackenzie Delta and nearshore Beaufort Sea*
2. *review the current state of this knowledge in part by organizing, facilitating, and reporting on a workshop of key stakeholders which includes expert researchers, scientists and decision makers involved in northern natural gas development in the above geographic region*
3. *provide a report that summarizes information gaps and potential areas for further research that will enable a comprehensive assessment of natural gas exploration, development and gathering systems in the Canadian Mackenzie Delta and the near-shore Beaufort Sea*

This report is the result of a process that included preparation for a workshop, discussions at the workshop in Inuvik in January 2002, gap analysis, and review of comments on a draft report. The workshop brought together stakeholders that included scientific experts in a variety of fields, local people, interested parties and decision-makers. The prime purpose was to identify potential impacts to the environment and associated knowledge gaps. The workshop involved plenary sessions that provided overviews of development scenarios as well as breakout groups. Participants in the breakout groups identified potential impacts, mitigation measures and research and knowledge gaps for their particular discipline. All participants had the opportunity to review and comment on the draft report so that a final report could be submitted to the Environmental Studies Research Fund.

> *The renewed interest in the Mackenzie Delta means that we again need to look at the state of preparedness for development. Is there a need for a new process that builds on the success of BEMP, MEMP and BREAM?*
>
> Dr. David Stone
> Director, Northern Science and Contaminants Division
> Department of Indian Affairs and Northern Development

The EIAs that may be developed for the Mackenzie Delta region will provide answers to the questions associated with project descriptions on a local and regional scale. The purpose of this exercise is to anticipate these assessments, stimulate the inception of critical new work and identify knowledge gaps for questions that are beyond the terms of reference of EIAs from proponents.

This report is about information gaps associated with natural gas development in the Mackenzie Delta and the nearshore Beaufort Sea. This report is about natural gas exploration, development and gathering systems and the potential environmental impacts. The report is about research to determine and mitigate potential impacts; it is not about fundamental and basic scientific research.

Table 1 provides a summary of the potential impacts, mitigation measures and knowledge gaps by discipline. Each of the discipline chapters discusses the material in Table 1 in more detail.

There were three overarching considerations that came from this project as follows:

1. the urgent need to review the funding base for the Delta region
2. the need for processes that will ensure dialogue and collaboration among all parties who have a stake in the future of the Delta region
3. the recognition that the nature of industrial footprints are smaller and softer than they were in the past

Additional recommendations and conclusions are provided at the end of this report. Implementation of these recommendations will help all parties move forward.

> *Our scientific capacity with respect to the north is, frankly, not in good shape. Rising costs, and perhaps even more important, the need to devote scarce resources to urgent problems for immediate decision have meant that the carefully planned long-term research projects of DOE and other agencies have been seriously curtailed. This situation has meant that the number of highly qualified young scientists who can today enter on a career of northern research is distressingly low. It means, too, that there are formidable obstacles to the entry of native northerners, who have the potential to become leading environmental scientists, into our science programs.*
>
> From the Intervention by Dr. E.F. Roots, Science Advisor
> Department of the Environment to the Beaufort Sea
> Environmental Assessment and Review Panel, Ottawa, 1983

Table 1 Summary of Knowledge Gaps

Discipline	Potential Impact	Mitigation	Knowledge Gap
Climate Change	• potential changes to the distribution and abundance of all natural resources • effects of extreme weather patterns on gas development facilities • effects of flooding on projects • increased risk of fire • changes to sea level • changes to freezeup and breakup dates • melting of permafrost could cause lakes to drain and could cause more frequent landslides • increase in storm surges from the Beaufort Sea • thinning of Arctic sea ice • potential impacts of projects in combination with climate change on surface water; landscapes; emissions; permafrost; bank erosion and disruption of habitats	• lower emissions • conserve and sequester carbon	• monitor intensively both climate and the response of the ecosystem to increase the level of confidence in future scenario forecasting • identify the most appropriate global climate and weather models for use in the Delta Region • develop regional climate scenarios for the Delta Region at an appropriate scale • develop appropriate simulations for critical areas related to development • analyze past changes in climate, hydrology and terrestrial ecosystems using the instrumentation record, traditional ecological knowledge and various proxy data sets

Discipline	Potential Impact	Mitigation	Knowledge Gap
Air	• relative importance of long-range transport of air borne pollutants into the Delta Region vs. local sources • impact of increased airborne particulates on the timing and rate of snowmelt	• control emissions	• monitor air quality in and around the communities as well as at remote sites within the Delta Region • obtain information on the concentration of airborne contaminants and their loading into the local environment • obtain information on the concentration of airborne contaminants in the local environment due to temperature inversions and ice fog production
Permafrost	• the variable nature of permafrost creates a challenge for the stability of structures and facilities	• winter construction • consolidate footprint • chilled drilling muds • avoid sensitive areas • pipelines aboveground at 1.5 m	• identify and map key characteristics and spatial distribution of permafrost with focus on sensitive, ice-rich soils • monitor areas where the risk of effects of climate change on permafrost is high • continual monitoring of permafrost and ground-ice layers at potential near-shore development sites

Discipline	Potential Impact	Mitigation	Knowledge Gap
Soils	• removal of vegetation and modification of microclimatic variables that control ground thermal regimes • compaction of soil • disturbance and removal of soil layers • contamination	• effective waste disposal • reduce, reuse and recycle • re-inject waste materials into subterranean reservoirs • spill response plans including spill sheets and trays • avoid sensitive areas • consolidate development • directional drilling	• identify and monitor sensitive soils • develop a better understanding of effects of industrial development on permafrost • develop a better understanding of baseline weathering processes and nutrient cycling
Surface Water and Groundwater	• physical changes to the flow regime, channel processes, sediment load and ice cover • chemical changes associated with contaminants	• effective waste disposal and spill response • avoid sensitive areas • consolidate footprint • directional drilling • route selection	• monitor water quality • review and summarize existing water quality data • identify compounds that will be used by industry and their disposal processes • monitor water balances in sumps • identify and monitor sensitive watersheds
Vegetation	• effects of air emissions on sensitive vegetation such as lichens • loss of rare plants or rare plant communities • loss of plants of medicinal or nutritional value • cumulative effects of climate change on distribution and composition of plant communities	• optimize location and size of surface facilities • optimize duration, intensity and sequence of development activities • optimize reclamation potential • control access	• develop an integrated system for mapping vegetation

Discipline	Potential Impact	Mitigation	Knowledge Gap
Wildlife	• direct alteration or loss of habitat • habitat fragmentation • blockage or deflection of movements • change in wildlife populations from increased access and associated hunting • sensory disturbance • increased mortality from animal control actions and vehicle-animal collisions • cumulative effects of all human activities in the Delta region, particularly on resource use by beneficiaries of comprehensive claims	• control of garbage • prior identification and knowledge of critical habitats • construction during the winter season • improved, reevaluated and enforced harvesting regulations • prohibition on all feeding of wildlife	• develop a better understanding of the effect of increased access for predators including reference to lesser-known species of prey (beavers) and predators (wolverines) • develop a better understanding of the effects of climate change on vegetation • develop a better understanding of the effects of development on vegetation communities • develop ecological land classification maps • review current wildlife-human interaction training
Migratory Birds	• to be completed	• to be completed	• to be completed
Fisheries and Aquatics	• impacts of seismic energy on fish mortality and habitat use • impact of stream crossings on fish habitats • potential for creation of a frost bulb as a result of the transport of chilled gas • impact of sound from ice roads on distribution of fish • impact of increased access on fishing pressure • impacts of contaminants	• implement national guidelines to minimize the effects of seismic surveys • schedule and preplan activities to avoid important habitats during critical times of the year • complete avoidance may be necessary to ensure an isolated or important stock is not endangered • consider fishing restrictions • effective waste disposal, recycling and spill response	• map and identify critical fish habitat • investigate the impact of sound propagation from the use of ice roads • develop a more detailed understanding of the local hydrological table • investigate the effects of a pipeline on the freeze/thaw cycle stream bank soils • improve and increase the extent of water quality monitoring

Discipline	Potential Impact	Mitigation	Knowledge Gap
Oceanography	• alteration and disruption of normal physical processes • changes in chemistry of the receiving environment • alteration and disruption of the formation patterns and physical characteristics of river and sea ice • compaction and disruption of near-shore bottom sediments • changes in chemical makeup of bottom sediments	• application of pollution control equipment to specification • band the discharge of oil-based cuttings • monitor accumulation of contaminants in sediments on the ocean floor	• quantify level of contaminants in sand and gravel from abandoned artificial islands and berms • determine the ecological significance of seabed gravel deposits • determine potential impacts of a variably-stable shoreline on project infrastructure • assemble information to determine the effects on ice on foundation berms and gravel causeways
Marine Mammals	• sensory disturbance to marine mammal species from seismic studies and increased development activity • displacement from habitat due to increased activity and increase noise levels • an increase in the number of human/polar bear interactions • localized oil spills on polar bears • interference and disturbance of coastal denning sites for polar bears	• best management practices that include ramping-up procedures for seismic surveys and safety zones around vessels • effective waste control • educate workers regarding safety in bear country and enforced environmental guidelines • detection and deterrent systems for polar bears	• develop a better understanding of the impact of seismic studies on hearing abilities of beluga whales • develop a better understanding of the impact of vessel traffic on the movements of beluga whales • develop a better understanding of the impact of climate change on sea ice and its subsequent effects on ringed seal populations

Discipline	Potential Impact	Mitigation	Knowledge Gap
Biodiversity	• exposure to pollutants or man-made materials • exposure to a single and potentially hazardous anthropogenic event • localized disturbances of habitats that are under-represented on the landscape • small disturbances that could impact large concentrations of a single species	• best environmental management practices	• review recent environmental impact assessments in the north • examine and investigate suitable reclamation techniques for Arctic ecosystems • develop an ecological land classification system for the Mackenzie Delta and upland areas
Resource Use	• potential effects on future hunting, trapping, fishing, whaling, herding and non-consumptive recreation • increased travel time to traditional hunting or fishing areas • decrease in number of animals harvested • changes to community culture • perception of human-caused changes to the landscape	• review regulations	• map resource use • incorporate traditional ecological knowledge into characterization of resource use (e.g., levels and type of use) • review Inuvialuit harvest studies to update and expand based on more recent information and map information at a finer spatial scale • develop harvest quotas • understand the implications of structures associated with natural gas developments to people traveling in the Delta region • identify land use categories from the community conservation plans and their attributes for any given parcel of land or water

Discipline	Potential Impact	Mitigation	Knowledge Gap
Cumulative Effects	• changes in air quality • effects on waterbodies • contaminant effects on human health • sensory and habitat effects on wildlife • changes in harvesting patterns due to changes in access • sensory disturbances to people using the region (e.g., light, noise, odour and viewshed)	• to be completed	• develop a regional database comprehensive maps • develop an adaptive assessment, review and follow-up process • develop a regional effects management strategy • develop a clear process to incorporate traditional ecological knowledge into cumulative effects assessments • define roles and responsibilities clearly among all players • develop guidelines for assessing and managing cumulative effects

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Opening Remarks by The Honourable Nellie Cournoyea, Chair and CEO, IRC

It is my pleasure to welcome all of you to Inuvik this evening. I understand that this workshop has been put together to look at the key research gaps that may be associated with the development of the natural gas reserves of the Delta.

I am sure that you can appreciate that the development of the natural gas reserves of the Delta is of critical importance to the future of the Inuvialuit. Many of us worked long and hard to negotiate a land claim that would ensure that Inuvialuit would be meaningful participants in Canadian society. We will be meaningful participants with respect to our participation in the range of benefits that will come from gas developments. We will also influence the terms and conditions that will govern industrial developments in this region.

I am pleased to see representatives of the institutions established by the Inuvialuit claim here this evening. I note that the Screening Committee and Review Boards are represented as well as the IGC, WMAC and FJMC.

I am pleased to see that Industry will be making presentations to this workshop. I note that the representatives of industry include Imperial, Shell, Petro-Canada, Devon and Conoco.

I am, of course, heartened by Imperial Oil's announcement on behalf of the Canadian Producers that this group has made a formal decision to proceed to the project definition stage in partnership with the Mackenzie Valley Aboriginal Pipeline Corporation.

I look to undustry to design and implement best practices that will minimize adverse impacts on the land. I do not need to remind you that the subsistence economy is vital to the people of this region; you must do everything that you can to see that development does not unduly compromise the subsistence economy.

I know that you will have interesting discussions over the next two days and I look forward to reading your report.

I have been advised that there are a large number of government officials here from both the territorial and federal governments. I know that you are all working hard to prepare your Departments to ensure a timely review of any applications for development that may be coming forward in the not too distant future.

I hope that all of you who are from out of town will take the time to listen carefully to the Inuvialuit elders who will be participating in this workshop with you. The elders have valuable information to share.

Some of the issues that you will be discussing include climate change as well as the potential effects of development on beluga, caribou, ducks and geese. I remember the people who were studying these issues in years gone by. I remember Tom Barry, Jimmy Bourque, Ian Stirling and Ian McTaggart-Cowan when they first coming up here to do their studies. We have learned a lot about the Delta and there is a lot more to learn. The potential effects of climate change are worrisome to the people in communities like Sachs Harbour. We have learned a lot, and yet, in many cases, the research studies have just confirmed what the elders already knew. I encourage you to design your future studies in collaboration with the people from the HTCs.

I wish you success in your deliberations. I trust that you will enjoy your stay in Inuvik. Thank you very much.

1 Introduction

> *This gathering will help shape the focus of future environmental research in the Mackenzie Delta and Beaufort Sea area.*
>
> Mr. Ricki Hurst
> Manager of Pipeline Preparedness, INAC, Yellowknife

1.1 Development of Natural Gas Reserves in the Mackenzie Delta

The level of exploration and development of natural gas reserves in the Mackenzie Delta region is unprecedented. During the winter of 2000/2001, over 7000 km of 2D seismic and 1000 square kilometres of 3D seismic were completed in the Mackenzie Delta region. Similar high levels of activity continued during the winter 2001-2002. A number of exploration drilling projects have been completed on land and four exploratory wells are proposed in the nearshore Beaufort Sea.

A number of natural gas pipeline projects have been proposed to transport natural gas and natural gas liquids from the western Arctic to southern Canada and the United States. The Arctic Gas Pipeline project has filed a project information package with the National Energy Board to build a natural gas pipeline from Prudhoe Bay to the Mackenzie Delta and then down the Mackenzie Valley to Alberta. The Mackenzie Gas Project is conducting environmental and engineering studies to develop natural gas reserves on the Delta (e.g., the Parson's Lake, Taglu and Niglintgak leases), and construct a pipeline to transport natural gas and natural gas liquids via Norman Wells to northern Alberta. The Alaska Gas Producers have recently completed a feasibility study to construct a natural gas pipeline from the North Slope of Alaska to the Mackenzie Delta, then south along the east or west side of the Mackenzie River to Alberta and, ultimately, Chicago.

The number and extent of seismic activities and exploration drilling programs have put pressure on the regulatory agencies and raised concerns over potential cumulative effects. Given that the startup of field production facilities in the Mackenzie Delta and the construction of a pipeline along the Mackenzie Delta is not likely before 2006 or 2007, this is an ideal time to review the state of knowledge on the potential for associated environmental impacts and the range of mitigation measures for reducing or eliminating them. A comprehensive review of the existing information and systematic analysis of the data gaps eliminates the risk of "reinventing the wheel" and ensures that the most important research gaps receive priority attention.

1.2 Challenges Facing Industry and Government

All concerned parties, including industry, federal and territorial government agencies, co-management boards and regional governments, have recognized they need to increase their levels of preparedness to deal with the possibility of formal applications for development.

> *We are relying on Industry to design and implement best practices in the Inuvialuit Settlement Region that will strive to reduce negative impacts on the environment.*
>
> The Honourable Nellie J. Cournoyea
> President and CEO, Inuvialuit Regional Corporation

Regulatory agencies need to be confident they adequately understand the nature of both the project being proposed and the nature of the residual impacts after mitigation. Therefore, there is a need to forecast scenarios for development and anticipate the key questions that will need to be addressed in environmental impact assessments. The questions relate to not just the ecology of the region but also the availability and potential effectiveness of new mitigation measures.

During the preparation of this report, the concerned parties highlighted three requirements in facing the challenge of moving forward:

1. dialogue is critical
2. existing information must be used well
3. additional work must be undertaken if environmental assessments are to proceed in a timely manner. This work will require funding that is supplemental to the existing, approved budgets of the co-management boards, the Government of the Northwest Territories, Environmental Studies Research Fund, non-government organizations and the federal government;

Dialogue is critical. Although this obvious point has been made repeatedly, people seem to need to be reminded constantly that effective communication requires sustained effort as well as good will. As evidenced by this workshop, dialogue among disciplines always adds value to end products. The climate change experts need to be working with local hunters, trappers, fishermen and whalers and, in turn, these people need to be working with the marine mammal people and so on. Dialogue is critical for effective land use planning at the local level.

> *Long term protection of ecosystems can best be achieved through active communication and co-operation of all parties concerned, including the combination of renewable resource and land management activities.*
>
> Principle Number Three from the Inuvialuit Renewable Resource Conservation and Management Plan (IRRCMP 1998)

All stakeholders need to get involved in the planning process for new projects early in the game. The earlier that industry knows of potential constraints, the more freedom they have to adjust their environmental management systems to accommodate the interests of the communities with respect to the conservation of natural resources. Similarly, the earlier that natural resource managers know about the preliminary footprints proposed by industry, the more they can do to help promote win-win solutions. Members of the Environmental Impact Screening Committee and the Environmental Impact Review Board are in a position to make site visits to proposed development sites with health, environment and safety staff from industry to discuss plans for development in the field. Industry is in a position to review the location, size, duration, intensity, sequence, reclamation potential, associated access and access control options.

Good use of existing information is also critically essential. The results of the Northern Oil and Gas Action Program (NOGAP), Beaufort Environmental Monitoring Project (BEMP), Mackenzie Valley Environmental Monitoring Program (MEMP) and Beaufort Regional Environmental Assessment Program (BREAM) need to be carefully reviewed by individuals proposing new research. Proposals for new work need to be vetted by the communities. In addition, there is a need for a process that will ensure that the results of the studies done at Prudhoe Bay are made available to all concerned.

> *Some aspects of the Mackenzie Delta are unique. At the same time, we need to recognize that many of the environmental issues associated with the Mackenzie Delta have been studied to death at Prudhoe Bay. There have been hundreds of millions of dollars spent answering many of the questions that regulators will have about the Mackenzie Delta.*
>
> Dr. Steve Johnson, Senior Vice-President
> LGL Environmental Research Associates, Sidney, BC

To ensure future endeavours are successful, funding allocations for the next five years need to be seriously reviewed at the level of Deputy Minister, Regional Director General, CEO, Board Chair, Environmental Studies Research Fund Chair and NGO President. This should also be done collaboratively among these individuals and others at their level.

1.3 Report Objectives

To assist government agencies and industry in preparation for the regulatory review of potential natural gas developments in the Mackenzie Delta, the Environmental Studies Research Funds (ESRF) and Indian Affairs and Northern Development Canada initiated a study to identify important information needs relevant to the assessment of potential effects of natural gas development on the environment and harvesting in the Mackenzie Valley region, and the mitigation of these effects. The ESRF's Board of Directors set the following objectives for the study:

1. Document past and ongoing research on the potential environmental impacts of natural gas exploration, development and gathering systems in the Mackenzie Delta and near-shore Beaufort Sea;
2. Review the current state of this knowledge in a workshop of key stakeholders, which includes expert researchers and scientists, decision makers, co-management agencies, local communities and industry

3. Based on the analysis of past and ongoing research and the results of the workshop, identify the information gaps and potential areas for research that will facilitate comprehensive assessment and mitigation of environmental impacts.

KAVIK-AXYS Inc. were contracted to convene the workshop of stakeholders (held in Inuvik in late January 2002) and to prepare this followup report. KAVIK-AXYS formed a project team made up of KAVIK-AXYS staff and individuals from the following companies:

LGL Limited Environmental Research Associates

North/South Consultants Inc.

Salmo Consulting Inc.

McGill University

The National Hydrology Research Institute

1.4 Environmental Studies Research Funds

ESRF is a research program that sponsors environmental and social studies designed to assist the decision-making process related to oil and gas exploration and development on Canada's frontier lands. Initiated in 1983, the ESRF receives its legislative mandate through the *Canadian Petroleum Resources Act,* which was proclaimed in February 1987. Funding for the ESRF is provided through levies on frontier lands paid by interested holders such as the oil and gas companies. The ESRF is directed by a joint government-industry-public management board and is administered by a secretariat, which resides in the National Energy Board office in Calgary, Alberta.

1.5 Existing Related Information

KAVIK-AXYS Inc. and LGL environmental research associates have already produced a general overview of the key issues and data gaps for the Mackenzie Delta and nearshore Beaufort Sea (KAVIK-AXYS and LGL 2001)[1]. In addition, Truett and Johnson (2000) recently completed a comprehensive review of the ecological research associated with the Prudhoe Bay oil and gas field development and effects on the biophysical environment.

[1] This report can be viewed under the library tab at www.axys.net.

In addition, during late 2001 and early 2002, the boards and agencies responsible for environmental assessment and regulation in the Northwest Territories (NWT) developed draft guidelines on how a cooperative environmental assessment and regulatory review of a northern gas pipeline project in the Northwest Territories might be conducted. Following release of a draft cooperation plan in March 2002 and public and agency review, a final cooperation plan was developed. The Final Cooperation Plan was publicly announced in late June 2002 in Inuvik.[2]

[2] This report can be viewed at www.mveirb.nt.ca.

2 Project Methods

2.1 Project Advisory Team

Indian and Northern Affairs Canada established a Project Advisory Team (PAT) to oversee the work of the consultant group. Membership on PAT included representatives of industry, government and the co-management boards established by the *Inuvialuit Final Agreement.* The organizations represented on PAT included:

- Indian and Northern Affairs Canada as Chair (R. Hurst and R. McKechnie)
- Joint Secretariat (N. Snow)
- Fisheries Joint Management Committee (R.K. Bell)
- Devon Canada Corporation (P. Millman)
- British Petroleum (C. Pyc)
- Government of the Northwest Territories Department of Resources, Wildlife and Economic Development (R. Case)
- Environment Canada (S. Harbicht)
- Fisheries and Oceans Canada (J. Dahl)
- Canadian Arctic Resources Committee (K. O'Reilly)

2.2 Workshop Preparation

Under the direction of the Project Advisory Team, a workshop of stakeholders in Inuvik was convened as the primary mechanism to identify information gaps. Prior to the workshop, participants were provided with:

- an overview of the likely development scenario for natural gas production in the Mackenzie Delta region
- briefing notes on the ecosystem components of the Delta region and the types of environmental effects that could result from development as it is described in this report

2.3 Process to Identify Knowledge Gaps

2.3.1 Process

A rigorous process was developed to help ensure that the workshop focused on the identification of knowledge gaps that are specifically associated with the assessment and mitigation of effects associated with natural gas development in the Mackenzie Delta region (Figure 2-1).

To identify knowledge gaps, it was necessary to simultaneously consider two types of information:

1. the activities that are likely to occur during the planning, construction and operation of natural gas development in the Mackenzie Delta region
2. the probable responses of the biophysical environment and resource uses to these activities

As shown in the left-hand column of Figure 2-1, we need to address what we currently know about the natural state of ecosystem components and resource use, as well as how these components may respond to specific human activities associated with natural gas development. It is important at this stage to focus on the essential information needs for understanding ecosystem responses; that is:

- What do we need to know about the baseline state of the physical environment, a species, a biological component or function, or a resource use to enable us to assess and quantify changes that may result from an industrial or human activity associated with natural gas development in the Mackenzie Delta region?
- How will the physical environment, a species, an ecosystem component or function, or a resource use change in response to an industrial or human activity?

> *It is essential that we ensure there is scientific rigor in this process. We learn by developing hypothesis and testing them to acquire knowledge. This saves you from collecting vast amounts of data. If you fail to reach this stage then you will have to continue to go on and on, collecting more and more information.*
>
> Dr. Hunfrey Melling, Research Scientist, Fisheries and Oceans Canada

Concurrently with this process, the analysis of knowledge gaps required a clear understanding of the probable development scenario for natural gas in the Mackenzie Delta. From this, the project activities were identified that are most likely to affect the biophysical environment and resource use, as well as the details of the activity (e.g., location, timing and duration of activities, numbers of people, amount and type of emissions and effluents, water requirements) required to assess and quantify effects. In some cases, additional or more detailed information was required to allow adequate assessment of effects and development of mitigation approaches. In some cases, there was also a need to clarify specific processes or activities to better understand any resulting environmental effects.

Once information needs regarding environmental knowledge and the effects of industrial development were identified, then the gaps in knowledge required to assess potential effects and mitigation were determined. The output from this step was essentially the desired end point for each of the breakout groups at the workshop.

To delve into the issue of knowledge gaps, the following key questions were reviewed:

1. What knowledge gaps exist?
2. What is it that we do not understand?
3. Are we talking about research gaps or information gaps (both are subsets of knowledge gaps)?
4. What do we know already?
5. What else do we need to know to assess and manage potential effects?

> *Scientists think they are always right just because they have their information in writing. Well, they are not always right. David Stone and David Thomas have said that scientists have gotten it wrong sometimes. The Inuvialuit have all kinds of valuable information about the environment that is valuable; it is not al written down – this has to come together somewhere – maybe you should talk to us more.*
>
> Billy Day, Inuvialuit Elder
> Member of the Environmental Impact Screening Committee
> Member of the Fisheries Joint Management Committee

2.3.2 Evaluation Matrices

To aid workshop participants in systematically addressing knowledge gaps, a set of matrices were prepared for each of the major development activities (e.g., seismic exploration, exploration drilling, production areas) for the breakout groups to complete. In the first column of the matrix, the potential effects for each discipline area that could result from that activity were to be identified. In the remaining columns, the following details for each effect were then to be provided:

- **Environmental Management System or Accepted Best Practice:** What is our current ability to mitigate or manage the effect (e.g., how, how effective, certainty of effectiveness)?
- **Probable Degree of Concern:** With mitigation, is this effect likely to result in changes to the ecosystem component or resource use that would be of concern to regulators, communities, resource managers or researchers?
- **Information Requirement:** What information do we need to effectively assess the effect? (This could include: information on the current state of the ecosystem component or resource use, the response of the ecosystem component or resource use, or information on the industrial or human activity [e.g., better quantification of an activity])
- **Methods Needed to Obtain Information:** A brief description of how the information needs might be fulfilled.

Acetate versions of these matrices were provided to the facilitators for each of the breakout groups. These matrices were provided as guidelines only and not all breakout groups chose to use them in a systematic way because they preferred to have a more general discussion.

2.4 Inuvik Workshop

A workshop was held in Inuvik on January 24 to 26, 2002. The objective of the workshop was to identify the knowledge gaps associated with natural gas development in the Delta region.

A goal of the workshop was to strongly focus the analysis on information that is required to better understand ecosystem responses to industrial activities, and allow accurate prediction and quantification of potential effects, as well as management of these effects through refined project designs and mitigation. A second goal of the workshop was to tie the information needs directly to the assessment and management needs of regulators, agencies, directly affected stakeholders and industry.

2.4.1 Participants

Representatives of industry, land claim organizations, government, regulatory agencies and environmental non-government organizations were invited to participate in the workshop. A list of the people who participated in the workshop is provided in Appendix A.

Land claim organizations were invited to send representatives from local communities, as well as representatives of their organizations and co-management agencies. While some community representatives did attend the workshop, concerns were expressed that too few community representatives were present and, as a result, information needs associated with local knowledge were not adequately addressed.

> *I am disappointed at the lack of representation from the communities at this workshop.*
>
> Mr. Billy Day, Inuvialuit Elder
> Member of the Environmental Impact Screening Committee
> Member of the Fisheries Joint Management Committee

2.4.2 Breakout Groups and Discipline Leads

PAT agreed to hold a plenary session in combination with five breakout groups organized into the following groups of environmental disciplines:

- Group 1: Air and climate change
  Physical and chemical oceanography
- Group 2: Soils, terrain stability and permafrost
  Water and waste management
- Group 3: Fisheries and aquatics
  Marine mammals (including polar bears)
- Group 4: Terrestrial vegetation, wildlife and biodiversity
  Migratory birds
- Group 5: Resource Use
  Cumulative effects

Lead persons for the various environmental disciplines were designated to lead these discussion groups at the workshop.

While an effort was made to invite a wide range of expertise in both local knowledge and western science for all subject areas, as a result of the range of individuals who actually attended the workshop, there was considerable variation in the depth of expertise for certain subject areas. In some cases, several individuals expert in both local knowledge and western science were available in the same group (e.g., marine mammals). In other breakout groups, few or no experts were present (e.g., water quality). The availability of expertise in each breakout group had a direct effect on the ability of that group to discuss existing information and issues and, ultimately, to identify important information gaps.

2.4.3 Workshop Overview

The agenda for the Inuvik workshop is provided in Appendix B. The workshop began on the evening of January 24, 2002 and ended in the afternoon on January 26, 2002.

During the first evening, presentations were given on the overall objective of the workshop, an historical overview of past information gap analyses, and the probable development scenarios for natural gas in the Mackenzie Delta region. On the second day, participants were tasked with assessing knowledge gaps specific to the topic areas of their breakout groups. On the third day, each breakout group reported back to the plenary session. On the afternoon of the third day, several participants were asked to bring together the recommendations from each group to aid in the development of an action plan for knowledge gaps.

Historical Overview

This gap analysis is not the first to be conducted for the Mackenzie region. Considerable effort was made during the 1980s through to the mid-1990s to identify potential effects and the types of information that would be required to assess these effects (e.g., Northern Oil and Gas Program, Mackenzie Environmental Monitoring Program, Beaufort Environmental Monitoring Program, Beaufort Regional Environmental Assessment and Monitoring Program). To assist workshop participants in better understanding what previous exercises had been completed and the key conclusions from these exercises, Dr. David Stone provided a historical overview of previous information gap analyses. Key information from this presentation is provided in this report.

Development Scenarios

To assist workshop participants in clearly understanding the types of activities that are likely to occur during the planning, construction and operation of natural gas facilities in the Mackenzie Delta region, the following presentations were made at the workshop in Inuvik:

- an overview of industry's plans by Ian Scott of the Canadian Association of Petroleum Producers
- an overview of geophysical exploration and exploration drilling by Mr. Peter Millman of Devon Canada Corporation
- an overview of development, production and transportation by Mr. Terry Antoniuk of Salmo Consulting Inc. functioning as a consultant to Conoco Canada Resources Ltd.

A synthesis of these presentations appears in this report.

Assessment and Identification of Knowledge Gaps

Following a presentation on the process for identifying information gaps, participants adjourned to specific breakout groups for the remainder of Day 2. Each breakout group began with a presentation by the discipline leads on their area(s) of concern to set the stage for the systematic identification of knowledge gaps.

During the morning session of Day 2, each of the breakout groups reported back to the plenary session. Each group was asked to focus on the most important information needs identified by their group, the rationale for these information needs, and the general approach(es) required to address the information gap.

During the concluding session on the afternoon of Day 2, the plenary group was asked to help integrate the multiple information needs from the five breakout groups. A number of common information needs from the various biophysical and resource use disciplines were identified (Section 15.1). No attempt was made to prioritize the multiple information gaps developed by all of the groups. Following this discussion, a presentation was made by Ruth McKechnie describing how information from the workshop would be used to develop an action plan. The afternoon session ended with concluding remarks from Billy Day, David Stone and Tom Beck.

2.5 Presenting and Reviewing Results

After the workshop, the consulting team was tasked with summarizing the discussions of each of the breakout groups, as well as the plenary discussions on knowledge gaps and the action plan. This involved:

- acquiring the summary notes and completed matrices from each of the leads and/or recorders for each of the breakout groups
- editing, updating or completing briefing notes on potential effects and important baseline information for each subject area. Of note, prior to the workshop, not all discipline leads for all subject areas were available to complete their required briefing notes. As a result, some briefing notes had to be developed by the consulting team to complete the summary report.
- documenting the important background information on each subject area (based on the briefing notes), the types of effects that could result from the expected industrial and human activities associated with natural gas

development, and the probable responses of the environment and resource use to project-specific effects and cumulative effects

- documenting the results of the information gap analysis from each of the breakout groups. This was typically the responsibility of the discipline lead; however, due to time constraints or conflicts of several discipline leads alternative individuals had to prepare the written text
- summarizing the information gaps that were common to many of the discipline groups

Delays in the receipt of materials and the need to find alternative leads to prepare specific subject materials resulted in a longer completion period for the report.

Once the draft report was completed, all participants in the workshop had the opportunity to review and comment on the draft before the final report[1] was submitted to the Environmental Studies Research Fund.

In presenting this information, it is understood that a number of proponents may be advancing EIAs for their proposed projects. These EIAs may include baseline studies that will fill the information gaps for some regional areas such Parson's Lake, Kurk, Taglu and Niglintgak, where leases are held and projects may develop. Devon Canada is also completing baseline studies and an impact assessment for offshore exploration drilling in the nearshore Beaufort Sea adjacent to the Mackenzie Delta. Baseline studies for the Mackenzie Gas Project have also been underway since May 2001 and are ongoing, with a focus on the north Mackenzie Delta and the Parson's Lake area. The EIA for this project is likely to be submitted in late 2003. A number of baseline surveys were also completed by the Alaska Pipeline Group (primarily along the Yukon North Slope and the western Mackenzie Delta).

Government agencies such as Fisheries and Oceans Canada and co-management boards such as the Fisheries Joint Management Committee have identified research questions for the Delta region and are continuing studies to answer these questions. PAT is mindful of the fact that long-term budget planning is currently being conducted by most of the stakeholders involved with the development of this report.

[1] This final report is posted on the web at www.esrfunds.org.

The information for each environmental discipline is organized where possible in the following categories:

- Chapter Overview
- The Nature of the 'Ecosystem (or Social Component', when appropriate)
- Response of 'Ecosystem or Social Component' to Disturbance
- Mitigation
- Knowledge Gaps

Additional categories have been added where necessary to adequately present the subject information.

3 Historical Context

Late summer 1969: The hunter was on the land with his family, hunting in an area of the Mackenzie Delta where his ancestors had hunted for generations. White whales had been sighted and the ensuing days had become a time of celebration and harvest. The annual hunt had secured meat for local residents for many years and it continued to be an important part of the Inuvialuit yearly cycle.

As he set out across the bay, a new horizon spread before him. No longer were there just the annual two or three sealift ships, as there had been at this time of year for as long as he could remember. Instead, a regular procession of ships and barges inched east and west.

There had been changes in the region over the past few years. Large planes now arrived and departed frequently at the community airstrip. Vessels anchored offshore in the summer months and transferred heavy equipment to onshore staging areas. Helicopters moved through the sky year-round, back and forth between the town and the delta.

Since 1961, when Gulf Canada had pushed through its first exploratory well in the region, the hunter had heard rumours of large oil and gas reserves beneath the delta and the seabed. On that late summer day in 1969, the hunter and his family were seeing the initial stages of the quest to locate the large hydrocarbon reserves that were thought to exist throughout the Mackenzie Delta and the southern Beaufort Sea. The helicopters, vessels and ships that were moving throughout the area were a manifestation of industry's feverish desire to map, drill and extract these reserves.

By 1970, Imperial Oil had found at Atkinson Point on the Mackenzie Delta what everyone had been looking for — oil. By the mid 1970s, local residents noted more activity in the region, and the local gossip centred around the three unusual looking ships that had arrived in the region — offshore drillships. No longer was exploration restricted to islands and onshore areas. Efforts were being made to drill offshore wells and explore the seabed for oil.

To further the development boom in the region, the Mackenzie Valley was being considered as a potential route for a pipeline that would transport oil and gas to the southern markets. Both the Foothills Pipeline and the Arctic Gas Pipeline identified the valley as part of their proposed route. Residents up and down the valley spoke of jobs and prosperity.

For such a project to proceed, the Berger Inquiry was established to investigate the feasibility of building a pipeline through the valley. By 1977 though, the inquiry had recommended that pipeline construction be delayed for 10 years and the proposed section connecting the Alaskan North Slope to the Mackenzie Delta region not be built at all.

In the early 1980s, the region saw the construction and operation of 22 artificial offshore islands in deep water. More offshore wells had been established by drillships. At the same time, a consortium of oil companies released the Beaufort Sea Mackenzie Delta Environmental Impact Statement. This report emphasized the demand for regional development and outlined possible development. It also touched on concerns that local residents had been voicing since development had begun in the region — the potential impacts of development on the environment and its residents.

As development continued in the region through the 1980s, oil fields such as the extensive Amauligak find by Gulf Canada were located. At the same time, industry and government established a cooperative funding program in 1984 with the name Northern Oil and Gas Action Program (NOGAP). Its goal was to fund research related to oil and gas technology and the environment. In the mid 1980s, world oil prices and demand were on the decline. It was also becoming apparent that the high expectations for a large number of oil reserves in the Mackenzie Delta and southern Beaufort Sea were not being met. As oil exploration efforts slowed in response to this decline, interest in gas reserves in the region increased due to a renewed demand. A second stage of NOGAP was initiated, and $10 million of funding became available. Export and development licenses were granted to Gulf Canada, Shell Canada and Esso Resources.

On Thursday, March 23, 1989 at 12:01 am, the nature of oil and gas development in the Arctic changed forever. The Exxon Valdez ground its hull onto Bligh Reef in Prince William Sound in Alaska and released 10.8 million gallons of crude oil into the surrounding marine ecosystem. Confidence in the idea that oil and gas from the North American Arctic could be developed and marketed in a sound and clean manner faded. Overnight, the world was exposed to the realities of a large-scale Arctic oil spill, and coastal residents were to feel its effects in many ways for years to come.

As the 1990s began, a number of large natural gas reserves had been found in the Mackenzie Delta. A surplus in southern fields though, would make them economically unviable. Low world oil prices and the lack of large oil reserves in the Mackenzie Delta region limited the feasibility of oil development in the region. Consequently, NOGAP funding was terminated.

Throughout the 30 years of development in the region, environmental research had only begun to increase in intensity in the late 1970s. With the release of the Beaufort Sea Mackenzie Delta Environmental Impact Statement in 1982, environmental concerns came to the forefront. This report and the fast pace of development made the government of Canada starkly aware of the concern that local residents had been voicing for years: the need for a monitoring process that would evaluate the potential impacts of hydrocarbon development on the environment.

A research program was needed that would identify the impacts of oil and gas development on valued ecosystem components. Specifically, this program would address environmental issues for which there was little baseline information or where impact mechanisms were poorly understood.

Consequently, the Beaufort Environmental Monitoring Project (BEMP) was conceived in 1983 by the Departments of Environment and Indian Affairs and Northern Development. At its inception, the long-term goal of this program was: "To provide the technical basis for design, operation and evaluation of a comprehensive and defensible environmental research and monitoring program to accompany hydrocarbon development activities in the Beaufort Region". To meet this goal, BEMP would have to:

- determine the most significant environmental resources and features likely to be affected by development
- formulate and test impact hypothesis
- recommend mitigation measures and provide ongoing evaluations of their success

- adapt to new information, identified gaps and changes in the most likely scenarios for hydrocarbon development (INAC and Environment Canada 1984)

As a result, 21 impact hypotheses were established, and 19 of them were fully evaluated. Throughout the five-year span of BEMP, changes were made to the impact hypotheses to accommodate the consideration of oil-based drilling muds, the effects of westward tanker traffic and concerns for bowhead whales.

As the potential for a Mackenzie Valley Pipeline grew, it was deemed necessary to implement a similar monitoring program that would address the development and transport of hydrocarbons through the valley. Following the same approach as BEMP, the Mackenzie Valley Environmental Monitoring Project (MEMP) was initiated in 1985 and ran until 1987. Through its duration, 25 impact hypotheses were identified and developed.

By the late 1980s, a number of things had changed in the region since the inception of BEMP and MEMP. By the end 1989, the north had witnessed the reality of a large-scale oil spill. Companies were no longer going it alone, but forming joint ventures and proposing extensive development and transportation scenarios.

Land claim negotiations in the Beaufort region that had run through the 1970s, were finally settled with the Inuvialuit Final Agreement in 1984. As a result of the settlement, not only were the Inuvialuit given title to almost 35,000 km^2 of land, there was the formation of a number of environmental comanagement boards. These included the Wildlife Management Advisory Council (Northwest Territories and Yukon), the Fisheries Joint Management Committee, the Environmental Impact Screening Committee, and the Environmental Impact Review Board. With these organizations in place, industry would be more accountable for their development plans and activities, and the potential impacts that they might have on the environment.

Many of the other native groups that inhabited the Beaufort Sea region and the Mackenzie Valley had tabled similar claims. For many of these groups, these settlements were a priority before any development proposals would be considered. Government and local communities had formally recognized the value of traditional ecological knowledge in environmental monitoring, and its inclusion was now an essential part of the process. Global warming and cumulative effects were two new issues that had come to bear on the potential impacts of development. In the northern context, their impact was poorly understood, and they had to be considered in light of any development projects. Because of these changes, a new environmental monitoring process was proposed, and it would build upon the work and information that had been gathered from BEMP and MEMP. The Beaufort Regional Environmental Assessment Program (BREAM) was initiated in 1990 and ran until 1994. The BREAM process reevaluated the impact hypothesis of BEMP and MEMP and eventually established 32 impact hypotheses. Much of the work of BREAM was focussed on the effects of catastrophic oil spills and their impact on harvestable resources and the environment.

Through 10 years of environmental monitoring, and the ensuing MEMP, BEMP and BREAM processes, there were a number of unique and credible components that made these programs successful. All the programs involved a cooperative workshop approach that included representatives from government, industry and local communities. Not only did this provide neutral ground for discussion, it allowed for the identification and monitoring of issues that were of greatest concern to all participants. The valued ecosystem component approach focused discussions and research priorities. These discussions and workshops enabled an iterative and flexible process that constantly reviewed the hypotheses and made an effort to incorporate new research and information. The result was rigorous decision-making that involved all participants.

However, there were criticisms of all three programs. Community representatives felt that more time and effort should have been directed at addressing the social impacts that might have resulted from development scenarios. It was felt that little had been done to answer the uncertainty of the social and economic implications of such large-scale developments in the region. It had also been noted that because of the comprehensive and detailed nature of all three programs, they were inherently slow and cumbersome.

The NOGAP, MEMP, BEMP and BREAM processes have provided extensive information with regards to the potential impacts of development on the environments of the Beaufort Sea and Mackenzie Delta region. These programs were built upon a sound framework of inquiry and have provided for the participation by all concerned parties. As the demand for hydrocarbons increases worldwide, industry, governments and the consumers of North America are again turning to the Beaufort Sea and Mackenzie Delta region for a viable answer. In light of this, and a heightened awareness worldwide about the environment, there is the need to proceed cautiously with effective environmental assessment and monitoring programs for the region. However, this should not be done exclusive of the foundation of information and processes that have been laid down by the NOGAP, MEMP, BEMP and BREAM programs. A critical eye is required to evaluate the information and processes that exist and to take decisive actions in making the best possible use of this body of work for future and ongoing environmental monitoring efforts in the region.

4 Development Scenario

To identify the potential effects of natural gas development on the environment of the Mackenzie Delta region and near-shore Beaufort Sea, it is first necessary to understand the nature of the potential projects. This chapter describes the probable scenario for the development of natural gas reserves of the Mackenzie Delta.

The following summary of past and potential natural gas exploration and development in the Mackenzie Delta and near-shore Beaufort Sea region (Delta region) is based on a submission prepared by the Canadian Petroleum Association (now Canadian Association of Petroleum Producers [CAPP]) for the Beaufort Sea – Mackenzie Delta Land Use Planning Commission (Owens 1988). This summary has been developed with the assistance of representatives of Conoco Canada Ltd. and Devon Canada Corporation.

The proponents of development in the Mackenzie Delta region are committed to the application of best practices to their projects. Advances in technology such as directional drilling have increased industry's flexibility with respect to some aspects of their proposed operations. Representatives of industry at the Inuvik workshop in January 2002 expressed interest in a dialogue with stakeholders that identifies environmental concerns sooner rather than later. The early identification of concerns allows industry to consider the full range of options that can be used to reduce and mitigate potential impacts.

> *We should be careful not to beat ourselves up too much here. The 1993 IUCN Guidelines for Environmental Protection were written in response to a request from the Russians, the Norwegians and the other circumpolar countries to describe the state-of-the-art of oil and gas development in the Mackenzie Delta. These countries looked to Canada to see how to do things properly. This was a time when the international companies were moving to Russia. Canada clearly has the opportunity to build on the successes of the past. I am heartened by the level of participation by Industry in this workshop. The confrontation that was evident in years gone by is missing now. This is thanks to the fair-minded people in the region and the flexibility of Industry.*
>
> Dr. Tom Beck
> Past-Chair, Inuvialuit Environmental Impact Screening Committee

4.1 Industrial Activity

4.1.1 History of Industry

The development of natural gas reserves began in the western Arctic and subarctic in 1921 with the drilling of the first well in the Norman Wells area. Development continued in and around Norman Wells through to the 1950s, when interests started to shift north along the Mackenzie River Valley into the delta region. A pipeline to carry the produced oil from the Norman Wells field to market was built by Interprovincial Pipe Line Ltd. from Norman Wells to Zama Lake in northern Alberta and began operating in 1985.

Onshore geophysical surveys initiated in the Mackenzie Delta region in 1958 and 1959 were subsequently extended to near-shore areas of the Beaufort Sea. Shell Canada Limited (Shell), Gulf Oil Canada Limited (Gulf) and Imperial Oil Ltd. (Imperial), obtained rights to large tracts of land in the delta area and exploratory drilling began in 1962. By 1968, 38 onshore wells had been drilled but none had discovered significant amounts of oil or gas. Those early wells, however, did confirm and extend interpretations of the region's geology. In 1968, oil was discovered in Prudhoe Bay on the Alaskan Beaufort Sea coast and that event spurred further seismic and exploration activity in the delta. The first significant oil discovery was made in 1970 by Imperial at the Atkinson H-25 well on the Tuktoyaktuk Peninsula. The following year, the large Taglu natural gas field was discovered on Richards Island by Imperial.

Exploration moved to the shallow, near-shore waters of the Beaufort Sea in 1973 when Imperial constructed an artificial island for use as a drilling platform. Drilling in the Beaufort Sea using drill ships was initiated by Dome Petroleum (Dome) in 1976. Other drilling followed in the shallow water off the Mackenzie Delta and, as drilling experience was gained in near-shore areas, drilling efforts were extended to deeper waters by Dome, Imperial and Gulf.

To date, approximately 170 wells have been drilled at onshore locations in the Mackenzie Delta region, while about another 70 have been drilled in the southern Beaufort Sea. This exploration effort has resulted in significant discoveries of both oil and gas reserves, even though exploration of the sedimentary basin is only in its early stages.

Discovered reserves of natural gas in the Mackenzie Delta and southern Beaufort Sea are estimated by the Geological Survey of Canada at 10.1 TCF (trillion cubic feet), a quantity equal to approximately 10 percent of the known reserves of natural gas throughout all of Canada. Undiscovered natural gas in the area may represent 20 percent of Canada's future supply.

Compared to the larger hydrocarbon reserves that have been found on the North Slope of Alaska, reserves in the Mackenzie Delta region are smaller and more scattered. Because of the high cost associated with developing such reserves, there has been no development to date.

Geophysical surveys have been completed over most of the onshore Mackenzie Delta and adjacent Tuktoyaktuk Peninsula and have been extended over much of the submerged delta lying offshore. Exploration interest has remained highest, however, in the Mackenzie Delta and southern Beaufort Sea.

4.1.2 Present and Future Industry Activity

Since 1999, interest has been renewed in the Mackenzie Delta due to an increase in gas prices and an increasing use of natural gas in Canada and the United States for heating and electrical power. As a result, exploration in the Mackenzie Delta and Beaufort Sea region has increased dramatically.

Industry representatives have expressed interest in pipeline transportation systems and three proposals have been discussed to transport natural gas from the Mackenzie Delta and Alaskan North Slope to market.

The description of likely future petroleum development presented here is based on plans currently being put forward by Shell, Imperial, Conoco Canada Resources Limited (Conoco, formerly Gulf) and ExxonMobil Canada (ExxonMobil). The overall nature of development plans for the region is speculative, and as presented here, includes overlapping and in some cases, potentially conflicting proposals. Nonetheless, the importance of the petroleum industry as an economic force and a user of land in the region will increase in the future.

Advances in technology, coupled with experience gained in permafrost environments, have allowed simpler and more cost-effective designs to be adopted for recent development proposals. Natural gas production will most likely first involve the two major gas fields on Richards Island (Niglintgak and Taglu) together with a third at Parsons Lake on the mainland. Subsequent development will likely include the connection of smaller onshore, and eventually shallow offshore, reserves by extending gathering pipeline systems from initial facilities and pipeline networks.

4.2 Natural Gas Development Phases

Natural gas development is typically divided into four main phases: exploration, construction, production and reclamation. Seismic surveys and exploratory drilling are conducted during the exploration phase to locate and delineate economic reserves of hydrocarbons. Most disturbance associated with exploration is temporary. Permanent production, processing, and transportation facilities are constructed during the development phase to allow gas to be produced and sent to market over a period of twenty years or more. When reserves are depleted, facilities are removed and disturbed areas are reclaimed (see IUCN 1993).

Exploration in the Mackenzie Delta region is seasonal, with most onshore activity occurring in the winter under frozen conditions and much offshore activity occurring during summer during the open-water period.

4.2.1 Seismic Surveys

Geophysical programs identify potential natural gas-bearing geologic structures and provide better information on known structures. These surveys use sound waves that are transmitted from a surface source through the earth and are reflected by changes in geological deposits. These reflected sound waves are recorded by surface sensors known as geophones. Subsurface conditions can then be determined by interpretation of the reflected sound waves.

Two- and three-dimensional geophysical surveys are used. Two-dimensional (2-D) surveys provide geophysical information for one 'slice' through the structure of interest. This information is obtained by placing sound sources and recorders on the same line. Three-dimensional (3-D) surveys are more expensive than 2-D surveys and involve creation of a grid composed of receiver lines running across the structure with perpendicular source lines. This pattern provides geophysical information for the entire area beneath the grid rather than one 'slice'. It also provides information on the potential for directional drilling.

To obtain information on subsurface conditions, seismic lines must span an area larger than the actual geological structure. Line spacing is determined by the size and depth of the structure.

4.2.2 Onshore Seismic Programs

The required energy can be produced with a number of methods, but most onshore seismic surveys use shot holes or vibroseis techniques. The shot hole method involves the detonation of small explosive charges placed in holes drilled with a small drilling rig to a depth below the surface weathering zone (generally 15 to 30 m). These shot holes are usually placed at regular intervals along a series of straight, surveyed lines. Following drilling, geophone arrays are placed on the surface, and the explosives are detonated to produce the required acoustic waves. Precise surveys are an important part of geophysical programs, because field recordings are subsequently integrated into a single map using computer analysis. Once acoustic signals are recorded, the geophone arrays are removed, and cleanup is conducted.

In past developments, shrubs and trees were removed along seismic lines using bulldozers. This resulted in disturbance of permafrost and associated erosion and thermokarst (slumping) that is still visible (McKendrick 2000). Disturbance is now minimized by packing snow and driving over (walking down) vegetation to maintain intact root systems and organic mats. This minimizes the melting of permafrost and encourages natural plant re-growth. Advances in survey technology, computer processing and the use of global positioning systems (GPS) also mean that tree clearing and line-of-sight can be minimized along geophone lines by hand cutting narrow and meandering lines.

The vibroseis technique is generally confined to roads or other hard surfaces such as ice. With this method, a group of heavy vehicles each lower and then vibrate a heavy pad at specific points on the ground or ice surface. A series of identical or similar sweeps are made at closely-spaced intervals. These vibrations create the acoustic waves used for the survey.

By their nature, seismic surveys are conducted from self-contained units and those carried out in the Mackenzie Delta region have been staged from communities using existing infrastructure and support bases. Access is provided by temporary winter roads and seismic crews are housed in mobile camps pulled by tracked vehicles. Crews for 3-D programs are larger than those required for 2-D programs (greater than 50 versus less than 40 persons), and activities continue for longer periods because of the number of lines involved.

In the Mackenzie Delta region, several hundred thousand kilometres of on-land seismic survey have been completed to date and extensive programs were conducted in the winters of 2000/2001 and 2001/2002.

4.2.3 Marine Seismic Programs

In offshore areas, seismic surveys have been carried out from marine vessels during summer or from the ice surface during winter. Winter ice-borne surveys are similar to onshore surveys.

During summer seismic programs, acoustic energy is generated in the water column with rapid release of compressed air from air guns. These airguns are placed at regular intervals on one to two kilometre-long 'streamers' or cables towed behind a vessel. One streamer is used for 2-D programs, and air guns are detonated at timed intervals. During 3-D programs, two identical air gun arrays are towed parallel to each other at the same depth and operated at the same pressure. Port and starboard arrays are fired alternately. The reflected acoustic signal is received by a towed array of hydrophones, which convert the reflected signals for recording and subsequent interpretation.

The primary environmental concern during marine seismic programs in the Arctic is the effect of air guns on fish and marine mammals, and much research has been conducted on this topic. Shipboard observers monitor the presence of marine mammals and seismic operations are shut down when animals are present within a predefined buffer area. In addition, the intensity of air gun releases is gradually increased as seismic operations begin to avoid startling animals; this is referred to as 'ramp-up'.

4.3 Exploration Drilling

Once potential gas-bearing structures are identified, the only way to confirm the presence of natural gas and the internal reservoir characteristics is to drill an exploratory well. The location of a drill site is optimized by considering the characteristics of the formation, surface conditions, season of operation, available equipment and land use restrictions (Owens 1988; IUCN 1993).

In the Mackenzie Delta region, drilling has most often been carried out in winter to take advantage of easier transport of heavy equipment over frozen ground and the relatively simple clearing and grading required to prepare a winter drill site. A 1 to 3 ha pad is constructed to provide room for drilling equipment and support services such as camps and drilling mud sumps. Historically, drilling has been carried out from 1.5 to 2.5 m thick gravel pads, ice pads, or, alternatively, from platforms placed on piles; all approaches are designed to prevent thawing of ice-rich ground.

Drilling rigs and support equipment are normally divided into modules to facilitate transport. Once onsite, the derrick, drilling mud-handling equipment, power generators, fuel and water tanks and miscellaneous equipment are assembled. A self-contained support camp may be placed on the wellsite or on a nearby site, or drilling personnel may commute from a remote campsite. Water for camp use is trucked in or obtained from nearby surface waterbodies. Sewage is sent to a lagoon and incinerated, or treated and spread on the surface. Clean combustible wastes are incinerated onsite and other waste materials and liquids are transported to approved disposal sites.

Once drilling begins, drilling fluid or mud is continuously circulated down the drill pipe and back to the surface to balance underground hydrostatic pressure, cool the bit and flush out rock cuttings. Drilling mud is retained in a closed loop system or 'sump' to reduce makeup and disposal requirements. Sump size depends on the depth of the well, expected drilling duration and season (i.e., summer when runoff may add to fluid volume as land use permits require a 1.2 m freeboard). Drilling fluids may be reused at subsequent wells, or disposed of by approved methods.

Sumps are easiest to abandon during the winter, when fluids are frozen. In permafrost areas, the frozen sump is backfilled and capped with excavated material, providing a thick insulating layer to prevent thawing from the surface. As sumps are constructed below the active layer (the layer that thaws), the drilling fluid is not expected to thaw from below. The soil cap is either seeded or allowed to revegetate naturally. If a sump located in permafrost is abandoned during the summer, free liquid is tested and chemically treated for surface disposal or mixed with the previously excavated fill and solids prior to backfilling the mixture into the sump.

In the Mackenzie Delta region, onshore drilling activities were historically staged from temporary support facilities at Camp Farewell, Tununuk Point and Swimming Point. Camp, storage and transhipping facilities were established at both Inuvik and Tuktoyaktuk. Preparation of some drill sites also required the mining of gravel deposits. Drilling operations were supported by aircraft, river barges, tugs and smaller vessels and by winter truck traffic over ice and snow roads throughout the region.

Drilling in offshore areas has taken place from artificial islands constructed from dredged bottom sediments, from special temporarily-anchored drilling structures, and from drill ships in deeper water, as well as from ice pads within the landfast ice in winter, built up on top of dredged sediments.

Offshore exploratory drilling initially involved support from the same bases as onshore drilling, but as exploration efforts moved further offshore, support was supplied largely from Tuktoyaktuk, McKinley Bay, Herschel Basin and from large marine vessels. Temporary facilities at Summers Harbour and Wise Bay, located at the northern tip of the Parry Peninsula, were also used in support of past offshore exploration.

4.4 Development and Production

Production of natural gas requires construction and operation of a facility and pipeline network. Key components during this phase include production drilling, processing facilities, pipelines and support facilities.

4.4.1 Production Drilling

Drilling for production purposes is similar to exploratory drilling in most respects, but typically involves increased numbers of personnel and multiple drill rigs operating over extended periods of time. Production drilling in the Mackenzie Delta region will likely involve clusters of production wells drilled directionally from a single drilling pad or platform. More than one well cluster will often be required for the development of a single field, but the cluster drilling approach will reduce land disturbance. Land required for each production wellpad is likely to be two to six hectares. Where a number of clusters are required to properly develop a field, all-season road access between clusters could be constructed.

Gravel resources in the region are limited and the cost of moving gravel is high. As a result, additional efforts to locate suitable sources will be required, and designs that limit the amount of gravel required at onshore production and processing facilities will be given close attention.

Similar cluster drilling techniques will likely be used in offshore areas using appropriate platforms, which may include artificial islands or anchored offshore structures.

4.4.2 Processing Facilities

Produced natural gas is composed of methane with some ethane, propane and butane (natural gas liquids). This mixture comes from the well under high pressure and contains free water that may be readily separated, or vapour, which is more difficult to remove. Other impurities that create operational complexities may include carbon dioxide, nitrogen, sand and hydrogen sulphide.

Processing equipment is used at well clusters or a central facility to remove impurities and allow the gas to be transported via pipeline. The size and type of treating equipment depends on the nature of the reservoir, the volume and nature of produced fluids and the method of transporting produced hydrocarbons to market.

Separators are used to remove free liquid and dehydrators are used to remove water from the gas to prevent formation of ice crystals. Dehydrators work by forcing the gas through glycol or solid materials (molecular sieves) that remove water. Water removed by processing is usually disposed of through injection into disposal wells drilled for that purpose. Where necessary, compressors are used to maintain desired flow rates and pressures.

Chemical injectors are used for injection of corrosion inhibitors or methanol into the wells and pipelines to prevent icing. Heaters may be used to compensate for the natural refrigeration of the gas caused by the pressure drop. In remote areas, processing equipment is powered using fuel gas from sweet gas production or fuel gas generated by stripping hydrogen sulphide from a small amount of raw sour gas. This is accomplished by putting the raw gas in contact with an amine solution that strips the hydrogen sulphide and carbon dioxide. To allow the amine solution to be reused, the acid gas is then removed and flared. The main sources of emissions from sweet gas facilities are dehydrators, compressors and heaters while at sour gas facilities, the amine train is an additional source. The gas fields being considered for development in the Mackenzie Delta are all sweet gas.

One possible design alternative would be to mount processing equipment on barges and float the barges to an appropriate site along river channels. Once onsite, the barges would be placed within a specially excavated lagoon, which would then be isolated from the river channel using an earthen dam and pumped dry, leaving the barge firmly in position for use. A reversal of the process would allow processing facilities to be moved elsewhere. Land use requirements for processing facilities designed in this way would be significantly reduced compared to an installation using gravel pads.

4.4.3 Pipelines

The development of natural gas in the region will require the installation and operation of a wide variety of pipelines ranging in size from small field lines to large transmission lines that transport processed gas to market.

Buried or elevated field pipelines are used to transport raw natural gas from production pads to dehydration or processing facilities. These gathering pipelines are generally less than 10 km in length and 8 to 24 NPS (inches in outside diameter). Gas is transported in common gathering pipelines to a central industry facility or large diameter transmission pipeline for transportation to market. These main gathering pipelines may be elevated or buried and are typically medium to large diameter (18 to 36 NPS). Transmission pipelines are large diameter (greater than 39 NPS) and have block valves at regular intervals (25 to 50 km) to allow flow to be shut in.

Compression facilities are placed at regular intervals to maintain pipeline pressure and flow. The spacing chosen reflects specific design requirements of the pipeline system, but compressor stations are usually situated from 50 to 300 km apart. Compression facilities would be 4 to 9 ha in size and placed on a 1 to 1.5 m thick gravel pad.

Pipeline right-of-way width requirements are dependent on the pipe diameter, burial depth and number of lines being placed. Small-diameter gathering lines can be installed by crews using small-scale equipment within the confines of rights-of-way 15 to 30 m in width. In contrast, large-diameter transmission lines require hundreds of workers using specialized heavy equipment and rights-of-way 30 m or more in width. Pipeline routing may be constrained by terrain features and watercourse crossing locations, and large diameter or thick-walled pipelines must follow straighter lines than small diameter lines.

Additional temporary working area along the pipeline right-of-way is required during construction to accommodate equipment and soil storage. Land is required on a temporary basis for construction camps, stockpiling of pipe and equipment and access to the pipeline right-of-way.

Sequential activities during pipeline construction include:

1. temporary access construction
2. clearing and grading
3. trenching and blasting
4. pipe welding and installation
5. backfilling, cleanup and reclamation

Pipelines are buried in excavated trenches at least one metre below grade to protect pipes from damage. Following backfilling, the pipe is pressure tested with air or fluid to confirm its integrity. Where water is required for testing, it is obtained from an approved waterbody. After use, water is tested, treated if necessary and disposed of on surface or in another approved waterbody. Rough cleanup is normally done immediately following construction and final reclamation is completed during the subsequent growing season.

During operations, impurities that build up on the inner walls of the pipeline are removed by 'pigging'. This involves insertion of a plastic ball or plug into the pipeline. This pig is slightly smaller than the pipe and scrapes deposits off as it is pushed through the line by the natural gas stream. The pig and impurities are removed at a pigging trap located at another production pad or facility for treatment and disposal.

4.4.4 Support Facilities

Production of gas will create a requirement for lands in addition to those dedicated to production, processing and transport. Land for support bases, harbours, sea lanes, temporary and permanent roads, waste disposal sites, communications installations, wharves, stockpile sites and airstrips will be needed. In addition, requirements for local resources such as gravel will entail the use of land.

Camps and Support Bases and Harbours

Many if not all of the campsites, support bases and harbours previously used to support exploration in the Mackenzie Delta region will likely continue to be used during the development phase. For the first phase of gas development, only a small number of support facilities will be required.

Camp, storage, transhipment and communications facilities in the communities of Inuvik and Tuktoyaktuk will play an important role in future development. Previously used camp and staging areas at Tununuk Point, Camp Farewell, Swimming Point, Lucas Point and Pullen Island will also be logical locations to place future camps or storage and staging facilities.

Future offshore development may require base camp and support facilities at harbours along the Beaufort Sea coast; it is likely that any major offshore support facilities that might be required would be developed jointly by operators in the region. Such shared facilities could be developed at North Point or Hansen Bay on Richards Island, or at other previously-used harbour and shore base sites (e.g., Tuktoyaktuk, McKinley Bay, Summers Harbour, Wise Bay, Herschel Basin).

Roads

During the exploration phase, industry uses only temporary ice and snow roads. While it is unlikely this general approach will change during exploration, a need for all-weather roads linking production clusters and paralleling some gathering lines may arise.

Communications Sites

Increased requirements for radio communications and navigational aids will be part of the development of natural gas reserves in the Mackenzie Delta region. Some navigation systems require the placement of transceiving equipment at prominent, preferably elevated points along the coast and such sites are in short supply. Communications sites at Herschel Island, Stokes Point, Carry and Hooper Islands, Atkinson Point, Warren Point and at Atertak, near Tuktoyaktuk, would likely be used.

Waste Management

Disposal of wastes arising from exploration has been handled on a project-by-project basis, but coordinated waste management will be required during development and production.

Chemicals used for gas production and dehydration include: downhole and pipeline corrosion inhibitors, ethylene glycol, triethylene glycol and methanol. Wastes produced by production operations include produced water, process wastes and sludges, glycol and lube oil filters, used lube oil, oil- and chemical-contaminated debris, wash fluids and solvents, used drums and containers, batteries and chemical and inert solid wastes. These wastes are generally transported offsite to approved disposal facilities.

Gravel

Past petroleum-related activity in the Mackenzie Delta area has relied in part on the use of local supplies of gravel. The gravel was used to construct working pads of sufficient thickness to insulate underlying permafrost and thereby ensure a firm foundation for drilling and other activities on a year-round basis. While efforts are being made to design production and processing facilities in a way that will minimize the need for gravel, there will nevertheless be a substantial future requirement for this relatively scarce local resource. Gravel, or lack of it, may affect the location and design of facilities required to develop the region's natural gas reserves. As petroleum development proceeds, there will be increasing demands on existing supplies of gravel, as well as intense effort to find additional deposits.

4.5 Development Scenarios

To date, development in the Mackenzie Delta region has been restricted to the Ikhil well that provides natural gas to the community of Inuvik. Continued petroleum activity in the region will ultimately be dependent on construction of a transportation system to move natural gas to markets.

4.5.1 Delta Region Development

A number of proposals to move natural gas from the Mackenzie Delta region have been put forward over the years. While previous proposals are referenced, the following discussion of probable natural gas development scenarios is based on the most recent proposals advanced by industry.

At present, the most probable development scenario includes initial production (prior to 2010) from the three proven fields. These include, but are not limited to, Niglintgak and Taglu on Richards Island and Parsons Lake on the mainland. Subsequent development will likely include the connection of smaller onshore, and eventually shallow offshore reserves by extending gathering pipeline systems from initial facilities and pipeline networks.

The current concept for development of these three anchor reserves includes:

- field production pads, dehydration facilities, and elevated, in-field pipelines in the Taglu (Imperial), Parsons Lake (Conoco and ExxonMobil) and Niglintgak (Shell) fields
- a 130-km long, multiphase, buried gathering pipeline system from these fields to a compression facility located near Inuvik
- a multiphase transmission pipeline and associated compression facilities to transport dehydrated natural gas and liquids from the Inuvik-area compression facility to a liquids extraction and compression facility to be constructed at Norman Wells
- a single-phase transmission pipeline and associated compression facilities to transport natural gas from the Norman Wells compression facility to existing natural gas transmission systems in northern Alberta

Field production facilities would include one to three production pads per field with three to ten wells per wellpad. These pads would be about two to six hectares in size and composed of 1 to 2.5 m thick gravel or a metal pad on piles. Drilling mud and fluids would be managed in onsite or remote sumps. Development of a multi-phase pipeline allows simultaneous transportation of both natural gas and natural gas liquids, which greatly simplifies field processing requirements. This differs from previous scenarios that assumed that natural gas liquids would be stripped at one or more gas processing facilities and transported to market in a separate liquids pipeline.

Field facilities will be operated remotely, likely from a control centre near Inuvik, and all weather access to the fields will not be required. Seasonal access would be provided by ice or winter roads during frozen conditions; helicopters or fixed wing aircraft would be used at other times of year.

Onshore reserves would likely be connected first due to lower cost. Gas reserves that would be connected after the initial stage of development could include those at Kadluk, Netserk, Issungnak, Kumak, Amauligak, Itiyok, Arnak, Hansen and Tuktoyaktuk.

Movement of natural gas from the Mackenzie Delta region in a liquefied form using ice-breaking or submarine tankers has been considered, but, to date, specific feasibility studies have not been completed.

4.5.2 Transmission Pipeline Development

Two other groups have recently considered a proposal to transport natural gas from the Alaskan North Slope to southern markets. The general route includes a subsea component along the north coast of Alaska and the Yukon to a landfall in the Mackenzie Delta region and then a buried pipeline running up the Mackenzie Valley. These proposals are not based solely on natural gas production from the Canadian Arctic and could transpire independent of development of facilities and transportation systems from the Mackenzie Delta region.

4.5.3 Ongoing Exploration Activity

Land uses associated with continued exploration in the region are not expected to be substantially different from those already experienced, but the rate of exploration will depend on market conditions and the presence of production and transportation facilities that improve economic viability.

Seismic surveys and exploration drilling could conceivably take place anywhere in the region, as virtually the entire area is underlain by sedimentary formations with a potential to contain natural gas. However, over the next decade it is likely that most exploration will be centred on regions where exploration has occurred in the past and where natural gas has already been found. Continued use of existing support bases, camps, storage sites, airstrips and dock sites will likely occur.

The recent upsurge in seismic activity will not persist. Once 3-D coverage exists for the region, seismic activity will drop significantly. This could happen within two to three years (i.e., 2004–2005).

5 Climate Change

5.1 Chapter Overview

> *The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level would allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable sustainable economic development.*
>
> Article 2 of the UNFCCC

Global climate change is a complex issue. Nevertheless, there is good evidence that climate change is occurring, that the northern hemisphere is getting warmer and that the various effects of climate change will be more pronounced in northern areas, such as the region of the Mackenzie Delta, than they will be elsewhere. This chapter provides examples of some of the changes that are already happening and others that may happen in the future.

There is a special need to anticipate the effects of climate change in the Mackenzie Delta region. There is also wisdom in framing the climate change issue as a risk management problem for mankind. The way to manage the risk is to take out insurance with respect to the ways in which we meet our energy needs over the long term.

There are opportunities for engineers to design new projects for the Mackenzie Delta region that will minimize the potential emissions of green house gases.

There is a need to improve the predictions of climate change for the Mackenzie Delta region by refining the models. The results of modeling need to be examined in relation to the areas designated for development (e.g., what kind of flooding and storm surge could happen on Richards Island?). Plans for monitoring the effects of global climate change in the Inuvialuit Settlement Region need to be reviewed carefully with the communities.

5.2 The Nature of Climate Change

There is good evidence that climates are changing, in part due to human activities (IPCC 2001, Internet Site). However, there is still controversy about the causes of climate change.

A natural greenhouse effect is not contested. However, since the beginning of the industrial revolution in the 19th century, the concentration of carbon dioxide in the global atmosphere has increased. The increase in the proportion of carbon dioxide in the atmosphere has coincided with increased burning of fossil fuels and a reduction of forest cover around the planet. The northern hemisphere has become warmer since 1900.

The United Nation's Intergovernmental Panel on Climate Change (IPCC) concluded that "The balance of evidence suggests a discernible human influence on global climate" (IPCC 2001). Vinnikov et al. (1999) provided one example that suggests the importance of climate change caused by the activities of people. They compared modeled and observed changes in northern hemisphere sea ice. Assuming that the 5000-year model run had a variability similar to that found in nature, they suggested that there was a less than 0.01 percent chance that a random trend would be larger than or equal to the observed trend in northern hemisphere sea ice over the period 1953 to 1998. They suggested that this is strong evidence for the observed decrease in sea ice being related to anthropogenic climate change.

5.2.1 Vulnerability of the Canadian North

Climate change is a complex issue. Any changes in the atmosphere, ocean or polar ice regions affect the entire climate system and these relationships are generally nonlinear. For example, a decrease in sea ice or continental snow cover results in a decrease in the regional reflectance of light and an increase in heat absorption and therefore air temperature. This positive feedback mechanism leads to further decreases in sea ice and snow cover and therefore further increases in air temperature. Such feedback processes are important to the climate system, and their complexity can limit our ability to understand the changes that may be occurring in the environment.

The Canadian North is characterized by unique aspects of climate and terrain, with similarly unique vulnerabilities to climate change. Furthermore, the most pronounced warming of any region in Canada is expected in Arctic regions should the climate respond, as predicted, to increasing carbon dioxide levels. Due to these factors, a special need exists to anticipate the effects of such a change in this region.

5.2.2 Changes in Climate System

Increases in greenhouse gas (GHG) emissions could contribute to regional and global changes in temperature, precipitation and other climate variables. An increasing body of observations, such as those listed below, gives a collective picture of a warming world and other changes to the climate system:

- the global average surface temperature has increased over the 20th century by about 0.6°C
- globally, since 1861 when temperatures began to be recorded, the 1990s were the warmest decade and 1998 was the warmest year on record
- snow cover and the extent of ice has decreased
- sea levels are rising and the heat content of the ocean has increased
- emissions of GHGs and aerosols due to human activity continue to alter the atmosphere in ways that are expected to affect the climate
- concentrations of atmospheric GHGs and their radiative forcing have continued to increase as a result of human activity
- new evidence shows that most of the warming observed over the last 50 years is probably attributable to the activities of people

The burning of fossil fuels, changes in land use and land cover and natural GHGs sources are increasing the atmospheric concentration of GHGs and aerosols and affecting the radiative balance of the atmosphere (GHGs warm while aerosols cool the atmosphere). Aerosols are short-lived relative to GHGs and predictions are for aerosol emissions to decline globally. Therefore, aerosol emissions will not counter the global long-term effects of the longer-lived GHGs.

5.3 Responses to Climate Change

5.4 Responses in General

The air, sea, water, land and people's health and well-being are sensitive to the rate and magnitude of climate change, and to changes in climate variability. These changes will negatively affect human populations in some regions and benefit them in others. The specifics are difficult to predict, but in general, climate change will put additional stress on the natural world.

At the same time, opportunities to develop nonrenewable resources in the future may be constrained, at times, by the effects of climate change. This could affect the availability of jobs, revenue, training opportunities, education opportunities and royalties.

Climate extremes could have consequences with the potential for large-scale and possibly irreversible impacts that have yet to be reliably quantified. Adaptation is a necessary strategy at all scales to complement climate change mitigation efforts. Sometimes, people with the least resources have the lowest capacity to adapt and are the most vulnerable.

5.5 Responses in the Canadian North

Climate models predict an increase in mean global temperature of 1.4 to 5.8°C by 2100, a mean sea level rise of 15 to 95 cm, and spatial and temporal changes in patterns of rain and snowfall (Cohen 1997, IPCC 2001, Earth Policy Institute 2002 – Internet sites). Sea level rises could flood many areas in the outer Mackenzie Delta, and result in increased rates of erosion along the entire Beaufort Sea coast. Regional changes will probably vary considerably from global means, particularly in the polar regions. Ongoing research is aimed at improving the ability to model such regional changes (Stewart et al. 1998).

Changes that could occur in Northern Canada as a result of climate change include (Rouse et al. 1997; Cohen 1997, Internet site; Smedsrud and Furevik 2000, Internet site; IPCC 2001, Internet site; Earth Policy Institute 2002, Internet site):

- extreme weather patterns (probable increases in precipitation including rainfall intensity in the Mackenzie Delta region)
- a longer growing season

- an increased frequency and volume of flooding
- an earlier start to the fire season
- an increased frequency and severity of forest fires
- rising ocean levels
- reduced flow of the Mackenzie River during fall and winter months — annual minimum levels could be lower than the extreme low levels observed in 1994/95
- changing freezeup and ice breakup dates in both freshwater and marine environments
- melting of permafrost, which could cause catastrophic lake drainage, lake formation, more frequent landslides and an increased rate of peat decomposition leading to increased local input of GHGs
- additional landslides triggered by forest fires and heavy rainfall
- deeper snowpack
- potentially more severe storm events
- northward shift of the treeline and increase of shrub tundra
- northward shift of ecosystems with mixing and change of currently associated plant and animal species
- variation in timing of spring melt
- increased magnitude of storm surges from the Beaufort Sea due to reduced sea ice and increased fetch that will lead to coastal recession as ice rich sediments become exposed and melt during the summer
- thinning of the Arctic sea ice
- reduced salinity in the ocean from melting sea ice and increased inflow of freshwater from the melting of glaciers and other land ice that will affect thermohaline circulation in the North Atlantic Ocean
- threats to some wildlife species (e.g., caribou, seals, walrus, polar bears) as a result of increasing temperatures, deeper snowpack and changes to sea ice
- some fish species may flourish at the expense of others

- increased marine productivity leading to increased number of fish species

Although confidence in predictions of future climate change at a global scale is relatively high, the confidence in local or regional changes is not. There is a need for further research into the effects of climate change on the Mackenzie Delta region. Given the low confidence in predictions of climate change and its impacts, monitoring of both climate and ecosystem response is required. One method to consider the response to changes in climate is to consider past warming and cooling events (Edlund 1986, Harington 1986).

5.6 Mitigation

Mitigation involves measures, largely at the project design stage, to minimize GHG emissions that could contribute to further climate change. Significant technical progress relevant to GHG emission reduction has been made since the IPCC's Second Assessment Report in 1995. There is no single path to a low emission future, and countries and regions may have to choose their own path. Lower emissions scenarios may require different patterns of energy resource development.

Forests, agricultural land and other terrestrial ecosystems could mitigate the effects of increased carbon dioxide levels by storing carbon. Although not necessarily permanent, conservation and sequestration of carbon may reduce risks and allow time for other options to be further developed and implemented.

5.7 Knowledge Gaps Related to Climate Change

5.7.1 Effects of Industrial Operations on Climate Change

The cumulative effects of multiple land use activities in a region are often difficult to recognize. To understand potential cumulative effects of climate change, information must be obtained on the following topics:

- the industrial contributions to local environmental change
- predicting and preventing potential negative future environmental effects
- models for upset scenarios
- the scale of local emissions of carbon dioxide, nitrogen oxides, sulphur oxides, other gases (e.g. benzene, hydrogen sulphide) and particulate matter,

under both normal operating parameters and in an emergency (e.g., well blowout, leaking pipe)

- the industrial contribution to permafrost degradation through mechanical actions (damaging vegetation cover) or increasing GHG emissions (flaring)
- risk assessment models for industry-induced permafrost degradation in the production zone and along the pipeline corridor

5.7.2 Effects of Climate Change on Industrial Operations

Gas development in the Mackenzie Delta region, along the Arctic coastline and offshore will be affected by the melting of permafrost and changing water levels and ice conditions. The following is needed:

- measure to be used by industry to cope with the predicted effects of climate change
- new risk assessment models for changes in sea ice, storm surges and increased water levels in the delta and near-shore Beaufort Sea
- new risk assessment models for increased permafrost melting (due to climate change) in the production zone and along the pipeline corridor
- new studies on the effects of permafrost melting on buried pipelines and the associated environmental risks
- further studies on the effects of permafrost melting on elevated pipelines and the associated environmental risks
- measures for protecting pipelines from the high discharge associated with catastrophic lake drainage. This risk is exacerbated by the fact that lakes that drain catastrophically do not always drain through the existing lake channel. Drainage may occur anywhere around the perimeter of the lakes (constrained of course by topography), resulting in new channels that may be many metres in depth.
- management of the contents of current and past sumps if large-scale permafrost melting occurs or catastrophic lake drainage exposes and releases sump contents
- effects of sump contents released into waterways

- changing weather patterns and their effects on increased sea levels and storm surges, and the warning time required to prepare for storm surges
- the rates of change in Arctic ice melting (land and sea ice), sea level rise and discharge of the of the Mackenzie River through the many channels of the delta
- improvements to existing weather models to predict with confidence the changes to flow patterns of marine water streams due to climate change
- the risks related to changes in ice jamming and resulting bed scour of the major channels of the Mackenzie Delta in the vicinity of pipeline crossings
- the rates of channel migration change along the main channels of the Mackenzie Delta, and the implications for channel crossings and onshore infrastructure

5.7.3 Air and Water Quality

As the air quality in the region is presently relatively pristine, there has been little research on present conditions. Essential areas for information gathering are:

- the role of climate change in increasing or decreasing the impacts of local sources of airborne contaminants
- the relative importance of long-range transport of airborne pollutants into the delta region vs. local sources
- existing air quality in and around the major settlements (e.g., Inuvik, Aklavik, Tuktoyaktuk), as well as at remote sites within the delta
- precipitation and snowpack chemistry, especially the deposition of airborne contaminants to the snowpack and the concentration and distribution of these contaminants due to blowing snow and meltwater processes
- data from monitoring airborne pollutants and their loading into the local environment
- the concentration of airborne contaminants in the local environment due to temperature inversions and ice fog production
- increases in airborne particulate matter due to dust production

- the impact of increased airborne particulates on the timing and rate of snowmelt

5.7.4 Climate Change

> *Where there are threats of serious irreversible damage, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent such environmental degradation.*
>
> Second World Climate Conference 1991

General Research Needs

The following information is required to understand what future changes are likely to occur, prior to considering the potential impacts of development:

- the relative importance of the impacts of climate change versus the impacts of new gas development and the synergy between the two
- how much climate change is or will be the result of natural GHG concentrations and how much is due to anthropogenic GHGs
- improved confidence in predictions of the effects of climate change, especially at a local and regional scale

Research Needs Specific to the Mackenzie Delta

To develop answers for the above questions, the following information and tools are required (from Marsh 2000):

- the most appropriate models for prediction of climate change and weather for use in the Mackenzie Delta region. This will require a comparison of climate and weather models at a variety of scales under present conditions.
- regional climate scenarios for the Mackenzie Delta region at an appropriate scale. This will require high-resolution, regional model simulations at a fine grid square (approximately 10 km) for an area containing the Mackenzie Delta.

- appropriate simulations using the above input data for critical areas related to development, including hydrologic, river and lake ice, snowcover, sea ice and storm surge simulations
- a detailed analysis of past changes in climate, hydrology and the aquatic and terrestrial ecosystems. These may utilize both the instrumentation record, as well as traditional knowledge and various proxy data sets.
- appropriate monitoring programs to identify ongoing changes in the physical and biological environment to increase the level of confidence of future scenarios
- a combination of monitoring actual changes and models as modeling abilities improve over the next decade

6 Permafrost, Soils, Surface Water and Groundwater

6.1 Chapter Overview

Permafrost and Terrain

The interaction of climatic and terrain features in the Mackenzie Delta dictate the characteristics of the continuous permafrost layer. Any changes in these determining factors could affect the integrity of permafrost and terrain stability. The extraction of natural gas in the Delta region could initiate changes in the permafrost layers.

Other industrial activities, could also have a harmful effect on the integrity of permafrost:

- the warming of surrounding soil layers by a subsurface pipeline carrying 0°C gas
- changes to surface waterbodies
- the extraction of borrow material
- changes to the near-shore environment through construction
- clearing and disturbance of surface materials

The existence of permafrost in the development area presents a unique challenge to development. It is known that permafrost layers can affect development in the following ways:

- the variable nature of permafrost can affect the integrity of underground sumps
- the variable nature of permafrost creates a challenge to the stability of structures and facilities

Mitigation can reduce the impacts of permafrost on industry and the impacts of industry on permafrost. However, some aspects of permafrost in the Delta region are not fully understood. The following areas exist as knowledge gaps and need to be investigated:

- comprehensive mapping and identification of sensitive ice-rich soils and permafrost layers
- effects of climate change on permafrost integrity
- changes in the near-shore ice environment as a result of construction

Soils

Almost 90 percent of the soil material in the Delta region developed on mineral parent material. In the lower Mackenzie Delta, thousands of years of deposition have left large deposits of alluvial material, glacial deposits and local accumulations of peat and organic soil. Sands and silts comprise much of the material in point bars, levees and flood plain deposits, while limited amounts of organic soil material exist in layers greater than 40 cm. Soil layers are integral to the health and functioning of the region's ecosystems. The existence of a diverse flora and fauna, as well as many biotic and abiotic processes depend upon the soil layers. As development moves into the Delta, activities could affect the soil layers in the following ways:

- removal of vegetation and modification of microclimatic variables that control ground thermal regimes
- compaction of soil layers through vehicle use and facility construction
- disturbance and removal of significant soil layers
- contamination of soil layers through accidental spills and sump leaks

Industry can mitigate these impacts. There are aspects of the soil layers that are poorly understood. To gain baseline information on Delta soils, the following steps need to be taken:

- comprehensive mapping and identification of sensitive soil zones in the Delta region
- a better understanding of the issues related to permafrost is required, since soil layers and distribution are affected by the presence of permafrost
- a clearer understanding of the nutrient cycling processes in Arctic soils

Surface Water and Groundwater

The Mackenzie Delta is covered by an intricate network of channels of various types (distributary, river, network, lake, reversing and tidal) and a multitude of lakes of different types and origin (abandoned channel, arcuate, flood plain, thermokarst and dammed). The greatest proportion of Mackenzie Delta discharge flows through three main channels with Middle Channel carrying the most water. Smaller channels connect and recharge Delta lakes and bays. Underneath the Delta, groundwater flows through alluvial deposits and taliks. These hydrological processes are essential to the biotic and abiotic activity in the Delta. Development in the Delta could alter the water quality and quantity and affect the health of the Delta ecosystem in the following ways:

- changing the sediment load
- disturbance of local terrain could change local and regional drainage patterns
- spills or leaks of contaminants into substrate or waterbodies could affect the quality of the water

The nature of the Delta presents unique challenges to industry. The maze of surface waterbodies and the saturated soils can affect development and structures in the following ways:

- changing the volume on existing sumps
- surface or subsurface water erosion of terrain, creating an unstable foundation

Mitigation steps need to be taken by industry to lessen the impacts of water on industry and the impacts of industry on water. Some aspects of the hydrological system in the Delta are poorly understood. To gain a clear baseline understanding of the Delta hydrology and potential impacts, the following steps need to be initiated:

- evaluation and establishment of a comprehensive water quality monitoring program in the Delta
- monitoring of water balances in existing sumps to check for contamination hazards
- comprehensive mapping and identification of sensitive watershed areas

6.2 Permafrost and Terrain Stability

6.2.1 The Nature of Permafrost and Terrain

The Mackenzie Delta is a large estuarine-type Delta characterized by a low-lying alluvial plain dissected by a network of anastomosing river channels, oxbows, channel scars and lakes (Figure 6-1). Three large channels deliver most of the river's discharge to the Beaufort Sea. Smaller tributary, distributary and feeder channels drain adjacent uplands, mountains and wetlands and connect the thousands of lakes that comprise roughly a quarter of the Mackenzie Delta's 12,995 km^2 area. Storm surges and tidal activity in the Beaufort Sea also influence the outer part of the Delta (Marsh and Schmidt 1993; Shaw et al. 1998; Solomon 1994).

The Mackenzie River is a large, north-flowing river that drains much of northwestern North America. Accordingly, it displays a number of distinctive hydrologic characteristics linked to the climatic differences between the northern and southern parts of its basin. These characteristics have their greatest impact in the Mackenzie Delta, the northernmost part of the drainage area. For example, the rivers and the lakes that comprise the Delta are covered by up to 1.8 m of ice for as long as 9–10 months of the year. Snowmelt and spring flooding begin in the southern part of the basin long before they arise in the Delta. Progressively colder climates generate permafrost conditions that range from sporadic discontinuous permafrost in northern Alberta, to deep continuous permafrost in the Mackenzie Delta. The unique nature of the Mackenzie Delta ecosystem is a function of disparities in permafrost, patterns of ice freezeups and breakups, ice jams and varying conditions of Arctic climate and tundra vegetation.

The Mackenzie River transports considerable heat energy (sensible and latent) into the Mackenzie Delta and Beaufort Sea region. The 'warm' water flowing through the Delta causes the ice-rich riverbanks to thaw and accelerates riverbank erosion. Thermal and mechanical erosion combine to produce channel migration rates upwards of 30 m/a. The high rates of erosion contribute to a daily sediment yield of approximately one million tons (Dome Petroleum Limited et al. 1982a). The large number of thermokarst lakes, pingos, ground ice slumps and periglacial features such as patterned ground, tundra tussocks and ice wedge polygons differentiate the Mackenzie Delta from Deltas typical of more temperate environments.

The surficial geology and physiography of the Mackenzie Delta region are closely related to the history and pattern of Quaternary glaciation. Most of the lower Mackenzie Delta and adjacent Yukon Coastal Plain were glaciated by a lobe of north flowing ice that filled the Mackenzie Valley during the early Wisconsin Interval. Ice continued to cover parts of the Delta up to 10,000 years ago (Rampton 1982). Surficial deposits include recent fluvial and lacustrine deposits of sand and sandy-silt throughout the modern Delta. The Delta during the Pleistocene epoch was east of the modern Delta and is now mantled by glacial till (ground moraine) overlying fluvial glacial deposits, marine clay, kame deposits and Deltaic sand (Heginbottom and Tarnocai 1983; Rampton 1982). Silts and sands with high organic content are found throughout the Delta, and in places may exceed 50 cm in thickness.

Permafrost and ground ice underlie much of the Mackenzie Delta where their distribution and thickness are determined by a variety of factors, including climate and glacial history. However, on the local scale, permafrost characteristics are complicated by the presence and pattern of lakes and river channels. Permafrost underlies all exposed ground surfaces and shallow lakes and rivers. The ground beneath deeper lakes and channels (greater than 2 m) remains unfrozen. The extent of these unfrozen zones (called taliks) is directly proportional to the lake size and bottom temperature. In the case of large deep lakes, taliks may penetrate through the permafrost (Figure 6-2).

The nature and extent of permafrost and ground ice in the Mackenzie Delta have a direct bearing on the geotechnical properties of the ground as well as on surface and subsurface hydrology and soil development. Permafrost creates a frozen shell that derives its strength and stability from ice. However, over much of its distribution, permafrost is close to its limiting temperature and is therefore inherently unstable. Any change in the ground surface temperature (natural or anthropogenic) may cause a shift in the subsurface thermal regime that could induce thawing and instability. Terrain instability, as a result of thermal erosion, thaw-related slope instability (slumping and flow slides) or ground subsidence due to thermokarst, could be serious obstacles to economic development in the Mackenzie Delta.

The Mackenzie Delta and the shallow near-shore area of the Beaufort Sea are underlain by perennially cryotic ground or permafrost. Permafrost is defined as ground that remains at or below 0°C for at least two years (Permafrost Subcommittee 1988). The term 'permafrost' refers only to the thermal condition of the ground (not the ice contained within it). It reflects a thermodynamic balance between the ground surface temperature (which is controlled by air temperature and incoming solar radiation) and the geothermal gradient (French 1996; Williams and Smith 1989). On a regional scale the spatial distribution and depth of permafrost is closely related to climate. Local variations in permafrost conditions are due to differences in the nature of the ground surface. The slope angle and aspect, presence of surface water, vegetation patterns and snow cover, all define the boundary layer conditions that determine the ground surface temperatures, which, in turn, control the ground thermal regime (Judge 1979). Paleoclimatic, geologic, tectonic and subsurface hydrologic conditions can further influence permafrost conditions.

Permafrost underlies approximately 26 percent of the Earth's land surface (Williams and Smith 1989), and is divided into continuous and discontinuous zones defined on the basis of distribution and depth. Globally, permafrost depths globally range from greater than 1000 m (1450 m in Siberia) to a few metres near its southern limit.

Even though the Mackenzie Delta lies within the continuous permafrost zone it is highly variable in thickness ranging from great than 500 m thick beneath the Pleistocene Delta to less than 300 m in the modern Delta (Mackay 1963; Judge 1979). Pleistocene permafrost is much older and tends to contain higher volumes of ground ice.

Due to the high heat capacity of water, large lakes and deep river channels inhibit the development of permafrost. Lakes and channels that do not freeze to their bottoms will be underlain by thaw zones (sub-lake and sub-channel taliks, respectively). Depending on the diameter, depth and water temperature of the lake, taliks may be 'supra-permafrost' or 'through permafrost' in nature. The pattern of permafrost and unfrozen ground is complicated by channel migration and lake drainage. Permafrost also underlies much of the shallow coastal shelf of the Beaufort Sea. This permafrost is relict in nature and is a legacy of the late Pleistocene Epoch when lower sea levels exposed much of the coastal shelf to cold, periglacial conditions. Cold seabottom temperatures (close to 0°C) and high rates of sedimentation help preserve this relict permafrost condition.

Solar heating associated with the prolonged periods of daylight during the summer produce relatively warm air temperatures. In the inner Delta around Inuvik and Aklavik, July maximum daily temperatures regularly reach 25°C. Cold ocean temperatures and sea ice cause cooler, damper conditions near the coast. For example, maximum summer temperatures at Tuktoyaktuk often reach no higher than 10-15°C and consistently may remain below 10°C.

The seasonal change in ground surface temperatures above and below 0°C produce seasonal freezing and thawing of a thin surface layer of ground called the active layer. The active layer acts as a buffer between permafrost and warm summer air temperatures and is a critical part of the stability of permafrost. Active layer depths can vary from a few decimetres in the high Arctic to more than two metres in parts of the discontinuous permafrost zone. In the Mackenzie Delta, active layers penetrate to depths of 1–2 m in the inner Delta and less than 0.6 m near the Beaufort Sea coast and outer islands. Changes in the pattern of climate or in the ground surface conditions (e.g., increased snow cover, removal of vegetation) will affect the rate and depth of active layer formation and possibly lead to the instability of the upper part of the permafrost. The seasonal freezing and thawing of the active layer and the seasonal pattern of temperature change in the upper part of the permafrost produce a number of distinctive features unique to Arctic tundra, including patterned ground, gelifluction lobes, active layer detachments, seasonal frost mounds, icings, frost cracks, ice wedges and tundra tussocks.

The current generation of general circulation models predict a warming of 2-5°C and increased precipitation for Arctic environments in response to global climate change (Schlesinger and Mitchel 1987; Houghton et al. 1990). As the mean temperature of the areas underlain by permafrost is close to 0°C, long-term exposure to a rise in temperature makes this permanently frozen ground inherently unstable. Because climate is the basic control of permafrost process and condition, climate change has always been relevant to permafrost science. For example, Mackay et al. (1972) showed that Pleistocene permafrost is preserved along parts of the Arctic coastal plain and the Mackenzie Delta. Past climate changes produced episodes of permafrost aggradation and degradation that are recorded stratigraphically. Modern permafrost sections may display evidence of previous warm periods. For example, Burn and Smith (1990) describe evidence of thermokarst and deepening of the active layer during the Holocene climatic optimum.

6.2.2 The Nature of Ground Ice

Permafrost in the Mackenzie Delta contains vast amounts of ground ice. The term 'ground ice' refers to all types of ice formed in freezing and frozen ground (Permafrost Subcommittee 1988). It ranges from disseminated ice crystals in a soil matrix (pore ice) to thick (10–20 m), horizontally layered bodies of nearly pure ice that extend for several square kilometres. Ground ice can be divided into two broad categories: epigenetic and syngenetic. Epigenetic ground ice forms in situ as permafrost aggrades while syngenetic ground ice forms in combination with deposition. The latter includes various forms of buried ice — most notably buried glacier ice.

Many processes and landforms unique to permafrost regions are directly related to the aggradation and degradation of ground ice. The freezing of water in the ground involves a complex group of processes in which grain size, ground temperature, soil water content and chemistry, water transfer processes and rates determine the type and rate of ground ice formation. Even though many types of ground ice are recognized (Mackay 1972; Pollard 1991) in the Mackenzie Delta, pore ice, wedge ice, segregated ice and intrasedimental ice are most significant in terms of volume and frequency of occurrence (Mackay 1989). There are more than 1300 pingos in the Tuktoyaktuk Peninsula (Mackay 1963), thus pingo ice is widespread but only locally significant. One of the most widely used ground ice classifications (Mackay 1972) identifies 10 types of ice and three primary sources of water, but excludes buried ice. Ground ice contents can be expressed two ways, either volumetrically (as a percent of the total volume of frozen ground) or gravimetrically (usually expressed as percent dry weight). When ice contents exceed the saturated moisture content of the enclosing sediment, the surplus is called excess ice. When permafrost containing excess ice thaws, the ground subsides in proportion to the volume of excess ice; this is called thermokarst. Permafrost containing massive ice is particularly thaw sensitive due the high content of excess ice. Massive ice is defined as a large mass of ground ice having a gravimetric ice content greater than 250 percent (Mackay 1989). The Mackenzie Delta is one of the most ice-rich permafrost environments on Earth; massive ice is widespread and gravitmetric ice contents are regularly in the range of 1000–

5000 percent. Using data from the Mackenzie Valley Geotechnical Data Bank (Lawrence and Proudfout 1977), Pollard and French (1980) estimated that ice represents 47.5 percent of the total volume of earth material in the upper 10 m of Richards Island. Richards Island is thought to be typical of conditions in the Pleistocene Delta. Pore ice and segregated ice were estimated to comprise 80 percent of the total ground ice volume, while 14.3 percent of the volume of the upper 9.5 m of permafrost of Richards Island is excess ice. Ice wedge ice was also found to be an important source of ground ice.

Ground ice is one of the most problematic features of permafrost and a major potential constraint for development in the Mackenzie Delta region. Knowledge about the distribution, origin and nature of massive ground ice and ice-rich sediments is necessary to assess potential impacts of thermokarst in response to the natural and anthropogenic disturbance of permafrost.

Of central importance to the investigation of ground ice is the distribution, nature and origin of massive ice. The general pattern of ground ice distribution has been established through a series of regional studies in the Mackenzie Delta (e.g., Dallimore and Wolfe 1988; French and Harry 1988; Harry et al. 1988; Mackay 1963, 1966, 1972a, 1972b, 1974, 1989, 1992; Mackay and Dallimore 1992; Pollard and French 1980; Pollard and Dallimore 1988). Research in the Mackenzie Delta by Mackay established the technical basis for much of our understanding about ground ice, including its classification (Mackay 1972) and genesis (Mackay 1989; Mackay and Dallimore 1992). Two types of massive ice are recognized: buried surface ice and intrasedimental ice. The former refers to any type of surface ice mass that is subsequently incorporated into permafrost; however, buried glacier ice is potentially the most significant. Intrasedimental ice forms in place by freezing of groundwater and can include any combination of segregation and intrusive ice (Mackay and Dallimore 1992). Differentiation between buried glacial and intrasedimental ice in the Mackenzie Delta is the focus of considerable debate.

Since degradation of permafrost is a predicted outcome of global warming, then thermokarst could conceivably become one of the more important processes in the Mackenzie Delta. Detailed field studies from Mayo in the Yukon Territory by Burn (Burn 1990; Burn and Smith 1990) have linked recent thermokarst to forest fires. Similar conclusions were obtained for studies in the Mackenzie Valley (Dyke 2000; Harry and MacInnes 1988; Mackay 1995).

As development proceeds within the Mackenzie Delta, various activities can affect the stability of the permafrost layer. The combined effects of climate change and development may have widespread impacts on the permafrost in the region. Changes in the integrity of the permafrost could have a significant effect on development activities and structures.

6.2.3 Issues Related to Permafrost and Terrain

Industry Impacts on Permafrost and Terrain Stability

Thermokarst is an important erosional geomorphic process unique to areas underlain by ice-rich permafrost. The International Permafrost Association glossary defines thermokarst as the process by which characteristic landforms result from the thawing of ice-rich permafrost or the melting of massive ice (van Everdingen 1998). The importance of thermokarst often is discussed in terms of its anthropogenic origin and impact (e.g., as a response to construction of buildings, runways, pipelines and highways) or global warming. However, it should not be forgotten that thermokarst is a naturally occurring erosional process.

The current usage of the term thermokarst applies to processes and landforms associated with the thaw of all forms of ground ice, regardless of origin (French 1996). It therefore includes both the thaw degradation of epigenetic ground ice as well as the formation of dead ice topography caused by melting buried glacier ice in disintegration moraines.

Thermokarst occurs throughout the Mackenzie Delta region. For example MacKay (1963, 1966) mapped several hundred ground ice slumps using aerial photographs. The nature and magnitude of thermokarst is directly related to two variables:

- the thermal stability of the upper part of the permafrost, including the depth of the active layer
- ground ice content

The stability of permafrost reflects a thermal equilibrium controlled by the mean ground surface temperature and the ground's geothermal gradient. Any change in the ground surface conditions (natural or anthropogenic) or in summer climate patterns will change the surface energy balance and the depth of the active layer.

Any number of things may produce an increase in active layer depth, most notably:

- warmer summer temperatures
- longer summer (thaw) season
- change in surface moisture conditions
- change in or removal of surface vegetation
- removal of a layer of sediment

If the subsequent increase in thaw depth results in melting of ground ice, then thermokarst may result. Ground ice differs from most other common minerals on the Earth's surface in that over most of its distribution and duration, it is very close to its melting point. The potentially unstable nature of ground ice makes it highly sensitive to slight increases in ground temperature. The thawing of permafrost containing excess ice will result in a net lowering of the ground surface proportional to percent volume of excess ice. Pollard and French (1980) estimated that thawing of the upper 10 m of permafrost on Richards island will produce 1.4 m of ground subsidence.

Two types of thermokarst are described in the literature:

1. thermokarst subsidence
2. thermal erosion

Both of these types are widespread in the Mackenzie Delta. Thermokarst subsidence is primarily vertical in direction and involves downwearing while thermal erosion involves lateral removal of sediment and is a backwearing process (French 1996). Thermokarst subsidence tends to occur in flat to low-relief areas and often produces surface ponding and shallow depressions. The formation of thermokarst tundra ponds and degradation of ice wedge polygons are common examples in the Mackenzie Delta of this type of thermokarst. Changes caused by large forest fires in the Inuvik area during the 1960s produced nearly a doubling in the depth of the active layer and widespread thermokarst subsidence (Heginbottom 1974; Mackay 1995).

By comparison, thermal erosion occurs on slopes where melting of exposed ground ice causes the slope face to retreat laterally. In this case, large pools of supernatant water and liquefied sediment collect at the base of the exposure and then gradually flow away, keeping fresh ice exposed and sustaining the process. Very distinctive 'C-shaped' depressions called retrogressive thaw slumps are a common expression of thermal erosion. Mackay (1986) documented 150 m of coastal retreat due to thermal erosion near Tuktoyaktuk between 1935–1985 while de Krom (1991) measured 30 m of retreat in a single summer by thermal erosion in a retrogressive thaw slump at Herschel Island.

One of the most important considerations for development in the north is the thermal stability of permafrost layers and the thaw sensitivity of the associated terrain. Changes in permafrost integrity could lead to significant changes in terrain stability, and cause subsequent problems for industrial development. Unless measures are taken to protect the stability of permafrost, development is likely to cause ground warming and terrain instability in the case of thaw-sensitive materials. Similarly, the presence of thaw-sensitive materials and areas characterized by natural or induced permafrost instability will affect the planning, placement and maintenance of development structures. From a development perspective a number of scenarios need to be considered.

Pipelines Carrying Product Above 0°C

Pipelines may be placed underground for a combination of practical and aesthetic reasons, including the need to minimize blockage or deflection of wildlife movements. In placing the pipeline underground, a trench is dug, the pipeline is installed section by section, and the trench is covered. Depending on its size, the pipeline may be buried within the active layer or in permafrost. If the product flows through the pipeline at temperatures above 0°C, this will have a warming effect on the surrounding ground material. A pipeline in close proximity to permafrost is likely to cause considerable thaw. If the thawed sediments are ice rich, then thaw will cause loss of support, instability and possibly shifting and damage to the pipeline (KAVIK-AXYS and LGL 2001; Johnston 1981; Williams 1979). A small-diameter, ambient temperature pipeline can be placed in the active layer with only limited complication; however, large-diameter pipelines pose a considerable challenge and require specialized construction (Williams 1979). Since any change to the tundra surface has the potential to disrupt the permafrost then all phases of pipeline construction and maintenance require special consideration.

Alteration of Surface Waterbodies

Overlying surface waterbodies play an important role in determining the existence of underlying permafrost layers. Shallow lakes and streams that freeze to the bottom are usually underlain by permafrost, whereas deeper bodies of water tend to have a sublake talik. Changes or alterations in the distribution and drainage of surface waterbodies could affect the integrity and stability of underlying permafrost (KAVIK-AXYS and LGL 2001).

Borrow Extraction

During the construction phase of development, gravel substrate will be required for roadbeds, airstrips and work platforms. Industry proposes to obtain gravel supplies from local glacial features such as eskers and moraines. The removal of gravel and the disturbance of the surface material will expose underlying layers of permafrost and ground ice. The removal of surface layers will lead to a warming and thawing of these layers. This enhances the potential for thermokarst. The ice-rich nature of many of the Mackenzie Delta aggregate deposits is problematic and perplexing. The presence of ice in these coarse-grained deposits makes it difficult to estimate gravel reserves. Furthermore, thaw degradation within borrow pits makes extraction difficult and costly. The potential for thermokarst continues long after a borrow pit is abandoned; the long-term impacts include potential widespread subsidence, ponding, modification of surface drainage and changes in vegetation cover.

Changes In Near-shore Ground Ice Environment

Subsea permafrost is present beneath the shallow continental shelf in the Beaufort Sea. Given that most of this permafrost formed subaerially when sea levels were lower, it is not surprising to find similar patterns in ground ice content as in areas near the coast. In this setting, the sub-sea permafrost has been submerged for several thousands of years. During this period, the permafrost has gradually warmed to correspond with seabottom temperatures and is therefore very close to its melting point. In addition to subsea permafrost formed in this manner, there are areas where more recent coastal retreat has submerged extremely ice-rich permafrost in the near-shore zone. Natural gas development in the Mackenzie Delta region will involve drilling through subsea permafrost and include structures built in the offshore and shoreline environments. Such facilities may include gathering systems, compressor stations and processing plants. The construction of these facilities and the effects of climate change may bring about changes in the near-shore ground ice environment. Melting subsea and near-shore ground ice will produce instability and potential problems for seabottom structures and landing and onshore facilities.

Clearing and Disturbance of Land Surface

The overlying soil and vegetation are important in determining the depth of the active layer and the thermal characteristics of underlying permafrost. Organic soils and peat layers have a lower thermal conductivity relative to mineral soils, and tend to insulate ground layers from warm summer temperatures. Mineral soils have higher thermal conductivities and respond more rapidly to changes in temperature. The effect of surface disturbance and removal of surface material can be threefold:

1. even if there is no change in the surface temperature, active layers will penetrate permafrost depths proportional to the thickness of sediment removed
2. surface disturbances may change surface albedos and in cases where darker soils are exposed, can increase the depth of summer thaw
3. where excavation has exposed ice-rich permafrost, thaw will proceed until a new active layer is formed and a thermal equilibrium is re-established

In areas of new permafrost or seasonal frost, the removal of surface materials can lead to more rapid and deeper frost penetration and frost heaving during winter months. In either situation, the removal of the overlying soil material will upset the interactive factors that determine the current permafrost regime (Smith 1986).

During construction, overlying vegetation layers are cleared away. These layers of vegetation serve three roles:

1. vegetation insulates the ground surface from the direct warming effects of solar radiation and air temperatures
2. vegetation tends to have lower albedo than soil materials and thus reflects more radiation
3. vegetation helps maintain the moisture balance in the active layer

Once these layers of vegetation are removed, underlying ground layers may increase in temperature resulting in deeper active layers and the associated degradation of permafrost. With the disturbance of surface material or vegetation, the integrity and stability of the upper part of the permafrost could be altered and lead to problems for development and ecological processes.

Permafrost Impacts on Development

One of the challenges for development in the Mackenzie Delta region relates to the variable characteristics of permafrost and periglacial processes. Ice-bonded permafrost has strength comparable to rock. While thawing, ice-rich permafrost produces a slurry of viscous mud. The placement of structures requires a solid foundation and underlying support. If construction maintains the frozen condition of the underlying permafrost (using ice pads, gravel pads or thermosyphons), then few problems arise. Indeed, there are situations where earthwork structures are deliberately frozen to increase their strength. However, if construction fails to protect the thermal equilibrium of underlying permafrost, gradual degradation could lead to loss of support and severe damage to structures (Johnston 1981).

Underground Sumps

During exploration and development, wastewater and waste drilling muds are produced. Currently, the accepted method for treating these fluids is to re-inject them into confined underground geological structures. The layers of permafrost associated with these sumps are important in preventing them from leaking. If permafrost layers shift, thaw or refreeze, then the integrity and impermeability of the sump structure could be compromised. The movement of waste material into significant soil layers and surrounding groundwater discharges could impact the ecological integrity of the area.

Slump and Slope Movement Effects on Infrastructure

The freezing and thawing of the active layer causes small-scale cyclic frost heaving and thaw subsidence of surface materials. Large sediment clasts or objects buried in the active layer are subject to vertical stresses that push them to the ground surface. During the summer, thawed silts and clays become plastic and subject to fluid displacement. These processes produce patterned ground. On slopes the cyclic heaving and contraction produces a gradual downslope movement of near-surface sediments and the formation of gelfluction/solifluction lobes. It is also possible for the downslope stresses on the active layer to cause translational slope failure along the permafrost table. In this case, a large slab of tundra literally slides down the slope as an active layer detachment leaving the underlying permafrost exposed. The net result is that the active layer is a dynamic part of the landscape. The stability of the upper part of the permafrost layer and the active layer may be further affected by the thermal contraction cracking of the ground. Over time, repeated cycles of cracking produce linear V-shaped ice bodies called ice wedges. The seasonal warming and cooling of the upper part of permafrost can also lead to permafrost creep.

This heaving, shifting and slumping creates a challenge for the placement and construction of pipelines, structures, roads and airstrips. The movement of the underlying and surrounding ground layers could stress the integrity of buried and surface pipelines. All-weather roadbeds could experience upheaval and movement. Planning and construction phases need to accommodate this dynamic component of permafrost environments. However, if the permafrost layers are poorly understood or there are changes to permafrost integrity, the design may not be sufficient to accommodate these changes. This could lead to conditions of instability and affect surface and subsurface structures.

6.2.4 Mitigation Related to Permafrost and Terrain

Over the years of industrial and community development in the north, many specialized techniques and strategies have been developed to accommodate the variable nature of permafrost (Jonhston 1981). These techniques can be employed to minimize the impact of development on the permafrost layers, and to lessen the effects of changing permafrost on development sites and structures.

Winter Construction and Development

During the winter, the active layer is completely refrozen and merged with the permafrost. This offers a stable platform for development structures and activities, and removes the challenge of a semi-solid and thawing terrain. Exploratory wellsites, camps, seismic sites, roads and airstrips can be constructed and utilized during the winter. By focusing movement and construction activities during the winter months, engineers can take advantage of the intrinsic strength of permafrost materials. Added benefits of working during the winter are:

- ice-covered rivers and lakes can be used as winter roads to limit impacts on the tundra
- the snow cover on the tundra helps protect it when it is necessary to travel and work on the land

Winter programs allow access to areas that are otherwise inaccessible during the warmer seasons. At the same time, there are potential environmental problems associated with winter activities that disrupt the vegetation cover or inadvertently disturb the tundra.

Concentration of Development

Contemporary footprints no longer require the large expanses of terrain or extensive road networks constructed in the past, in part because of directional drilling. The use of temporary winter roads, the elimination of waste storage pits and the ability to centralize facilities, reduces the amount of land that is disturbed during development. Industry also has the ability to carefully plan and locate their activities. This further reduces their impact by enabling them to select less sensitive areas of permafrost.

Use of Chilled Drilling Muds

Permafrost integrity can be affected by the use of drilling muds that are warmer than ambient permafrost temperatures. To avoid this, chilled muds can be used in the drilling process to prevent localized permafrost thawing due to contact with warm drilling fluids (ESRF 2002; KAVIK-AXYS and LGL 2001).

Avoidance of Sensitive Areas

With the prior identification and knowledge of sensitive permafrost zones, industry can avoid these areas. By concentrating facilities and working in winter, industry can further reduce its footprint on the land and minimize impacts.

Aboveground Pipelines

Industry could use either aboveground or belowground pipelines to transport products. Aboveground pipelines reduce the potential impact of thermal degradation of the permafrost layers. However, aboveground pipelines may block or deflect wildlife movements. If they are built at a minimum height of 1.5 m above the ground with widely-spaced supports and they are separated from access roads by at 100 m, wildlife will be able to pass underneath. Under this construction mode, pipeline supports need to be refrigerated and the pipeline needs to be able to be able to expand and contract along its length. (KAVIK-AXYS and LGL 2001).

Chillers for the Transport of Subsurface Product

Belowground pipelines that carry warm gas present the risk of thermal degradation of the surrounding permafrost layers. To minimize this impact, gas can be put through aboveground chillers to lower its temperature, before it enters the subsurface pipelines (KAVIK-AXYS and LGL 2001).

6.2.5 Knowledge Gaps Related to Permafrost and Terrain

The characteristics of permafrost in the Mackenzie Delta region are determined by the complex interaction of many factors. To predict the impacts of development on permafrost, the key characteristics and spatial distribution of permafrost need to be clearly identified. These characteristics include: thickness, distribution, presence of taliks, thermal regime, ground ice occurrence, geological history, response to disturbance, sensitivity to climate change, delineation between permafrost and ground ice and active layer features.

Location and Sensitivity of Ice-Rich Soils

A comprehensive set of maps that detail the location and sensitivity of permafrost layers are required. These maps can be constructed using landscape attributes that include vegetation cover, geological information, soil temperature, terrain type and elevation. These maps should be built upon and incorporate new borehole data, a digital elevation model for the Delta region, assessments of ground ice, temperature data from industry logs and refined vegetation cover maps. Current environmental monitoring reports and data from exploration can be continually fed into this mapping system and maintained on the World Wide Web.

Effects of Climate Change on Permafrost

Changes in local and regional climate could result in a warming of the atmosphere. This will initiate thawing and changes to permafrost layers. The extent of these climatic changes is poorly understood. This knowledge gap needs to be investigated by monitoring high-risk areas and establishing coastal monitoring sites. To understand how permafrost has changed in the past with respect to climate, old sites and structures should be investigated.

Changes in the Near-shore Wave Environment

As industrial development proceeds, structures and facilities will be built in the near-shore and shoreline environments. Staging platforms and pipelines will alter oceanographic processes such as sediment transport and wave action. The impact of changes in these processes on the presence of ground ice and permafrost layers in the near-shore environments is unknown. Significant changes in these layers could be detrimental to structures such as pipelines and processing plants. Continual monitoring of permafrost and ground ice layers at potential near-shore development sites needs to be done, and the near-shore physical processes assessed. Possible impacts of climate change on ground layers and offshore physical processes should also be monitored.

6.3 Soils

6.3.1 The Nature of Soil

Surficial sediments and soils of the Mackenzie Delta reflect the combined influence of fluvial, glacial and periglacial processes, vegetation and cold climate. Many surfaces are derived primarily from alluvium principally from Cretaceous shales and other sedimentary rocks that underlie the western and central Mackenzie Basin. Alluvium is also derived from reworked till and glacial fluvial deposits. Almost 90 percent of the region's soils have developed on mineral parent material. The soils are uniformly fine grained, ranging from silty loam on upper levees to silty clay in inter-levee depressions.

The lower Mackenzie Delta consists of alluvial deposits from the widening and slowing of the river as it enters the Delta region. Point bars alternate between thick layers of sand and thinner layers of silt and organics. Such fine material, together with the local organic material and the underlying permafrost, maintain generally high soil moisture and low soil temperature.

Given the relatively short period since deglaciation and the slow nature of weathering processes under such cold conditions, the most common Mackenzie Delta soils are Regosolic in nature. Regosols are immature soils developed on recently-formed sediments, such as dune sands, wind-blown loess deposits, alluvial plains and glacial tills. Although the upper part of the profile may be modified by the presence of organic matter, these soils are too young for distinct horizons to have formed. Cumulic and Brunisolic Turbic Regosols are found under various climatic conditions ranging from Arctic climate in the Mackenzie Delta, Subarctic in the Mackenzie Valleys to Cryoboreal and Boreal humid to semiarid regimes in the Peace and Saskatchewan River valleys. The parent materials are typically plain alluvial deposits that may be calcareous or noncalcareous. In the Inuvik area, Brunisolic Regosols soils are characterized by faint, thin Ah and B horizons.

Much of the Delta's surface is patterned by earth-hummocks and poorly sorted circles (mud boils), indicative of freezing and thawing processes occurring in the active layer. The cyclic freezing and thawing mixes near surface soil materials through cryoturbation.

Less that three percent of the Mackenzie Delta region is covered in organic layers that exceed 40 cm in depth. Surface sphagnum materials have accumulated in the soils under recent conditions and subsurface layers contain mesic sedge peat; an indicator of an earlier permafrost-free period. Along the Beaufort Sea coast, well-drained soils are reworked and deposited by wind and water (Dome Petroleum Limited et al. 1982).

6.3.2 Issues Related to Soils

In view of the slow rate of soil formation in this environment, industrial development in the Mackenzie Delta region will undoubtedly affect soil generation processes and patterns of soil distribution. The chemical, mechanical and biological weathering processes involved in soil formation are an important part of the biogeochemical dynamics of this ecosystem. The formation of soils also has a bearing on hydrological patterns and the biotic makeup of the region. Changes in the nature or rate of these processes could affect the biotic and abiotic health of the Delta. The magnitude of potential impacts is directly related to the scale of the disturbance. Gas exploration and subsequent development is likely to cause three types of impact:

- contamination of surface and soil deposits
- change in surface energy balance and microclimate
- physical modification either through removal of soil or through compaction

Contamination of Soil Layers

Contamination may arise from several sources. Fuel storage and refueling of land-based vehicles, aircraft and drilling equipment will inevitably include small spills and may potentially involve large spills of diesel, gasoline or aviation fuels. These spills could injure or kill local vegetation and wildlife such as lemmings, ground squirrels or weasels. If spills seep into surface drainage systems, the impacts could be far reaching.

The development of natural gas relies on the use of various chemicals and compounds. Waste materials, such as dirty water, drilling muds and domestic sewage are the result of various stages of development and exploration. Waste storage and disposal are an important part of the planning process and are critical in the application for permits.

The technology surrounding the handling of drilling muds is rapidly evolving. In the 1970s, large surface sumps were used for both drilling muds and camp wastes. Drilling muds can be either water-based or synthetic; synthetic oil based muds are expense and tend to be recycled, leaving only solids as waste products. Sumps are still used in many drilling programs but the volume of wastes has been greatly reduced by re-cycling fluids and removing solids. Furthermore, the sump concept is being rethought. In some cases, drilling wastes are being re-injected into geologic formations and bio-remediation techniques are being developed to digest harmful hydrocarbons. However, an accidental spill, the leaking of a sump or a fractured pipeline could lead to the contamination of the surrounding soil layers. These contaminants could alter nutrient cycling in the soil, kill soil organisms and have a negative impact on the surface vegetation (KAVIK-AXYS and LGL 2001).

Alteration of Microclimate – Thermal Pollution

Despite all efforts to minimize impacts on the ground surface (e.g., limiting movement of land-based vehicles to winter, using ice and snow roads and ice platforms), the process of exploration will cause changes in the pattern of surface vegetation, snow distribution, surface water and surface albedo. Subtle changes in the way solar radiation is either absorbed or reflected by the ground surface is likely to cause a seasonal and annual warming of the soil environment. This will change the pattern and rate of soil development, which may, in turn, change vegetation succession and through subsequent feedback, alter permafrost dynamics (Williams and Smith 1989).

Disturbance and Removal of Significant Soils

Construction practices that cause the degradation or removal of soils will have potentially catastrophic impacts on active layer and permafrost dynamics (French

1997). Physical disturbance of ice-rich permafrost will lead to thermokarst and accelerated erosion, which destroys the immature soils that may exist. These changes also induce changes in the rate and intensity of frost heaving and resultant cryoturbation. The disturbance of surface stability as well as destruction of soil textures could eventually lead to the deterioration of dependent ecological elements and processes (KAVIK-AXYS and LGL 2001).

Compaction of Soil

Development in the region will see the construction of transportation routes, work platforms, staging areas and support infrastructure. Heavy machinery and buildings will compact soil layers and this may prevent or change the rate of natural geochemical and hydrological processes. These changes in turn could affect the functioning and health of the surrounding ecosystem (KAVIK-AXYS and LGL 2001).

6.3.3 Mitigation Related to Soils

In response to the potential effects of industrial activity on Delta soils, industry is being forced to meet high standards of waste management and to implement practices that will minimize impacts. New technologies exist in virtually all aspects of natural gas exploration, drilling and development.

Effective Waste Disposal and Spill Response

Development involves the use and production of materials and substances that pose a contamination hazard to the soils of the Mackenzie Delta region. This threat is minimized through effective waste disposal and recycling. Compounds and chemicals are disposed of by re-injecting them into geological formations that act as confined subterranean reservoirs. Waste materials that cannot be reused, recycled or disposed of onsite, are taken offsite to waste disposal facilities. Site management has become a big part of environmental protection; for example the use of spill sheets and trays to catch leaks and spills during refueling. Industry has also established spill response plans and employs personnel trained in the implementation of such plans. With these practices in place, sites should be well prepared to immediately deal with a spill and minimize its effect (IUCN 1993).

Avoidance of Sensitive Areas

With the prior identification and knowledge of sensitive soil areas and vegetation communities, industry can plan to avoid these areas. Transportation pathways, drilling platforms and staging areas can be located in areas that may not be as ecologically significant. By concentrating its facilities and working in winter, industry has reduced the footprint of drilling and development on the land and has minimized the potential impacts on the soil layers. The close connection between soils, vegetation and permafrost means that areas underlain by ground ice need to be avoided.

Concentration of Development

Current development scenarios no longer require the large expanses of terrain or extensive road networks that were the hallmarks of earlier development. Temporary winter roads, the elimination of waste storage pits and the ability to centralize facilities all work towards reducing the amount of land that is disturbed during development. Industry has the ability to carefully plan and locate their activities. This further reduces impact through preferential use of less sensitive areas of the Delta.

Many of the stages of development can be performed during the winter season, using temporary ice-based structures. Ice provides a solid foundation for drilling and work platforms and disappears with the approach of the summer season. The amount of compaction and disturbance of the soil layers is reduced by scheduling these activities to occur during the winter season.

Use of Directional Drilling

Technology has improved and advanced techniques are being used in the routing of pipelines and roads. Directional drilling is effective in permitting a pipeline to be placed underneath a river channel or through a sensitive area without disturbing the surface. These techniques will minimize surface disturbance and reduce the risk of soils being exposed to erosion, slumping or slope failure.

Tundra Vehicles and Helicopters

Construction can be done using machinery equipped with tundra tires. These vehicles will not compress the soil layers as much as tracked equipment, and they will lessen the impact of construction on soil layers. In some situations, helicopters can be used to access development sites and remove the need for roads.

6.3.4 Knowledge Gaps Related to Soils

To better understand the effects of development on the soil layers in the Mackenzie Delta region, knowledge gaps need to be addressed. Some of these requirements deal with unknown baseline data, whereas others are specific to the potential impacts of development.

Identification and Monitoring of Sensitive Soil Areas

The development of ecological land classification maps will help to identify sensitive permafrost zones, important soil and geological formations and important hydrological features. The development of these maps will lead to a better understanding of landscape features and functions, and enable industry to pre-plan and avoid sensitive areas.

Understanding Permafrost Issues

Soil layers in this region are influenced by permafrost and various periglacial processes (e.g., frost heave, thermal contraction cracking). The shifting and heaving of the active layer can affect soil processes and the formation and degradation of soil layers. A better understanding of the industrial effects on the active permafrost layer will provide insight into how soil layers will be affected.

Understanding Nutrient Cycling in Arctic Soils

Contaminants in Delta soils could affect the nutrient cycling processes. A better knowledge of baseline weathering processes and nutrient cycling is required for Arctic soils. This information is necessary for the development of site remediation and spill response procedures.

6.4 Surface Water and Groundwater

6.4.1 The Nature of Surface Water and Groundwater

The Mackenzie Delta is the largest Delta in Canada and the second largest Delta in North America, exceeded in surface area only by the Mississippi Delta. Among Deltas in the Arctic, it is second in the world only to the Lena River Delta. The Mackenzie River is 4241 km long and has a drainage area of 1,787,000 km^2

(Lawford 1986). The Mackenzie Delta plain is roughly 12,995 km^2 in area and extends from Point Separation in the south 200 km north to the Beaufort Sea, and from the Richardson Mountains in the west 65–70 km east to the Caribou Hills. It is an estuarine deposit built from sediments delivered by the Mackenzie and Peel Rivers. The mean discharge is 9730 m^3/s, the discharge during the summer is roughly 8500 m^3/s and during peak flood in late May and early June it may exceed 14,000 m^3/s (Mackay 1963). Over the last 10 years, several programs have focused on various aspects of Mackenzie River basin hydrology including the Mackenzie Basin Impact Study (MBIS), the Mackenzie GEWEX Study (MAGS) and ongoing research by Environment Canada's National Hydrologic Research Institute (NHRI) in Saskatoon. For example, MAGS has greatly improved the basic understanding of Mackenzie River hydrology and climate interaction, as well as contributing to a better understanding of cold, high-latitude, hydrological and meteorological processes and the role that they play in the global climate system (Stewart et al. 1998). MAGS involves a series of large-scale hydrological and related atmospheric and land-atmosphere studies within the Mackenzie Basin. The modeling component of MAGS provides a tremendous predictive capacity to assess both the impacts of climate change and human disturbance (e.g., Jasper and Kerr 1994).

The hydrologic regimes of Deltas are complex (Leopold et al. 1995). This is due largely to the dynamic interaction between surface runoff, groundwater flow and coastal processes (Wright 1982). However, the complexity of the Mackenzie Delta is amplified by:

- the effects of cold climate and permafrost
- the northward direction of flow

> *The Delta surface is covered by an intricate network of channels of various types (distributary, river, network, lake, reversing and tidal) and a multitude of lakes of different types and origin (abandoned channel, arcuate, flood plain, thermokarst and dammed).*
>
> Heginbottom and Tarnocai (1983)

Under mean flow conditions, roughly 25 percent of the Delta surface is water; however, during floods and storm surges, this figure is much higher (Mackay 1963). The Mackenzie River and its tributaries recharge and maintain a natural flow of water through this network of channels. East, Middle and West Channels accommodate much of the flow through the Delta. Middle Channel contributes the greatest proportion of incoming discharge. At Horseshoe Bend (opposite Aklavik), the Middle Channel transports 80-90 percent of total Delta inflow. A myriad of small channels link the main lakes and channels, drain bays and connect the Delta to the Beaufort Sea tidal zone. Delta lakes depend on surface water and groundwater for recharging and maintaining their levels. Rainstorms in the headwater regions and spring snowmelt influence the nature and flow rates of surface water. Storm surges influence the channels and small bays of the outer Delta.

Permafrost is characterized by very low hydrologic conductivities and thus acts as an aquitard. Normally continuous permafrost divides groundwater systems into sub- and supra-permafrost zones (Pollard et al. 1998). However, despite being part of the continuous permafrost zone, the permafrost underlying the Mackenzie Delta is relatively permeable because the larger (deeper) lakes and channels have through taliks that link sub- and supra-permafrost hydrologic systems. Furthermore, some recent large alluvial deposits are unfrozen and permit the flow of large volumes of groundwater.

The existence of groundwater and surface water is essential to the health of the productive Delta ecosystem. The subsistence economy of the local people is based on wildlife that depend upon the health and productivity of the Delta's aquatic systems. Water flowing through the Delta maintains ongoing physical and chemical processes that sustain ecosystem health.

6.4.2 Issues Related to Surface Water and Groundwater

Industry Impacts on Surface Water and Groundwater

Changes in the quantity or quality of groundwater or surface water could impact the health and integrity of the Mackenzie Delta ecosystem (Dome Petroleum Limited et al. 1982). Accordingly, two types of impact can be distinguished:

- physical changes to the flow regime (seasonal patterns in discharge and velocity), channel processes (erosion and sedimentation), sediment load and ice cover
- chemical changes associated with contaminants

Development in the Mackenzie Delta region could affect the quality and quantity of surface and groundwater systems. Habitat destruction and even modest levels of pollution may directly and indirectly affect wildlife that depend upon these waters. Both aquatic and terrestrial habitats are vulnerable to small changes in the physical environment. For example, seasonal increases in sedimentation resulting from accelerated bank erosion related to degrading permafrost may impact local fish populations though the destruction of breeding habitat or the dissipation of food supplies. Similarly, small changes in water levels (natural or anthropogenic) could impact the nesting and staging habitats of ducks, geese and swans as well as beaver and muskrat habitat. Smaller tributaries, lakes and wetlands that provide sheltered local habitats for many key flora and fauna are probably at greatest risk because even the smallest scale perturbation (e.g., channel diversion, dam, river crossing) may dramatically modify the ecosystem. By comparison larger channels and lakes require larger and longer-term perturbations before significant impacts occur, however the resulting impacts are likely to affect larger areas and larger numbers of animals. The cascading structure of drainage systems dictates that many impacts accumulate in a downstream direction. Disturbances in headwater areas may have their greatest impacts downstream. This is particularly the case with many contaminants that tend to accumulate downstream.

Water quality has become a major concern for three reasons:

- the impact of contaminants such as PCBs, mercury and other heavy metals such as cadmium could extend through the food chain as a result of bioaccumulation
- even trace amounts of contaminants may be toxic

- contaminants, such as those related to natural gas development, selectively affect certain species and disrupt the food chain

Small changes to the geochemical and hydrological processes could affect the overall health of the Delta ecosystem.

Changes in Sediment Loads Resulting from the Erosion of Shorelines

Data on suspended sediment concentrations entering the Mackenzie Delta and within its channels and lakes are relatively scarce. Baseline comparisons are problematic. Heginbotton and Tarnocai (1983) report that measured concentrations for the Mackenzie River above the Arctic Red River are mostly in the 100–1000 mg/L range. Extreme concentrations occur during flood events, for example concentrations as high as 9,640 mg/L were recorded in 1974 in conjunction with a flood event that produced a discharge of 28,000 m^3/s (corresponding daily sediment yield of 2.33×10^7 tons). Concentrations drop below 100 mg/L by September and fall lower as ice covers form. In the Peel River system suspended sediment concentrations of 200 to 1900 mg/L were measured during the summer in 1973. The maximum occurred during a flood event with a 2830 m^3/s discharge.

Industrial development around waterbodies, including river crossings (road or pipeline), borrow extraction, fjords and landing sites have the potential to degrade shoreline materials by removing protective vegetative cover, disrupting permafrost or dissipating lateral support and over-steepening of slopes. Similarly, changes in water levels will shift erosional patterns and also may destabilize lake or river channel banks. Once shorelines are destabilized, bank materials will tend to erode at an accelerated rate until a new equilibrium is reached. Shoreline material and sediments washed into the watercourse increase both suspended and bed sediment loads and contribute to changes in channel configuration (new depositional features). Localized disturbances of this nature will have only limited impacts, but the impact of large-scale changes (e.g., climate change) or development (dams, water course diversions, artificial islands) may be felt through larger areas of the Mackenzie Delta system. The result would likely affect water and aquatic habitat quality (ESRF 2002; KAVIK-AXYS and LGL 2001).

Changes in Flow and Drainage Regimes

The previous section focused on changes within the river system; however, changes to the surfaces adjacent to and inland from lakes and channels also will have an effect on the system. Activities that change the local topography, even at an apparently insignificant level, can alter surface drainage patterns and affect subsurface water flow. The recharge of surface waterbodies could be affected and wetter or drier areas that did not previously exist could be created. Furthermore, changes to the distribution of surface waterbodies can affect the integrity of underlying permafrost layers. A small change in local topography could initiate a chain of events leading to significant changes in the larger drainage patterns. Such large-scale changes will impact wildlife, habitat quality, future development and the local subsistence economy (KAVIK-AXYS and LGL 2001).

Changes in Water Chemistry due to Fuel or Contaminant Spills

The use of toxic chemicals, hydrocarbons and industrial compounds could lead to the contamination of both surface and subsurface water systems. Contaminants may enter surface and subsurface hydrologic systems directly through a spill or may seep through soil layers into the groundwater systems. Ground-penetrating radar surveys in the high Arctic have shown that diesel fuel remains highly mobile even under sub-zero temperatures. Surface spills can preferentially move along the top of the active layer into nearby waterbodies. The composition of drilling muds has become an important environmental issue. In the past (1950s to 1970s) water-based drilling muds containing a variety of compounds, many of which were harmful, were widely used in the Mackenzie Delta region. These muds were disposed of in surface sumps. The cold, impermeable nature of permafrost was thought to provide adequate containment while effluents froze in place. Recent studies have shown that many of these sumps have leaked. Even though today's drilling muds contain less harmful materials (many use a synthetic oil base), and in most cases, recycling technologies effectively remove most of the harmful constituents, their potential for contamination remains a concern.

If a large fuel or chemical spill were to occur, the impact upon the flora and fauna of a widely integrated system such as the Mackenzie Delta channel system could be substantial (KAVIK-AXYS and LGL 2001; ESRF 2002).

6.4.3 Surface Water and Groundwater Impacts on Development

Under normal conditions hydrologic processes are complex and often unpredictable (Chow 1964). For example, the presence of permafrost and the effect of cold winter air temperatures complicate northern hydrology considerably (Prowse and Ommanney 1990). Processes associated with surface and subsurface water in the Delta region present many challenges for oil and gas development. The interaction between permafrost and groundwater may produce a number of problematic landforms, including icings, icing mounds and blisters, frost blisters, pingos, ice dikes and sills and localized frost heaves. Some of these features are seasonal and therefore form quickly. Icings (also called aufeis or naled) are a common feature of small streams and areas of spring or soil water discharge. River icings occur in winter when the build-up of ice in the river channel blocks flow and causes local overflow and flooding. Braided rivers in the Richardson and Barn Mountains may produce icings two to five metres thick and several tens of kilometres in area (Pollard 1988; Pollard and van Everdingen 1992). Most of the channels within the Mackenzie Delta are too deep to form icings, but many of the tributary channels and basins display considerable icing development. Icings temporarily store winter discharge and contribute to spring flooding (Reedyk et al. 1995).

Sumps Affected by Changes in Water Balances

Sumps, whose role is to contain waste materials and used drilling muds, usually are situated in confined geological zones in the development area. In areas with thin permafrost or through taliks, groundwater could enter the sump and fill it before the drilling program is finished. Continued use of the sump will fill it beyond its design capacity. The result may be a spill of waste materials into the environment or possibly the loss of integrity of the sump walls and subsequent loss of containment. This could have detrimental effects on the physical and biological nature of the surrounding ecosystem (French 1978, 1980). New drill fluid technologies involving the separation of fluid and solid components (shakers, stilling tanks, desander and desilter centrifuges) and recycling of much of the fluid component of drilling mud has changed the way that drill wastes are handled. Water-based drill muds often still require either a surface or subsurface (formational) containment system, but their volumes are greatly reduced.

Erosion of Unstable Terrain

The interaction between watercourses and development structures can lead to accelerated erosion. For example, icings can cause accelerated channel erosion during the spring flood by blocking main channels and forcing high-energy flow to the channel banks and through small sub-icing channels. Artificial structures such as a river crossing may induce a similar effect. Constrictions in flow created by metal drains and bridges may induce icing formation where none previously occurred. Not only can the constant overflow and freezing associated with such 'induced' icings make linear facilities unusable during the winter, but their presence during spring flooding could trigger catastrophic washout of the structure. Another common problem pertains to the possibility of linear thermokarst arising from the tundra disturbances of tracked vehicles or shallow pipelines. Alterations of topography, terrain and permafrost may alter the drainage patterns and lead to the degradation of the terrain (ESRF 2002; KAVIK-AXYS and LGL 2001). In this case, a thaw depression develops along the vehicle track or pipeline right-of-way that becomes a natural channel for runoff. Continued erosion by channeled flow and ongoing thermokarst can result is deep gullies. Lawson et al. (1978) document a full range of tundra disturbances associated with North Slope oil and gas exploration in the 1950s.

Structures and facilities need to be designed to accommodate current groundwater and surface water flows.

6.4.4 Mitigation Related to Surface Water and Groundwater

Experience gained during previous periods of oil and gas development in the Mackenzie Delta, Canadian High Arctic, Alaska and Siberia together with the development of stricter environmental regulations have led to major improvements in northern development technology. In response to the potential impacts that could affect the groundwater and surface water systems, industry has the ability to implement practices that will minimize their effects. For example, new construction guidelines for oil and gas exploration in Northern Alaska described by Crory (1991) or drilling technologies from Siberia can be readily applied in the Mackenzie Delta region.

Effective Waste Disposal and Spill Response

Development involving the use and production of materials and substances that pose a contamination hazard to aquatic systems can minimize potential impacts through effective waste disposal and recycling. Compounds and chemicals can be disposed of by re-injecting them into geologic formations. However, groundwater aquifers need to be avoided in this approach. Waste materials that cannot be reused, recycled or disposed of onsite, are taken offsite to waste disposal facilities. Industry establishes spill response plans and employs personnel trained in the implementation of such plans. With these practices in place, sites should be well prepared to immediately deal with a spill and minimize its effect (IUCN 1993).

Avoidance of Sensitive Areas

With prior identification and knowledge of sensitive areas in the drainage basin, industry can plan their activities to avoid these areas. By concentrating their facilities and working in winter, industry can further reduce its footprint on the land and minimize its impacts.

Concentration of Development

Current development scenarios no longer require the large expanses of terrain or extensive road networks required in the past. Temporary winter roads, the elimination of waste storage pits and the ability to centralize facilities all work towards reducing the amount of land that is disturbed during development. Industry also has the ability to carefully plan and locate their activities. This further reduces their impact by enabling them to select less sensitive areas of the drainage basin.

Use of Directional Drilling and Route Planning

Because of the nature of the Delta, it will be difficult for development to occur without crossing streams and channels. Prior identification of critical channels and sensitive areas will enable industry to avoid these areas and minimize crossings.

Technology has improved and advanced the techniques used in routing pipelines and roads across waterways. Directional drilling is effective in placing a pipeline underneath a river channel, with minimum disturbance. These techniques will minimize the effects of a crossing on the water channel and the associated shoreline. Reduced disturbance of shorelines will minimize the potential for increased sediment loads.

6.4.5 Knowledge Gaps Related to Surface Water and Groundwater

To better understand the effects of development on the hydrology of the Mackenzie Delta, knowledge gaps need to be filled.

Water Quality Monitoring and the Identification of Industrial Compounds

Due to the use of industrial compounds, water quality in the Delta region must be monitored. Existing water quality data should be reviewed and summarized. Based upon this summary, monitoring stations should be prioritized and activated with respect to the most probable development scenario (KAVIK-AXYS and LGL 2001; ESRF 2002).

To further the knowledge base of how industry may affect water systems, a better understanding is required of the industrial compounds in use. Steps need to be taken to identify the compounds used by industry, and the disposal processes.

Monitoring of Water Balances in Sumps

Sump integrity could be affected by changes in water balance, as well as by changes in permafrost and soil degradation. To understand the potential impacts of these changes, a long-term monitoring program should be implemented for existing sumps. Sumps could be investigated to record their physical traits, condition and their integrity with respect to their surrounding physical environment.

Identification and Monitoring of Sensitive Watershed Areas

The development of ecological land classification maps will help to identify sensitive permafrost zones, important soil and geological formations, soil layers and important hydrological features. These maps will lead to the identification of sensitive areas of the watershed, and enable industry to plan their development scenarios.

7 Vegetation

7.1 Chapter Overview

> *The most important research imperative is the need for a long-term perspective. Instead of planning and thinking in 1- to 3-year blocks of time, researchers should view disturbance problems in terms of at least a decade or, better yet, quarter- and half-centuries.*
>
> McKendrick 2000

Many of the plant species that exist in the Mackenzie Delta have unique and effective adaptive strategies. The vegetation communities and plant species in the delta are key to determining the presence or absence of wildlife species. They are not only important to the local peoples for wildlife harvesting practices, but also for food and medicinal uses.

As development moves into the region, some of these communities and plant species could be altered or eliminated. Changes to the insulating surface vegetation, and consequent impacts to permafrost processes, contamination by industrial discharges and alteration of topography and groundwater regimes are all possible ways that vegetation could be impacted. To address these impacts, industry could implement environmental planning strategies, minimize surface disturbance, avoid sensitive vegetation resources where possible, install emission controls and conduct construction activities during the winter season.

A wide range of stakeholders are concerned with the potential impacts on vegetation and wildlife habitat that could occur as a result of development. These stakeholders include the people who live in the region of the Mackenzie Delta, the general public, regulators, industry, co-management boards and the environmental non-government organizations. These parties are in an excellent position to collaborate and apply their knowledge about Arctic vegetation to address some of the knowledge gaps that exist. An integrated mapping system, and an ecological land classification system of the Mackenzie Delta region would be effective in delineating vegetation communities, including uncommon and unique communities and wildlife habitats. An extensive body of local knowledge exists on the medicinal and traditional uses of local plants. This information could be incorporated with information on rare plants and plant communities to create a comprehensive database. Limited information exists on local air quality and nitrogen oxides depositions, and a baseline database needs to be developed for this area. As research in the region continues and efforts to address these knowledge gaps are initiated, industry will be able to implement effective mitigation measures that address potential impacts.

7.2 The Nature of Vegetation

> *Now we come to the wind, the fierce, cold, relentless, drying wind typical of the arctic climate. It affects plants profoundly. It dries them out in summer and, much worse, it "sandblasts" them in winter with wind-driven snow particles. The snow carried by the wind isn't soft and fluffy; it is hard and abrasive. It consists of millions of sharp snow particles driven by gale-force winds just above the surface, the material of blizzards. Snow abrasion is a far greater threat than low temperatures to a plant's well-being in the arctic winter.*
>
> E.C. Pielou 1974

The Arctic environment is harsh. Plants have evolved a set of adaptations that allow them to survive in this inhospitable physical environment. Plants in the Mackenzie Delta region are adapted to:

- a short growing season
- a cold, dry climate. The mean annual temperature at Inuvik is -10°C and annual precipitation of rain and snow combined is less than 200 mm. This is drier than anywhere else in North America except for the southwestern desert (Pielou 1974).
- cold, poorly drained, acidic soils with low fertility
- permafrost

- frost heaving (thermokarst)
- strong winds. The major environmental factors that determine the distribution and abundance of plants in the Arctic are all influenced by the wind (Webber et al. 1980).
- local topography. Site location, aspect and exposure can influence vegetation type.

Some of these factors have an overwhelming effect on the growing season of plants in the north. Summer temperature is one of the major determining factors that affect plant species. If plant tissues are not warm enough, photosynthetic processes cannot occur and growth is limited. Cooler temperature regimes mean that natural biological processes such as decomposition occur at a much slower rate than they do in the south. Dead plant material is slow to decompose, and accumulates in the soil as peat. Because the tundra absorbs more carbon than it releases, much of the carbon becomes locked up in the peat layers of the tundra (Pielou 1974). Slow decomposition also reduces the amount of mineral nutrients available in the soil. Nutrients such as nitrogen and phosphorous become stored in the peat layers. In turn, this has a limiting effect on plant growth and development (Pielou 1974). The interactions between the factors mentioned above determine the makeup and distribution of the vegetation communities across the delta landscape.

Plant species have spread from glacial refugia and from unglaciated southern regions since the last ice age. The plant species that exist in the Mackenzie Delta region today have evolved a number of strategies that enable them to thrive in diverse and abundant vegetation communities.

In wet tundra, which covers much of the Arctic, only five percent of the plant's biomass is aboveground and visible. The remaining 95 percent is underground in the form of roots and rhizomes. Plants store carbohydrates in these underground root systems.

On exposed sites, the vegetation community consists of plants that are adapted to dry, cold and windy conditions. These plants have low structures with long-lived leaves, low photosynthetic rates, high leaf-resistance, buds protected by scales, hairs or persistent plant parts, rigid leaves and deep roots. Some plants further protect themselves from the wind by keeping their dead leaves. This layer of dead leaves protects the plant from the wind and acts as an insulating layer that traps and maintains a layer of warm air around the plant. Sites that are more sheltered from the wind harbour plants that require more moisture and are not adapted to withstand the relentless wind.

Annual plants are the least adapted to the short growing season in the Arctic. Annuals must go through their whole life cycle, from germination to seed production, in one season and die before winter sets in. They tend to be tiny, inconspicuous and rare (Pielou 1974).

Most of the plant species in the Arctic are perennials, and are adapted to living several to many years under challenging conditions. They possess long-lived root systems that have many rhizomes. However, frost heave can damage these plants, whose roots and rhizomes, especially when young, can be injured or broken by the shifting soil.

The most important tree species at treeline are white and black spruce (*Picea glauca* and *Picea mariana,* respectively). Both species are adapted to harsh conditions, particularly the black spruce because its root system will grow in an active soil layer as shallow as 25 cm. Other tree species at treeline include tamarack (*Larix laricina*), balsam poplar (*Populus balsamifera*), trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*).

7.3 Issues Related to Vegetation

The potential impacts on vegetation that are associated with natural gas development include (KAVIK-AXYS and LGL 2001):

- introduction of non-native and highly competitive species through reclamation and re-seeding projects
- losses or modifications of vegetation communities due to surface disturbance that are uncommon on the landscape or that are important elements of biodiversity
- impacts of air emissions from gas processing and compressor stations on sensitive vegetation groups (e.g., lichens)
- accidental wildfires could damage vegetation communities and surface layer insulation, thereby increasing the thickness of the active layer

- alteration of soil and terrain characteristics that, in turn, affect revegetation and reclamation potential
- losses or modification due to surface disturbance of vegetation communities that provide habitat for important medicinal, nutritional and rare plants
- compaction of vegetation layers due to winter road and ice pad construction
- contamination of vegetation communities due to industrial discharges, spills and exposure to waste materials from development activities
- potential loss of wetland vegetation communities and species due to water withdrawal for industrial activities
- potential loss of vegetation communities due to permafrost slumping and slope collapse
- cumulative losses of certain vegetation communities in combination with the effects of other human activities (e.g., collection of firewood)
- cumulative impacts of climate change on distribution and composition of plant communities

Not only have plant species in the Arctic had to adapt to an extreme physical environment, some have also evolved ways that enable them to survive natural disturbances such as flooding, ice wedging, trampling and dust deposition. These natural disturbances can be compared to man-made disturbances in the Arctic (Table 7-1). Information gathered by studying the responses of vegetation to these natural disturbances could be used to guide rehabilitation and mitigation efforts for vegetation communities.

The experiences at Prudhoe Bay in Alaska are also a valuable source of information regarding the disturbance of vegetation by man-made sources. Many of the disturbances are upwards of a half-century-old and provide insight into long-term vegetation responses.

Table 7–1 Typical Disturbances Associated with Oil and Gas Development and their Natural Analogs

Modern Man-made Disturbance	Natural Feature Analog
Exploration site (1940 – 1950s)	Thermokarst Landslides along eroding streams and lakes
Exploration site (1970 – 1980s)	Braided stream channel (gravel) Pingo Thaw-lake/pond
Exploration site (1990s)	Small ephemeral or permanent pond
Winter haul road (dry)	Upper margin of drained lake Pingo Landslides along eroding streams and lakes High-centre polygon
Winter haul road (wet)	Drained lake basin Low-centre polygon Natural thermokarst
Production pads and roads (gravel fill)	Braided stream channel (gravel) River delta
Wheel ruts (pre-1970) Buried cable trenches	Caribou trails
Dust fallout from roads	Loess deposit from river or sand dunes
Gravel spilled on tundra	Stream deposited gravel Animal burrows
Seeded and fertilized site	Enriched caribou carrion site
Nutrients from wastewater	Enriched caribou, muskox or moose carrion site Squirrel and fox dens Thermokarst
Overburden stockpile	Pingo River bluff Stabilized dunes
Impoundments	Ponds and lakes
Brine spills	Storm surges drowning tundra Saline marshes and estuaries
Oil spills	Natural oil seeps

__Source__: McKendrick (2000)

Some information exists on the rehabilitation and recovery responses of plant species in different habitats.

> *Natural and artificial revegetation proceed most quickly in moist habitats with intact soil. Dry habitats are the slowest to recolonize and the most susceptible to long-term damages from brine and oil spills. Disturbances that change moisture conditions or significantly alter soil properties present greater re-vegetation challenges than simple alterations of the plant community.*
>
> McKendrick 2000

7.4 Mitigation Related to Vegetation

> *Some small, rare and unique ecosite phases may require complete protection.*
>
> Dr. Paul Latour, Habitat Biologist
> Western Arctic Canadian Wildlife Service, Environment Canada
>
> *Deeper gas reservoirs mean more options for the optimal location of surface facilities. The earlier we know about areas that may need protection the better.*
>
> Dr. Doug Mead, Senior Environmental Scientist
> Shell Canada Limited

The following measures can be implemented by industry to minimize the impacts of development on vegetation:

- environmental protection planning and emission controls to minimize impacts associated with emissions, contaminant wastes and small scale clearing by the gas industry
- winter construction to minimize disturbance of vegetation during the growing season when plants are most sensitive
- documentation of unique, rare, valuable or sensitive vegetation species and communities prior to development, and implementation of mitigation plans such as habitat avoidance, minimize impacts to these resources

7.5 Knowledge Gaps Related to Vegetation

A number of steps can be taken to improve the knowledge base and, in turn, lead to the development of more effective mitigation practices:

- An integrated mapping system that describes habitats and delineates vegetation communities is required.
- The locations of rare plants, rare vegetation communities and traditional harvesting sites for important nutritional and medicinal plants need to be mapped. These efforts could be incorporated into the mapping efforts mentioned above. An associated database with relevant information on each species may prove useful.
- Baseline knowledge of air quality and nitrogen oxides deposition in the region needs to be collected and documented. There is limited information on the air quality and the effects of nitrogen oxides on vegetation in the Mackenzie Delta region. This baseline data should be obtained prior to the start of development.
- Historically, reclamation projects for vegetation communities have been completed throughout the Arctic. The focus of most of the projects was to re-establish vegetation cover, insulation cover and stop erosion. Whether these efforts have resulted in re-establishing native vegetation species or the diversity of the natural pre-disturbance plant communities in the long-term is unknown. The information and results from these projects needs to be reviewed. Some reclamation approaches are not well understood and require more work. Little has been done to document and establish viable seed stocks for reclamation. The long-term effects of fertilizers on surrounding native plant species are not well understood.
- Other human activities and land uses in the region could have a cumulative effect on vegetation communities. The nature of these effects requires further investigation.

A vegetation and ecological land classification (ELC) system for the Mackenzie Delta and Mackenzie Valley is needed prior to the start of major field studies for proposed developments, and is considered to be one of the most important information needs relative to vegetation. Maps that show this information are critical in completing quantitative analyses for other disciplines such as wildlife habitat, traditional land use, biodiversity and assessment of cumulative effects.

The development and use of an ELC system would:

- provide a standardized method for classifying and mapping ecological units based on climate, landform, vegetation and soil units
- help quantify the distribution and availability of soil types, terrain units, moisture regimes and vegetation communities. In turn, information on soils, terrain, moisture regimes and vegetation can be used to quantify the availability and quality of wildlife habitat
- enable the storing and interpreting of information from traditional land use studies. Site-specific information on resource use (e.g., food and medicinal plants, hunting sites, travel routes and campsites) can be recorded on additional data layers
- provide a means to assess the cumulative effects to soils, vegetation, wildlife, some aquatic resources and resource use (including traditional land use)
- allow for the assessment of landscape level, community level and associated species level changes and in turn relate them to regional thresholds

An ELC system would provide standardized base mapping for local communities and management boards for planning and assessment purposes. This would accommodate Indian and Northern Affairs Canada and the management board requirements for mapping products to monitor land use and land lease permits. A mapped ELC system with additional data layers would reduce the argument from proponents that mapping required to fully understand the potential impacts of their projects is not affordable.

A large body of knowledge already exists on the ecosystems of the Mackenzie Delta as a result of an extensive half-century of research. For example, vegetation mapping was completed for areas in the immediate vicinity of the Mackenzie River during the initial planning work for oil and gas development in the late 1970s to 1980s. This past work is valuable for predicting potential impacts of development on vegetation communities.

Although some work has been initiated on vegetation classification using thematic mapping from Landsat images, no attempt has yet been made to develop a regional ecosystem classification for the Mackenzie Delta and Mackenzie Valley.

Some work related to a comprehensive ELC initiative has already started, but there is need for leadership and coordination. Existing programs include:

- the establishment of geographic information systems in the Inuvialuit, Gwich'in and Sahtu Settlement Regions at a 1:250,000 scale
- completion of a vegetation classification system for the Mackenzie Valley using Landsat TM data by the Government of the Northwest Territories Department of Resources, Wildlife and Economic Development. The study area includes the Mackenzie Delta, Mackenzie Valley and areas south to the Northwest Territories border.
- Development of a vegetation classification system for the Mackenzie Gas Project for the area of the Mackenzie Delta associated with the proposed leases and pipeline routes, based on dominant vegetation cover. The system is designed specifically for interpretation of colour 1:30,000 scale air photos for the Mackenzie Delta.
- In the summer of 2001, Ducks Unlimited began classifying vegetation and wetlands using Landsat TM imagery over a portion of the Mackenzie Delta in the Gwich'in Settlement Area and the Inuvialuit Settlement Region.

8 Terrestrial Wildlife

> *The native people, through long, hard-won experience and careful observation, have a deep, integrated understanding of the northern environment which is an invaluable national resource; it is essential that full use be made of this knowledge in northern development and environmental protection. But the knowledge that comes from past experience is in itself not sufficient to deal with totally new situations, such as introduction of toxic pollutants or the impact of a large-scale technical economic system on a non-industrial society. Similarly, the engineering and technological developments by industry, based on thorough study and testing, are essential to identify and evaluate the resources and find ways of extracting them or taking them to market; but they cannot in themselves give an understanding of the integrated response of a stressed ecosystem or determine the value of, say, a particular breeding area for waterfowl.*
>
> From the Intervention by Dr. E.F. Roots, Science Advisor
> Department of the Environment to the Beaufort Sea
> Environmental Assessment and Review Panel, Ottawa, 1983

8.1 Chapter Overview

The key issues for terrestrial wildlife associated with the potential impacts of gas development in the Mackenzie Delta region as identified by KAVIK-AXYS and LGL (2001) are:

- direct alteration or loss of wildlife habitat
- habitat fragmentation
- blockage or deflection of movements
- change in wildlife populations from increased access and associated hunting
- sensory disturbance of wildlife (bear, wolverine and wolf dens; migrating and calving ungulates)

- increase in risk of mortality from animal control actions and vehicle-animal collisions
- cumulative effects of all human activities in the Delta region, particularly on resource use by beneficiaries of comprehensive claims

These issues were the subject of discussion at the Environmental Studies Research Fund workshop help in Inuvik, January 2002. Attention focused primarily on five species selected as valued ecosystem components: beaver, moose, Arctic fox, grizzly bear and caribou. Common knowledge gaps relevant to all of these species were identified:

- the need for a vegetation classification system
- effects of access
- the need for zero tolerance on the feeding of wildlife
- the need to control potential contaminants
- the need for adaptive management systems

Beaver

There is an extensive amount of knowledge and information about the beaver's natural history and its importance to the local economy in the Inuvialuit Settlement Region. Even though fur prices fluctuate, the beaver remains an important species in the subsistence economy. Development could affect the population by improving access to remote populations, altering important habitat structures, contaminating waterways or fragmenting home ranges. The distribution of beaver in the Delta region is confined to specific habitats. Industry can implement practices such as contaminant control, avoidance of sensitive areas and winter construction that will minimize these impacts. However, research and knowledge gaps still exist. Little is understood about how the vegetation communities will be affected by development and how wildlife species may be affected. A better understanding and classification of the vegetation and habitat types is required for the whole region. With this in place on GIS platforms, modeling can forecast effects on beaver and their habitat.

Moose

The moose is a common, large, browse-dependent herbivore found throughout the delta. It has, and continues to play, an important role in the terrestrial component of subsistence economies of local people. Development of gas reserves throughout the delta could result in changes in natural habitat that may directly or indirectly affect moose populations. The distribution of moose in the Delta region is confined to specific habitats. Moose could be affected by improved access to remote areas of the delta, fragmentation of habitat, sensory disturbance and exposure to contaminants. Industry can implement a number of practices that will reduce the radius of the zone of influence surrounding developments and the magnitude of associated disturbance coefficient. Preplanning and identification of prime habitat, winter construction and efficient contaminant control will lessen the impacts of development. However, there are still a number of areas that require further investigation and research before a full understanding of development impacts and mitigation practices can be attained. Very little is understood about how vegetation communities and wildlife habitat will be affected by climate change. The whole region requires a more comprehensive classification and mapping of vegetation and wildlife habitat. Ecological land classification mapping will work towards achieving this goal. Once these maps are on a GIS platform, habitats can be identified and modeling can forecast effects on moose and their habitat.

Arctic Fox

Arctic fox are widespread, mobile and effective scavengers that are physically well adapted to the environment of the Mackenzie Delta region. For decades, Arctic foxes have been a mainstay in the Northwest Territories fur trapping industry. As the development of natural gas reserves proceeds through the delta, there are a number of ways that the fox and its habitat could be affected. Improved access to remote regions of the delta, the alteration and disruption of habitat and increased mortality rates due to human-fox interactions could all result from increased development in the delta. However, industry and concerned parties can implement a number of practices that will help mitigate and lessen these potential impacts. Prior identification of critical fox den sites, winter construction, proper disposal and incineration of garbage, no feeding of wildlife, and the review of current trapping regulations will work towards lessening the effects of development on Arctic foxes. There are still areas of research and information that require more effort to fully understand impacts on Arctic fox. Ecological land classification mapping, a review of the current literature on the Arctic fox, and developing more effective training methods for wildlife avoidance and human interactions areas that need further attention and development.

Grizzly Bear

Grizzly bears are large, long-lived omnivores with extensive habitat requires. Grizzly bears are vulnerable to human disturbance. Grizzly bears are both attracted and repelled by human activities. Unless habituated to the presence of humans, grizzly bears will avoid areas occupied by people; however, once they associate people with food (e.g., garbage, food stored at work camp, petroleum-based liquids such as grease and anti-freeze), they may be attracted to facilities. This leads to increased mortality through consumption of toxic wastes and shooting of animals. It is critical that all food items and garbage be effectively managed.

Cumulative impacts on core security areas require further study. There is a need to compile and analyse all data available for grizzly bears and develop comprehensive ecological land classification maps for the region to enable grizzly bear core security areas and sensitive habitats to be characterized and mapped. This will allow planned development to minimize impacts.

Caribou

Caribou are migratory animals with large habitat requirements that are an important food source for predators and the Inuvialuit. They are particularly vulnerable to disturbance during the spring migration when the females are expecting. Impacts on caribou can be mitigated through project design features that minimize the impact of linear disturbance and avoid critical habitat at key times of the year. Knowledge of caribou in the Mackenzie Delta region needs to be synthesized. There is a need to confirm the vision, goals, objectives and thresholds for the management of the Cape Bathurst and Bluenose caribou herds and transpose these goals onto a GIS platform for land use planning purposes. More research is needed on the natural mortality of caribou and their response to stress.

8.2 Beaver

8.2.1 The Nature of Beaver

The beaver is a large specialized aquatic rodent found in the immediate vicinity of water (Hoffman and Pattie 1968). Within the boreal forest, the beaver uses open water and emergent zones of rivers, streams, and wetlands for cover and denning. The majority of its food is obtained from the ground and shrub strata of shoreline forest and shrub communities.

Beaver may use lodges, burrows or both for cover (Rue 1964). Lodges are frequently situated in areas of lakes and ponds that provide shelter from wind, wave and ice action. A convoluted shoreline, that prevents the buildup of large waves or provides refuge from waves, is a habitat requirement for beaver colony sites on lakes.

The home range of beavers in the Northwest Territories was estimated to be a 0.8 km radius from the lodge (Aleksiuk 1968), while the mean distance between beaver colonies in an Alaskan river habitat was 1.59 km (Boyce 1981). The maximum foraging distance from a food cache in an Alaskan river habitat was approximately 800 m upstream, 300 m downstream and 600 m on oxbows and sloughs (Boyce 1981).

Beaver require a permanent supply of water and prefer a stable water level (Slough and Sadleir 1977). Beaver can usually control water depth and stability on small streams, ponds and lakes; however, larger rivers and lakes where water depth and/or fluctuation cannot be controlled are often partially or wholly unsuitable for the species (Murray 1961; Slough and Sadleir 1977). Beaver utilize soil for dam and lodge construction, and will excavate burrows along shorelines where bank dens are required.

Shoreline steepness and bank height are major factors affecting food accessibility. Slopes of 45° or more can effectively block beaver access, particularly where banks exceed two metres in height.

The proximity of woody vegetation to the shoreline also affects habitat suitability. Trees and shrubs closest to the pond or stream periphery are generally utilized first (Brenner 1962; Rue 1964). The distribution of beaver in the Delta region is confined to specific habitats.

8.2.2 Issues Related to Beaver

With the development of gas reserves in the near-shore and onshore areas of the delta, there are a number of ways that beaver populations could be affected. Negative impacts experienced by the beaver population could affect the local subsistence and trapping economy.

Habitat Alteration

Construction may alter terrain and drainage patterns. These changes could affect the survival of the local beaver population if waterways drain or flood, and become uninhabitable.

Habitat Fragmentation

As development expands through the region, the construction of some infrastructure and a network of roads and pipelines could effectively dissect natural habitat. Pipelines, roads and compressor stations act as barriers to the movements of beavers in their habitat. An all-season road may divide up a sequence of ponds that are the home territory for a beaver colony. As a result, their home range may be cut in half, and the beavers may have to abandon their lodge in search of new territory. This may prove difficult if beavers already heavily populate the area.

Increased Access by Humans

As development proceeds, roads, transportation routes and pipeline rights-of-way will be constructed throughout the delta. Areas of the delta that were previously inaccessible by vehicle or snow machine, will become more accessible once this network of travel routes is in place. Pipeline rights-of-way can be traveled by snow machine and all season roads will improve access for vehicle traffic. Isolated beaver populations that may have been accessible only by boat prior to development will become more vulnerable to hunting and trapping pressure. This could cause declines in beaver populations.

Increased Access by Predators

The establishment of roads and pipeline rights-of-way not only increases human access but also provides effective and direct travel routes for natural predators. Cleared travel routes such as seismic lines will provide easier access for animals such as wolves, wolverine, bears and foxes. These travel routes will become particularly deadly in the long daylight of early spring (Pearson and Nagy 1976). Isolated beaver populations that may have required a predator to travel long distances or through demanding terrain, may be exposed through the placement of these direct and cleared travel routes.

Sensory Disturbance

Compressor stations, increased air and vehicle traffic, as well as an increased human presence in previously isolated regions could affect beaver populations. In response to these disturbances, beaver populations may relocate resulting in intraspecific competition. This may prove to be difficult if not impossible if beavers already heavily populate the area.

Contamination

The danger of a large-scale oil spill in association with natural gas development does not exist. However, compounds used by industry, if leaked into the environment, may contaminate beaver habitat. Drilling mud, produced water, petroleum products, solvents and domestic sewage are examples of contaminants that could be toxic to beavers or bioaccumulate through food chains. The impacts of bioaccumulation may not be evident until humans eat beaver.

Cumulative Effects of Habitat Loss

Hunting, trapping, habitat loss, habitat fragmentation and climate change could have a cumulative effect on beaver populations.

8.2.3 Mitigation Related to Beaver

Over years of industrial presence in the north, industry has developed a number of practices that will mitigate some of the impacts mentioned above.

Habitat Fragmentation

With prior identification and knowledge of beaver habitat, industry can plan to avoid these sensitive areas. By consolidating facilities and working in the winter, industry can reduce the amount of terrain that they alter. This reduces the potential for large-scale habitat fragmentation.

Improved Access

Increased access either by ice road or permanent road may increase the harvesting pressure on beaver populations. Governments and co-management boards may need to re-evaluate regulations; new harvesting limits, the establishment of restricted and protected areas and enforcement can reduce the impact of hunting and trapping.

Contaminants

Natural gas development will involve the use and production of materials and substances that could contaminate beaver habitat. The possibility that these compounds may be introduced into the aquatic environment can be minimized through effective waste disposal and recycling. Compounds and chemicals can be disposed of by re-injecting them into subterranean reservoirs. Waste materials that cannot be reused, recycled or disposed of in an inert way onsite, are taken offsite to regional waste disposal facilities.

As development is planned, industry should establish environmental management systems that include spill response teams and procedures to deal with accidental spills. With these practices in place, spills can be dealt with immediately (IUCN 1993).

Winter Construction

Winter construction can use temporary platforms and roads made of ice to perform exploratory drilling, seismic activities and pipeline construction. Development during this time of year minimizes the alteration of local topography and reduces the risk of affecting beaver habitat. Winter construction avoids disrupting beaver colonies during critical times of the year, when they are rearing young, repairing habitat structures and storing supplies for the winter.

8.2.4 Knowledge Gaps Related to Beaver

As a species, the beaver has been trapped and used extensively in the Mackenzie Delta region for centuries. From these activities, local knowledge and scientific studies, the ecology and behaviour of the beaver is well understood. However, there is uncertainty about the potential impacts and cumulative impacts of development on beaver and beaver habitat.

Increased Access

Development will create new access to areas of the delta that were previously inaccessible. This could increase harvesting and predation pressure on beaver populations. To better understand this impact and possible mitigation measures, previous studies on this topic should be reviewed and summarized in one current document. Studies have been done for larger species such as caribou and on predation rates by wolves, but no studies exist for the smaller and lesser-known prey (i.e., beaver) and predator species such as wolverine. More research may be required to address this information gap.

Ecological Land Classification

The mapping of habitat types and vegetation has been started for the Mackenzie Delta region. These efforts need to be continued as a matter of priority in an effort to create ecological land classification maps. These maps can be integrated with geographic information systems (GIS) platforms to create effective and powerful planning tools. Ecological land classification maps will identify critical wildlife habitat and the modeling of potential impacts of development. Industry can then take these areas into consideration during the planning stages.

Climate Change

Recent changes in climate have resulted in a general warming trend in the north. Little is understood as to how these changes may affect the local vegetation communities. Warmer temperatures may enable certain species to move further north and out-compete current species. Species specifically adapted to colder temperatures may not be able to thrive in warmer climates and subsequently die off. More research is required as to how the local vegetation communities may be affected by climate change, and how these changes may impact wildlife species. The long-term effects of development and industrial emissions on vegetation are not well understood. Wildlife species that depend on plants for food and shelter could be affected.

8.3 Moose

8.3.1 The Nature of Moose

Moose are large, browse-dependent herbivores. They occupy a variety of habitats and prefer edges or disturbed areas where vegetation is in an early successional stage. Moose use the shrub and ground strata of deciduous, mixed and coniferous forests and shrubland cover types. During the spring and summer season, the emergent and submergent zone of wetlands is also used as a food source.

Cover provides protection from predators, insects and extreme weather during movement, feeding and resting. However, for much of the year, habitats selected for food also provide adequate cover, particularly against predators. For example, lakes and ponds used for feeding in summer offer relief from insect harassment (US Fish and Wildlife Service 1980) and high temperatures (Telfer 1984). Riparian areas surrounding wetlands provide escape cover from predators.

From spring to late fall, moose use relatively open habitat types with productive shrub strata such as wet meadows, shrublands, riparian areas, muskeg and upland deciduous stands as well as regenerating burns and clearcuts (Dorn 1970; Cairns and Telfer 1980; Rolley and Keith 1980; Mytton and Keith 1981; Nietfeld et al. 1984; Pierce and Peek 1984; Risenhoover 1989). Moose calving grounds are typically wet marshy lowlands, which support early spring forage, interspersed with upland islands that have a dense cover of trees or shrubs (US Fish and Wildlife Service 1980; Rausch 1967).

During winter, the habitat preferences of moose are partially influenced by winter severity and snow depth, although browse availability is a major factor governing the distribution of moose. Under deep or crusted snow conditions, moose prefer areas that support both high browse-yield (e.g., shrublands, regenerating clear cuts burns and upland deciduous forests) and mature coniferous forests offering thermal cover and reduced snow depths (Doerr 1983; Nietfeld et al. 1984; Pierce and Peek 1984; Telfer 1978, 1984).

LeResche (1974) has concluded that "regardless of how far moose habitually move between seasons, home range during a given season seldom exceeds five to 10 kilometres squared". Within that area, the quality or suitability of a particular habitat may be largely dictated by its proximity to other habitats. In general, an interspersion of cover types, rather than a homogeneous vegetation community, is considered prime moose habitat, since such a complex ensures that suitable forage and cover are provided in close proximity to each other. The distribution of moose in the Delta region is confined to specific habitats.

8.3.2 Issues Related to Moose

The moose is an important species in the subsistence economy of the Inuvialuit and Gwich'in people. Impacts to moose populations thus could affect local people. The development of gas reserves in the Mackenzie Delta region could affect moose in a number of ways.

Habitat Alteration

Construction may alter the local terrain and change the local drainage patterns. These changes may alter prime moose habitat, and make it uninhabitable.

Habitat Fragmentation

The construction of infrastructure, transportation routes and pipelines may fragment moose habitat in the region. Pipelines, roads and compressor stations may act as barriers to moose movements. Moose may avoid these artificial structures, and either travel a greater distance to avoid them, or leave their home territory in search of a new one. This may prove to be difficult if the area is already heavily populated with moose.

Increased Access by Humans

As development in the region proceeds, roads, transportation routes and pipeline rights-of-way will be constructed. Areas previously inaccessible by vehicle or snow machine will become more accessible once this network of roads and rights-of-way are in place. Moose populations that may have been only accessible by boat prior to development will become more vulnerable to hunting pressure and moose populations may decline.

Increased Access by Predators

The establishment of roads and pipeline rights-of-way not only provides ease of access for humans, but also provides effective and direct travel routes for natural predators. Cleared travel routes such as seismic lines will provide natural predators such as wolves with easier and more direct access. Moose populations that were isolated prior to development, may have been more difficult to reach and required more effort on the behalf of the predator.

Sensory Disturbance

Compressor stations, increased air and vehicle traffic as well as an increased human presence in previously isolated regions of the delta could have a negative effect on moose populations. In response to these disturbances, moose could leave their current home ranges and try to relocate. This will result in intraspecific competition.

Contamination

The danger of a large-scale oil spill is remote. However, other compounds used by industry may pose a contamination threat to moose if they are leaked into the environment. Drilling muds, produced water, petroleum products, cleaning solvents and domestic sewage are examples of contaminants that could be directly toxic to moose. Heavy metals such as cadmium may bioaccumulate through food chains, and only become evident at a later stage, such as in the humans that consume moose.

Cumulative Effects of Habitat Loss

Hunting, habitat loss, habitat fragmentation and the effects of climate change could interact in a cumulative way on the moose populations in the Mackenzie Delta region.

8.3.3 Mitigation Related to Moose

Industry has developed a number of practices over the years that will mitigate the impacts mentioned above.

Habitat Fragmentation

With prior knowledge of the distribution of moose habitat, industry can plan activities to avoid sensitive areas. By concentrating facilities and building in the winter, industry can reduce the amount of habitat that they affect. This will reduce habitat fragmentation.

Improved Access

Improved access either by ice road or permanent road may increase the harvesting pressure on moose populations. Governments and co-management boards may need to re-evaluate regulations; new harvesting limits, the establishment of restricted and protected areas and enforcement can reduce the impact of hunting.

Contaminants

Natural gas development will involve the use and production of materials and substances that could pose a contamination threat to moose. The possibility that these compounds may be introduced into the aquatic environment is minimized in the current work environment through effective waste disposal and recycling. Compounds and chemicals can be disposed of by re-injecting them into subterranean reservoirs. Waste materials that cannot be reused, recycled or disposed of in an inert way onsite, can be taken offsite to regional waste disposal facilities. As development is planned, industry should establish environmental management systems that include spill response teams and procedures to deal with accidental spills. With these practices in place, spills can be dealt with immediately and effects on the local environment can be minimized (IUCN 1993).

Winter Construction

Winter construction can use temporary platforms and roads made of ice to perform activities such as exploratory drilling, seismic activities and pipeline placement. Frozen ground makes it easier to complete construction projects without altering or changing moose habitat. Winter construction will not disturb moose during critical times of the year when they are rearing young and mating.

8.3.4 Knowledge Gaps Related to Moose

The moose plays an essential role in the subsistence economy of the Inuvialuit and Gwich'in people. Moose were, and still are, a major resource for various items including clothing, shelter, tools and food. From local knowledge and scientific investigations, much is known and understood about moose habitat, life history strategies and populations. However, there is uncertainty about the potential impacts and cumulative impacts of development on moose and moose habitat.

Increased Access

Development will create new access to previously inaccessible areas of the delta. Harvesting and predation pressure on moose populations could increase. To better understand this impact and possible mitigation measures, previous studies on this topic should be reviewed.

Ecological Land Classification

As previously identified, detailed ecological land classification mapping is needed for the Mackenzie Delta region to identify critical wildlife habitat and model potential developmental impacts.

Climate Change

More research is required as to how the local vegetation communities may be affected by climate change, and how these changes may impact wildlife species.

Identification of Prime Moose Habitat

A better understanding of prime moose habitat in the Mackenzie Delta is required. Once vegetation mapping and ecological land classifications is started, surveys and local ecological knowledge can be used to identify preferred moose habitat.

8.4 Arctic Fox

8.4.1 The Nature of Arctic Fox

The Arctic fox is one of two species of fox that exist in the Mackenzie Delta and southern Beaufort Sea region. With its dense underfur, short legs, and small ears and nose, the Arctic fox is far better suited to the cold northern environments than the red fox. The Arctic fox is common in coastal areas as well as in inland habitats.

A fox may have a home range from 3 to 25 km^2. As a scavenger, Arctic foxes are mobile and some individuals have been documented as having traveled upwards of 2000 km (an Arctic fox tagged at Prudhoe Bay was trapped at Baker Lake, Northwest Territories). Arctic foxes exist on a wide range of food sources that include the remnants of seal carcasses, eggs, birds, hares, lemmings and seal pups. In late winter, foxes search for den sites in sandy, sloping terrain that are close to rivers or lakes.

Breeding occurs in late March and April, and by mid- May to June, litters of pups are born. Litter size averages six pups, but Arctic fox populations are cyclic and depend upon the rise and fall of lemming populations. A rise in lemming numbers can result in a litter of ten pups. In poor lemming years, some foxes do not breed at all, and those that do have small litters. Pups are raised through the summer, and by the end of August, they are abandoned and left to fend for themselves. Foxes mature at the age of 10 months, and have a life span of about 4 years.

Natural predators are few and wolves are the only significant predator. Arctic foxes are susceptible to various diseases including rabies.

Even though the cost of fox pelts has fluctuated widely over the past 30 years, the Arctic fox continues to play an important role in the fur trapping industry in the Northwest Territories. The community of Sachs Harbour was established to access the abundant Arctic fox populations on Banks Island.

8.4.2 Issues Related to Arctic Fox

Increased development in the Mackenzie Delta and in the near-shore region of the Beaufort Sea could impact Arctic fox. The Arctic fox is an important species in the local trapping economy of the Inuvialuit and Gwich'in people. Impacts to fox could affect the local trapping economy.

Habitat Alteration

As development expands through the region, the construction of infrastructure, transportation routes and pipelines will change habitats. Structures such as pipelines, roads and compressor stations may act as barriers to the movements of foxes through their home ranges and fragment their habitat. Activities such as borrow extraction may alter or directly impact sites that are prime den locations. Disturbances or disruptions may displace foxes. Movement to a new home range may result in intraspecific competition.

Increased Access by Humans

As development in the region proceeds, roads, transportation routes and pipeline rights-of-way will be constructed. Arctic fox populations that may have been previously inaccessible may experience increased trapping pressure. As a result, populations may start to decline.

Increased Access by Predators

The establishment of roads and pipeline rights-of-way not only provide ease of access for humans, but also provide effective and direct travel routes for natural predators. Cleared travel routes such as seismic lines will provide natural predators such as wolverines with easier and more direct access to fox dens and pups. Arctic fox populations that were isolated prior to development, may have been more difficult to reach and required more effort on the behalf of the predator.

Sensory Disturbance

Compressor stations, increased air and vehicle traffic and an increased human presence in previously isolated regions of the delta could affect foxes. In response to these disturbances, foxes may move out of their current home ranges and try to relocate. This will result in intraspecific competition.

Contamination

Compounds used by industry, may pose a contamination threat to foxes if they are leaked into the environment. Drilling muds, produced water, petroleum products, cleaning solvents and domestic sewage are examples of contaminants that could be directly toxic to Arctic fox. Arctic foxes may not directly encounter these substances, but they could bioaccumulate in foxes through the consumption of contaminated food such as rodents, birds and eggs.

Cumulative Effects of Habitat Loss

Hunting, trapping, control actions and changes to habitat could interact in a cumulative fashion on foxes in the Mackenzie Delta region.

Attraction to Development Sites

Arctic foxes are attracted to developments. Foxes can develop a dependency on garbage and haul-outs as part of their regular diet. Such a dependency may increase their risk of mortality due to conflicts with people. As foxes habituate, their chances of coming into contact with toxic substances increases.

8.4.3 Mitigation Related to Arctic Fox

Industry has developed a number of practices over the years that will mitigate the impacts mentioned above.

Habitat Fragmentation

With prior identification and knowledge of fox habitat, industry can plan to avoid sensitive areas. Using local knowledge, potential and current den sites can be located and flagged prior to development. These sites could be protected and avoided during borrow extraction. By concentrating facilities and building during the winter, industry can reduce the amount of terrain and habitat that they affect. This will reduce habitat fragmentation. The highly mobile nature of the Arctic fox will also enable it to avoid development.

Arctic Fox Response to Improved Access

Increased access either by ice road or permanent road may increase the trapping pressure on fox populations. Governments and co-management boards may need to re-evaluate and possibly restructure current harvesting regulations; new harvesting limits, the establishment of restricted and protected areas and enforcement of these regulations can reduce the impact of hunting and trapping. A zero tolerance regulation should be put in place with regards to the feeding of wildlife.

Arctic Fox Response to Contaminants

The possibility that these contaminants may be introduced into the environment is minimized in the current work environment through effective waste disposal and recycling practices. As development is planned, industry establishes environmental management systems that include spill response teams and procedures to deal with accidental spills. With these practices in place, spills can be dealt with immediately and effects on the local environment can be minimized (IUCN 1993).

Winter Construction

Winter construction can use temporary platforms and roads made of ice to perform activities such as exploratory drilling, seismic activities and pipeline placement. Winter construction activities will not impact or disturb foxes during critical times of the year, such as the time of denning and the rearing of pups in early spring.

8.4.4 Knowledge Gaps Related to Arctic Fox

The Arctic fox plays an important role in the local trapping economy. It has been trapped extensively in the delta for many years and from these activities, local ecological knowledge and scientific investigations, much is known and understood about the habits, life history strategies and population cycles of the Arctic fox. However, research gaps regarding the impact of development on Arctic fox still exist and need to be addressed.

Ecological Land Classification

As previously identified, detailed ecological land classification mapping is needed for the Mackenzie Delta region to identify critical wildlife habitat and model potential developmental impacts.

Current Literature and Review of Local Knowledge

To better understand the impacts of development on Arctic fox in the Mackenzie Delta region, a literature review should be completed. An effort should be made to compile and organize relevant local knowledge on Arctic fox populations, their habits and habitat use. Reviewing the scientific and local knowledge will provide a better understanding of the local Arctic fox populations and assist in the planning efforts of industry. This review should involve someone with on-the-ground experience at Prudhoe Bay.

Training and Orientation of Workers

The mortality rates for Arctic foxes and other species of wildlife increase when animals are attracted to development sites by domestic wastes. Education and incentive programs need to be implemented and strongly enforced on development sites. If workers are made aware of the consequences of deliberate or improper disposal of garbage and protocols are enforced, the number of wildlife and human interactions may be reduced. More effort needs to be put towards such programs, and regulations need to be enforced with zero tolerance.

8.5 Grizzly Bear

8.5.1 The Nature of Grizzly Bear

Grizzly bears are efficient omnivores whose diet includes ground squirrels, voles, lemmings and hares. Riparian habitats are particularly important to bears as the nutrient sources on river terraces and other well-drained sites include *Hedysarum* sp. or peavine. Bears select this plant for its roots, which are high in carbohydrates. Bears are capable of rapid weight gain in August and September when they become hyperphagic and gorge on seasonally-abundant foods such as berries, fish and marine mammal carcasses. Ground squirrels are the single most important energy source for grizzly bears.

Ground squirrel densities are highest in areas where there are high proportions of sand and gravel (Slaney 1972) (e.g., the Pleistocene uplands of Richard's Island.)

These well-drained sites are easy to excavate and become frost free early in the year. They also have deep active layers. Ground squirrels in the Mackenzie Delta region are larger than their southern counterparts and they are actively hunted by grizzlies (MacPherson 1965, Pearson and Nagy 1976). There are extensive gravel deposits on the eastern and northern regions of Richard's Island and in two elongated sections east and west of Parson's Lake.

Winters are long and cold in the Mackenzie Delta region and summers are cool and short. Grizzly bears are slow to mature and reproduce in this region. The age of first reproduction is six to seven years, the mean litter size is two to three cubs; not all litters survive and the breeding interval is three to four years (Nagy and Branigan 1998). Although hard data on the longevity of bears in the Mackenzie Delta is limited, life spans probably do not exceed thirty years.

Grizzly bears are in their dens in the Mackenzie Delta region between October and May. Dens are typically located on southerly to westerly aspects in sandy soils, sometimes in deep accumulations of snow, occasionally in peat and they are often associated with shrub cover (Martell et al. 1984).

Male grizzly bears generally emerge from their dens in April, followed by the females in May, after giving birth to and nursing her cubs in the winter while hibernating. Exact dates of emergence are correlated with spring weather conditions. After they emerge from their dens, grizzlies feed on carcasses and over-wintered berries, on caribou and reindeer calves and on early green vegetation on exposed slopes with southern exposures.

The cubs stay with their mothers until the spring of the year that they are two. Dispersing female cubs often inherit portions of their mother's home range. Dispersing, subadult males often travel great distances and, because of this, they often interact with humans and may end up being killed through control actions.

Grizzly bears require large tracts of relatively undisturbed habitats to maintain healthy populations (Shideler and Hechtel 2000). Grizzly bear home ranges in the Mackenzie Delta region can be as large as 2000 km^2 and Nagy and Branigan (1988) estimate that there are approximately 670 bears in the Mackenzie Delta region.

The Inuvialuit and the Inupiat have used grizzly bears on the North Slope for food and hides for centuries.

8.5.2 Issues Related to Grizzly Bear

Grizzly bears may be both attracted and repelled by the activities of people. Harding and Nagy (1977) studied the responses of grizzly bears to industrial disturbances on Richards Island during the 1972–1975 period. Bears were distributed evenly over the study area during summer but avoided camps by one kilometre or more. Impacts of industrial activities included slight loss of habitat, disturbance of denning areas resulting in abandonment of dens and relocation of problem bears.

Grizzly bears in the Mackenzie Delta must travel actively and extensively to survive. Grizzlies are omnivorous and they spend a large part of each day during the short, cool summers searching for food. As a result, bears may be attracted to the activity of humans. Any activities conducted during the bears' active months will require storage of any attractants (food and garbage) in bear proof facilities (not plywood huts). Petroleum-based liquids such as oil, grease and anti-freeze must be stored, as they will attract animals. Consumption of these products by grizzlies can cause severe illness and death. Daily incineration of garbage is essential.

8.5.3 Mitigation Related to Grizzly Bear

Grizzly bears are a high profile species in the Inuvialuit Settlement Region and they are listed as vulnerable to population decline by the Committee on the Status of Wildlife in Canada (Nagy and Branigan 1998).

Grizzly bears are co-managed under the terms of the Inuvialuit Final Agreement by the following agencies and land claim organizations:

- the Government of the Northwest Territories: Department of Resources, Wildlife and Economic Development
- the Government of Yukon: Department of Renewable Resources
- the Aklavik, Inuvik, Paulatuk and Tuktoyaktuk Hunters' and Trappers' Committees
- the Inuvialuit Game Council
- the Wildlife Management Advisory Council (Northwest Territories and North Slope)
- Heritage Canada/Parks Canada

- Environment Canada

The management of grizzly bears in the Inuvialuit Settlement Region is also affected by the other regulatory authorities, industry, the Environmental Impact Screening Committee and the Environmental Impact Review Board.

The single most important issue with respect to the potential impacts of development on grizzly bears in the Mackenzie Delta region in the short term is the need for effective management of all food items and garbage. This potential impact can be mitigated.

In the longer term, the most important issues is the impact of cumulative effects on core security habitat. It may not be possible to mitigate this impact. As already discussed, comprehensive ecological land classification system maps are needed to model habitat requirements and identify key areas to avoid. For example, Pearson and Associates (1980) describe the importance of the careful section of borrow sites to prevent destruction of prime ground squirrel habitat, since ground squirrels are a mainstay in the grizzly bear diet. They further state that it is important to select borrow sites before grizzly bears start looking for den sites in the fall.

8.5.4 Knowledge Gaps Related to Grizzly Bear

There is currently no single guiding framework for the analysis of potential impacts of development on grizzly bears, however, a grizzly bear management plan is under development. Grizzly bear habitats in the Mackenzie Delta region need to be characterized and mapped in terms of their distribution, relative availability, quality and quantity. The core security areas and areas vulnerable to disruptions in habitat connectivity need to be identified. This would be facilitated by detailed and complete ecological land classification maps. High-quality output from GIS systems that describes relative habitat suitability is required for planning purposes. The principles and goals of the co-management plan for grizzly bears in the Inuvialuit Settlement Region also need to be transposed onto a GIS system.

Existing knowledge and information, including scientific studies, local knowledge and traditional ecological knowledge on grizzly bears in the Mackenzie Delta region, need to be compiled and analyzed. A regional database of information collected during population studies is needed including radiolocation and habitat data to allow identification of areas important to grizzly bears.

8.6 Caribou

> *Industry and Tourism: Developers will know about and consider the seasonal needs of the Cape Bathurst, Bluenose-West, and Bluenose-East caribou herds when undertaking developments. Policies and guidelines for development activities on the seasonal ranges of the three herds will have been developed and implemented. Developers and tourism outfitters will be implementing measures to mitigate the impacts of their activities.*
>
> Nagy et al. 1999
> Draft Co-management Plan

8.6.1 The Nature of Caribou

This section focuses on barren-ground caribou (*Rangifer tarandus granti*) with the exception of the following comments on reindeer and woodland caribou.

The Western Arctic reindeer herd, which is presently on the Tuktoyaktuk peninsula, is presently in the process of being moved to the Delta area. Richards Island will be used as summer range and the Husky Lakes – Noel Lake area will be used as winter range (Note: reindeer are not technically wildlife but this subspecies, introduced in 1935, is a valued ecosystem component in the Mackenzie Delta region).

Woodland caribou (*Rangifer tarandus caribou*) occur in small groups in some forested parts of the Delta region (Martell et al. 1984). The workshop in Inuvik identified the need to refine the current understanding of the distribution, abundance and productivity of woodland caribou in the Mackenzie Delta region.

Spring

Caribou herds undertake predictable annual and seasonal migrations that optimize their forage intake (Russell et al. 1993). Spring migration is an energetically stressful period for caribou, especially for adult females, as they are pregnant and likely suffering from late winter food shortages (Adamczewski et al. 1993). Food is scarce once the animals cross the treeline and they have to rely on energy stored as glycogen and fat. Pregnant cows have the combined energy demands of migration and pregnancy. Migrating caribou tend to move along paths of least energetic resistance oriented along a general bearing towards a calving ground or wintering area (Jakimchuk 1979). Movements often follow well-developed trails etched into the land by frequent use.

Most of the cows and calves spend a good portion of every day traveling along one of the long migratory routes between the winter range and the calving grounds. Adult bulls will follow behind at a later date and do not migrate with the larger groups as a way of avoiding wolves.

Caribou are efficient travelers, traversing distances greater than any other terrestrial mammal (Fancy et al. 1989) and with the lowest net cost of locomotion of terrestrial species (Fancy and White 1987). Increased amounts of locomotion potentially resulting from disturbances may not have as severe an impact on caribou as for other species affected by disturbances (Grindal 1998). In general, caribou spend about half of every day of the year feeding (see the hyperlink: www.taiga.net/caribou/pch/slides/pch10.html).

Griffith et al. (1998) concluded that warm spring weather in recent years has resulted in earlier green-up and higher biomass of vegetation on calving grounds in the Arctic, and that these changes correlate with increased calf survival and recent population changes in Arctic caribou herds in Alaska.

Summer

The dominant influence on caribou movements between late June and early August is harassment by mosquitoes and warble and bot flies (White et al. 1975; Roby 1978; Dau 1986). Harassment by insects greatly disrupts normal activity patterns, reducing feeding time while increasing the time spent running and walking. Lactation demands are high for females and access to high-quality, insect relief areas is important.

Caribou seek cool, windswept areas to avoid insects. As wind speeds increase and exceed six metres per second, harassment by mosquitoes drops to zero (www.taiga.net/caribou/pch/slides/pch14.html) and caribou are able to spend more time feeding (www.taiga.net/caribou/pch/slides/pch16.html). Coastal winds, cooler temperatures and fog suppress mosquitoes but not oestrid flies (Ballard et al. 2000). Harassment by warble and bot flies continues after mosquito harassment subsides in late July (Murphy and Curatolo 1987) ending by mid-August. Warble and bot flies are intolerant of shade. Fly-harassed caribou often seek relief in the shade of elevated pipelines, buildings and even parked vehicles (Murphy and Lawhead 2000). Caribou may escape mosquito harassment by moving to the sea coast (Murphy and Lawhead 2000).

During the open-water season, rivers and lakes tend to divert movements of caribou to favoured, often traditionally-used water crossings (Jakimchuk 1979; Gunn 1989; Heard 1989). River crossing points are generally along low gradient reaches or where braiding permits crossing of narrow channels (Jakimchuk 1979). Caribou are excellent swimmers and have been observed crossing water bodies up to three kilometres wide.

High quality forage is widely available in summer and caribou range nomadically over large areas. This is a time of high-energy demand as cows allocate nutrients to lactation, and insect harassment reduces foraging effort and increases energy expenditures.

Bergerud et al. (1984) considered predation and hunting to be major factors affecting the abundance of caribou. Caribou are the major prey of wolves. As well, caribou are a significant prey item for grizzly bears (Banci and Moore 1997; Gau and Case 1997).

Fall

The onset of fall in the Arctic brings the first frosts that kill the mosquitoes, black flies, deer flies, bot flies and warble flies that persecute people, caribou and other wildlife during the long days of the Arctic summer.

The caribou herds disperse once the frost has killed the insects and the caribou feed actively and gain fat reserves for the winter. Fall migration may be triggered by a combination of photo-period, temperature and snow storms. This period is important for females to improve their body condition prior to the rut as body condition dictates pregnancy rates (see hyperlink: www.taiga.net/caribou/pch/slides/pch19.html).

Winter

The Arctic winter brings freezeup of the larger lakes and snow that persists on the ground. The days are short and cold and caribou are widely dispersed at relatively low densities. The animals are relatively tolerant to disturbance at this time of the year.

Snow depth has a profound effect on the amount of time that caribou need to spend digging craters to get at lichens, grasses and sedges; the deeper the snow, the more time is spent pawing at the ground (see hyperlink: www.taiga.net/caribou/pch/slides/pch12.html) and the less time is spent actually eating (see hyperlink: www.taiga.net/caribou/pch/slides/pch13.html). Lichen, which is low in protein, high in carbohydrate and highly digestible, is the principal food of caribou.

Distribution and Historical Use

Figure 8-1 shows the distribution of the Cape Bathurst, Bluenose-West and Bluenose-East caribou herds. The Cape Bathurst herd and Bluenose-West herd numbered 88,000 – 106,000 animals in 1992 while there were 14,000 to 19,000 animals in the Bluenose-East herd.

> *On the mainland, the Cape Bathurst herd is harvested by 5 Inuvialuit and Gwich'in communities. The Bluenose-West herd is harvested by Inuvialuit, Gwich'in and Sahtu Dene and Metis in 12 communities. In addition, Inuvialuit from Sachs Harbour on Banks Island rely on caribou from these two herds. Similarly, on the mainland, the Bluenose-East herd is harvested by Sahtu Dene, Metis and Inuit from 4 communities. In addition, Inuvialuit from Holman on Victoria Island harvest these caribou. Some non-native resident, non-resident, and non-resident aliens also harvest from these herds for both meat and trophy antlers.*
>
> Nagy et al. 1999

The Inuvialuit Harvest Study (July, 1987 to December, 1992) records the fact that caribou are harvested on and near the Taglu, Niglintgak and Parson's Lake fields.

> *Caribou were common on the Caribou Hills and the Eskimo Lake basin in the 1890's as evidenced by the deep-worn trails that were clearly visible in 1927 and 1928. By the early 1900's, caribou in this area had declined rapidly probably as a result of hunting by whalers.*
>
> Martell et al. 1984

8.6.2 Issues Related to Caribou

Caribou and reindeer (the genus *Rangifer*) are a relatively plastic species in terms of their tolerance to the activities of man (Bergerud 1974). When the activities of people resemble natural threats they can generate strong responses from caribou. Caribou react strongly to any stimulus that reminds them of their predators. Grindal (1998) observed intense responses by caribou in the central barrenlands of the Northwest Territories to wolves and ravens. It is possible that caribou respond strongly to any large birds because they remind them of golden eagles and other raptors that prey on caribou calves. Wolves are a major predator of caribou (Banfield 1974), and can affect their movement patterns over the landscape (Scotter 1995).

Grindal (1998) noted that the proximity of the stimuli appeared to be important in determining the intensity of the response, the closer the disturbance event, the more intense the behavioural response by the animals. Grindal (1998) notes that snow machines and trucks are regularly used for hunting in the Northwest Territories, and caribou subjected to hunting pressures in this manner would likely associate these vehicles with danger. Mahoney et al. (1997) recorded caribou responding to snow machines at a distance of 500 m in Newfoundland.

Caribou are more sensitive to disturbance at certain times of the year than at others, and particularly sensitive at the time of calving and for the first two or three weeks after the calves are born (Cameron and Whitten 1980; Jakimchuk 1980; Dau and Cameron 1986; Curatolo and Murphy 1987; Cameron et al. 1992; Nelleman and Cameron 1996). They are least sensitive during migration and in winter (Jakimchuk 1980).

8.6.3 Mitigation Related to Caribou

Murphy and Lawhead (2000) analyzed in detail measures to mitigate the impacts oil and gas developments on caribou in the Prudhoe Bay area of Alaska. They proposed the following design features:

- a minimal gravel-fill footprint
- elevated pipelines at least 1.5 metres above ground level
- more than 100 m of separation between pipelines and heavily-traveled roads
- roadless developments in new 'satellite' fields
- driver education and training, and traffic control (e.g., road closures and convoying) at critical locations and periods, such as calving grounds during calving season
- buried pipelines (crossing ramps) or higher-than-normal (to 2.5 m) sections of elevated pipelines in exceptional circumstances where infrastructure or landscape features potentially funnel animals into narrow passageways
- special considerations for coastal and riparian travel corridors, such as low-density development or development free-zones

8.6.4 Knowledge Gaps Related to Caribou

Participants in the workshop in Inuvik noted that the information gaps for caribou in the Mackenzie Delta region do not include concerns about the geographic definition of calving areas nor the definition of the general distribution of the Porcupine, Cape Bathurst or Bluenose herds. The state of caribou research has moved beyond these general, important first questions.

The details of the natural mortality of caribou are not well understood. More research is required including the deployment of satellite radio-collars equipped with GPS and mortality transmitters.

There is a need to continue to develop probability models that rely on variables that capture the relative exposure to (e.g., Gunn et al. 2001). The energetics model that has been developed over the last 24 years for the Porcupine herd by Don Russell and others (www.taiga.net) could be modified for caribou in the Inuvialuit Settlement Region and tested for its utility as a cumulative effects tool.

There is concern about the potential for displacement of the Cape Bathurst herd and a need to better understand their fall and winter. Fifteen new satellite collars will be put on caribou in 2002 to improve our understanding of the distribution of caribou from the Cape Bathurst herd. Future research may also include additional telemetry on the three predators of caribou; wolves, grizzly bears and golden eagles.

There is a need to assess potential cumulative effects issues on caribou such as habitat fragmentation. To assess potential habitat fragmentation issues, two major types of information are required:

- characterization of caribou habitat (e.g., distribution, quality and quantity) based on vegetation classification
- spatial information on the type, timing, duration and intensity of human use and infrastructure

There is concern with respect to potential cumulative effects on the Bluenose-West herd. Human activity in the Inuvialuit, Gwich'in and Sahtu Settlement Regions has the potential to affect the distribution of the Bluenose-West herd. This, in turn, could affect the ability of the communities to hunt caribou. There is a need for a management agreement for the Bluenose herd as noted by Nagy et al. (1999).

The available information on the distribution of the Porcupine, Bluenose and Cape Bathurst herds needs to be synthesized and summarized in one document and posted on the World Wide Web. This can build on the material on the Porcupine herd that is posted at www.taiga.net. The draft co-management plan for caribou in the Inuvialuit Settlement Region includes a comprehensive list of actions that are needed to move the management of these herds forward at the same time that industrial development proceeds.

All existing mitigation measures to reduce the impact of natural gas developments on caribou could be synthesized into a document that would provide the basis for a workshop among caribou research scientists, representatives of the communities and representatives from industry. Such a workshop would benefit from the participation of the scientists who have extensive experience on the ground at Prudhoe Bay.

9 Migratory Birds

9.1 Chapter Overview

The purpose of this section on migratory birds is to review and summarize existing information relevant to migratory birds in the Mackenzie Delta and Inuvialuit Settlement Region (ISR) where natural gas field development is proposed. Another equally important purpose is to identify concerns, issues, information gaps and research needs which should be addressed in order to understand and evaluate the impacts of proposed industry development on migratory birds and on local subsistence harvesters of migratory birds The information presented below is based on briefing notes prepared before the Inuvik workshop and on notes taken during discussions of migratory birds during the wildlife breakout group on 25 January 2002. Specific attention is given to comments provided by Inuvialuit and Gwich'in representatives who participated in the workshop, and by local, regional and national resource managers who participated in the discussions.

To identify data gaps and issues that need to be addressed, it is first necessary to evaluate the concerns of local residents and disciplinary experts who have worked for many years in the ISR and Mackenzie Delta area. Concerns relating to migratory birds need to be evaluated in the context of what is already known, what is not known, and what remains to be investigated. Concerns and issues need to be discussed and evaluated in the context of available published and unpublished information about similar petroleum developments in similar arctic habitats elsewhere, with the hope that proposed gas field developments in the Mackenzie Delta can proceed with a minimum of negative impacts on migratory birds.

9.2 The Nature of Migratory Birds

9.2.1 Waterfowl

Waterfowl as a group are probably the most important group of migratory birds for local residents in the Mackenzie Delta and ISR. At least 20 species of waterfowl are regularly harvested in this area and aside from a few loons and seabirds and moderate numbers of ptarmigan and grouse, very few other species of birds are hunted in the Mackenzie Delta and ISR region.

9.2.2 Tundra Swans

Swans are a high profile and highly valued species in the Mackenzie Delta area. Of the two native species of swans in North America, the tundra swan is by far the most abundant in the Mackenzie Delta and its surrounding areas. The other species, the trumpeter swan, may occasionally breed in small numbers in the wooded southern sections of the Mackenzie Delta.

Swans are harvested in the Inuvialuit Settlement Region by local residents; 124 tundra swans were reported taken during the Inuvialuit Harvest Study in 1998 (Fabijan 2000).

Throughout their range, tundra swans nest mainly in arctic tundra wetlands. They are common nesters in tundra areas of the Mackenzie Delta and surrounding areas, and are much rarer in forested areas (Martell et al. 1984). Tundra swans nesting near the Mackenzie Delta are part of the 'Eastern Population' that spends the winter in eastern North America (Limpert and Earnst 1994).

The Mackenzie Delta is probably the most important breeding area in Canada for tundra swans -- about one third of the entire Eastern Population breeds in the Mackenzie Delta area (Canadian Wildlife Service 2000). The Eastern Population, which occupies the Mackenzie Delta and other areas of the Western Arctic, increased an average six percent per year during the 1990s (Canadian Wildlife Service 2000). However, the year 2000 mid-winter population index for the Eastern Population declined to just over 103,000 birds, a decrease of five percent from the previous year (Canadian Wildlife Service 2000). The North American population of tundra swans is over 150,000 birds (Limpert and Earnst 1994).

Tundra swans migrate in large flocks to their breeding grounds in May and early June, and nest in June-July (Johnson and Herter 1989). They typically remain in the Beaufort Sea-Mackenzie Delta area until fall migration in September-October.

Tundra swans nest on the shores of lakes and ponds. Nest sites are usually slightly elevated, presumably so the swans will have good visibility for detecting predators and rival pairs (Limpert and Earnst 1994). The nest is a large mound of vegetation that is often used for more than one year (Limpert and Earnst 1994).

The young are cared for by both parents and the family stays together until they arrive back at the breeding grounds the next spring (Limpert and Earnst 1994).

The food of tundra swans is almost entirely aquatic plants except during winter when agricultural crops are also eaten (Carboneras 1992).

Tundra swans moult while on the breeding grounds. Adults with young moult near the nesting site. Along the Canadian Beaufort Sea coast there are two known concentration areas used by moulting tundra swans; the outer Mackenzie Delta, especially Moose Channel and near Tent Island, and in the Babbage River delta (Hawkings 1987). During moult, adult swans are flightless for a period of about 35–40 days (Bellrose 1980).

Recent studies in the oil fields on the North Slope of Alaska suggest that tundra swans are fairly tolerant of most petroleum industry related development activities (Ritchie and King 2000). However, some activities do have a high potential to disturb tundra swans, as follows: (1) vehicular traffic, especially during the pre-nesting period; (2) arctic foxes and other mammalian predators (grizzly bears, wolverines), and (3) humans on foot (Ritchie and King 2000). In recent years, increases in the numbers of mammalian predators in the oil fields on the North Slope of Alaska have been responsible for local declines in tundra swan productivity and there is the potential for this problem to become more serious if predator populations remain artificially inflated in that area. Additionally, there is the potential for increased tundra swan mortality caused by collisions with overhead powerlines and other tall structures in the Alaskan oil and gas fields on the North Slope (Ritchie and King 2000).

9.2.3 Geese

Four species of migratory geese commonly nest in the Mackenzie Delta area: the Canada goose, lesser snow goose, greater white-fronted goose, and brant. The Mackenzie Delta area is an important nesting, moulting, and feeding/staging area for these geese. All four species migrate to temperate regions of North America to spend the winter.

Geese are important to people in the Mackenzie Delta area as a seasonal source of food. The outer Mackenzie Delta is especially important to local goose hunters. Just over 6400 geese were reported harvested by the six communities in the Inuvialuit Settlement Region in 1998. Over 4200 were snow geese taken mainly in Tuktoyaktuk and Sachs Harbour, 1500 were greater white-fronted geese and over 350 were Canada geese (Fabijan 2000).

No goose population occurring in the Mackenzie Delta area is considered to be 'endangered', 'threatened' or of 'special concern' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002, Internet site). All four of these geese are listed as 'secure' by the Government of the Northwest Territories (GNWT 2000).

9.2.4 Canada Goose

Canada geese are fairly common breeders in the Mackenzie Delta. The delta is also important for the large numbers of Canada geese that breed farther south then migrate to the delta to moult and feed after the nesting season (i.e., during July through August) (Alexander et al. 1988, Johnson and Herter 1989). Several subspecies and populations occur in the Beaufort Sea area (Dickson 2000). The Shortgrass Prairie Population is the dominant population in the Mackenzie Delta area. This population winters in the central United States (Dickson 2000; Hines et al. 2000). The population of Canada geese living in the entire Inuvialuit Settlement Region including Banks Island and Victoria Island, numbers over 75,000 birds and is apparently increasing (Hines et al. 2000). The Mackenzie Delta section of the ISR has about 350 breeding pairs of Canada geese, mostly in the wooded portion of the delta (Hines et al. 2000). The North American population of all Canada geese is over 4,000,000 and may be as high as 8,000,000 (Dickson 2000).

9.2.5 Lesser Snow Goose

Lesser snow geese are local nesters and abundant migrants in the Mackenzie Delta area (Johnson and Herter 1989). The Western Arctic Population of lesser snow geese occurs in the Beaufort Sea region (Kerbes et al. 1999). More than 95 percent of the Western Arctic Population nests at the Egg River colony on Banks Island, Northwest Territories (Kerbes et al. 1999). The number of birds nesting on Banks Island has increased greatly since the 1960s from about 105,000 in 1960 to 165,000 in 1976 to 479,000 in 1995 (Kerbes et al. 1999). The rest of the Western Arctic Population nests in small scattered colonies, the largest of which are in the Kendall Island and Anderson River migratory bird sanctuaries (Johnson and Herter 1989; Alexander et al. 1991; Canadian Wildlife Service

2000). The birds that nest in the Kendall Island Migratory Bird Sanctuary are situated close to proposed developments in the Taglu and Niglintgak gas fields. The Western Arctic Population winters in western North America mainly south of British Columbia (Mowbray et al. 2000). The world population of snow geese is estimated at between 5 and 6 million birds (Mowbray et al. 2000).

The North Slope of the Yukon Territory and nearby northeastern Alaska are very important staging areas for snow geese during fall migration. An estimated 300,000 snow geese and lesser numbers of greater white-fronted geese spend time on the coastal plain, feeding and building fat reserves, before continuing their southward migration (Hupp et al. 1995). In years when the Alaska and Yukon north slopes are covered by snow, the Mackenzie Delta is used as an alternate staging area. In 1975 over 320,000 snow geese staged in the delta for several weeks before migrating southward (Alexander et al. 1991).

Snow geese nest in colonies in subarctic and Arctic tundra near the coast and often near ponds, lakes, coastal salt marshes or other waterbodies (Mowbray et al. 2000). Snow geese form pairs on the wintering grounds and migrate in large flocks composed of pairs and family groups to the nesting areas (Mowbray et al. 2000). After nesting, goose families stay together for fall migration, the winter period, and during spring migration. Family groups break up shortly after returning to the breeding grounds and the parents start a new family (Mowbray et al. 2000).

The diet of snow geese consists almost entirely of plant material (Mowbray et al. 2000). During fall staging in northern Alaska and the Yukon, snow geese feed largely on particular parts of two plant species; the underground stems of tall cotton-grass and the aerial shoots of northern scouring-rush (Brackney and Hupp 1993).

9.2.6 Greater White-fronted Goose

Greater white-fronted geese are common nesters in the ISR, mostly near the coast of the Beaufort Sea (Johnson and Herter 1989). The Mid-Continent population is the form nesting in the Mackenzie Delta region. They winter mainly in Texas, Louisiana, and Mexico (Ely and Dzubin 1994). The Mid-continent population currently numbers over 100,000 birds (Carboneras 1992). The world population of greater white-fronted geese is unknown although it is over 500,000 birds.

Greater white-fronted geese are herbivores, their diet during the summer consists mainly of sedges, grasses, berries and underground parts of plants (Ely and Dzubin 1994). The outer Mackenzie Delta area is a very important moulting and brood-rearing area for greater white-fronted geese. The outer Delta is also important for white-fronts for autumn staging; during some years more than 20,000 use the Delta concentrating mostly near Shallow Bay (Alexander et al. 1991).

9.2.7 Brant

Brant are common migrants and fairly common breeders in the Mackenzie Delta area (Johnson and Herter 1989). Two subspecies and four populations of brant occur in North America. The Pacific black brant, *Branta bernicla nigricans*, is the common form that breeds in the Mackenzie Delta area. A separate population, the Western High Arctic Population known as the gray-bellied brant, breeds in the western Canadian High Arctic and winters mainly in Puget Sound, Washington. There is debate as to whether this population is a separate subspecies or just a form of Pacific black brant. It likely migrates through the Mackenzie Delta along the Beaufort Sea coast. The gray-bellied brant is of special management concern due to its small population (less than 10,000 individuals), potentially distinct genetic stock, and very restricted wintering area (Canadian Wildlife Service 2000).

Populations of brant fluctuate dramatically depending on many factors, such as weather conditions on the breeding and/or wintering grounds, abundance of main foods like eelgrass and sea lettuce, and human disturbance and harvesting (Carboneras 1992). The mid-winter population index of Pacific black brant in the year 2000 was 127,000, an increase of 6.7 percent over 1999 (Canadian Wildlife Service 2000). Between 1995-1998 in the ISR, including the Mackenzie Delta, the Tuktoyaktuk Peninsula and Liverpool Bay, it was estimated that there were over 6,000 brant were present during the breeding season (Canadian Wildlife Service 2000).

Brant nest in colonies of from less than five pairs to several hundred pairs. Nests are usually built on tundra habitats close to water (Johnson and Herter 1989). Brant families stay together for the southward migration and through the winter (Reed et al. 1998).

During the breeding season brant feed on grasses and sedges, aquatic plants, mosses and lichens (Carboneras 1992; Reed et al. 1998). Later during the moulting and brood-rearing period, coastal wetlands and salt marsh habitats are particularly important feeding areas for brant. The outer west side of the Mackenzie Delta supports several important feeding areas for moulting and brood-rearing brant.

9.2.8 Ducks

The Mackenzie Delta-Beaufort Sea area is very important for many species of ducks for breeding, staging, and moulting. About 24 species of ducks occur in the Mackenzie Delta area, although only 15 are common as breeders or migrants (Martell et al. 1984).

Ducks are important in the subsistence economies of communities in the Mackenzie Delta-Beaufort Sea area. In the three Inuvialuit communities near the Mackenzie Delta, about 670 dabbling ducks, 189 seaducks and 38 diving ducks were harvested in 1998 (Fabijan 2000). A substantial subsistence harvest of king and common eiders takes place every year in the ISR, mainly near the community of Holman on western Victoria Island. An average of about 3,400 eiders per year were killed at Holman during 1988-1994 (Fabijan et al. 1997). During 1996-1998, an annual average of about 2,600 king eiders and 25 common eiders were killed during the Holman hunting season (Byers and Dickson 2001).

Important waterfowl habitat is present throughout the Mackenzie Delta and the surrounding area. Ducks generally nest in or near wetlands. Wetland habitat is also used for brood-rearing by many ducks. Wetland habitats that are particularly important to ducks include lakes and ponds with emergent vegetation especially for nesting diving ducks.

Ducks, like other waterfowl, moult their flight feathers during the summer and are flightless for a period of up to several weeks. Some duck species gather in large flocks in the near-shore waters of the Beaufort Sea during their moult period. Other species gather on larger usually relatively deep lakes for their moult period. Many ducks use near-shore marine waters as staging locations during spring or fall migration. Major river deltas such as the Mackenzie Delta, have open water earlier in the spring than surrounding area and these areas are crucial to ducks and other waterbirds while they wait for the freshwater ponds to thaw. Especially during late springs, migrant waterfowl have no option except open leads in the sea or the early-opening water off major rivers.

During fall migration, even after the moult period is over, large numbers of various ducks particularly long-tailed ducks and common eiders, remain for several weeks in near-shore marine waters, feeding and fattening up prior to their southward migration.

The main predators of ducks in the Mackenzie Delta-Beaufort Sea region are the Arctic fox and red fox. Three species of jaegers, the long-tailed, the parasitic, and the pomarine, are also important predators on ducks mainly in tundra habitats. Other important predators include wolf, grizzly bear, caribou, various owls, hawks and eagles, ravens, and glaucous gull.

No duck population that occurs in the Mackenzie Delta area is considered to be 'endangered', 'threatened' or of 'special concern' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002). Species of ducks that are common in the Mackenzie Delta area that are listed as 'sensitive' (species not at risk of extinction or extirpation but may require special attention or protection to prevent them from becoming at risk) under the Northwest Territories 2000 classification are northern pintail, lesser scaup, long-tailed duck, white-winged scoter, surf scoter, common eider, and king eider (GNWT 2000).

Three main groups of ducks (dabbling ducks, diving ducks and seaducks) occur in the Mackenzie Delta area. A brief description of the status of the commoner species follows.

Dabbling Ducks

Common dabbling ducks of the Mackenzie Delta region are mallard, northern pintail, green-winged teal, American wigeon, and northern shoveler.

Northern pintails, the most numerous dabbling duck in the region, are common breeders in the Mackenzie Delta-Beaufort Sea area (Johnson and Herter 1989). Northern pintails are one of the world's most numerous ducks. Pintail populations fluctuate greatly from year to year. In surveyed areas of North America, numbers have varied from 9.9 million in 1955 to only 1.8 million in 1991. This fluctuation has been linked to differences in the number of pintails breeding in the prairie region of the United States and Canada (Hestbeck 1995). The population estimate in 1997 was of just over 3.5 million birds, well below the North American Waterfowl Management Plan goal of 5.6 million (Miller and Duncan 1999).

Northern pintails, like most dabbling ducks, build their nests on the ground in a variety of habitats. Pintails often nest farther from water than other ducks and their families may have to move relatively far (up to 3 km) to good brood-rearing habitat (Austin and Miller 1995). The mother and young stay together for 4-6 weeks then break up just before the ducklings can fly (Austin and Miller 1995). At most times of the year, northern pintails feed almost exclusively on grains, plant seeds, and pondweeds. Some aquatic insects, crustaceans, and snails are also consumed (Austin and Miller 1995). During nesting, animal prey, especially aquatic insects, Diptera larvae, midge larvae, and snails form a much larger percentage of the diet (Austin and Miller 1995).

Mallards are common breeders in the wooded Mackenzie Delta and uncommon migrants and breeders in the surrounding areas (Martell et al. 1984). Mallards are probably the world's most widespread and numerous duck; the world population exceeds 30 million (Carboneras 1992). The North American population is about 17-18 million (Carboneras 1992).

Green-winged teal are fairly common breeders in the Mackenzie Delta and uncommon visitors and rare breeders in the surrounding areas (Johnson and Herter 1989). The world population of all subspecies is over 9 million (Carboneras 1992). The North American population is estimated at 7 million (Carboneras 1992).

American wigeon are abundant breeders in the forested Mackenzie Delta and fairly common migrants in the surrounding areas (Johnson and Herter 1989). Their breeding range is northwest North America, wintering on the Pacific and Atlantic coasts (Carboneras 1992). The population is estimated at over 6,500,000 (Carboneras 1992).

Northern shoveler numbers fluctuate significantly from year to year in the Mackenzie Delta from common to uncommon; they are normally less abundant on the Beaufort Sea coast (Johnson and Herter 1989). The world population is estimated at several million (Carboneras 1992).

Diving Ducks

Common diving ducks of the Mackenzie Delta-Beaufort Sea region are greater scaup, lesser scaup, and common goldeneye. Scaup build their nests very close to the water edge of ponds and lakes in emergent vegetation. The common goldeneye nests in holes in trees.

Two species of scaup are present in the Mackenzie Delta and surrounding areas; the greater scaup and the lesser scaup. The greater scaup is the less abundant, however scaup nesting on ponds in tundra habitats are likely to be greaters (U.S. Fish and Wildlife Service 1999). The lesser scaup is a common nester in the Delta itself with highest numbers in the forested parts. Both species winter on ocean coasts and inland lakes south of the breeding range (Carboneras 1992).

The North American population of scaup (it is not possible to differentiate the two species of scaup during aerial surveys used to estimate scaup populations) in 1998 was estimated at about 3.5 million, down from just over 7 million in 1984 (Allen et al. 1999). A significant decline of lesser scaup of between 5–10 percent per year has occurred in North America since 1983 (Allen et al. 1999).

Common goldeneyes are uncommon breeders in the wooded Mackenzie Delta, much less common in surrounding areas (Martell et al. 1984). They winter mainly along sea coasts south of the breeding range. The North American population exceeds 1,000,000 (Carboneras 1992).

Seaducks

Common seaducks in the Mackenzie delta and surrounding region are long-tailed duck, common eider, king eider, white-winged scoter, surf scoter, and red-breasted merganser (Martell et al. 1984). Seaducks are important in the subsistence economies in the Mackenzie Delta and ISR (Fabijan et al. 1997, Fabijan 2000). Eiders and long-tailed duck are most common in near-shore waters of along the Beaufort Sea coast. Scoters and red-breasted merganser breed in the wooded Mackenzie Delta although numbers of these species use the near-shore Beaufort Sea during spring and fall migration.

Seaducks are known to be susceptible to disturbance and predation during the nesting period, (Larsen 1960, Ahlen and Andersson 1970, Quinlan and Lehnhausen 1982) and during the moulting period when they are flightless (Johnson 1982). Recent studies in the coastal lagoons of Alaska suggest that increased disturbance associated with petroleum industry activities may be correlated with declines in annual abundance of long-tailed ducks (Noel et al. 2001). Other studies indicate that increased numbers and concentrations of predatory birds (common ravens, glaucous gulls) and mammals (arctic foxes, grizzly bears) as a result of increased garbage and other food wastes in the North Slope oil fields have had marked negative impacts on seaducks nesting nearby in tundra habitats and on coastal islands (Truett and Johnson 2000). Other possible causes of population declines in Beaufort Sea seaducks include increased hunting, lead poisoning, and disease.

There is mounting evidence that Beaufort Sea populations of king and common eiders have declined markedly, possibly by up to 50 percent, in recent decades (Suydam et al. 2000). Similarly, there is growing evidence that long-tailed duck populations may also be declining (Johnson et al. in prep., Noel et al. 2002). The reasons for these declines are currently unknown. There is growing concern that these species of seaducks may be listed as 'threatened' if further declines occur. If these species are listed, there may be restrictions on the harvests of these species by subsistence hunters.

Long-tailed Duck

Long-tailed ducks are circumpolar in breeding distribution; they winter along coasts and on large lakes south of their breeding range. They arrive on their breeding grounds in May and early June, and nest in June-July. Long-tailed ducks are the most numerous duck breeding in the coastal tundra area of the Mackenzie Delta (Martell et al. 1984).

Long-tailed ducks build their nest in upland habitat near a small pond with open water in the center and emergent vegetation around the edges, usually concealing the nest under a small willow (Johnson and Herter 1989). Once the females begin incubation, most male long-tailed ducks concentrate in large flocks in shallow food-rich lagoons and bays along the Beaufort Sea coast to moult during late July through August. They become flightless at this time and are particularly vulnerable to disturbances (Johnson 1990, Johnson and Gazey 1992). While in these habitats, they feed primarily on marine invertebrates, mainly mysids and amphipods (Johnson 1984). Soon after they regain flight, most male long-tailed ducks migrate out of the Beaufort Sea area. Non- or failed-breeding females begin to move to these near-shore areas in early August and, by September, females with newly-fledged young also move to coastal lagoons to feed. During this period in some years, as many as 100,000 long-tailed ducks may be present in these coastal Beaufort Sea habitats mainly in Alaska (Johnson and Richardson 1981, Taylor 1986, Alexander et al. 1988, Johnson and Herter 1989).

King Eider

King eiders are abundant in the Beaufort Sea area (Johnson and Herter 1989). Their breeding range is circumpolar along Arctic coasts. They overwinter mainly in marine waters south of their breeding range (Carboneras 1992).

King eiders nest on the ground on tundra habitats, often near ponds or lakes (Suydam 2000). The brood leaves the nest soon after the clutch completes hatching and the female leads them to brood-rearing areas (Suydam 2000). The female usually attends the brood for up to 50 days by which time the young fledge (Suydam 2000). Several broods may join together in groups called crèches which may number over 100 ducklings attended by several females.

King eiders eat a wide variety of foods. When at sea, mollusks, crustaceans, echinoderms and algae are important foods (Suydam 2000). While nesting they feed in freshwater habitats and vegetation such as sedges, buttercups and bur reeds are eaten, as well as various larvae of aquatic insects and crustaceans (Suydam 2000).

King eiders migrate to specific locations to moult, often in areas distinct from the nesting or wintering areas (Johnson and Richardson 1982). In the Beaufort Sea area, male king eiders move to moulting areas in the Chukchi and Bering seas starting in late June until early August (Suydam 2000). Failed breeders and non-breeding females also soon move to the moulting areas with the males. Females with broods moult near the breeding area (Suydam 2000). In the Beaufort Sea, king eiders form large flocks during the moult migration which concentrate within several kilometers of shore as they pass major points of land (Woodby and Divoky 1982, Suydam et al. 2000).

Common Eider

Common eiders are also numerous in the Beaufort Sea region, but far less so than king eiders (Johnson and Herter 1989). Their circumpolar range extends along Arctic and northern coasts. Most common eiders winter south of their breeding grounds in marine water (Carboneras 1992). Six subspecies are recognized worldwide: the Pacific eider, is the subspecies occurring in the Beaufort Sea region. Pacific eiders range from northeast Siberia, eastwards through Alaska and the Yukon to Coronation Gulf, Northwest Territories (Goudie et al. 2000).

In the Mackenzie Delta and area, common eiders are common nesters on near-shore sand and gravel islands along the Beaufort Seas coast (Cornish and Dickson 1994), often nesting in colonies (Goudie et al. 2000). Studies in Alaska indicated that more nests were present on islands with vegetation, driftwood, and/or other debris that could be used as nesting habitat (Johnson 2000). Females lead the brood to water as soon as the last duckling hatches and dries. As with king eiders, several broods may join together in crèches sometimes numbering over 100 ducklings and attended by several females.

Females and young of the year typically remain in coastal Beaufort Sea areas until fall migration in September through October, but some late migrant eiders (mainly common eiders) remain in the eastern Beaufort Sea until final freezeup in November.

Red-breasted Merganser

Red-breasted mergansers are common to uncommon breeders in the Mackenzie Delta region primarily in the wooded Delta (Johnson and Herter 1989). The North American breeding range is tundra and boreal forest regions south of the High Arctic. They winter south of the breeding grounds on seacoasts and a few large inland bodies of water (Carboneras 1992). No estimates of the total world population are available. The population in Canada and Alaska has been estimated at about 250,000 (Titman 1999). They were thought to be increasing in numbers during the early 1990s in western North America (Goudie et al. 1994).

Scoters

All three species of scoter has been recorded in the Mackenzie Delta-Beaufort Sea area, but only two -- the surf scoter and the white-winged scoter -- are common.

Surf scoters are common breeders in and near the Mackenzie Delta and common migrants throughout the surrounding areas (Johnson and Herter 1989). This species breeds from western Alaska through central Canada to Labrador and winters along the Pacific and Atlantic coasts (Carboneras 1992). In the forested Mackenzie Delta, they are abundant breeders; large flocks gather on salt and freshwater to moult (Martell et al. 1984). An estimate was made in 1994 of

536,000 surf scoters breeding in western North America (Goudie et al. 1994). The population of surf scoters in Alaska is thought to be possibly declining (U.S. Fish and Wildlife Service 1999).

White-winged scoters are abundant breeders in the forested Mackenzie Delta and fairly common migrants along the Beaufort Sea coast (Martell et al. 1984, Johnson and Herter 1989). Their breeding range in North America is generally north of 50° N, from Alaska to Hudson Bay. They winter on shallow marine waters south of the breeding grounds (Carboneras 1992). The population of the New World subspecies was estimated at 592,600 breeding birds in western North America and about 200,000 birds in Russia in 1994 (Goudie et al. 1994). They are considered to be possibly declining in Alaska (U.S. Fish and Wildlife Service 1999).

9.2.9 Raptors

The ISR and Mackenzie Delta areas support 7 species of raptors, but only four species are common; the rough-legged hawk, golden eagle, peregrine falcon, and gyrfalcon. All four of these species typically nest on cliffs and/or rocky outcrops. In the Mackenzie Delta this important nesting habitat is only available along the edges of the Delta, so nesting habitat and breeding densities are relatively low compared to the foothills and more mountainous areas in the Mackenzie and Barn mountains. Densities of all four species typically increase in the late-summer/fall period, however, when adults and young move to the coastal areas where there is an abundance of prey in the form of shorebirds and waterfowl. The other three regular species – the northern goshawk, northern harrier, and bald eagle, are all occasional breeders in suitable habitat in the region (Johnson and Herter 1989).

All members of the Falconiformes (hawks, eagles and falcons) are listed as species of concern or vulnerable by the Committee on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Appendix II. Appendix II lists species that are not necessarily now threatened with extinction but may become so unless trade is closely controlled. (CITES 2002).

Both falcon species are known to hunt prey (mainly birds) many kilometers offshore, often landing on ships and other man-made offshore structures to eat their prey or rest. Falcons will occasionally stay on moving ships for hours or even days and may travel for many kilometers in this manner.

Rough-legged Hawk

Rough-legged hawks are uncommon visitors to the Mackenzie Delta proper; most nesting is in the foothills and mountains farther inland and to the west of the Delta. Some post-breeding families and failed breeding adults from those higher-density nesting areas move to the outer Delta during summer and remain until late September.

The rough-legged hawks breeding range is circumpolar in tundra regions. They winter south of their breeding grounds to south-temperate regions (Orta 1994a). Population estimates are unavailable for much of the species' range. An estimate of 50,000 birds in North America was made in 1986 (Orta 1994a).

Rough-legged hawks typically nest on cliffs, rock outcrops, or riverbanks; usually with a good view of the surrounding area (Orta 1994a). They build bulky nests of sticks and twigs, usually lined with grass, feathers, and hair (Orta 1994a). The main food of the rough-legged hawk on the breeding grounds is lemmings (Orta 1994a). Voles, mice, shrews, and ground squirrels are also eaten. Small mammals usually make up over 80 percent of the diet on the breeding ground (Orta 1994a). Clutch sizes in some areas are highly correlated with lemming abundance (Orta 1994a). Young remain with their parents for 3-5 weeks after they fledge, and thereafter become independent (Orta 1994a).

Golden Eagle

Golden eagles nest mainly in the foothills and mountains to the west of the Mackenzie Delta. Some birds use the coastal plain or the outer Delta during summer through late September.

They breed in nearly all parts of Canada south of the tree-line (Godfrey 1986). The population in North America during the late 1980s was estimated at 70,000 birds (Orta 1994b).

Golden eagles build large bulky nests of sticks and branches lined with vegetation usually on cliff ledges. (Orta 1994b). They usually lay two eggs, but often only one chick survives; the stronger (first hatched) chick often kills the other chick (Orta 1994b). The young are dependent on adults and fed by them for several months after fledging (Orta 1994b). Nest failure or non-breeding is frequent, and survival of young through their first year is low (Orta 1994b).

Golden eagles feed mainly on medium-sized mammals such as ground squirrels, rabbits, hares, and marmots. Ptarmigan are important prey in some areas and carrion is also an important food, especially during winter (Orta 1994b).

Gyrfalcon

Gyrfalcons are uncommon visitors to the Delta; they occur mainly during summer through fall and may remain in the Delta throughout some winters. They are common breeders in the foothills and mountains west of the Mackenzie Delta. On the Yukon North Slope, 107 nesting territories have been located, with the highest densities along the Firth and Anker rivers (Wildlife Management Advisory Council North Slope 2002, Intranet site). Gyrfalcons are circumpolar breeders and residents in the Arctic, moving southward during the winter (White 1994a). The world population is estimated at 5,000-17,000 pairs, and the North American population is estimated at over 2,500 pairs (White 1994a). They are listed by CITES in Appendix I; they are considered to be near-threatened (White 1994a).

Gyrfalcons do not build their own nests, but instead use old tree or cliff nests of common ravens and golden eagles (Clum and Cade 1994). They will drive ravens off and occupy their freshly-built nests (Clum and Cade 1994).

Gyrfalcons feed mainly on birds, particularly willow and rock ptarmigan, although they also eat waterfowl, gulls, terns, shorebirds, and other birds (Clum and Cade 1994). They also take some mammals, including mice, lemmings, hares, and ground squirrels (Clum and Cade 1994).

Peregrine Falcon

Peregrine falcons are uncommon from spring through fall throughout the Mackenzie Delta area. They occur nearly throughout the world and have been divided into 19 subspecies. In North America, three subspecies are recognized, two of which occur in the Mackenzie Delta region (White 1994b). *Falco peregrinus tundrius*, the Arctic or tundra peregrine, is the subspecies breeding north of the tree-line in the ISR. *F. p. anatum*, the continental or American peregrine, is the subspecies breeding in the wooded portion of the Mackenzie Delta (White 1994b).

Both of these subspecies were formerly considered endangered due to dramatic population declines caused by the toxic effects of widespread use of DDT and other pesticides. Both subspecies are now considered more secure; their populations have recovered following successful recovery programs and restrictions on pesticide use in the United States and Canada (Mesta 1999).

The world population of peregrines was estimated at 12,000-18,000 pairs during the 1980s, and has further increased since then (White 1994b). Peregrine falcons in the Mackenzie Delta region most commonly nest on a cliff ledge along rivers inland from the relatively flat coastal plain or the Delta itself.

Peregrine falcons prey mainly on birds, but they occasionally also take mammals and insects (White 1994b).

9.2.10 Upland Game Birds

Grouse

Two species of ptarmigan occur commonly in the Mackenzie Delta and ISR (Martell et al. 1984). Both species occupy mainly tundra areas during the breeding season and disperse more widely during the winter. Ptarmigan are brown during the summer and moult into a white plumage for the winter. Both species of ptarmigan are hunted by local residents in the ISR area; the 1998 harvest study indicated that 993 ptarmigan taken as part of the subsistence harvest. The three communities near the Delta reported harvesting 447 ptarmigan during 1998; most were taken near Tuktoyaktuk (Fabijan 2000).

Willow Ptarmigan

Willow ptarmigan are fairly common residents in the Beaufort Sea area (Johnson and Herter 1989). The range of the willow ptarmigan is mainly north of the tree-line or in some high alpine areas. Some southward movement occurs during winter (Hannon et al. 1998). The size of the willow ptarmigan's population is not known. They are widespread and abundant in many parts of their range and are not considered threatened (Hannon et al. 1998). They are common throughout the Mackenzie Delta area except in the forested areas where they are very rare (Martell et al. 1984).

Rock Ptarmigan

Rock ptarmigan are common residents in the Mackenzie Delta area (Johnson and Herter 1989). The rock ptarmigan's range is circumpolar north of the tree-line and in some high alpine areas. They are mainly resident, but make some southward movements during winter (Holder and Montgomerie 1993). The size of their population is not known. Rock ptarmigan are very rarely recorded in the forested portion of the Mackenzie Delta (Martell et al. 1984).

9.2.11 Shorebirds

More than 30 species of shorebirds have been recorded in the Mackenzie Delta area (Martell et al. 1984). However, less than 15 species occur regularly in significant numbers. Species which are common nesters in the wooded portion of the Delta are common snipe, spotted sandpiper, lesser yellowlegs and least sandpiper. The most abundant species nesting on the upland tundra are American golden-plovers and whimbrel. The most abundant species nesting in tundra habitats in the coastal portion of the Delta is are semipalmated plover, pectoral sandpiper and red-necked phalarope. Large numbers of many species use the shoreline habitats of the Mackenzie Delta and surrounding region during spring and fall migration.

Shorebirds are not an important group of birds to subsistence hunters in the ISR. Harvest statistic reports (Fabijan 2000) make no mention of shorebirds in the reported harvest. Harvest of shorebirds, with the exception of common snipe and American woodcock, is prohibited in Canada by non-native hunters. Common snipe are common nesters in most of the Mackenzie Delta.

Shorebirds generally arrive in the Mackenzie Delta region in early June and most have departed by mid-September. Tundra habitats have abundant insect prey and available plant cover, which combine for good nesting and brood-rearing habitat for many species of shorebirds. From late July through mid-September, after breeding, a habitat shift occurs and most tundra-nesting shorebirds move to marine shoreline habitats for a period of fattening prior to their fall southward migration (Connors 1984). Shorebirds that nest in the Mackenzie Delta over-winter far to the south in the vast area between the southern United States and southern South America.

None of the shorebird species presently known to breed near the Mackenzie Delta is considered threatened or endangered in Canada (COSEWIC 2002). The Eskimo curlew is an extremely rare (possibly extinct) shorebird that historically occurred in the Mackenzie Delta region. The Eskimo curlew is listed as Endangered by COSEWIC (2002, Internet site) and 'at risk' by the Government of the Northwest Territories (GNWT 2000). It was last reported in the Northwest Territories at the

Kendall Island Migratory Bird Sanctuary in 1985 (Northern Prairie Wildlife Research Center 2002).

Twelve species of shorebirds occurring in the Mackenzie Delta region are listed as Sensitive by the Government of the Northwest Territories (GNWT 2000).

Phalaropes are very numerous in the near-shore Beaufort Sea during late-summer prior to fall migration. They were selected as an important VEC (Valued Ecosystem Component) in the Beaufort Region Environmental Assessment and Monitoring Program (BREAM) (Vonk 1993). Shorebirds feed primarily along shorelines throughout their stay in the Mackenzie Delta/Beaufort Sea region, with peak feeding between late July to September after most nesting and brood-rearing has finished. At this time shorebirds accumulate fat reserves for the southward migration.

9.2.12 Songbirds

Of the 58 species of songbirds listed by Martell et al. (1984) as occurring in the Mackenzie Delta region, less than 35 are considered common breeding species. More than 25 species are regular nesters in the forested Mackenzie Delta. By contrast only about 5 species commonly nest in tundra habitats. The songbird species that nest only in the forested Delta are all at the extreme north-west edge of their extensive North American ranges.

None of the songbirds in the Mackenzie Delta area is listed by COSEWIC (2002, Intranet site) as being 'endangered', 'threatened' or of 'special concern'. Species occurring in the Mackenzie Delta region that have a small population or have a very limited range in North America are the gray-headed chickadee, bluethroat, wheatear, yellow wagtail, Harris's sparrow, and Smith's longspur. The gray-headed chickadee is listed as 'may be at risk' (species that may be at risk of extinction or extirpation, and are therefore candidates for detailed risk assessment) under the Northwest Territories classification (GNWT 2000). Songbirds occurring in the Mackenzie Delta that are listed as sensitive (species not at risk of extinction or extirpation but may require special attention or protection to prevent them from becoming at risk) under the Northwest Territories 2000 classification are bank swallow, boreal chickadee, American pipit, blackpoll warbler, American tree sparrow, Harris's sparrow, and rusty blackbird (GNWT 2000).

The most numerous songbird by far in tundra areas is the Lapland longspur. The other common tundra-nesting songbirds in the Mackenzie Delta region are savannah sparrow, horned lark, American pipit, and American tree sparrow (some also nest in the wooded portion of the Delta). Snow buntings are very numerous in the Mackenzie Delta region during migration, but they nest in small numbers in this area.

Two songbirds in the Mackenzie Delta region are strongly-attracted to human activities; common raven and gray jay. Both species are common in the forested parts of the Mackenzie Delta. Typically ravens are uncommon away from the forest, but in recent years as human activities have increased in tundra regions of North America, ravens have become regular visitors to camps and villages. Ravens are efficient predators of small prey. Away from the influence of man, their diet includes carrion, birds eggs and nestlings, and small mammals. Around man, they are attracted to garbage and landfills. Increases in human food waste and reductions of predators in the North has resulted in dramatic increases in raven populations in some tundra areas, such as the North Slope oil fields in Alaska (Day et al. 2000, Truett and Johnson 2000).

It has been speculated that increased anthropogenic food supplies in winter may enable ravens to over-winter more successfully. Subsequently, during spring and summer, ravens then disperse widely and prey on a wide variety of birds and small mammals. Man also provides artificial nesting sites (e.g., buildings, communications towers, drilling rigs) that were traditionally unavailable in tundra habitats prior to settlement by southerners (Truett and Johnson 2000). These human-related alterations in the natural environment may result in local increased raven densities and populations. An increase in the number of ravens can have a subsequent severe impact on other local nesting birds. When artificial food sources become unavailable (i.e., when a garbage dump is closed) ravens will often prey-switch and feed heavily on colonial-nesting birds, such as geese and eiders, and can sometimes greatly reduce populations of these species.

Gray jays are also attracted to man. Like the common raven, gray jays are attracted to anthropogenic sources of food and will aggregate near human settlements and camps. The natural diet of the gray jay is primarily insects, fruits, eggs, and nestling birds (Strickland and Ouellet 1993). Gray jays are much smaller than ravens and thus are not a significant predator on most species.

9.2.13 Summary of Important Species

In summary, the most important migratory bird species to local residents are those important in the subsistence economies of local hunters, e.g., waterfowl (ducks, geese, swans) and ptarmigan. Species of importance to resource managers include these same species, but also include raptors, shorebirds, and songbirds, all recognized as migratory birds under the Canada-US-Mexico Migratory Bird Treaty (U.S. Fish and Wildlife Service 2002).

9.3 Issues Related to Migratory Birds

Important issues related tomigratory birds that were identified by the breakout gap discussion in Inuvik are summarized in Table 9-1.

Table 9-1 Recommended Mitigation and Research for Migratory Birds

Issue	Level of Concern	Effect	Recommended Mitigation and Research
Climate Change	Medium	Changes in habitat and reductions in bird populations and subsistence harvests	Monitor climate and migratory bird habitats in inner and outer Mackenzie Delta
Pollution and Contamination	High	Contamination of food supply	Reduce or eliminate the disposal of pollutants and contaminants into air, water and soil. Monitor pollutants and contaminants in air, water, soil and birds in inner and outer Mackenzie Delta
Habitat Alteration/ Fragmentation	High	Changes in bird habitats and reductions in bird populations and subsistence harvests	Reduce extent of clearing during seismic surveys. Establish standard habitat classification system and monitor bird populations and habitats and monitor subsistence harvests in the inner and outer Mackenzie Delta

Table 9-1 Recommended Mitigation and Research for Migratory Birds (Cont'd)

Issue	Level of Concern	Effect	Recommended Mitigation and Research
Increased Access	Medium	Reductions in bird populations and subsistence harvests	Minimize permanent new access roads and implement an access management system. Monitor bird populations and subsistence harvests in areas with increased access
Activity, Noise and Disturbance	Medium	Reductions in bird populations and subsistence harvests	Establish aircraft, vessel and vehicle travel corridors away from bird concentration areas and traditional hunting areas. Monitor bird populations and the subsistence harvests near noisy industry activities
Barriers to Movements	Medium	Reductions in bird populations and subsistence harvests	Avoid creation of permanent continuous barriers (roads, pipelines, fences) and monitor subsistence harvests in the inner and outer Mackenzie Delta
Garbage and Predators	High	Increased numbers and densities of predators, reductions in bird populations and subsistence harvests	Carefully manage and monitor all refuse and garbage management systems and eliminate sources of artificial food. Monitor predator populations near camps and communities in the inner and outer Mackenzie Delta

Table 9-1 Recommended Mitigation and Research for Migratory Birds (Cont'd)

Issue	Level of Concern	Effect	Recommended Mitigation and Research
Inadequate Baseline Information	High	Inability to document impacts and manage species because of poor baseline of pre-development information	Conduct baseline studies of songbirds and shorebirds in the inner and outer Delta and near proposed development sites prior to major industry activities. Monitor bird populations in the inner and outer Mackenzie Delta during development
Outdated Information	Medium	Inability to document impacts and manage species because of poor baseline of pre-development information	Conduct focused studies on important bird species in the inner and outer Delta and near proposed development sites prior to major industry activities. Monitor bird populations in the inner and outer Mackenzie Delta during development
Inadequate Information Management	Medium	Inability to document impacts and manage species because of difficult or poor access to relevant information	Establish information management systems and consult with other researchers in northern areas where petroleum developments have also occurred
Priorities and Decisions	High	Priorities and decisions regarding resource use and management (including migratory bird use and management) not in the best interests of cultures and economies of northern communities	Direct consultation and involvement of northern residents, communities, and local advisory bodies in setting priorities and making decisions about resource use and management

9.4 Mitigation Related to Migratory Birds

Measures and approaches to mitigate migratory birds effects are summarized in Table 9-1.

9.5 Knowledge Gaps Related to Migratory Birds

9.5.1 Issues and Concerns

Research and information gaps for migratory birds need to be considered in the context of issues and concerns expressed by (1) local Mackenzie Delta area residents who depend on migratory birds and other wildlife for food, and (2) resource managers who have local, regional, and/or national mandates to manage populations of migratory birds.

Major issues and concerns relating to migratory birds expressed by local Mackenzie Delta residents and disciplinary specialists at the Inuvik workshop are summarized below.

9.5.2 Climate Change

Climate change may be affecting local migratory birds habitats and may eventually change the distribution and abundance and availability of species important in local subsistence economies. Inuvialuit hunters have reported that some species of migratory birds not previously common in the Mackenzie Delta area or other parts of the ISR appear to have become more common in recent years. These observations, in the context of the broader scientific debates about potential impacts of global climate change, have led to concerns by local residents throughout the North that climate change may be occurring and that the distribution and abundance and ultimately the availability of species that are important in subsistence economies may not be available in the future.

9.5.3 Pollution and Contamination

Air and land/water pollution may contaminate migratory birds and other wildlife harvested for food and eventually may affect local residents. Of special concern is that air pollution (increases in NOx levels) from gas field development and leaky sumps (reserve pits) from earlier and future drilling operations may contaminant local migratory birds and their habitats. Since some migratory birds (mainly waterfowl and ptarmigan) form a significant part of the subsistence harvest by local residents, the major concern is that contaminants may move up through the food chain and contaminate local residents.

9.5.4 Habitat Alteration/Fragmentation

Migratory bird habitat alteration and fragmentation may change the distribution and abundance and availability of species important in local subsistence economies. Of particular concern is the large amount of migratory bird habitat that is being altered (fragmented) during clearing (scraping away of standing vegetation) associated with seismic surveys. Seismic lines may also affect drainage patterns and may cause erosion. These habitat alterations/fragmentations have the potential to affect the distribution and abundance of some species of migratory birds, and ultimately to affect the subsistence harvest by local residents.

9.5.5 Increased Access

Increased human access may increase competition among and between local and non-local hunters, and may change the distribution and abundance and availability of species important in local subsistence economies. The main concern is that new roads will improve access and will result in increased numbers of hunters, which will result in short-term increases in harvests, and eventually will result in decreases in local migratory birds populations and reduced subsistence harvests.

9.5.6 Activity, Noise and Disturbance

Increased activity, noise, and disturbance may change the distribution and abundance and availability of migratory bird species important in local subsistence economies. The main concern is that increased industry activity and associated noise and disturbance (aircraft overflights, vehicle traffic along roads, vessel traffic in waterbird habitats) may affect the ability of hunters to harvest migratory birds during subsistence hunts. Some effects may be of a direct nature (i.e., may directly affect the distribution, abundance, behavior and condition of the birds themselves) (see Davis and Wisely 1974, Derksen et al. 1988, Ward et al. 1994). Other effects may be of an indirect nature and may affect the numbers and movements of the hunters themselves as they avoid or are restricted from hunting in areas of concentrated industry activity. Both indirect and direct effects could ultimately affect the subsistence harvest of migratory birds. It has been well documented that some migratory geese are easily disturbed by aircraft overflights and react by flushing and circling before landing and resuming feeding. This disturbance is thought to have a significant negative impact to the geese by reducing foraging time and increasing energetic costs and thus lowering fat deposition required for migration and reproduction (Davis and Wisely 1974, Derksen et al. 1988, Derksen and Ward 1993, Ward et al. 1994).

9.5.7 Barriers to Movement

Barriers to natural movements may increase mortality and result in declines in some migratory bird populations. There is concern that migratory birds may collide with tall industry-related structures (towers, tall buildings, powerlines) in the Mackenzie Delta area and that this may result in local population declines to some species, such as ducks, geese and swans. Another related concern is that linear structures such as pipelines and roads may act as barriers to natural movements of brood-rearing or family groups of migratory birds such as goose and swan broods. The ultimate concern is that obstructions to natural movements within the wetland complexes of the Mackenzie Delta and ISR may result in local declines of species important in the subsistence economies of the Delta region.

9.5.8 Garbage and Predators

Increases in predator populations (gulls, ravens, foxes, bears) caused by increased availability of food from artificial sources (dumpsters, garbage dumps, landfills) may result in increased predation and declines in some migratory bird populations, especially populations of colonial nesting migratory birds. Predators that also are scavengers, such as gulls, ravens, foxes, bears and sometimes wolverines, are known to aggregate near artificial sources of food, such as human food wastes and other garbage . These aggregations may also result in artificially high overwinter survival of young predators and subsequent high densities of predators that may then prey on local nesting birds. This is an especially serious situation near nesting colonies of migratory birds (e.g., Kendall Island Game Sanctuary, which supports nesting colonies of several species of migratory birds). Predators can decimate an entire colony of nesting geese or eiders. The Kendall Island Migratory Bird Sanctuary overlaps much of the proposed Taglu and Niglintgak gas fields. Increased predator populations which may be subsidized during winter by nearby garbage sources (camps) and more distant landfills (Inuvik) may put increased pressure on nesting migratory birds in the sanctuary. The ultimate concern is that artificially high densities of predators may result in declines in migratory bird populations that are important in the subsistence economies and cultures of local Mackenzie Delta residents.

9.5.9 Inadequate Baseline Information

Information on some groups of migratory birds, especially songbirds and shorebirds, is currently insufficient to serve as an appropriate baseline for future comparisons. Although much research has been conducted over the past several decades in the Mackenzie Delta and ISR on the 'high profile' species such as waterfowl and raptors, far less baseline research has been conducted on other groups of migratory birds such as songbirds and shorebirds. There is growing international concern about declines in songbird and shorebird populations and alteration and loss of songbird and shorebird habitats. Large-scale clearing associated with terrestrial seismic surveys in the Mackenzie Delta has raised further concerns about damage to important songbird habitats and populations in the Mackenzie Delta, especially the wooded southern portion of the Delta. There has been far less research on all species of migratory birds in the forested portion of the delta compared to tundra habitats in the outer delta.

9.5.10 Outdated Information

Information on some important species of migratory birds is now outdated and should be updated to serve as an appropriate baseline for future comparisons. Significant changes in the world and North American populations of some species of waterfowl are known to have occurred since the last comprehensive surveys of the Mackenzie Delta. Extensive surveys of some migratory birds, mainly waterfowl and marine birds, were conducted in the late 1980's and early 1990's, and much of the information from those surveys was related to potential petroleum development in the near-shore Beaufort Sea. Concern has been expressed that much of the information from these earlier surveys may not be relevant to proposed developments in Mackenzie Delta. In addition, the information that may be relevant (i.e., information for marine areas where gas field developments are proposed) (Taglu, Niglintgak), may now be out of date. The present size and location of nesting colonies of waterfowl (ducks, geese and swans) is needed. Up-to-date fine-scale information delineating nesting, brood-rearing, moulting and staging habitats particularly for both waterfowl and shorebirds is needed to serve as a baseline for future comparisons during industry development.

9.5.11 Information Management

Large amounts of highly relevant published and unpublished information relating to impacts on migratory birds in areas where petroleum development has occurred in other northern areas (i.e., Alaska) is not centralized and may not be easily available/accessible to researchers working in the Mackenzie Delta/ISR area. Extensive research has been conducted over the past several decades on the effects of petroleum development activities on migratory birds and other fish and wildlife resources. This research includes the Beaufort Sea Project (Searing et al. 1975, Richardson et al. 1975, Barry 1976, Blood 1977), BEMP (ESL Environmental Sciences Limited and Seakem Oceanography Ltd. 1988), MEMP (LGL Limited et al. 1988), BREAM (Vonk 1993), NOGAP (Northern Oil and Gas Action Plan, over 500 reports), and ESRF-related studies (Environmental Studies Research Fund, several hundred reports) in Canada, and various similar studies in Alaska (see Truett and Johnson 2000 for review). Much other research has been conducted in northern Canada and the United States by local, regional and national resource management agencies and by public and private research institutions. Additional research has been conducted in other northern regions such as Greenland, Norway, and Russia; some of this research is directly relevant to issues and concerns related to industrial development in the ISR/Mackenzie Delta area. There are currently no central repositories or databases from which this mass of information can be easily accessed and reviewed.

9.5.12 Priorities and Decisions

Research priorities may be disproportionately influenced by forces from outside the Mackenzie Delta area (i.e., from the 'South'), and thus may not represent the best interests of local Delta cultures and economies. There is a general concern that decision-makers from the South may not understand the unique aspects and circumstances of northern cultures and economies. There is the further concern that this lack of understanding may result in inappropriate setting of priorities and decisions concerning resource use and management, including migratory bird use and management, in the North.

10 Fisheries and Aquatic Systems

10.1 Chapter Overview

At 13,000 km^2, the Mackenzie Delta provides a diverse mixture of habitats for many species of fish. Freshwater fish (e.g., lake trout, grayling, northern pike) prefer the variably-sized channels and some of the 24,000 lakes for nurseries, migration routes and overwintering habitats. Marine and euryhaline species (e.g., saffron cod, Arctic flounder), as well as anadromous and semianadromous species (e.g., Dolly Varden, smelt, Arctic cisco) can be found in the channels and ponds of the delta where the water ranges from near-fresh to almost marine. The nearshore and offshore habitats of the delta provide habitat for marine (e.g., Arctic cod, eelpouts, flounders) and euryhaline species (e.g., Pacific herring, Arctic flounder).

One of the critical elements of the region's aquatic habitats is the band of warm, brackish water that exists in the nearshore zone. This band of water provides important feeding habitat for many fish species and is critical in the life cycle of the Arctic cisco.

As the development of natural gas reserves proceeds in the region, there is the potential for impacts on fish species and their associated habitats. Improved access, seismic programs, hauling along ice roads and the accidental introduction of contaminants could have direct and potentially damaging impacts on the fish. Changes in water quality and drainage patterns, water withdrawal and the construction of gathering and transportation routes could affect fish habitat and indirectly impact fish species.

In response to these potential impacts, there are procedures that industry and concerned parties can implement that will minimize their effect. One of the most effective mitigation tools is prior knowledge of critical areas of aquatic habitat. With prior knowledge of these areas, many of the impacts can be avoided through effective pre-planning and adherence to environmental guidelines.

However, for development activities to proceed in the region and for effective mitigation to be put in place, there are topics where more understanding is required. Water quality monitoring and a more detailed understanding of the hydrological table is required. Hauling along ice roads and the construction of channel crossings need to be further investigated to determine the extent of their effect, and the mitigation steps that may be taken to reduce this effect. One of the most important knowledge gaps is a comprehensive mapping and surveying of the Mackenzie Delta to identify critical habitat areas for different fish species. With this knowledge of critical habitats, as well as studies to address the other information gaps, steps can be taken to implement effective mitigation procedures, and as a result, development activities in the region may have little if any impact on fish and their aquatic environment.

10.2 The Nature of Fisheries and Aquatics Systems

10.2.1 Physical Aquatic Habitat Characteristics

The Mackenzie Delta, located at the mouth of the Mackenzie River, is approximately 13,000 km^2 in area (Hirst et al. 1987). The delta has been classified into three basic units (Hirst et al. 1987):

1. *Channel System*: covers approximately 15 to 20 percent of the total delta surface area
2. *Basin System*: covers approximately 40 to 50 percent of the delta and is composed primarily of ponds and as many as 24,000 lakes
3. *Delta Plain*: comprises areas high enough above flood level to support a mature spruce forest. The delta plain is not as dynamic as the channel or basin systems and it receives little sediment deposition.

There are two general physiographic types in the delta:

1. low-lying floodplains with poor drainage and vegetative cover consisting mainly of sedges and willows
2. upland areas with good drainage and vegetative cover consisting mainly of shrubby ericaceous species (i.e., heather-like species)

The Mackenzie Delta channels are prone to erosion. Warm river water thaws the ice-rich silty banks, causing erosion and substantive channel migration. Through this erosional process, substantive quantities of suspended sediments are introduced to the southeastern Beaufort Sea.

In the floodplain regions, substrates consist primarily of recently deposited fine-grained materials (i.e., silts and clays) from rivers. Floodplains are distributed along all river channels that discharge to Mackenzie Bay and on some barrier islands. The relief is generally flat but also contains landforms such as pingos and polygonal ridging (Slaney 1976).

Upland areas, which are underlain by Pleistocene fluvial, estuarine and morainal materials, are not typically flooded and nor eroded by the Mackenzie River. Substrate composition is inconsistent and may be fine-grained materials or coarse gravel. The relief ranges from gently sloping hills to steep banks created by thermokarst slumping (Slaney 1976).

A major influencing feature of the coastal region of the southeastern Beaufort Sea is the Mackenzie River, which provides the single largest contribution of freshwater to the Canadian Arctic coast. In this region the coastal environment is characterized by the Mackenzie Delta, with its myriad of channels, lakes and coastal bays. Additionally, numerous small coastal streams empty into the estuarine zone, creating smaller estuarine habitats within the larger estuary. Fjord-type environments are created where these smaller estuaries have shallow sills at their mouths. These small, fjord-type estuaries are frequently more saline than the larger coastal estuary to which they are connected.

In the channels, substrates are typically fine grained, although more coarse-grained, sediments occur in areas of eroded Pleistocene island materials. Island shorelines are a reflection of ongoing erosion through wave and current action; spits and mudflats are formed on most offshore islands (Slaney 1976). Spits and barriers are particularly common on the Tuktoyaktuk Peninsula (Lewis and Forbes 1975). Sediments along most of the continental shelf consist of clays and silts, originating from the Mackenzie River (Dome Petroleum et al. 1982).

The southeastern Beaufort Sea comprises the continental shelf, running from the coast to depths of approximately 100–200 m, the Continental Slope, which begins with a sharp drop from the shelf to depths of approximately 1000 m, and the Mackenzie Canyon (Dome Petroleum et al. 1982).

The coastal geology of the Canadian Beaufort Sea is influenced by storm events and the effects of fluvial, thermo-erosional, and ice-pressure processes (Dome Petroleum et al. 1982). High rates of coastal erosion may occur during storm events (Dome Petroleum et al. 1982). The coastline is composed of barrier beaches, ice-rich or unconsolidated coastal cliffs, and deltas. Due to the speed of coastal recession, the coastline has become highly indented in regions with numerous lakes (Lawrence et al. 1984).

10.2.2 Major Types of Aquatic Habitat

The Mackenzie Delta provides habitat for a variety of fish species, some of which inhabit fresh waters (lake trout, grayling, longnose suckers and pike) while others are euryhaline (i.e., tolerant of a wide range of salinities from near-fresh to marine; e.g., saffron cod, Arctic and starry flounder) or anadromous and semi-anadromous (e.g., Dolly Varden, smelt, broad whitefish and Arctic cisco). Freshwater habitats exist in the variably-sized channels and lakes across the delta. Some of the smaller channels provide nursery and foraging habitat for whitefish, smelt and coney, while the larger channels meet the feeding and overwintering needs of adult fish. These channels are also vital migration routes in the spring and fall. There are innumerable freshwater lakes throughout the delta and, depending on their size and depth, they can play important roles in the foraging and overwintering habits for a variety of freshwater species. Broad whitefish are common in both the large and small freshwater lakes of the delta and Tuktoyaktuk Peninsula.

Coastal and marine habitats are important to a variety of fish species. Along coastal areas, the quality of the habitat varies depending on the salinity, temperature and depth of the water column. This wide variation in physical characteristics in turn dictates habitat suitability for marine (e.g., Arctic cod, eelblennies, eelpouts, Pacific herring, flounders and saffron cod) and euryhaline species (e.g., Pacific herring, Arctic and starry flounder). These areas are important for spawning, overwintering, foraging and migration.

Offshore, higher salinity estuarine areas vary in depth from 5 to 20 m, and vary in their physical characteristics in response to the influence of river flow, winds, depth and season. Marine and euryhaline species exist in these habitats. Overwintering of most fish species is limited due to extremely cold water during winter (-1.8°C range). It is suspected that many species either move further offshore to deeper, warmer waters beyond the shelf, or retreat to the fjord-type coastal embayments or estuaries where water temperatures are warmer.

The relatively warm band of brackish water (5–10°C; 0–25 psu [practical saline units]) that lies adjacent to the shoreline of the delta and the Beaufort Sea is important to many fish species. This band of water is a result of the fresh, turbid water from the Mackenzie River and smaller coastal streams and rivers. The along-shore and offshore extent of the band of fresher, warmer water depends on the degree of mixing with the near-shore salt water. Solar heating during extended summer days also influences water temperature in the shallow coastal water. This band of water serves as critical feeding habitat especially for juvenile fish, and as a place where fish can grow and build fat reserves before the onset of the nine-month winter (Craig 1984, 1989; Griffiths et al. 1998). It also determines the extent to which fish species with low salinity tolerance can migrate along the coast. In contrast, the offshore marine environment is much colder (-1.5 to -1.8°C) and more saline (27–32 psu).

The near-shore band of brackish warm water is of vital importance in the life cycle of the Arctic cisco. Tributaries of the Mackenzie River serve as the only identified spawning grounds for this species, and part of the cohort produced in these spawning beds is vital to the subsistence fishery. Some of the young of the year are carried west by currents through this warm band of water, into the Alaskan Beaufort Sea. They take up residence in the Colville River, until they reach sexual maturity, and return to the Mackenzie River to spawn (Gallaway et al. 1983; Fechhelm and Fissel 1988; Fechhelm and Griffiths 1990). During their time in the Colville River, they are important to the local subsistence fishing industry.

10.3 Issues Related to Fisheries and Aquatic Systems

10.3.1 Impacts on Fish

The development and transportation of natural gas from the Mackenzie Delta has the potential to directly affect fish species in the brackish estuarine waters, as well as the species that inhabit freshwater lakes and streams. Development could further affect offshore marine species.

The issues related to the potential impacts of development have not changed substantially since they were identified 25 to 30 years ago. However, some of the impacts are better understood due to 30 years of fish and habitat studies in the Beaufort Sea and Mackenzie Delta region. In locations such as Prudhoe Bay, the impacts of oil and gas development on fish in the near-shore waters have been monitored and studied extensively. Gravel-filled causeways, docks and buried pipelines have been investigated for their impacts on fish populations. Such knowledge provides comprehensive and detailed assessment of the issues associated with development and fish in the Mackenzie Delta region (North/South Consultants 2001; KAVIK-AXYS and LGL 2001).

Seismic Programs

Depending on the characteristics of the energy wave (frequency, amplitude, sharpness or rise-time of the wave), the transmission of seismic energy is potentially damaging to fish. While onshore seismic activities that employ explosives may not directly transmit energy waves into the water, they may be propagated through the ground and into waterbodies above or near the source of energy. Offshore seismic activities seldom use explosives, however, they do directly transmit energy waves through the water column when used. Winter seismic operations typically employ explosives in shallow water areas that are not accessible to ship-based, open-water seismic programs. Explosives will transmit energy through the ground into waterbodies that may serve as vital overwintering habitats. These energy waves could be critically hazardous to fish species. In addition to possible physical damage to fish, the presence of such energy waves could cause fish to temporarily avoid a particular habitat.

Pipeline Crossings of Streams and Delta Channels

With the development of onshore gas reserves in the Mackenzie Delta, a system of flow lines and gathering lines will be required to gather the gas within the field and transport it to a main transmission line. Due to the geographical makeup of the delta, these pipelines will have to cross numerous streams and channels. The construction and presence of these pipelines across streams and channels could disrupt and alter fish habitat.

Both the construction practices and the existence of the pipe through the streambank could lead to the destabilization of the bank. The removal of the insulating soil layer could lead to melting in the ice-rich permafrost layers. An increase in soil moisture content would cause the surrounding soil and permafrost to become unstable. A pipeline running through the soil could warm up and destabilize the surrounding material. In both cases, destabilization could lead to an increase in bank and slope erosion. The subsequent deposition of sediments into the water column could significantly degrade the quality of fish habitat. Not only could the bottom substrate become covered in sediment, potentially affecting spawning and feeding, but also visibility in the water column could be decreased.

If the pipeline were to transport chilled gas to avoid permafrost degradation, then the possibility of creating a frost bulb around the pipeline may have an effect on freeze-up and thaw conditions in streams that are crossed. This potential problem may be more likely to interfere with fish movements in small streams and channels as opposed to large streams.

Hauling

Industry practices today confine exploration and development to the winter period due to the reduced impact on the environment and the ease with which vehicles can travel across frozen tundra and muskeg. The use of ice roads, however, could impact overwintering fish populations through the propagation of sound into the aquatic environment. The intense level of truck traffic that may be associated with hauling of granular materials from land-based borrow sources to site locations, combined with regular traffic and the occasional transport of large industrial components such as trailer camps and drill rigs, could result in the propagation of sound of sufficient magnitude and duration through the ice that fish may be displaced from critical habitats or be affected in other as yet unknown ways.

Water Withdrawal

Development will require a constant supply of freshwater and at times, supplies of saltwater. A 60-person camp can consume upwards of 150,000 L/day of freshwater (Truett and Johnson 2000). Removal of these quantities of water may affect water depths and the suitability of certain fish habitats, particularly in small, shallow lakes where no winter flow exists. Water depth is particularly relevant in determining whether or not a habitat is suitable for overwintering. Over a longer time frame, the removal of large quantities of water from rivers and lakes to the west of the Mackenzie Delta could affect groundwater and the watershed's ability to recharge itself and maintain minimum water levels. A kilometre of ice road that is 12 m wide at the base may require 2.3 million litres of water (Truett and Johnson 2000). Where ice roads cross very small lakes (e.g., 250 m wide and 2 m or less deep), the removal of water could adversely affect the already limited overwintering capacity of these lakes.

Improved Access

Winter development will require ice roads and possibly some permanent all-weather roads to access some parts of the gas fields. Both ice roads and permanent roads will improve access to areas of the delta that have previously been inaccessible or accessible only by boat or aircraft. Improved access may result in an increase in both subsistence and recreational fishing pressure. This, in turn, may have a negative impact on local fish populations and lead to their decline.

Introduction of Contaminants

Although the danger of a large-scale oil spill does not exist in areas currently being considered for development, other compounds used by the industry may pose a contamination hazard to fish and benthic communities if they are allowed to enter the aquatic environment. Natural gas liquids, drilling muds, produced water, petroleum products, cleaning solvents and domestic sewage are examples of contaminants that could be directly toxic to aquatic wildlife or bioaccumulate through the food chain (IUCN 1993). The impacts of bioaccumulation may not be evident until a later stage in the food chain, such as in fish species, marine mammals and humans. Other contaminants may directly impact one component of the food chain, such as the benthic elements. However, a decline in benthic organisms may in turn directly affect the fish species that are dependent upon them for food (Percy 1975).

10.3.2 Impacts on Aquatic Systems

Communities near the Mackenzie Delta rely on the main river and its tributaries as a source of drinking water as well as a source of food (e.g. fish, waterfowl and aquatic mammals). A number of marine mammals, birds and semi-aquatic mammals also depend on the river and the adjacent wetland habitats for food and shelter. Development in the region could alter and affect the quality and quantity of water supplies. In turn, these changes will have an impact on all species that depend on the integrity of the watershed.

Water Chemistry

Development of the gas fields in the delta region could have negative impacts on water quality and quantity for both the freshwater and marine systems. Activities that involve the use of chemicals or hydrocarbons could lead to the accidental contamination of the water column. This could be detrimental to both the human and wildlife populations that depend on these water sources.

Sediment Load

Development in and around waterbodies could lead to the erosion of shorelines and an increase in the sediment load. Not only could this affect water quality, it can have negative effects on the quality of aquatic habitats.

Water Flow and Drainage

Activities that change the local topography, even at an apparently insignificant scale, can alter the existing drainage patterns. The recharge of surface waterbodies could be affected, or wetter or drier areas that did not previously exist could be created. In turn, these effects could impact wildlife and the quality of wildlife habitat. Changes in the distribution of surface waterbodies can also affect the integrity of the underlying permafrost.

10.4 Mitigation Related to Fisheries and Aquatic Systems

Industry and participating parties can implement certain practices and procedures that will minimize some of the impacts mentioned above. The measures can mitigate impacts to fish habitat or fish.

10.4.1 Mitigation of Disturbance of Fish

Seismic Programs

Ample information exists regarding the impacts of seismic activities on fish species and national guidelines have been developed to minimize the impacts of explosive energy sources on fish and fish habitat (Wright and Hopky 1998). Research, supported by industry and Fisheries and Oceans Canada is ongoing in the delta to develop techniques for using explosives on lakes that will permit operators to conduct seismic exploration in accordance with the national guidelines (Wright 2002, pers. com.).

With prior knowledge of critical habitats, industry may be able to schedule and preplan its activities to avoid these habitats during critical times of the year. Other areas may be in use or important throughout the year, and complete avoidance may be necessary to ensure an isolated or important stock is not endangered.

Pipeline Crossings

It will be difficult for development to occur without crossing streams and channels because of the deltaic nature of the region. Through the prior identification of critical habitats, efforts can be made to ensure that pipelines and construction paths make a minimum number of crossings.

Technology has significantly increased over the past decade and advanced techniques are being used to optimize the routing of pipelines and roads across streams and rivers. These techniques will help to minimize the impacts that a crossing could have on the water channel and its associated aquatic habitat. Operation of gas pipelines to reflect ambient temperatures in the surrounding substrates will help avoid effects of permafrost degradation or creation of frost bulbs and associated effects on aquatic habitat.

Vehicular Traffic Across Bodies of Ice

A recent study (Stewart 2001) commissioned by the Fisheries Joint Management Committee reviewed existing literature on the impacts of ice roads on overwintering fish. It focused on information relevant to the movement of sand and gravel to locations within the Mackenzie Delta. The review did not locate any studies of the impact of under-ice noise and pressure from heavy trucks on fish overwintering in the Mackenzie Delta or elsewhere. However, based on the review of literature and the discussions with experts in physical and behavioural responses in fish exposed to sound and pressure waves, heavy trucks are unlikely to generate sound-pressure levels sufficient to damage fish or elicit startle responses. Given that some uncertainty exists regarding fish response to a large volume of ice-road traffic, habitat identification and preplanning will again assist in minimizing these impacts. Once important areas have been identified, ice roads routes can be planned to avoid the areas of the delta that serve as overwintering habitat.

Water Withdrawal

Construction and development in the delta will require large amounts of water (IUCN 1993). The removal of large quantities of water may affect the local hydrological cycle and, in turn, impact the aquatic habitats. Once critical habitats (e.g., overwintering habitats) have been identified, these areas could be avoided as potential water withdrawal sites. Industry could take smaller amounts of water from a larger number of non-critical sites, rather than taking water supplies from a limited number of sites. This would spread the effect out over a larger area and reduce the scale of its impact.

Improved Access

Increased access either by ice road or permanent road may increase harvesting pressure. To deal with this, local and territorial governments and interested parties will have to reevaluate and possibly restructure current regulations. New catch limits, the establishment of restricted areas and protected fish habitat, and the proper enforcement of these regulations will help to accommodate the effect of increased harvesting pressure. Industry may need to impose fishing restrictions on personnel.

Contaminants

Development will involve the use and production of materials and substances that could pose a contamination threat to fish and aquatic invertebrates. The possibility that these compounds may be introduced into the aquatic environment is minimized significantly in the current work environment through effective waste management and recycling. Compounds and chemicals are disposed of by re-injecting them into subterranean reservoirs. Waste materials that cannot be reused, recycled or disposed of in an inert way onsite, are taken offsite to regional waste disposal facilities.

As industry plans development, they establish spill response plans and have trained personnel onsite who practice these drills on a regular basis. With these practices, the site should be prepared to deal with a spill immediately and minimize its effect on the local environment (IUCN 1993).

Harvesting Regulations

It may be necessary for concerned levels of government to reevaluate the current harvest regulations. Changes may need to be implemented to compensate for the predicted increase in harvesting pressure. In the past, regional harvest statistics have been collected. This information is valuable for reevaluating harvesting regulations and gaining a better understanding of the marine and freshwater fisheries. Efforts need to be made in continuing the collection of these statistics.

10.4.2 Aquatic Systems

Some of the previously identified impacts may affect the quality and quantity of water available to other species. Changes in sediment load or the introduction of contaminants into the aquatic system may change water quality. Changes in water quantity could be brought about by water withdrawal by industry, as well as by operations that alter drainage and flow patterns of the surface and subsurface flow patterns (KAVIK-AXYS and LGL 2001).

To counter these effects, industry can implement measures mentioned previously to minimize impacts. Effective waste disposal, recycling and spill response will minimize the impacts of contaminants on the aquatic system. The use of preplanning and modern technology, and reclamation techniques will help to minimize the impacts that river and delta crossings will have on the sediment load and water quality. Preplanning and the identification of critical areas in the local drainage patterns, will minimize the alteration of local and regional drainage patterns.

10.5 Knowledge Gaps Related to Fisheries and Aquatic Systems

In the past, research has been done on the coastal, freshwater and estuarine fisheries and habitats in the Mackenzie Delta and near-shore Beaufort Sea region. Some of this research aids in addressing and evaluating the impacts of regional development on fish and fish habitat. However, to better understand where the knowledge gaps exist, this information (including impact, population and habitat studies) needs to be reviewed to determine if it forms a sufficient knowledge base of the marine and freshwater fisheries in the region. There are impacts that have been identified as either being poorly understood, or requiring more information to evaluate their significance.

Vehicles on Ice Roads

Little information is available about the extent that vehicles propagate sound through ice and into aquatic environments. It is unknown if this elicits a response from overwintering fish. Few studies have investigated this impact and further research is required to determine its significance (ESRF workshop).

Critical Habitat and Overwintering Capacity

As much of the construction work will occur during winter, it is important to know the location of critical overwintering habitats in advance. Construction may require the withdrawing of water, the construction of an exploratory drill pad or the use of seismic programs. These activities could have a direct effect on overwintering fish populations or habitats that are critical at other times of the year. Further research and surveys are needed to provide a better understanding of critical fish habitats in the delta and the near-shore regions. The identification of overwintering habitats should receive particular emphasis. This knowledge will assist in the preplanning and scheduling of activities, as well as in the reevaluation of current fishing and harvesting regulations.

Water Withdrawal from Local Drainage Systems

The withdrawal of water by industry may have an effect on the local hydrological system. It is not known if the watershed can recover from a prolonged and immediate removal of large quantities of water. The effects may be irreparable or possibly delayed until a later point in time. A better understanding, and a detailed mapping of the local hydrological table is required to predict and model the impacts (ESRF workshop). The alteration of the local landscape by development needs to be evaluated for its potential to cause either permanent or temporary changes in surface and groundwater flows (KAVIK-AXYS and LGL 2001). No information exists as to what impact these water withdrawals may directly have on the fish species, or on the aquatic invertebrates. Further research is required in this area.

River and Channel Crossings

The destabilization of shorelines by river crossings and the subsequent erosion of bank material pose a threat to water quality. Information is required as to what effects a pipeline will have on the freeze/thaw cycle of the soil surrounding the pipeline at streambank locations. If this cycle is altered, it may destabilize the bank and increase erosion into the water channel (ESRF workshop). To date, the use of directional drilling for large diameter pipelines through permafrost has been unproven.

Water Quality Monitoring

Due to industry's use of compounds that could pose contamination threats to the water column (both marine and freshwater), there is the need to closely monitor the water quality of the region. Existing water quality data for the delta should be reviewed and summarized, and based upon this summary, water quality monitoring stations should be prioritized and activated with respect to the most probable development scenario.

Additionally, the information available on the effect of drilling muds on water quality needs to be reviewed. A cost-benefit analysis of alternative drilling mud treatment methods needs to be conducted. Industry needs to continue with their efforts in developing less toxic drilling muds.

With the possibility of a spill or leak of a contaminant, the procedures used by industry in the handling and recycling of waste materials should be reviewed and updated if necessary. This process should also apply to spill response practices.

11 Physical and Chemical Oceanography

11.1 Chapter Overview

The planning, construction and operation of facilities for the production of natural gas in the Mackenzie Delta region may result in a number of effects to the physical and chemical ocean environment. Important potential effects include alteration of the physical environment and processes, alteration of ice formation and characteristics, changes in the chemical characteristics of the benthic environment and associated biota, and compaction or disruption of marine environments.

While a substantial volume of information was collected on the physical and marine environment of the near-shore Beaufort Sea during the 1970s through to the 1990s, the workshop participants identified a number of important information gaps; specifically;

- clarification on how climate change will affect the physical and chemical characteristics of the marine environment, as well as the ability of industry to operate under these conditions
- the potential for development to utilize marine borrow sources, including natural gravel deposits and abandoned artificial islands
- changes in coastal processes as a result of industrial activity and climate change, and effects of these changes on industrial infrastructure
- the potential effects of changes in permafrost as a result of industrial activities and climate change on coastline stability and industrial activity
- effects of ice on structures within the delta and the near-shore environment
- the most probable approaches for installation of subsea gathering systems and associated effects of construction on seabed and permafrost stability. Ice effects on the gathering system also need to be clarified
- better understanding of regional and site-specific air quality conditions and meteorological conditions, and effects of these changes on chemical oceanographic conditions

- information on the use and management of various wastes, including the need for development of standards for waste treatment and disposal

The group also identified the need to better understand the natural processes and components that have created and continue to shape the development of the Mackenzie Delta and the near-shore Beaufort Sea. Such information is needed to be able to assess the potential effects of development on these processes and components, particularly in light of potential cumulative effects from climate change.

11.2 Issues Related to Oceanography

> *It seems to me that we need to wary of five kinds of games that could be at play here: the anticipation game, the confidence game, the shell game, the synthesis game and the blame game.*
>
> 1. *The anticipation game — what if the environment changes faster than the rate at which we are acquiring information?*
> 2. *The confidence game — what are the consequences of making a mistake?*
> 3. *The shell game — what are the insidious things that we may not detect? We will never detect things like endocrine disrupting chemicals (e.g. TBT in anti-fouling paint) if we do not look for them; these could be time bombs.*
> 4. *The synthesis game — we need an intelligent gatekeeper who does not just provide a database but an indication of the quality of the database.*
> 5. *The blame game — who is responsible? Someone has to emerge as a Leader to make all this happen.*
>
> David Thomas
> President, AXYS Analytical

Proposed development for exploration and production of natural gas in the Mackenzie Delta will involve activities that could affect freshwater environments within the Mackenzie Delta, as well as estuarine and marine environments in the near-shore Beaufort Sea. Potential effects include:

- alteration and disruption of normal physical processes and characteristics including, temperature regimes, sedimentation patterns, currents, and hydraulic regimes
- alteration and disruption of the formation patterns and physical characteristics of river and sea ice
- changes in chemical makeup of bottom sediments due to the introduction of pollutants or contaminants associated with exploration, development and production of gas wells, as well as disposal of industrial, domestic and human wastes. Sources of metals, hydrocarbons, and other classes of contaminants include drilling fluids, produced water, biocides, well completion chemicals, and combustion products from waste disposal activities and various equipment (e.g., vehicles, generators, helicopters)
- changes in the chemistry of the receiving environment, particularly the benthic environment, as a result of pollutants and contaminants
- compaction and disruption of near-shore bottom sediments as a result of mechanical activities and facility construction

To assess information gaps for the assessment of potential effects on physical and chemical oceanography, information will be required on:

- the locational and operational parameters (e.g., footprint, probable life span of facility, emission and effluent inventory, maintenance) of specific activities associated with the planning, construction and operation of natural gas production facilities
- the existing baseline state of the chemical and physical marine environment
- the probable response of the chemical and physical processes and characteristics of the marine environment to natural gas developments
- the cumulative effects from natural gas development in combination with other industrial development and human use and climate change

11.3 The Nature of Oceanography

During the 1970s and 1980s, a great quantity of chemical, physical, and biological oceanographic data were collected in the Southern Beaufort sea, Mackenzie Delta and adjoining terrestrial areas. Much of this information is summarized in the Arctic Data Compilation and Appraisal Series (e.g., Cornford et al. 1982; Thomas et al. 1982; AMAP 1998). Although some data sets were on a regional scale, much of the data correspond to drilling activities for oil and gas at specific sites.

Comprehensive reviews of contaminants in the various environmental compartments of the Mackenzie River Estuary/Beaufort Sea Shelf are provided in Muir et al. (1992), Canadian Arctic Contaminants Assessment Report (CACAR 1997), and Arctic Monitoring and Assessment Programme (AMAP 1998). Special attention is given in these reviews to LRTAP (Long Range Transport of Atmospheric Pollutants), an issue that is important in estimating the contribution of project-specific activities to environmental effects, as well as project contributions to cumulative effects. For example, how will project-specific emissions and effluents interact with other industrial emissions in the region, as well as LRTAP? Information on the detailed geochemistry of petroleum hydrocarbons and polyaromatic hydrocarbons on the Mackenzie Shelf of the Beaufort Sea is given in Yunker et al. (1991, 1993, 1994 and 1995).

Indian and Northern Affairs publishes annual 'Synopsis of Research' reports, which summarize all research projects funded under the Northern Contaminants Program (e.g., Kalhok 1999). These research projects include:

- sources, pathways and fate of contaminants
- ecosystem contaminant uptake and effects
- human health
- education, communications and community based strategies
- international policy and program co-ordination

11.4 Issues Related to Oceanography

11.4.1 Contamination by Chemicals

During the exploration, construction and production phases of natural gas development, a number of chemicals may be routinely released into the marine environment. These include water-based drilling fluids and cuttings, oil-based drilling fluids and cuttings, anti-corrosion agents, scale inhibitors, cementing agents, completion chemicals, blowout-prevention fluids, produced water, biocides, gas treatment chemicals, refined oil products, crude oil, rig wash, drainage water, flocculating agents, sewage, carbon dioxide, carbon monoxide, methane, volatile organic compounds, nitrogen oxides, sulphur dioxide, hydrogen sulphide, halons, ozone depleters and combustion products (Thomas et al. 1983; Group of Experts on the Scientific Aspects of Marine Pollution [GESAMP] 1992; AMAP 1998). It is generally accepted that effects associated with the introduction of these substances into the receiving environment under routine operating conditions are limited in space and time, particularly if pollution control equipment is used to specification (Thomas et al. 1983).

11.4.2 Chemical and Physical Effects of Drill Cuttings

The direct discharge of drill cuttings covered with residual oil-based muds into the marine environment has been an issue of concern since drilling operations began in the Mackenzie Delta and Beaufort Sea regions. Environmental concerns associated with the release of drill cuttings include: (1) direct smothering of the benthic environment beneath the cuttings pile, (2) oxygen-depletion in a zone around the pile that restricts marine life, and (3) the potential for tainting of marine life which comes into contact with the substances found in the cuttings pile (e.g., hydrocarbons).

Dome et al. (1982) assessed the effects of oil and gas development as envisaged in the development scenario brought forward by Dome Petroleum, Esso Resources and Gulf Canada. Impacts associated with common wastes and related disturbances were judged at the time to be local in scale and limited in time.

Low toxicity oil-based muds have been used to drill four wells in the Beaufort Sea. The first, Nipterk L19A, was drilled during the spring of 1985. Adgo G-24 was drilled in late 1985. Erickson et al. (1988) studied the dispersal of washed drilling cuttings contaminated with oil-based muds from these two drilling projects. Approximately 15 percent residual oil remains on the washed cuttings. Further reduction of residual oil content on cuttings is difficult given the very fine cuttings (1 to 10 μm) associated with formations in the Beaufort Sea. At the third well, Minuk I-53, cuttings contaminated with oil-based muds were discharged directly to the ocean. The fourth well, Kaubvik I-43, cuttings were discharged overboard in ice-covered waters. Monitoring of these two locations showed that base oil was rarely detectable beyond 700 m from the point of discharge. This is in general agreement with findings from the North Sea (Grahl-Nielsen et al. (1980) and Addy et al. (1984) where detectable base oil is seldom found beyond 4000 m of the discharge point even for discharges involving multiple well drilling programs.

In the offshore oil and gas industry in the North Sea, legislation has been gradually introduced to the point that there is currently an effective ban on the discharge of oil-based mud contaminated cuttings to the seabed (Esbjerg Declaration 1997). There is every expectation that the discharge of oiled cuttings to any part of the arctic environment in Canada will also be banned.

11.4.3 Guidelines for Monitoring Oceanographic Effects

Guidelines for designing effects monitoring studies for the physical and chemical marine environment of the Beaufort Sea are outlined in Thomas (1992). In designing these monitoring programs, emphasis is generally placed on the sedimentary environment rather than the water column. Given the quantities of various wastes that are expected to be associated with oil and gas development in the Beaufort, effects in the water column resulting from point source discharges would be difficult to detect unless inordinate numbers of samples were obtained and analyzed. Instead, it is recommended that accumulation of contaminants in the sedimentary environment be measured since the sedimentary environment is commonly the end recipient of most contaminants and, therefore, provides an integrated measure of spatial and temporal trends and effects with acceptable accuracy.

11.4.4 Changes in the Physical Properties of Marine Waters

The physical properties of the estuarine or marine waters could be altered by various activities that include increase in shipping traffic, the construction of in-sea or near-sea structures, and the laying of sub-sea pipelines.

Sedimentation patterns and currents could be changed due to the construction of docks, causeways, and gravel drilling platforms (e.g., artificial islands) or with an increase in local shipping traffic. Temperature regimes may be affected by the introduction of processed water from production facilities or the presence of structures built in the water column.

11.4.5 Changes in the Chemistry of the Receiving Environment

The accidental introduction of wastes, which may include hydrocarbons, drilling muds, processed water, treatment fluids, chemicals, sludge, domestic sewage or industrial fluids, will alter the chemistry of the receiving waters, suspended sediments and benthic sediments of the delta and adjacent estuarine/marine environment. Such changes could be toxic to wildlife and vegetation, and will have a direct impact on the health and lifestyle of local and regional human populations. The introduction of small amounts of exotic chemicals such as non-ionic surfactants, antibiotics and pharmaceuticals may be important because of their endocrine disrupting potential.

11.4.6 Alteration of the Formation and Characteristics of Sea Ice

Sea ice in the region is not only important to wildlife and the health of the marine environment, but also plays an essential role in the subsistence practices of indigenous peoples. Developments that alter the freeze/thaw patterns or sea ice thickness could have detrimental effects on the ecosystem. In light of potential effects of climate change on sea and river ice (Section 5), assessment of the cumulative effects of project-specific effects with those of climate change will be important. The use of sea ice for the construction of winter ice roads, as well as the use of these roads by heavy industrial equipment, could impact the integrity and persistence of sea ice in the region.

11.4.7 Compaction and Contamination of Near-shore Sediments

The use of winter ice roads and offshore structure during winter programs, as well as near-shore development activities in the summer may lead to the compaction of bottom sediments. Over time, this could lead to a cumulative negative effect on the near-shore marine community.

An accidental introduction of contaminants into the marine environment may have a negative impact on the natural chemical environment of the sediment substrate.

Many of the issues noted above for the aquatic, terrestrial, estuarine and marine environments have been dealt with extensively in the past (e.g., Beaufort Environmental Monitoring Project, Mackenzie Valley Environmental Monitoring Project, Beaufort Regional Environmental Assessment Program). However, they must be revisited in the light of the potential effects of climate change and the need to assess cumulative effects. Impact assessments must now consider how a warming climate will affect the hydraulic environment of the delta and estuary, contaminant dynamics and pathways, and biogeochemical processes.

Possible land subsidence associated with the extraction of gas from the Mackenzie Delta will also need to be assessed. Although past assessments (e.g., MEMP) have concluded that land subsidence was not an important concern, this may no longer be the case, Because climate change may result in sea level changes and increased potential for storm surges (Section 5), as well as increased coastal erosion and degradation of permafrost, cumulative effects relating to land subsidence will need to be assessed.

11.5 Mitigation Related to Oceanography

To be completed.

11.6 Knowledge Gaps Related to Oceanography

As the physical and chemical marine environment varies considerably over the Mackenzie Delta region and throughout the year, it is difficult to identify specific and clear knowledge gaps without specific details on the development scenarios. As a result, some of the information gaps that are identified below may change, once specific details are available on future developments.

It is recognized that global climate change could profoundly alter the potential effects of oil and gas development in the Beaufort Region. It is likely that the effects of climate change could exacerbate some project-specific effects (e.g., permafrost degradation), increase the variability in environmental conditions (e.g., minimum and maximum temperatures), and/or result in new effects (e.g., sea level rise). As the specific effects of global climate change in the development region remain uncertain, it is not yet possible to quantify these effects or predict the changes in environmental variability. This uncertainty will need to be considered in:

- establishing seasonal timing restrictions for certain project activities
- completing the engineering design

The uncertainty in predicting the effects of climate change on the project and the receiving environment will also present challenges in the regulatory review process.

11.6.1 Climate Change

As discussed in Section 5, climate change is an overarching issue for the whole of the Beaufort Region with respect to gas development. Physical and chemical oceanography, climate change and weather are closely related, and together make up the more comprehensive ecological environment.

Climate change may result in a number or changes of importance to the physical and chemical marine environment in the Mackenzie Delta region; specifically:

- the timing and duration of the Mackenzie River freshet, break-up and freeze up
- spatial and temporal (seasonal) variations in ice-cover, light, temperature, freshwater, turbidity, currents and winds
- location, frequency, duration and magnitude of storms
- extent, quality, and duration of landfast and floating ice
- location and formation of fronts, ice edges, upwelling zones, and shelf breaks
- water column structure and stability (e.g., degree and spatial/temporal extent of stratification)
- the sediment regime, including sediment transport mechanisms and coastal processes
- the ice climate, including the frequency and location of ice scour, rubble fields and grounded ice
- biogeochemical cycles, distribution of nutrients, organic carbon, suspended particulates, primary production

11.6.2 Hydrology

The arctic hydrological regime could significantly affect oil and gas infrastructure in the Mackenzie Delta (e.g., in the poorly drained areas along the outer edge of the delta) and in the estuarine or near-shore marine environment. While a substantial number of studies on artificial structures and ice were conducted in the Mackenzie Delta during the 1970s to late 1980s, additional information is required to address:

- the potential impacts of less stable shorelines on project infrastructure

- the impacts of permafrost subsidence on project infrastructure

As noted earlier, these effects are likely to be exacerbated by the effects of climate change.

11.6.3 Borrow Materials

Development of infrastructure for production of natural gas (e.g., well pads, artificial islands, fill for caissons, supports for elevated flow lines) will require substantial volumes of borrow materials, including sand, gravels, and fill. To minimize dredging requirements in off shore areas, it may be desirable to use sand and gravel from abandoned artificial islands and berms to construct new drilling foundations/platforms. If this were to occur, the level of contamination (particularly hydrocarbons and metals) in the candidate borrow materials would need to be quantified.

Land and marine infrastructure in the outer Mackenzie delta and near-shore Beaufort Sea may also examine the potential to use seabed gravel deposits. As these deposits are relatively rare in the Beaufort Sea, they may have special ecological significance as habitat for benthic animals or as areas where whales rub themselves. An understanding of the ecological implications of the removal and use of seabed gravel resource was therefore identified as an important knowledge gap.

11.6.4 Structure Stability

Information needs to be assembled to address the effect of ice on structures such as foundation berms and gravel causeways. Particular emphasis should be placed on dynamic loading scenarios such as those that occurred at Minuk I 53 and at the Molikpak berm in the past.

11.6.5 Seabed Gathering Systems

No specific details are presently available on how seabed gathering systems may be constructed. It would be useful if the preferred methods and possible locations of subsea gathering lines could be identified.

There is also a need to determine the environmental effects associated with trenching for seabed gathering systems. Potential issues include stability of the seabed, depth of trenching to avoid ice keels, and the presence of permafrost.

11.6.6 Air Quality

A better understanding of baseline regional and site-specific air quality conditions and meteorological conditions (metadata, deposition) is required to evaluate the spatial and temporal impacts of development on the physical and chemical marine environment of the Mackenzie Delta region and near-shore Beaufort Sea. In particular, air dispersion modeling for the region is required to predict contaminant pathways and dispersion dynamics and the environmental significance of contaminant movements to the marine system.

11.6.7 Contaminant Input and Cycling

The Mackenzie Delta and near-shore Beaufort Sea ecosystems are complex. To allow for confident predictions of environmental impacts on physical and chemical oceanography to be made, better information is required on contaminant inputs and cycling in the Mackenzie River Delta. Important information gaps include:

- atmospheric boundary fluxes, atmospheric dynamics, and land-surface atmosphere exchanges (with vegetation and permafrost dynamics)
- discharge characteristics through well-defined flow networks (with groundwater and Mackenzie River flow)
- sea ice mass balance and dynamics
- estuarine controls on terrestrial and coastal shelf interactions
- direct groundwater discharge to the ocean
- Beaufort Sea dynamics
- biological and food chain dynamics

11.6.8 Waste Management

A comprehensive set of waste management guidelines based on known or anticipated dynamic processes in the receiving environment, need to be established for the Arctic (Beaufort Sea). Standards should address:

- treatment of various wastes
- procedures for handling, storage and transportation of wastes
- timing restrictions for disposal

- discharge rates
- dispersal techniques
- requirements for compliance monitoring

11.6.9 Mackenzie River/Beaufort Shelf Process Knowledge

The Mackenzie River/Mackenzie Delta/Beaufort Sea Shelf are linked as a complex, dynamic system. To truly understand the significance of changes or alterations to one part of the system, it is necessary to understand how the entire system operates, particularly as some consequences of changing variables are not linear. Presently, this understanding is incomplete and efforts should be directed at improving process-based knowledge and a predictive understanding of system dynamics. Only through such an understanding will it be possible to:

- predict quantitatively how the system will respond to natural changes in specific variables
- predict and assess the specific effects associated with each development
- undertake meaningful cumulative effects assessments of multiple activities acting on multiple species at multiple ecological levels
- design and implement effective science-based monitoring, mitigation and management strategies

For example, during winter, the discharge from the Mackenzie River forms a large pool of fresh or brackish water under the ice over the inner Beaufort Shelf. The processes that determine the size and formation, stability and the eventual breakdown of this huge (70 km^3) floating freshwater lake are not well understood. Yet understanding the dynamics of this lake are essential for determining the fate and food chain effects of contaminants and for determining the vulnerability of species using the habitat.

12 Marine Mammals

12.1 Chapter Overview

In the southern Beaufort Sea there are diverse marine mammals adapted to live and thrive in the marine ecosystems. Some species, such as the gray whale, narwhal whale, walrus and spotted seal do not occur in the area on a regular basis, and are therefore not considered in this report. The five species of marine mammal that do occur regularly in the region are the beluga whale, bowhead whale, ringed seal, bearded seal and the polar bear. All could be potentially be affected by gas development in the region and are therefore considered in this report.

As development moves into the onshore and offshore regions of the Mackenzie Delta, the associated activities could potentially affect these five species. Some activities could impact more than one species, whereas some activities may impact only one species. Seismic studies could cause negative impacts to both species of whale and the ringed seal. The use of explosives and vibroseis in seismic studies could result in sensory disturbance for these species and deter them from inhabiting certain areas of the delta and the southern Beaufort Sea region. Sensory disturbance from increased levels of construction and the transport of materials could affect all five species. Specific to polar bears is the potential for increased human contact due to their attraction to development sites. Such encounters could result in the need to relocate or terminate repeat nuisance bears.

In response to these potential impacts, the best mitigation approach for industry is the use of best management practices. This involves implementing strategies and practices to eliminate or minimize an impact. Seismic studies can be conducted by gradually increasing the amount of seismic energy used. This provides animals with time to either adjust to the disturbance or leave the area. Safety zones can be established around seismic activities. Once an animal is spotted within the safety zone, activities are shut down until the animal leaves. The potential for increased interactions with polar bears can be minimized by implementing polar bear monitors, educating workers about the feeding of wildlife and effective waste management.

During the 1980s through to 1990s, an extensive amount of work was done through the Beaufort Environmental Monitoring Program (BEMP) and Beaufort Regional Environmental Assessment Program (BREAM) programs to determine the potential impacts of hydrocarbon development in the Beaufort Sea and Mackenzie Delta region. Within these programs, the effects of development on these five species was extensively analyzed. Since that time, new areas of potential impact have been identified and require more research and investigation. Two research gaps related to beluga whales are whether or not they sustain hearing loss due to seismic studies, and what their reaction is to the movements of vessels within development areas. No research gaps were identified for the bowhead whale due to its tendency to inhabit offshore regions. More research is required to study the effects of climate change on the quality, quantity and extent of sea ice, and the implications that these effects may have on the ringed seal. The bearded seal is found in low densities in the nearshore regions, and due to this fact, no research gaps were identified for this species. No new research needs were identified for the polar bear. The investigation of the aforementioned research gaps, and a review of previous monitoring programs will provide industry with an effective body of knowledge to mitigate and minimize the impacts of development.

12.2 Beluga Whale

12.2.1 The Nature of Beluga Whale

To understand the potential impact of development on the beluga whale and to understand the associated knowledge gaps, it is first necessary to understand the animal itself.

> *To completely understand an animal and its behaviour it is helpful to imagine that you are the animal.*
>
> Alex Kaglik - Inuvialuit hunter and elder

The beluga whale (*Delphinapterus leucas*) is a small, toothed whale that occurs in Arctic and sub-Arctic waters of North America and Eurasia. 'Beluga' or 'belukha' is the ancient name used by northern Russian fishermen and hunters and means 'white one' in Russian. In Inuvialuktuun, the beluga whale is called 'Qilalugaq' and 'Kilalogak'.

The beluga whales may have the most versatile and sophisticated sonar system of any cetacean. Beluga whales have an elaborate system of vocalizations that they use for social communication. Beluga whales also have a well-developed echolocation capability. Echolocation signals occur at high frequencies (40–120 kHz), have powerful source levels (up to 218 dB re 1 μPa at 1m) and allow detection of small targets at ranges of up to 100 m. The hearing sensitivity of beluga whales ranges from 75–125 Hz to about 125 kHz (Johnson 1967, Awbrey et al. 1988). Unlike most cetaceans, the beluga whale's seven neck vertebrae are not fused, giving it a flexible, well-defined neck.

Depending on the aging method, females mature at either 5 or 10 years of age. They have a single calf every three years (Brodie 1971). The average life span is 35 or 40 years with older individuals (a 49 year-old female and 57 year-old male) recorded in the Canadian Beaufort Sea (Harwood et al. 2002). Mating occurs in the spring, and calves are born 14.5 months later (Brodie 1971, Sergeant 1973). It is likely that most mating takes place before belugas return to the Canadian Beaufort Sea in late May and June. Calving has not been observed but most likely occurs offshore in the Beaufort Sea before the animals occupy the Mackenzie estuary in July. Lactation lasts 21 months, thus the full reproductive cycle is 35 months; some females may be both pregnant and lactating (Sergeant 1973).

Beluga whales feed mainly on fish, shrimp and large invertebrates such as octopus and squid. Fish species include Arctic cod, saffron cod, sculpins, herring, smelt, capelin, Arctic char, Arctic cisco and rainbow smelt (Percy 1975, Lawrence et al. 1984, Lowry et al. 1986, Orr and Harwood 1999).

Beluga whales number in the tens of thousands in the Bering, Chukchi and Beaufort Seas. The eastern Beaufort Sea stock has been estimated, based on aerial surveys, at about 20,000 animals (Harwood et al. 1996). Taking account of corrections for unseen animals during the aerial surveys (Angliss et al. 2001) and the results of satellite tagging studies (Richard et al. 2001), it is clear that there are more than 20,000 beluga whales in the eastern Beaufort Sea stock.

During April and May, the Beaufort Sea stock of beluga whales migrates northeastward through the Alaskan portion of the Beaufort Sea (Moore et al. 1993). "The whales follow far offshore, shear-zone leads through the southeastern

Beaufort, and arrive along the west coast of Banks Island during late May and early June" (Fraker 1979).

Many of the animals then travel south to the mainland and then west along the land-fast ice edge off the Tuktoyaktuk Peninsula (Norton and Harwood 1986). Once the landfast ice begins to break up in late June, beluga whales penetrate the ice and enter the Mackenzie estuary where they concentrate in Kugmallit Bay, around Kendall Island and in Shallow Bay (i.e., Mackenzie Bay). The relative number of animals using each of these three areas varies among years and, in some years, particular bays may not be accessible to the beluga whales because of ice conditions. The use of these habitats by whales is clearly significant since they return to these areas in spite of being hunted there every year. The importance of the three estuarine areas has been enshrined under terms derived from the *Inuvialuit Final Agreement* (IFA 1984). The *Beluga Management Plan* (2001) identifies special beluga whale management area (the 1a zones) that are protected areas in which all industrial activities are to be excluded.

There is little evidence that feeding occurs during occupation of the summer estuaries. Most beluga whales taken in the Mackenzie estuary have empty stomachs as is the case in other Arctic estuaries (Smith et al. 1994).

The beluga concentration areas, which are located near major outflow channels of the Mackenzie River, are characterized by warm (e.g., 10 to 18°C), turbid freshwater. These areas are shallower than most adjacent areas in the Mackenzie estuary (Fraker et al. 1979).

Richard et al. (2001) used satellite telemetry to determine the movements of belugas that were tagged in the Mackenzie estuary. They found that the tagged animals spent only a few days in the estuary at a time. The animals then moved offshore into the Beaufort Sea, Amundsen Gulf and Viscount Melville Sound where they are thought to feed in the deeper waters.

By late August and early September, belugas start their fall migration moving west far off the coast of Alaska, toward their wintering grounds in the Bering Sea. The gaps in understanding of the behaviour of beluga whales in winter are summarized by Huntington (2001).

> *Mackenzie saw belugas from Garry Island in mid-July 1789, and Franklin observed them in the same area in mid-August 1825. Franklin also saw a few whales in western Mackenzie Bay in early July 1826, but was told by hunters at Shingle Point that beluga would come in great numbers "with the following moon".*
>
> Martell et al. (1984)

The average annual harvest of belugas by Inuvialuit between 1984 and 1996 has been 124 whales (Beaufort Sea Beluga Management Plan 2001). The annual hunt of beluga whales is extremely important to the subsistence economy and culture of the Inuvialuit. Archaeological records indicate that beluga whales have been harvested at the East Channel of the Mackenzie River for at least 500 years (McGhee 1974 cited in Fraker 1980).

12.2.2 Issues Related to Beluga Whale

During their time in the estuaries of the Mackenzie Delta and in the nearshore areas of the southern Beaufort Sea, beluga whales are potentially vulnerable to disturbance. Offshore development and associated activities could also affect whales as they spend the later part of the summer in the offshore.

There has been a great deal of previous analysis of the potential effects of nearshore and offshore oil and gas activities in the southeastern Beaufort Sea. The BEMP, Mackenzie Valley Environmental Monitoring Program (MEMP) and BREAM exercises focused on the potential for beluga whales to be disturbed making them less available to hunters and thereby reducing the harvest levels. These studies were conducted before the establishment of the Beluga 1a zones protecting the three core beluga whale areas in the Mackenzie estuary. The Beluga 1a zones protect the animals from industrial disturbance while they are in these key zones. However, recent studies have shown that beluga whales move into and out of estuaries during the late June-July occupancy period. It is not known how much turnover there is in the estuaries or whether the same animals keep returning to the estuary in any particular summer.

There is concern about the potential impact of industrial disturbances on beluga whales as they travel along the ice edge toward the estuary and as they move into and out of the delta throughout the summer occupancy period (ESRF workshop).

Clearly, many beluga whales are present in waters offshore of the delta where they could be exposed to disturbance that might affect the likelihood of them returning to the estuary during that summer. There was also a concern that noise from an industrial activity outside the delta could propagate into the Beluga 1a zones and disturb the animals.

An increased level of industrial activity in summer could displace whales and potentially affect the traditional beluga harvest.

12.2.3 Mitigation Related to Beluga Whale

To be written.

12.2.4 Knowledge Gaps Related to Beluga Whale

Impacts of Seismic Surveys

Limited studies have been conducted on the impacts of seismic exploration on beluga whales. Studies conducted by LGL Limited for Anderson Exploration (now Devon Canada) indicated that beluga whales avoided an active seismic vessel at distances of up to 20 km (Miller and Davis 2002). During the previous period of offshore exploration in the southeastern Beaufort Sea, there was a substantial amount of seismic exploration. A detailed analysis of the historic data has not been conducted, but it is clear that beluga whales continued to return to the delta in undiminished numbers suggesting that they either habituated to the activities or that the region is too important to avoid. Further research is required to determine thresholds for tolerance, and whether beluga whales are impacted in ways not yet discovered. Some of this information can be obtained by continuing to request monitoring of seismic operations.

It is not clear whether beluga whales will sustain either temporary or permanent hearing loss. Further research on captive animals is required in this area. The use of safety radii around operating seismic vessels and related shutdown procedures should be continued until research indicates that hearing loss is not an issue or that the received level criterion and related safety radius should be modified. In addition, the use of ramp-up procedures for loud noise sources can protect against temporary hearing loss in whales and seals.

Impacts of Exploratory Drilling and Vessel Traffic

The workshop identified this as an important knowledge gap. The key concern is how disturbance from various vessels affects the movement of beluga whales into the three Beluga 1a zones. Beluga whales are thought to be particularly susceptible to noise and disturbance when they occupy restricted leads in ice-covered waters. The concern is that the beluga whales may be prevented from entering one or more of the 1a zones thereby affecting the harvest of the animals.

The results of the workshop discussion are summarized in Tables 12-1 and 12-2.

Table 12-1 Impacts of Exploratory Drilling and Vessel Traffic on Beluga Whales

Activity	Accepted Best Practice	Impact	Concern
Offshore seismic activity (airgun)	Timing of operations Avoidance of key areas Avoidance of key times	Disturbance Changed movement patterns Altered migration patterns (both potentially resulting in reduced availability for harvest- the main concern/effect)	High
	Ramping up operations Establish safety zones around seismic vessel - temporary shutdowns when animals enter zone	Powerful seismic pulses may lead to temporary hearing loss	High
also other vessel traffic such as bathymetry vessels	Define timing accurately (of industrial activity and whale movements)	Change in harvest is issue Displacement, disturbance, movement	
	Communication from hunters and pilot, support vessels and planes and contractors and subcontractors communicate procedures to "on ground" people	Hearing-optimum frequency is in acute range of beluga whale but power of signal is not much stronger than commercial fish finder	Medium
	Cooperation among researchers and industry to reduce duplication and share data		
	Selection of frequency		

Table 12-1 Impacts of Exploratory Drilling and Vessel Traffic on Beluga Whales (cont'd)

Activity	Accepted Best Practice	Impact	Concern
Offshore drilling (stationary) i.e., pile driving, associated activity	Effects depend upon location and season Other issues like fuel, sewage, produced water, chemical spills are subject to offshore regulations for best practices	Disturbance No evidence of hearing damage (i.e., Sable Island pile driving)	Medium-High Low Low
Offshore traffic (mobile sources)	Timing Avoidance of key areas Establish specific routes for vessels Training of staff Communication	Disturbance • change in movement patterns • change in harvest (as above) • possibility of injury or mortality by direct contact	High
Accidental spills (vessel traffic causing medium spill of fuels)	Industry Beaufort Sea Oil Spill Co-op may be reconstituted	Evidence and experiments show limited impacts from oil spills; will depend on type of fuel, location, viscosity	Low
Catastrophic oil spill	Same season relief well capability	Impact will depend on season	Low

Table 12-2 Recommended Research on Beluga Whales and Noise and Traffic

Activity	Beluga Whales Recommended Research
Noise and Traffic (e.g. offshore seismic, support ship traffic, offshore drilling, research vessels, etc.)	Integration of all existing information (building on Beluga Stock Status Report) on distribution and abundance of beluga whales in the Mackenzie Delta region. Recognition by workshop participants that very much information exists over a long time series. One uncertainty is the reason for the site fidelity to certain estuaries, including the feeding potential in Mackenzie Delta region. Suggestion to try to better understand the ecological significance of the estuaries to the population. Site-specific reactions of Beaufort Sea beluga whales to noise and disturbance and a comparison to beluga whales in other geographic locations and stocks, with particular consideration of habituation to noise. This should integrate traditional knowledge from Inuvialuit hunters. Of particular concern are potential impacts of noise and disturbance on whales that are approaching the delta through restricted passages in the ice. Take a closer look at Fisheries and Oceans Canada's existing satellite tag data from 1995 and 1997 with detailed consideration of the movements when the beluga whales are in the Mackenzie estuaries. Undertake more satellite tagging. The techniques of whale capture and data gathering are well developed as is the technology. The research has resulted in excellent data that are improving our understanding of beluga whale movements, distribution and population numbers.. Continue to digitize whale data from 167 estuary surveys over the years of 1977–1985. This work is in progress. Pursue the issue of sound transmission and attenuation at various depths and in various waters to estimate the zone of influence. This should build on the work of Anderson/LGL undertaken in 2001.

12.3 Bowhead Whale

12.3.1 The Natural of Bowhead Whale

As of 1993, the Bering-Chukchi-Beaufort or Western Arctic stock of bowhead whales was estimated to number 8200 animals (95 percent CI 7200 to 9400) (Zeh et al. 1996, Hill and DeMaster 1998). At that time, the population was believed to be increasing at a rate of up to about 3.2 percent per year (Punt and Butterworth 1999), despite annual subsistence harvests of 14 to 74 bowheads from 1973 to 1996 (Suydam et al. 1995). The population is considered 'Endangered' by the Committee on the Status of Endangered Wildlife in Canada and by the U.S. Endangered Species Act, as well as being classified as a strategic stock by the U.S. National Marine Fisheries Service (Hill and DeMaster 1998).

In the early part of the 19^{th} century, it was believed that the Western Arctic stock of Bowheads numbered 20,000 individuals. Demand for whale oil was heavy throughout Europe and it was during this time that this large stock of whales was discovered, and their numbers heavily harvested.

Sixty feet in length, and weighing nearly a ton per linear foot, the bowhead or 'ice whale', is a large baleen whale that feeds on the plankton blooms of the Arctic regions. Using fringed baleen plates almost 12 feet in length, bowheads filter copepods and other small crustaceans from the water.

In winter, this population of bowheads is found in the Bering Sea, off the coast of Russia. Through April and May, the animals move north through the Bering Strait, then along the coast of Alaska to Point Barrow. After passing Point Barrow, bowheads head east and northeast through heavy ice toward Banks Island. Many of the animals move south into the southern Canadian Beaufort Sea during the summer. During their summering period, their distribution is thought to be correlated with zooplankton concentrations (Thomson et al. 1986, Ford et al. 1987, BEMP 1987-1988). Much of their food intake for the entire year is thought to occur during the summer (BEMP 1987-1988) although recent studies by Don Schell at the University of Alaska question this assumption.

By mid- to late August, bowheads start moving slowly west into the Alaskan Beaufort Sea. Migration continues into the Chukchi Sea, toward the Siberian coast, and eventually the animals move south through the Bering Strait.

Bowheads are extremely long-lived animals. It is likely that some live in excess of 100 years (George et al. 1999). Sexual maturity has been estimated to occur between the late teens and mid-twenties (Koski et al. 1992, George et al. 1999). Females give birth to a single calf every 3–5 years (Miller et al. 1992). Gestation is thought to be about 13–14 months (Koski et al. 1993).

There is an extremely important subsistence hunt of bowheads by Alaskan Inupiat during the spring (many villages) and autumn (three villages) migrations. The spring hunt occurs primarily along the Alaskan Chukchi coast northwest Alaska including Barrow). The autumn hunt occurs at Kaktovik, Nuiqsut (Cross Island) and Barrow along the Alaskan Beaufort Sea coast. The overall quota for this hunt is set by the International Whaling Commission. Within the overall quota, individual community quotas are determined by the Alaska Eskimo Whaling Commission. Recently, the bowhead whale has not been hunted regularly in the

Canadian Beaufort Sea. The Alaskan Inupiat are protective of the annual bowhead hunt, which has great cultural significance. At present, offshore industrial activities east of Nuiqust and Cross Island must cease when the bowhead hunt begins in early September (KAVIK-AXYS and LGL 2001). There is concern that industrial activity or presence may disturb the migrating whales causing them to travel further offshore where they would be inaccessible to the hunters.

12.3.2 Issues Related to Bowhead Whale

The BEMP and BREAM projects devoted a great deal of time to consideration of the potential impacts of offshore hydrocarbon development on the bowhead whale. In addition, there has been a large amount of research on bowhead whales and on potential effects of offshore industrial activities in both the Canadian and Alaskan Beaufort Sea.

The nearshore zone of particular interest to this project is not prime habitat for bowheads, which use deeper waters farther offshore of the Mackenzie Delta and along the Tuktoyaktuk Peninsula and the Yukon Coast. For this reason, bowheads were not considered a critical species for the discussions of potential effects in the nearshore zone.

12.3.3 Mitigation Related to Bowhead Whale

Use of best management practices and effective monitoring was deemed the most efficient method of examining potential impacts while at the same time protecting the animals. For example, marine seismic exploration programs should use ramp-up procedures to allow animals to move away, before full power is applied. Safety zones around the seismic vessels should also be used to protect animals from possible temporary hearing loss if they approach the airgun array too closely. If a whale enters the safety zone, then the airguns would be shutdown until the animal leaves the area. The size of the safety zone is determined through acoustic modeling and subsequent acoustic measurements. A key element of this approach is that a comprehensive monitoring program be conducted to document how animals react near the seismic vessel and remote from the vessel. The latter behaviour requires aerial monitoring to document how animals react several kilometres from the noise source.

Seismic exploration may be done in June or July when bowhead whales are not in the area; however, this timing would affect the beluga whales.

12.3.4 Knowledge Gaps Related to Bowhead Whale

As the bowhead whale lives farther offshore than the nearshore zone, knowledge gaps for this species were not identified.

12.4 Ringed Seal

12.4.1 The Natural of Ringed Seal

The ringed seal is the most widespread and abundant marine mammal in the circumpolar Arctic, and serves as an important element in the Arctic marine ecosystem. It constitutes the major prey species for the polar bear, is a major consumer of marine fish and invertebrates, and is an important food source in the local subsistence economies (Smith 1987).

Ringed seals are found year round in the Beaufort Sea, but seasonal movements during the open-water season are poorly understood. During winter, ringed seals occupy landfast ice and offshore pack ice. In spring the highest densities occur on stable landfast ice. Because of the relatively small amount of landfast ice in the southeastern Beaufort Sea compared to the large amounts of offshore pack ice, the numbers of ringed seals on the offshore pack ice may exceed the numbers on the fast ice. From mid- May through early June, ringed seals in the Beaufort Sea haulout on top of the ice to moult.

During summer, ringed seals are dispersed throughout open-water areas, although in some regions they move into coastal areas. In the eastern Beaufort Sea and Amundsen Gulf, ringed seals concentrate in similar offshore areas from one year to the next, often in large groups (Harwood and Stirling 1992). It appears that these concentrations are found in areas of greater food abundance and these areas may be related to oceanographic features. Similar summer concentrations have not been reported in nearshore waters of the central and western Beaufort Sea.

Ringed seals are capable of moving distances of 1000 km or more during the summer (Heide-Jørgensen et al. 1992, Kapel et al. 1998, Teilmann et al. 1999), although they tend to show site fidelity (Teilmann et al. 1999). Seals inhabiting the landfast ice of western Alaska migrate through the Bering Strait as they follow the receding pack ice northward in spring, then move ahead of the advancing ice in autumn (Reeves 1998). Some ringed seals from the eastern Beaufort Sea move westward to the Chukotka Peninsula (Smith 1987). Smith and Stirling (1978) suggested that there is a westward movement of seals out of Amundsen Gulf in late summer when many young-of-the-year move west past Cape Bathurst and Herschel Island. Recent information gathered from satellite tags deployed on four sub-adult ringed seals in Amundsen Gulf supports this suggestion (Harwood pers.comm). Shortly after tags were deployed in mid-September 2001, all four ringed seals migrated west and three seals with functioning tags migrated along the north coast of Alaska, each traveling over 3500 km in a six-week period. After reaching Point Barrow, one seal crossed the Chukchi Sea, another moved northwest toward Wrangel Island, and the third seal moved through the Bering Strait to St. Lawrence Island before moving back north.

Generally, female ringed seals have a longer life span than males (Lydersen and Gjertz 1987). Ringed seals can live for more than 40 years (McLaren 1958, Lydersen and Gjertz 1987), but their average lifespan is likely between 15 and 20 years (Frost and Lowry 1981).

Ringed seals mature, on average, at six to seven years (Frost and Lowry 1981). Gestation lasts about nine months after a delayed implantation of approximately three months (Smith 1973b). Ringed seals give birth in subnivean lairs to a single pup between March and early April (Smith and Stirling 1975, Kingsley 1990). Pups average 4.5 kg in weight and are typically nursed for 36 to 41 days (Hammill et al. 1991). Mating occurs in late April and May toward the end of the lactation period (Smith 1973b, 1987). Ringed seals are likely polygamous. Adult male ringed seals are territorial (Smith and Hammill 1981, Smith 1987), but likely abandon their territories shortly after the mating period (Smith 1987).

12.4.2 Issues Related to Ringed Seal

Seven years of work in coastal Alaska shows that ringed seals slightly avoid of active seismic vessels (by a few hundred metres) but do not abandon areas where seismic is being or has been shot. The U.S. National Marine Fisheries Service has determined that received levels of seismic pulses greater than 190 dB re 1 μPa may cause temporary hearing loss in seals.

Similar studies of the impact of on-ice seismic surveys using vibroseis have been conducted in Alaska. The results show only very localized and short-term impacts on ringed seals occupying lairs and holes on the landfast ice. These results are not applicable to the use of dynamite for offshore seismic surveys. The impacts of explosives on seals could be quite different and more severe than the use of airgun arrays or vibroseis.

Ringed seals were often seen near stationary offshore vessels or structures during the period of active hydrocarbon exploration in the Beaufort Sea. Recently, quantitative monitoring programs have been put in place to document the short and longer term effects of an offshore production island on ringed seal populations near Northstar Island near Prudhoe Bay, Alaska.

Various exploration and development activities could have local impacts on ringed seals that might affect their availability to hunters. This could occur even if there were no measurable impacts on populations.

12.4.3 Mitigation Related to Ringed Seal

Marine seismic arrays must be shut down when seals are seen within a zone where the received level of seismic pulses would be 190 dB or more. This safety radius is a few hundred metres in shallow coastal Alaskan waters.

12.4.4 Knowledge Gaps Related to Ringed Seal

Climate change could cause major disturbance to ringed seals and their main predator through its reduction of the extent, duration and quality of sea ice. A better understanding of these potential changes in sea ice and of ringed seal biology and population dynamics is necessary to document the impacts of sea-ice changes on ringed seals.

12.5 Bearded Seal

12.5.1 The Natural of Bearded Seal

Large and solitary, the bearded seal is found at low densities throughout the Canadian Beaufort Sea. Seasonal movements of bearded seals are directly related to the advance and retreat of sea ice and to water depth. Due to their limited capability to maintain breathing holes in fast ice, they prefer areas of shifting ice and shallow water. Their numbers in the Beaufort Sea are reduced during winter as a result of an autumn migration into the Bering Sea. From mid-April to June as the sea ice recedes, some of the bearded seals that overwinter in the Bering Sea migrate northward through the Bering Strait and into the Beaufort Sea. Nonetheless, a population of unknown size overwinters in the moving pack ice of the Beaufort Sea (Stirling et al. 1975).

The bearded seal is primarily a bottom feeder and is most abundant where it can feed in water depths of less than 200 m. It feeds on a wide variety of benthic invertebrates and demersal fish (Burns 1967, Burns and Frost 1979, Lowry et al. 1980, Finley and Evans 1983).

Males mature at 6 to 7 years and females first breed at 5 to 6 years. Gestation lasts about 11.5 months (McLaren 1958, Burns and Frost 1979, Smith 1981). Pupping occurs in late April and early May, and the pups are born directly on the ice. Pups are capable of entering the water shortly after birth. Females nurse their pups for 2 to 3 weeks; after this time the pups are weaned and feed on their own.

12.5.2 Knowledge Gaps — Bearded Seal

The workshop participants did not have time to discuss the bearded seal; however, they did conclude that this species habitat, the moving pack ice in winter, and its low density in areas influenced by the Mackenzie River plume in summer would limit the potential impacts of near-term development, which is focused on the delta and nearshore waters. The bearded seal is more relevant when offshore scenarios are considered.

There was very little time at the workshop to consider all the relevant issues about marine mammals and their supporting marine systems. Also, the question of climate change was part of all discussions even though it was not directly related to natural gas development in the delta.

12.6 Polar Bear

12.6.1 The Natural of Polar Bear

The polar bear is listed as a species of 'Special Concern' by the Committee on the Status of Endangered Wildlife in Canada. The southern Beaufort Sea population of polar bears comprises about 1,800 animals and supports an annual harvest of about 56 bears throughout Alaska and Canada. The population is subject to a joint management agreement between Alaskan Inupiat and Canadian Inuvialuit. The population is thought to be stable or possibly increasing slowly (Stirling and Taylor 1999).

The lifecycle of the polar bear revolves around the sea ice that is home to their dietary mainstay, the ringed seal and, to a lesser extent, the bearded seal. Seals concentrate in these shifting ice pans to access air and escape routes and this, in turn, attracts bears (Stirling 1990). Female bears with young cubs and young females prefer expansive areas of stable, fast ice, where the threat of attack from adult male polar bears is reduced. Ringed seals have lairs and give birth in these areas. These seals provide food for young polar bear families. In spring, bears move to open leads and shifting flow edges (Stirling et al. 1975).

In winter and spring, polar bears hunt seals in offshore leads that run parallel to the coast. With the approach of summer, coastal ice sheets recede and open water appears. Most polar bears in the southern Beaufort Sea move north, following the receding ice floes and pack ice. In summer, an occasional polar bear is stranded on land, where it will spend the summer scavenging along the coast, waiting for the ice to re-form in the fall. The presence of polar bears on land during the summer in the southern Beaufort Sea is an uncommon event. This is unlike the situation in southwestern Hudson Bay and eastern Baffin Island where bears regularly concentrate along the coast to await the coming of ice in the fall. With freezeup and another winter season approaching, bears spread out over the sea ice (Stirling 1990).

Polar bears mate in April and May, but implantation of the fertilized egg does not occur until September or October. In November to December, females establish den sites either in snowdrifts on land or in multiyear pack ice offshore. Cubs are born in December or early January at about 0.5 kg, and are nursed until they reach 7.5 to 10 kg. The family leaves the den in March or April and returns to the sea ice. Here the female resumes seal hunting, and teaches her cubs seasonal movements and hunting techniques for the next 2.5 years (Stirling 1990).

Female polar bears typically first mate at five years of age and have their first cubs at six years of age, but they can successfully mate at three years of age (Amstrup 2000). Females breed every 3 to 4 years and give birth to from 1 to 3 cubs. As a result, populations have a low reproductive rate and a potentially slow recovery time (Stirling 1990). Amstrup (1995) estimated that the southern Beaufort Sea population of polar bear had a growth rate of 2.2 to 2.4 percent per year. Males polar bears weigh from 450 to 600 kg, and females range from 150 to 300 kg.

12.6.2 Issues Related to Polar Bear

The potential effects of offshore hydrocarbon development has been previously examined in a series of workshops held under the BEMP and BREAM projects. These workshops identified the possibility that bears would be attracted to offshore or coastal facilities where they would pose a threat to human safety leading to the killing of the bears. Nuisance bears that were shot would be deducted from the community quotas thereby reducing the community harvests of polar bears.

This same possibility was identified at this workshop, as well as two additional concerns:

- potential impact on polar bears of an oil spill
- potential impact on coastal denning females

As the present study is focused on natural gas development, an oil well blowout is not considered; however, there is potential for a spill of diesel oil from a ship or shore facility. As there has been significant research on the impacts of oil on polar bears no new research is needed.

12.6.3 Mitigation Related to Polar Bear

There has been a great deal of offshore exploration in the southern Beaufort Sea over the past 25–30 years. During this period, operational procedures to minimize risk to polar bears have been developed. Industry best practices, including Inuvialuit polar bear monitors, should be used in future developments. Odours and refuse can be reduced through strict controls and practices. Concerted efforts are required to inform and educate workers about safety in bear country. Strict rules about garbage disposal and the feeding of wildlife lessen the chances of bears coming to sites (BEMP 1987-1988). There are a number of detection systems (e.g., infra-red detection units, dogs, trip-wire fence systems) and deterrent systems (e.g., rubber bullets, flare cartridges and air horns) that have proved effective in reducing the number of bears at development sites (BEMP 1987-1988). No new research needs were identified related to this concern.

The potential for interference with the maternal dens of polar bears is a site-specific concern that can be addressed in relation to each project. The concern is interference with active den sites. The availability of potential denning sites is not limiting to the southern Beaufort Sea polar bear population (Stirling year, pers. comm.), thus, exclusion of females from a few sites by the presence of industrial facilities is not expected to affect population size.

There was a brief discussion of the potential effects of climate change on polar bear populations in the Beaufort Sea. It was agreed that to extent that changes in sea ice formation and patterns occur, there could be impacts on ringed seal populations and polar bear populations

12.6.4 Knowledge Gaps Related to Polar Bear

No new research needs were identified regarding the impacts of development on polar bear, or mitigation measures. The need for long-term monitoring of polar bear populations is recommended, however, to identify and separate the effects of climate change from those of development.

13 Biodiversity

> *The basic goals expressed by the Inuvialuit and recognized by Canada in concluding this Agreement are:*
>
> *c) to protect and preserve the Arctic wildlife, environment and biological productivity.*
>
> Principle of the Inuvialuit Final Agreement (1984)

13.1 Chapter Overview

To be completed.

13.2 The Nature of Biodiversity

Often referred to as biodiversity, biological diversity refers to the variety of species and ecosystems on earth and the ecological processes of which they are a part (Environment Canada 1995). Embedded in the definition of biodiversity is the concept that all life forms have some value (ecological, economic, real or potential). As such, there is a direct link between the concepts of biodiversity and the concepts of traditional ecological knowledge. This section provides a brief orientation to the topic of biodiversity and how this subject applies to the Arctic.

Two objectives of the United Nations Convention on Biological Diversity are the conservation of biodiversity and the sustainable use of biological resources. On a worldwide basis, ecosystems, species and genetic diversity are being reduced at unnaturally high rates, mainly by human activities. Specifically, landscapes are being altered, species are being lost, and genetic variation within species is decreasing (Environment Canada 1995).

Subsequently, the Canadian Biodiversity Strategy stipulated that in order to conserve biodiversity, viable populations of native wild biota must be maintained "in their natural habitats, ecosystems, landscapes and waterscapes" (Environment Canada 1995), and identified three components of biodiversity: ecosystem diversity, species diversity and genetic diversity. To this end, the strategy addresses inventories at the landscape, species and genetic levels, and recommends addressing biodiversity within environmental impact assessments. Biodiversity is typically measured at three scales:

1. the species level
2. the community level
3. the landscape level

13.3 Issues Related to Biodiversity

Arctic ecosystems have low species diversity and simple structures, therefore, they can be disturbed easily and are slow to recover. Since human activity will increase in the Canadian Arctic, the responses of Arctic ecosystems to disturbance must be examined at all three of the above levels to reduce the potential for extensive, anthropogenic changes to populations of flora and fauna, species diversity and the patterns of soils and vegetation on the landscape. Consideration of the issues associated with biodiversity are complicated by the potential effects of climate change.

13.4 Response of Biodiversity to Disturbance

Arctic ecosystems are considered to be unusually susceptible to disturbances because (Osherenko and Young 1989):

- low temperatures retard decomposition, including that of man-made substances and other pollutants
- recovery from disturbance is slow due to the short growing season and limited nutrient availability. Also, severe climatic conditions and ice dynamics make environmental protection and cleanup more difficult.
- Arctic animal populations often occur in large concentrations, and are thus more vulnerable to catastrophes. Rookeries, calving grounds, nesting cliffs, spawning bed, polynyas and estuaries are examples of aggregation areas. Areas such as these may be underrepresented on the landscape.
- species diversity is inversely proportional to latitude in the northern hemisphere, therefore ecosystems and food webs are less complex and more fragile in the Arctic than at lower latitudes

Biodiversity is ultimately founded on genetic diversity, which provides the raw material for adaptability to environmental conditions, and through speciation. Since genetic diversity can be increased only through mutation, the best approach to avoiding changes in the natural range of its variability is to preserve the genetic diversity that currently exists. Thus, assessing potential influences on biodiversity involves addressing factors that make populations vulnerable to disturbances. In the Arctic, one such factor is that many Arctic animals occur in large concentrations at some time in the year and thus a possibly significant proportion of a population can be jeopardized by a single anthropogenic event. If the animals congregate for the purpose of staging or breeding, then small, incremental human impacts at the breeding grounds can also be detrimental if the animals have shown fidelity to a specific breeding area.

At the landscape level, human activities in the Arctic to date have tended to disturb small areas (Walker and Walker 1991) that may affect Arctic wildlife out of proportion to the extent of the disturbance (Forbes et al. 2001) by creating patches that either attract or repel wildlife (Truett and Johnson 2000; Nellemann and Cameron 1996; Volpert and Sapozhnikov 1998).

The emerging science of conservation biology is developing increasingly sophisticated methods to quantify biodiversity in the context of impact assessment. These models will allow assessors to identify potential changes to the nature of representative habitat types or ecosite phases in each of the three scales listed above. Ideally, projects should not fundamentally change the natural range of variability of biodiversity at any of these three scales. This includes changes to the type, size, shape and availability of ecological units on the landscape. Development of natural gas fields, pipelines and transportation corridors in the Mackenzie Delta could potentially affect habitat types that are under-represented on the landscape at any of the three scales listed above.

13.5 Mitigation Related to Biodiversity

To be completed.

13.6 Knowledge Gaps Related to Biodiversity

Many types of inventories are conducted at the landscape and ecosystem levels to develop policies and land-use plans. Also, resource managers often have well-developed inventories and understanding of individual game species; however, "the genetic diversity of the Earth's flora and fauna is very poorly understood" (Environment Canada 1995), even with established gene banks.

For the Mackenzie River and Delta areas specifically, an ecological land classification system has not been completed; however, the Government of the Northwest Territories is proceeding with the development of a vegetation classification system. Without such a classification system and mapping, it will not be possible to assess if the proposed developments will result in significant changes in habitat availability and biodiversity.

An ecological land classification and land use analysis should be completed for the Delta to determine if the proposed developments will result in impacts on uncommon ecosystem features.

There is a need to review the available indices of change and their potential application in the North. There is a need to standardize the use of measurable parameters and the ways in which they are measured (e.g., fragmentation statistics). Recent environmental impact assessments in the North should be reviewed to see how the issue of biodiversity was handled (e.g., Diavik Diamond Mine, DeBeers Snap Lake Diamond Mine (assessment underway) and the assessment of the Shakwak Highway). Although reclamation is a common means of addressing habitat alterations in southern areas, the combination of factors (discussed above) suggests that reclamation would be difficult in the Arctic. Suitable reclamation techniques will need to be examined.

14 Resource Use

14.1 Chapter Overview

This chapter provides an overview of resource use. As evidenced by the language of the *Inuvialuit Final Agreement*, potential impacts on resource use are one of the greatest concerns for the Inuvialuit as they look at new opportunities for development. Opportunities to hunt, fish, trap and whale are fundamentally tied to the cultural identity of the Inuvialuit.

The priority knowledge gap for resource use is the need to map current and future land use.

14.2 The Nature of Resource Use

Resource use includes any use of the natural environment by people. Resource use can be interpreted as:

1. use of renewable resources by residents and visitors for non-industrial activities
2. industrial activities

The first type of use principally includes hunting, fishing, whaling, trapping and tourism. Furthermore, the historical and existing social and cultural relationship of the Inuvialuit to the subsistence harvesting of wildlife suggests a focus on the use of renewable resources, principally fish and terrestrial wildlife, migratory birds and whales. The second type of use involves industrial uses of non-renewable resources, principally oil and gas exploration, production and transportation (both onshore and offshore); and mineral, kimberlite and aggregate mining.

These uses are referred to as social components (SCs) in recognition that it is uses that are assessed, not what is used (which are the ecosystem components on which the use depends).

Potential SCs for resource use include:

- hunting
- trapping
- fishing

- whaling
- herding (reindeer)
- non-consumptive recreation (e.g., naturalist tours)

The value of renewable resources to the Inuvialuit can be readily demonstrated through the attention given to such resources in the provisions and products of the *Inuvialuit Final Agreement* (IFA). This is evident by the formalization of community involvement through the various Inuvialuit organizations (e.g., the Hunters' and Trappers' Committees), the co-management groups (e.g., Fisheries Joint Management Committee, Wildlife Management Advisory Committee [Northwest Territories and North Slope], Environmental Impact Screening Committee and the Environmental Impact Review Board). Supporting these groups are the principles and objectives stated in the *Inuvialuit Renewable Resource Conservation and Management Plan* (1988) and the detailed description of these resources in the Community Conservation Plans for each of the six Inuvialuit communities.

The principles of the *Inuvialuit Final Agreement* are:

a) to preserve Inuvialuit cultural identity and values within a changing northern society
b) to enable Inuvialuit to be equal and meaningful participants in the northern and natural economy and society
c) to protect and preserve Arctic wildlife, environment and biological productivity

14.3 Issues Related to Resource Use

Effects on renewable resources due to disturbances, particularly industrial, may have impacts on wildlife harvesting. Such impacts are inextricably linked to cultural, social and economic impacts. Reflecting the importance of this concern, the IFA specifically requires proposed developments to be screened for impacts on present and future wildlife harvesting. Negative impacts on resource use may be one of the greatest concerns to the Inuvialuit.

The issues associated with each of the two types of resource use are different. For the first type, use of renewable resources, the concerns revolve around the impacts attributable to human disturbances, typically of intensive industrial activities, on those natural resource users. For the second type, use of non-renewable resources, the concerns revolve around the impacts of those industrial activities on socio-economics. In the current study, the use of non-renewable resources is the focus.

Generally, all issues relate to changes in the opportunity and success of harvesting. Opportunity is the ability of a user to obtain a resource, and this is influenced by the occurrence of the resource and ease of access by users. Success is the degree by which a desired outcome is reached (e.g., a successful hunt). More specifically, these resource use issues are made apparent as:

- increased travel time to hunting or fishing grounds (if animals no longer occur in traditional hunting grounds)
- decreased number of animals harvested
- changes to community culture
- perception of human-caused changes on the landscape

These issues arise because of the following effects, all typically examined by the other disciplines:

- increased access (including winter roads) suitable for motorized vehicles into previously inaccessible or difficult to reach areas
- increased river and marine traffic
- changes to habitat for terrestrial wildlife, birds and fish (including habitat loss, fragmentation, obstruction of movements and sensory alienation)
- local and distant sources of air emissions and waste discharges that introduce contaminants

14.4 Knowledge Gaps Related to Resource Use

Knowledge gaps for resource use include:

1. description and mapping of current and future land use, including non-industrial use (e.g., hunter, trapper and fisher travel patterns and habits) and industrial use (e.g., hunting camps and gravel pits)

2. identification of local knowledge and means of incorporating such knowledge through community participation into a characterization of various human and natural attributes (e.g., levels and types of human use, ecology of species, landscape changes and sea ice changes)
3. review of existing Inuvialuit wildlife harvest studies to identify opportunities to update and expand them and to map the information at a finer spatial scale
4. development of harvest quotas or identification of means to develop such quotas
5. understanding the implications of structures (e.g., aboveground pipelines) to hunters, trappers, whalers and fishers travelling across the Delta region, including visual, noise and light effects and alteration of traditional travel routes
6. identification of land use categories and assignment of them to land parcels
7. identification of any gaps associated with the resources in question (e.g., wildlife species occurrence, distribution, habitat requirements and response to disturbance)

15 Cumulative Effects

15.1 Chapter Overview

Cumulative effects in the Mackenzie Delta region resulting from potential industrial development (e.g., exploration, gas field production, interconnecting network of pipelines and roads, and processing facilities) must be assessed as part of the information requirements for submissions to the Environmental Impact Screening Committee (EISC) and Environmental Impact Review Board (EIRB). How such information will be provided and interpreted is evolving, with direction provided through EISC and EIRB guidelines.

Although cumulative effects is referred to as a discipline in the context of this study, its examination does not completely fit the convention intended for the other disciplines. Other disciplines refer to certain physical, chemical or biological constituents of the environment (i.e., ecosystem components [ECs]), which are the receptors of anthropogenic disturbances. The focus of this knowledge gaps study is to identify data gaps associated with the assessment of those cause-effect relationships.

Any of these relationships may include a cumulative effect if that relationship is influenced by human activities other than the specific project under review. Therefore, for the purposes of this study, it is suggested that needs (or 'gaps') related to review process and assessment method be discussed, examining the ways in which such effects should be considered both within each discipline's assessment and in a comprehensive fashion that encompasses all disciplines. In this way, issues unique to a cumulative effects context would be identified and clarified.

The guiding questions for identification of knowledge gaps for cumulative effects assessment are:

1. What information is required to assess cumulative effects (beyond that already provided by the environmental disciplines)?
2. What information is required to review such an assessment?

The natural history of individual ECs and the mechanisms of their response to disturbances are established elsewhere in this report. What remains for discussion here is the consideration of cumulative effects for these ECs.

15.2 Issues Related to Cumulative Effects

Cumulative effects issues include:

- developing a centralized regional database to support the preparation of baseline information for project-specific assessments and reviews and for any regional cumulative effects assessment initiatives
- acknowledging the concerns of community members (including views on acceptance, tolerance and comfort) and involving community members in any assessment
- delimiting reasonable and meaningful study area boundaries, particularly for effects and ECs with far-ranging movements (e.g., air emissions; effluent discharged into waterways; and migratory terrestrial, marine and bird species) (i.e., how distant does the assessment go?)
- delimiting temporal representation of pre-disturbance conditions (i.e., how long ago do we say was a time of no human disturbance?) and future conditions (i.e., how far into the future to we have to go?), including the possible use of certain future development scenarios
- establishing a basis for the inclusion, or not, of potential induced upstream projects (i.e., if other things may happen later, how should an assessment account for them?)
- identifying responsibilities and potential initiatives by the project proponent towards the mitigation of cumulative effects for which the project is contributing, particularly through jointly coordinated regional initiatives (i.e., what can be done to collectively minimize effects?)
- identifying ECs for which thresholds are most relevant and useful to assist in the evaluation of the significance of the project's contribution to cumulative effects, identifying if such thresholds are available or possible to derive, and what actions should be taken to determine such thresholds (i.e., which ECs are critical and have definite thresholds?)

The potential cumulative effects of proposed and anticipated development include:

- changes in air quality and deposition of airborne material
- effects on waterbodies (e.g., due to lake and river crossings, near-shore works)
- contaminant effects on human and animal health
- sensory and habitat effects on wildlife species due to aboveground pipelines (e.g., as may be the case in areas of continuous permafrost) and other surface infrastructure and facilities
- changes in harvesting patterns of renewable resources due to new or improved access along rights-of-way
- sensory disturbances to human users (e.g., light, noise, odour, viewshed)

15.3 Knowledge Gaps Related to Cumulative Effects

Knowledge gaps for cumulative effects include:

1. development of a centralized regional spatial database (i.e., supported by geographic information systems) that includes:
    - ecological land classification
    - scientific literature
    - visual and written record of local knowledge
    - environmental setting (focused on ECs)
    - land uses

    Features of this database include:

    - incorporation of extensive existing information
    - readily and publicly accessible
    - information maintained up-to-date
    - detailed (i.e., covers a large enough area and at a fine enough scale of resolution to usefully contribute to assessments and reviews)
2. formulation of an incremental and adaptive review and development strategy with followup whereby development proceeds on condition of effects and

compliance monitoring, with implication of project modification if effects are determined unacceptable

3. development of an overall regional effects management strategy led by government, involving jointly coordinated involvement of Inuvialuit and industry
4. improved means of continuous and informative communication and participation with community members; and identifying means of incorporating local knowledge into assessments
5. clarify jurisdictional and administrative contribution to assessing and managing cumulative effects, especially:
   - recognize and implement applicable provisions of the *Inuvialuit Final Agreement* (e.g., Regional Advisory Committee)
   - clarify roles and responsibilities amongst proponents, government, Inuvialuit institutions, co-management institutions and community members
   - define specific allowable uses within the Community Conservation Plan land use categories through a pre-planning process supported by government
6. provision of guidelines on assessing and managing cumulative effects, especially:
   - definition of adequate information requirements for proponent's assessments to support decision makers
   - identification of thresholds (correlated to ecosites, project type and receptor) based on scientific and traditional (from community) information; and, based on human perceptions of 'acceptable' change
   - conditions for the determination of significance of a project's contribution to cumulative effects and of overall cumulative effects (i.e., by all projects and activities), especially in the absence of thresholds
   - establishing a basis for delimiting study areas for far-ranging effects and ECs
   - establishing a basis for inclusion and consideration of induced projects

- identification of 'lessons learned' from other polar regions experiencing human use pressures
- development of meaningful and useful interpretation of cumulative effects, especially to harvesters of renewable resources.

16 Recommendations

16.1 Knowledge Gaps: Common Themes

It was not possible to prioritize all knowledge gaps over all disciplines either during or following the Inuvik workshop. The breadth and complexity of that task would require an interactive and more comprehensive approach. However, it was apparent during the presentation of knowledge gaps by each breakout group that some knowledge gaps were common to several or all disciplines. Common themes that emerged at the workshop included (in no particular order):

- the need to better understand the effects of climate change on the environment, industrial development and harvesting
- the need to better understand the potential effects of human activities and climate change on permafrost and ice
- concerns about changes in shoreline stability and effects on industry and the environment
- the need for an ecological land classification system to guide land use planning as well as the conservation of biodiversity and specialized habitats
- concerns about changes in nutrient cycling as a result warming of the active soil layers and effects on reclamation success and natural systems
- concern about changes and improvements in land access and effects on the environment
- concerns about cumulative effects on opportunities for fishing, hunting, trapping and whaling

16.1.1 Effects of Climate Change

The need to understand the implications of climate change on Arctic ecosystems was a common theme in all breakout groups. Most groups identified the need to be able to better predict how climate change will affect the physical environment of the Mackenzie Delta region, particularly in relation to permafrost stability, the marine ice regime, ice formation and hydrological processes in the Mackenzie Delta as well as use of habitats by fish and wildlife.

Climate change and its associated effects have and will continue to fundamentally change assessments of the future impacts of development in the Mackenzie Delta region. As noted by David Thomas during the workshop plenary session, because all previous impact predictions are based on data and understandings that may change significantly as the result of climate change dynamics, we will need to be cautious about how we predict ecosystem responses to future natural and human disturbances. Climate change also forces us to consider how future impacts may be assessed and managed, when baseline conditions may be continually changing due to the influence of climate change. Climate change must also be factored into the ability of a species to respond to multiple, human-caused and natural pressures while also adapting to the effects of climate change. In completing cumulative effects assessments for new projects, climate change and its effects on the natural and human environment will need to be considered in combination with the effects of past, existing and reasonably-foreseeable human activities and development. These challenges become particularly important in addressing potential environmental effects of natural gas projects and infrastructure that may remain in place for 30 to 50 years or more.

Climate change could also be a major influence on the long-term stability of infrastructure, including buildings, pads, roads and pipelines. Climate change is therefore an important factor in assessing the effects of environmental change on a project.

To be able to address cumulative effects, as well as effects of the environment on a project, information is required to:

- predict long-term climate change and its effects on different parts of the Mackenzie Delta and near-shore Beaufort Sea
- assess effects of climate change on the physical environment, particularly in relation to permafrost, sea ice, and the ice and hydrological regime within the Mackenzie Delta (including sub-sea permafrost at its critical temperature)
- predict how aquatic and terrestrial ecosystems will respond to climate change (e.g., vegetation growth and reclamation, habitat use by fish and wildlife)

16.1.2 Degradation of Permafrost and Ice

Climate change is expected to be a major influence on the stability and maintenance of permafrost and ice within the Mackenzie Delta region and the near-shore Beaufort Sea. As noted earlier in this report, a number of measurable changes in the distribution and characteristics of permafrost and ice are already detectable. Because of the influence of permafrost on terrain stability, groundwater flows, and erosion, changes in permafrost could lead to substantial changes in the distribution, diversity and productivity of vegetation, and the use of habitats by wildlife and fish. Changes in marine ice and river ice regimes may alter coastal processes, physical and chemical oceanographic characteristics, sediment deposition and seasonal use of the Delta and the near-shore Beaufort Sea by wildlife and fish, as well as hunters, fishermen, trappers and whalers.

Changes in permafrost and ice regimes could also have a dramatic effect on the long-term stability of industrial infrastructure, local communities and traditional harvesting sites, as well as winter transportation (i.e., ice roads, snow machine trails). Changes in ice regimes and climate (e.g., shorter winters) could also affect the use of ice islands as temporary platforms for industrial use.

Important overarching knowledge gaps involving permafrost include:

- the need to understand and ideally to predict the effects of climate change on permafrost stability and degradation, as well as ice formation and dynamics
- spatial predictions of the susceptibility of permafrost to melting and associated terrain degradation
- spatial predictions of potential changes in the marine ice regime (e.g., landfast ice, transition zone, pack ice), as well as the ice regime of the Mackenzie Delta

16.1.3 Changes in Shoreline Stability

Changes in shoreline stability as a result of climate change, permafrost degradation, land subsidence and hydrological changes could result in substantial negative impacts to the natural environment, as well as industrial infrastructure, harvesting camps and traditional harvesting sites. Spatial modeling of shoreline stability (and channel stability) is required as part of a broader suite of spatial modeling to predict future permafrost and ice conditions and potential hydrological changes.

16.1.4 Development of an Ecological Land Classification System

A detailed ecological land classification system does not exist for the Mackenzie Delta region. Specialists in terrain, permafrost and geotechnical areas, as well as vegetation and wildlife specialists identified a need to develop a standard ecological land classification system that would enable better mapping and spatial analyses of permafrost and terrain issues, soil, vegetation structure and diversity and wildlife habitat capability. A detailed ecological land classification system would also be useful in assessing potential changes in biodiversity, identifying specialized or unique habitats and assisting in planning of protected areas. An ecological land classification map for the Mackenzie Delta region would also be useful in developing predictive models for permafrost and shoreline stability.

16.1.5 Changes in Nutrient Cycling and Reclamation

Increases in the depth of the active soil layer and the length of the thaw period will result in changes in nutrient cycling and the composition and diversity of vegetation. In planning reclamation programs for future developments, it will be necessary to understand how climate change may alter nutrient cycling and vegetation growth and diversity. This could affect the selection of seed stock for reclamation mixes, the use and choice of fertilizers (if used) and revegetation success.

16.1.6 Changes in Land Access

Improved road access through much of the Delta region has resulted in a much wider distribution of vehicles and human activity than in the past. Concerns were expressed that improvements in road access could lead to changes in harvesting patterns and success, and to increased predation by large carnivores such as wolves. Information on the location and use of winter roads should be compiled for use in cumulative effects assessments.

16.1.7 Cumulative Effects on Harvesting Success

Traditional harvesting in the Delta region will be subject to a variety of pressures from increased industrial activity and human use. Some of the activities of Industry may directly affect the ability of people to access sites, as well as the quality of their experience. Other activities may result in a redistribution of species, changes in the abundance of species or changes in the quality of the harvest. To better assess potential future effects, it is recommended that the harvest statistics from the Inuvialuit Harvest Study be analyzed to provide an understanding of harvest locations and harvest success for various wildlife and fish species. Spatial analyses of these data would be helpful in predicting cumulative effects of development on traditional harvesting.

16.2 Knowledge Gaps: General Recommendations

A number of general recommendations were put forward during the closing plenary session of the workshop:

- planned research for the Mackenzie Delta that are 'on the books' for all government agencies, management boards, non-government organizations, the Environmental Studies Research Fund (ESRF), PERD and industry should be summarized and made publicly available (e.g., FJMC, DFO, ESRF and Industry co-funding beluga studies)
- environmental impact assessments and associated baseline studies expected from industry in the next five years should be identified so that it is clear where field studies associated with these assessments may fill knowledge gaps (e.g., Mackenzie Gas Project, Devon's Beaufort Offshore Exploration Drilling Program)
- the northern science capacity of the federal government has severely declined and, therefore, collaboration on research projects is encouraged to leverage the necessary funding. Co-funding of specific projects by all parties with access to funds should be considered. A new government funding program on research and monitoring for northern hydrocarbon development focusing on baseline and applied research should be established.
- the reports of the Beaufort Environmental Monitoring Project (BEMP), Mackenzie Valley Environmental Monitoring Program (MEMP), Beaufort Regional Environmental Assessment Program (BREAM), Northern Oil and Gas Action Program (NOGAP), the Panel on Energy Research and Development (PERD) and ESRF programs should be made accessible through the Internet (e.g., the Arctic Science and Technology Information System [ASTIS])

- building on existing efforts, an integrated regional database on the ecosystem components of the Mackenzie Delta region or the Inuvialuit Settlement Region should be developed on a geographic information system platform and made available to the public through the Internet
- ongoing dialogue among all stakeholders should be encouraged
- a process or mechanism should be implemented to learn from the experiences of Prudhoe Bay and apply the lessons learned to the Delta region
- the federal government, including Indian and Northern Affairs Canada should work closely with industry to encourage the early disclosure of detailed project descriptions wherever possible (e.g., preliminary information packages (PIP) and project descriptions). Early disclosure will increase the opportunities for discussion of best practices with the communities and co-management boards, and increase the likelihood of acceptance and success.
- DIAND should work with the Inuvialuit GNWT and federal regulatory authorities to summarize the existing 'land use planning' documents for the Inuvialuit Settlement Region. Senior elected and appointed officials from the federal and territorial governments should then meet with the Chair of the Inuvialuit Regional Corporation and the Chair of the Inuvialuit Game Council to discuss the need for a concise new statement of vision for the future of the Inuvialuit Settlement Region. They should also discuss the merits of discussing the need for a vision statement with the CEOs from Industry. The relevant background documents include:
    - Draft Beaufort Sea Land Use Plan
    - Beaufort Sea Environmental Impact Statement
    - Inuvialuit Conservation and Management Plan
    - Community Conservation Plans for Inuvik, Aklavik, Paulatuk, Tuktoyaktuk, Sachs Harbour and Holman Island
    - Beaufort Sea 2000 Conference: Renewable Resources for Our Children
    - Common Ground, the NWT Economic Strategy 2000

16.3 Action Plan and Implementation

An action plan to address the knowledge gaps is needed. An action plan would contribute to an effective dialogue among all stakeholders.

The urgency for the various information requirements needs to reflect two different timelines:

- the time at which specific activities associated with exploration and production of natural gas are likely to occur (i.e., how soon do we need information to address effects associated with these activities?)
- the length of time that is required to conduct adequate studies

As noted by several individuals during the workshop, given the probable development scenario for natural gas reserves in the Beaufort Sea region, there are both immediate and longer-term information needs for assessing and managing potential effects of hydrocarbon development in the Beaufort Sea region. For example, there is an immediate need to address knowledge gaps that pertain to effects of seismic exploration and exploration drilling programs, as well as associated infrastructure development. In contrast, because construction and operation of gas production and transportation facilities (e.g., gathering systems) is not likely to begin until the end of this decade, the filling of knowledge gaps associated with these industrial activities and their effects could be handled as a different phase of an action plan.

However, it is also important to consider the length of time that will be required to complete studies for specific knowledge requirements. Some knowledge gaps might be addressed through short-term programs (i.e., 1–3 years), whereas others may require longer-term multi-year programs (i.e., 5–10 years). For example, documentation of industrial practices might only require a short period to complete. In contrast, developing a better understanding of the ecosystems of the Mackenzie Delta could require a multi-year program with several different components.

To address these two different timelines, it is recommended that the action plan on knowledge gaps be based on a minimum of a five-year planning horizon. The plan would lay out the types of research that should be undertaken over the next five years, as well as the planning process that would be used to address outstanding and new knowledge gaps in the longer term. The action plan should set out specific objectives for fulfilling these knowledge gaps, as well as criteria for measuring performance.

Based on discussions throughout the sessions in Inuvik, concerns were expressed that (1) there is a limited time period to prepare for the ramping up of industrial activity in the Beaufort Sea region (i.e., 5 to 10 years); and (2) given the type and range of information needs and research, alternate funding mechanisms, over and above the ESRF program, need to be explored.

Appendix A: Breakout Group Members

Notes: **Boldface** indicates the person who was the facilitator for the breakout group.

* indicates a member of the Project Advisory Team.

Climate Change and Oceanography

1.	David Thomas – Lead, Oceanography	KAVIK-AXYS Inc.
2.	Philip Marsh – Lead, Air and Climate Change	Environment Canada
3.	**Rosaline Canessa**	KAVIK-AXYS Inc.
4.	Humfrey Melling	Fisheries and Oceans Canada
5.	Steve Blasco	Natural Resources Canada
6.	Bonnie Gray	National Energy Board
7.	Tim Taylor	Petro-Canada Inc.
8.	Sherri-Lynn Marshall	Natural Resources Canada
9.	Duane Smith	Chair, Inuvialuit Game Council
10.	Fred Roots	Science Advisor Emeritus, Environment Canada
11.	David Stone*	Indian Affairs and Northern Development

Permafrost, Soils, Surface Water and Groundwater

1.	Margo Burgess - Lead	Natural Resources Canada
2.	**Jeff Green***	KAVIK-AXYS Inc.
3.	Fred McFarland	Advisor, Indian Affairs and Northern Development
4.	Ruth McKechnie*	Indian Affairs and Northern Development
5.	Norm Snow*	Joint Secretariat
6.	Eric Chernoff	Resource Person, Environmental Impact Review Board
7.	Bill Livingstone	Devon Energy
8.	Jim Wall	Aurora Research Institute
9.	Bob Gowan	Indian Affairs and Northern Development
10.	Robert Jenkins	Indian Affairs and Northern Development
11.	Ethan Sawchuck	Inuvialuit Land Administration
12.	Meighan Wilson	Indian Affairs and Northern Development
13.	Steve Kokelj	Advisor, Indian Affairs and Northern Development
14.	Gavin Manson	Indian Affairs and Northern Development

Fisheries and Aquatic Systems and Marine Mammals (including Polar Bears)

1.	Rolph Davis* - Lead – Marine mammals	LGL Environmental Research Associates
2.	Michael Lawrence - Lead – Fisheries	North/South Consultants Inc.
3.	**Ricki Hurst***	Indian and Northern Affairs Canada
4.	Bob Bell*	Chair, Fisheries Joint Management Committee
5.	Eric Gyselman	Fisheries and Oceans Canada
6.	Herbert Felix	Environmental Impact Review Board
7.	Doug Chiperzak	Fisheries and Oceans Canada
8.	Roger Connolly	Inuvialuit Regional Corporation
9.	Lois Harwood	Fisheries and Oceans Canada
10.	Sam Stephenson	Fisheries and Oceans Canada
11.	Jesse Jasper	Environment Canada
12.	Ed McLean	Resource Person, Fisheries Joint Management Committee
13.	Peter Millman*	Devon Canada Corporation
14.	Jennifer Walker-Larsen	Gwich'in Renewable Resources Board

Terrestrial Vegetation, Wildlife and Biodiversity Migratory Birds

1.	Kevin Lloyd* Lead - Wildlife	KAVIK-AXYS Inc.
2.	Steve Johnson* Lead – Migratory birds	LGL Environmental Research Associates
3.	**Andrew McCoy***	KAVIK-AXYS Inc.
4.	Cynthia Pyc*	Mackenzie Delta Partnership
5.	John Nagy	Government of the Northwest Territories
6.	Denise Auriat	Gwich'in Renewable Resources Board
7.	Larry Carpenter	Chair, Wildlife Management Advisory Council
8.	Marsha Branigan	Government of the Northwest Territories
9.	Peter Clarkson	Gwich'in Renewable Resources Board
10.	Jim Bahr – Biodiversity	KAVIK-AXYS Inc.
11.	Dana Bush – Vegetation	KAVIK-AXYS Inc.
12.	Katherine Thiesenhausen	Resource Person, WMAC
13.	Doug Mead	Shell Canada Limited
14.	Jim Hines	Canadian Wildlife Service
15.	Paul Latour	Canadian Wildlife Service

Resource Use and Cumulative Effects

1.	George Hegmann* - Lead	KAVIK-AXYS Inc.
2.	**Liz Swift***	KAVIK-AXYS Inc.
3.	Michael Fabijan	KAVIK-AXYS Inc.
4.	Billy Day	Environmental Impact Screening Committee
5.	Stephen Harbicht*	Environment Canada
6.	Terry Antoniuk	Conoco Canada Resources Inc.
7.	Paula Pacholek	Indian Affairs and Northern Development
8.	Bill Carpenter	World Wildlife Fund
9.	Hans Arends	Inuvialuit Land Administration
10.	Linda Graf	Resource Person, Environmental Impact Screening Committee
11.	Ray Case	Government of the Northwest Territories
12.	Tom Beck	Past Chair, Environmental Impact Screening Committee
13.	Ross Goodwin	Arctic Institute
14.	Ian Scott	Canadian Association of Petroleum Producers
15.	Pat Winfield	Inuvialuit Regional Corporation
16.	Masood Hassan	Fisheries and Oceans Canada

Appendix B: Workshop Agenda

DRAFT AGENDA

Evening session: Thursday [illegible] January 2002

Time	Topic(s)	Presenter
19:00	**Workshop opening**	Ricki Hurst
	Opening Prayer	Billy Day
	Introduction of Ms. Cournoyea	Tom Beck
19:20	**Welcome to Inuvik**	Nellie Cournoyea
19:30	**Historical context**	David Stone
20:00	**Overview of industry's plans**	Industry rep
20:30	**The hydrocarbon impacts database**	Ross Goodwin
20:45	**Approach to workshop**	David Thomas
21:00	**Establishment of break-out groups**	Jeff Green
21:10	**Comments and discussion**	David Thomas
21:30	***Adjourn***	

Friday 25 January		
Time	**Topic(s)**	**Presenter**
8:30	**Instructions to break-out groups**	Jeff Green
8:45	**Overview of geophysical exploration and exploratory drilling (terrestrial and marine environments)**	Industry rep
9:15	**Break-out groups**	
	(Note: there are 5 groups with two discipline sets in each)	
1a	Air and climate change	Stewart Cohen
1b	Oceanography	David Thomas
2a	Soils, terrain stability and permafrost	Margo Burgess
2b	Waste management	TBD
3a	Fish and aquatics	Jim Reist
3b	Marine mammals	Rolph Davis
4a	Terrestrial vegetation, wildlife and biodiversity	Kevin Lloyd
4b	Migratory birds	Steve Johnson
5a	Resource use	George Hegmann
5b	Cumulative effects	George Hegmann
10:00	***Break***	
10:20	**Break-out groups (continued)**	
Noon	***Lunch (catered)***	
13:00	***Plenary session:***	
	Overview of development, production and transportation	Industry rep
13:30	**General discussion**	
13:45	**Return to break-out groups**	
15:00	***Break***	
15:20	**Break-out groups (continued)**	
16:45	**Closing of Day One and Orientation to Day Two**	Jeff Green
17:00	***Adjourn***	

DRAFT AGENDA

Evening session: Thursday 24 January 2002

Time	Topic(s)	Presenter
19:00	Workshop opening	Ricki Hurst
	Opening Prayer	Billy Day
	Introduction of Ms. Cournoyea	Tom Beck
19:20	Welcome to Inuvik	Nellie Cournoyea
19:30	Historical context	David Stone
20:00	Overview of industry's plans	Industry rep
20:30	The hydrocarbon impacts database	Ross Goodwin
20:45	Approach to workshop	David Thomas
21:00	Establishment of break-out groups	Jeff Green
21:10	Comments and discussion	David Thomas
21:30	*Adjourn*	

Friday 25 January		
Time	**Topic(s)**	**Presenter**
8:30	**Instructions to break-out groups**	Jeff Green
8:45	**Overview of geophysical exploration and exploratory drilling (terrestrial and marine environments)**	Industry rep
9:15	**Break-out groups**	
	(Note: there are 5 groups with two discipline sets in each)	
1a	Air and climate change	Stewart Cohen
1b	Oceanography	David Thomas
2a	Soils, terrain stability and permafrost	Margo Burgess
2b	Waste management	TBD
3a	Fish and aquatics	Jim Reist
3b	Marine mammals	Rolph Davis
4a	Terrestrial vegetation, wildlife and biodiversity	Kevin Lloyd
4b	Migratory birds	Steve Johnson
5a	Resource use	George Hegmann
5b	Cumulative effects	George Hegmann
10:00	***Break***	
10:20	**Break-out groups (continued)**	
Noon	***Lunch (catered)***	
13:00	***Plenary session:***	
	Overview of development, production and transportation	Industry rep
13:30	**General discussion**	
13:45	**Return to break-out groups**	
15:00	***Break***	
15:20	**Break-out groups (continued)**	
16:45	**Closing of Day One and Orientation to Day Two**	Jeff Green
17:00	***Adjourn***	

Saturday, 26 January 2002		
	Plenary session	
9:00	**Recap and Overview of Day One**	David Thomas
9:10	**Approach to Day Two**	Jeff Green
9:20	**Reports from break-out groups (5 at 10 mins each)**	Ricki Hurst
10:10	***Break***	
10:30	**Integrating data priorities**	Jeff Green
Noon	***Lunch (catered)***	
13:00	**General discussion of priorities**	David Thomas
14:30	**Towards an action plan to fill research gaps**	Ruth McKechnie
15:00	***Break***	
15:30	**Conclusions and Plenary Discussion**	David Thomas
16:15	**Closing remarks**	Billy Day
		David Stone
		Tom Beck
17:15	***Closing prayer and adjournment***	
18:30	***Banquet (Cash bar) Green Briar Dining Room***	

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Knowledge Gaps Associated With Exploration and Development of Natural Gas in the Mackenzie Delta Region

The Environmental Studies Research Funds

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SYNTHESIS OF EXISTING ENVIRONMENTAL KNOWLEDGE

- Understanding existing conditions
- Understanding ecosystem responses to project activities
- Understanding other pressures on the environment

POTENTIAL EFFECTS OF NATURAL GAS DEVELOPMENTS

- Understanding the proposed project
- Identifying project activities
- What else do we need to know to understand effects?

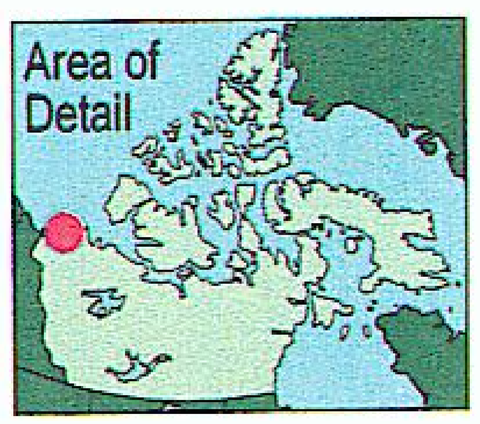
ANALYSIS OF KNOWLEDGE GAPS

1: Nature of the environment and existing conditions
2: Technical specifications for project activities
3: Responses of ecosystem components

ACTION PLAN TO FILL KNOWLEDGE GAPS

KNOWLEDGE GAPS ASSOCIATED WITH EXPLORATION AND DEVELOPMENT OF NATURAL GAS IN THE MACKENZIE DELTA

Identification and Analysis of Knowledge Gaps



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Acknowledgements:
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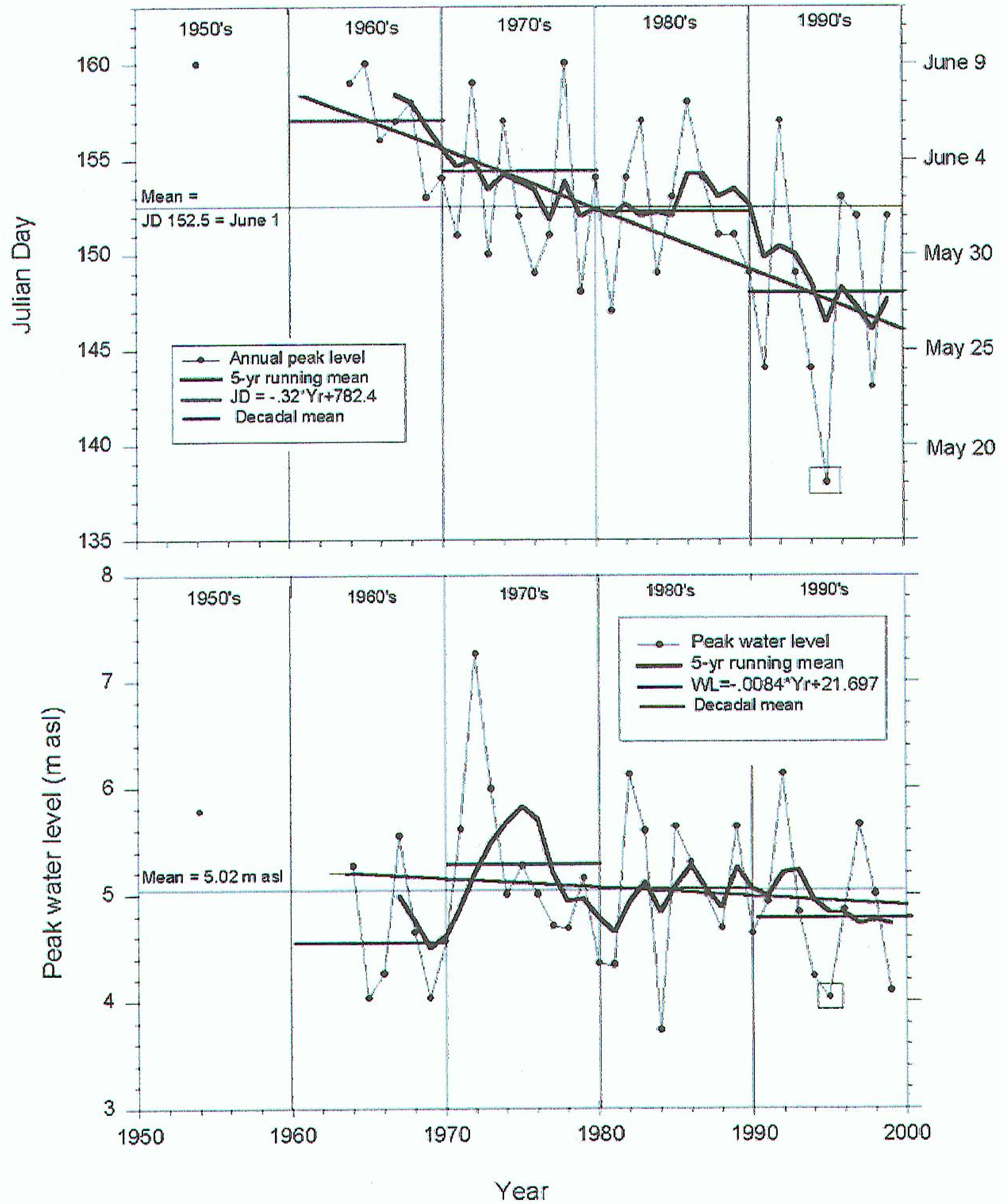
DATE Summer 2002		SCALE N/A	
DRAWN L.T.	CHECKED K.A.L.	FIGURE NO.	REV
REVIEWED J.E.G.	PROJECT KA031	2-1	3



Note that the date of the peak level has been occurring earlier in the spring, while there has been little or no change in the corresponding water level (Marsh et al. 2002).

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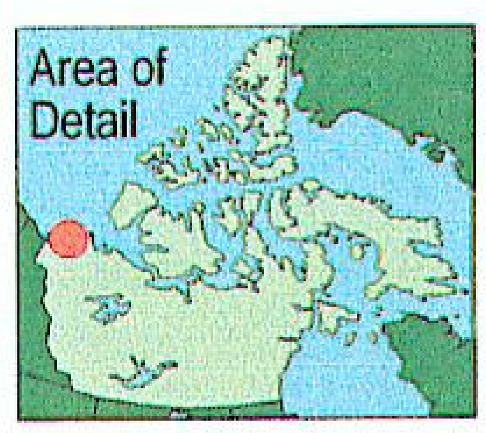
Change in Date and Peak Water Level at Mackenzie River East Channel at Inuvik.



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Acknowledgements:
Marsh, Onclin and Neumann 2002.
Water and energy fluxes in the lower Mackenzie Valley, 1994/95. Atmosphere-Ocean, in press.

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DRAWN L.T.	CHECKED K.A.L.	FIGURE NO. 5-1	REV 1
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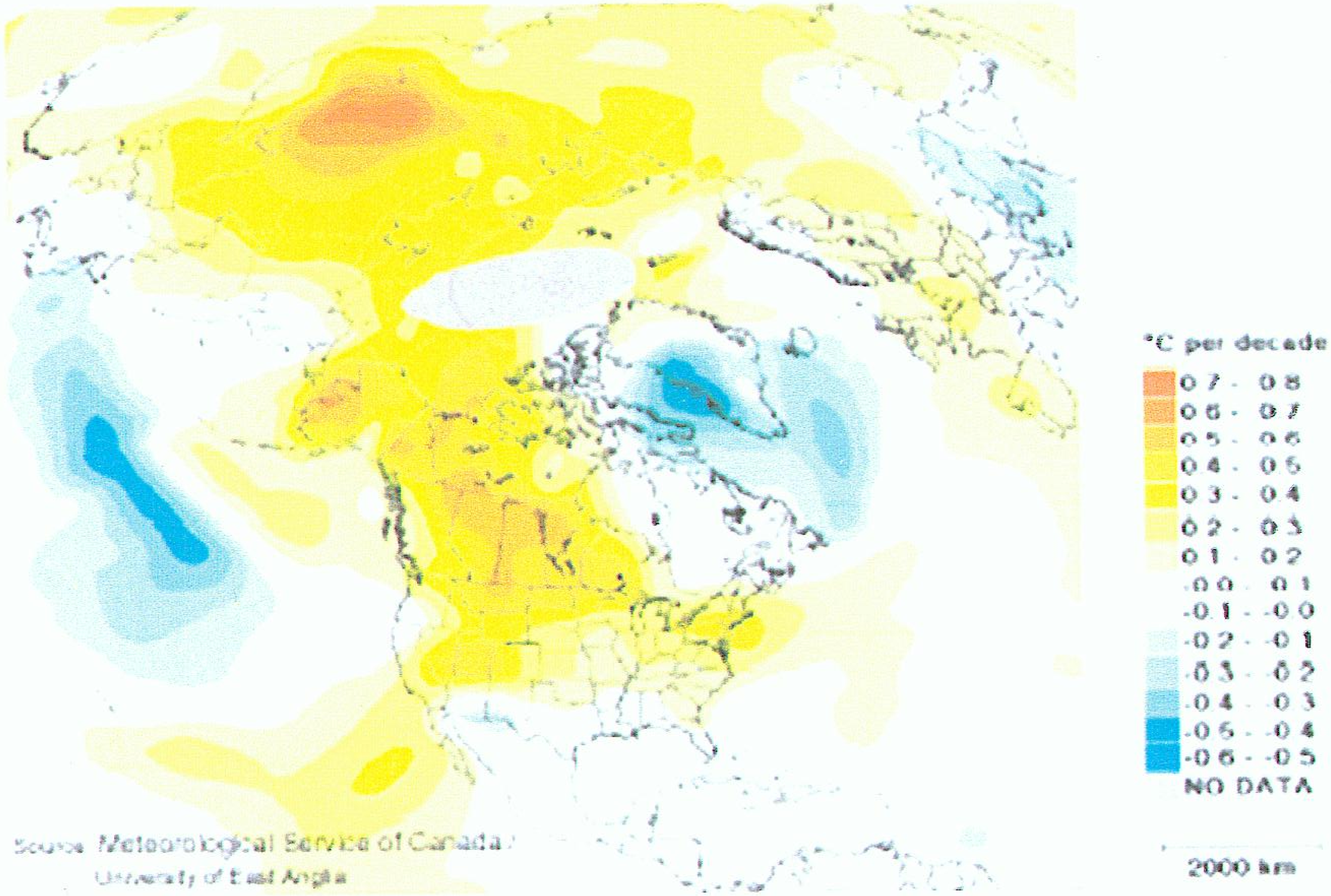

Note that the largest changes in North America occur over much of the Mackenzie Basin and the Mackenzie delta (Meteorological Service of Canada).

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Northern Hemisphere Changes in Air Temperature Between 1961 and 1990

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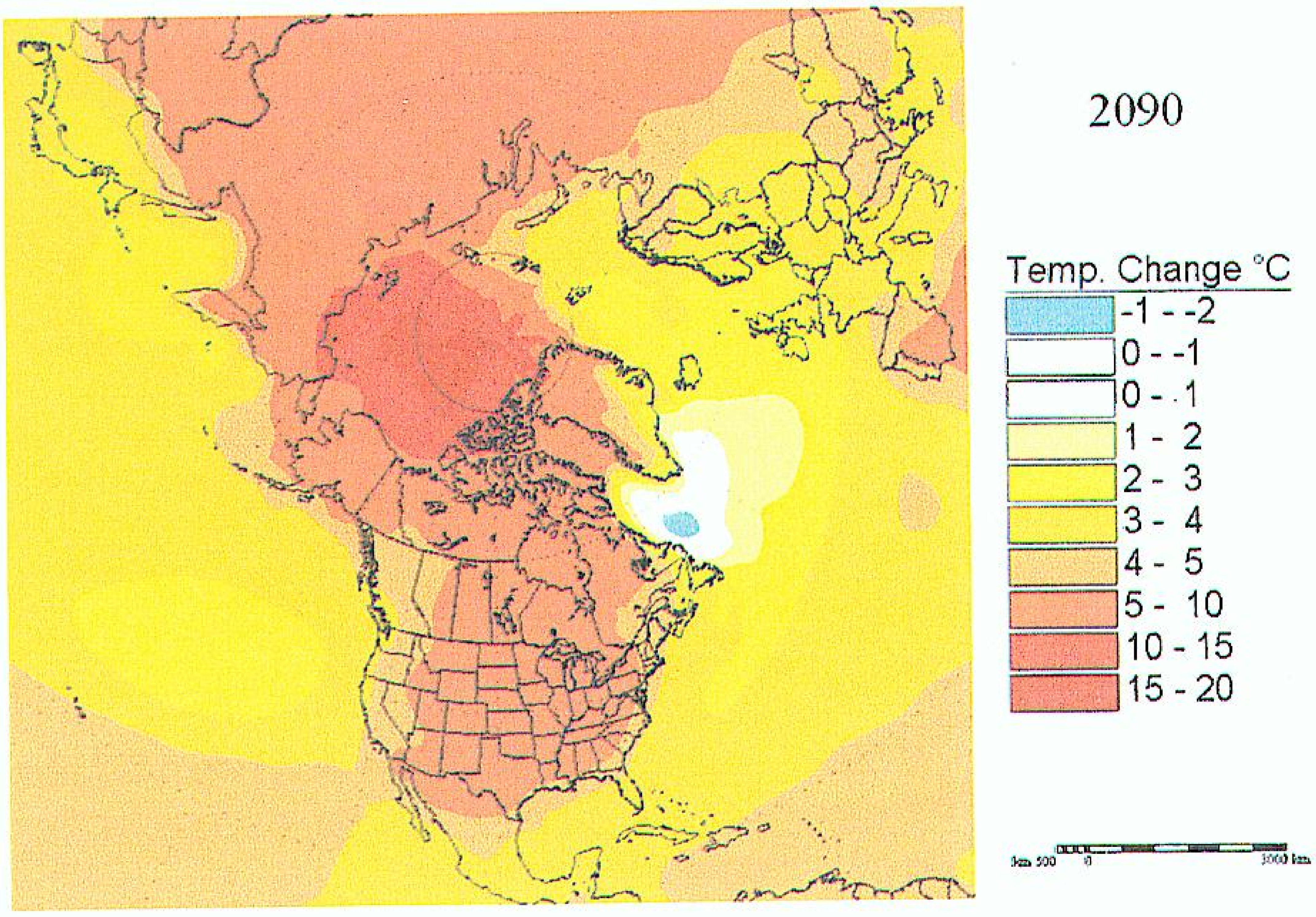
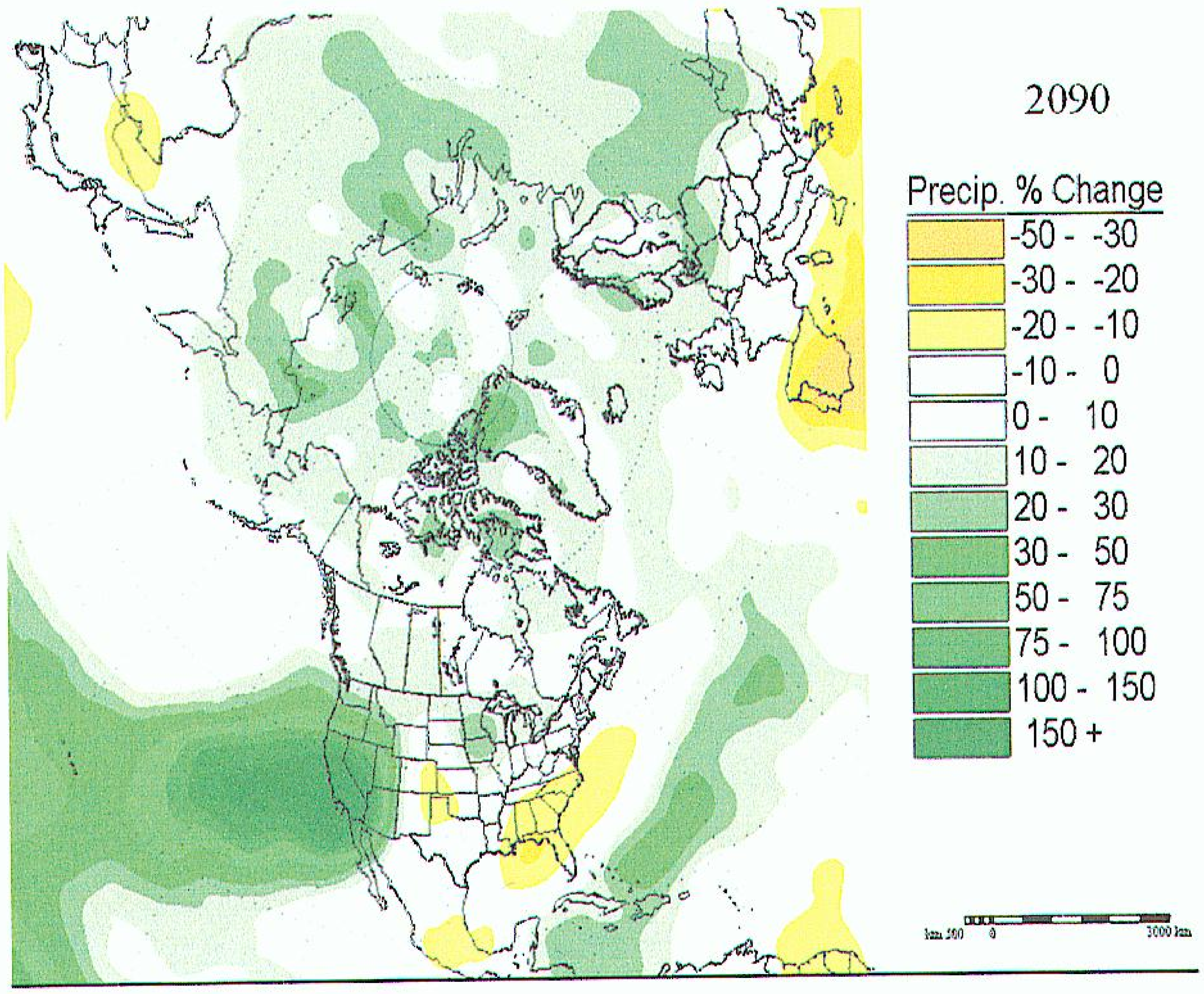
DRAWN L.T.	CHECKED K.A.L.	FIGURE NO. 5-2	REV 1
REVIEWED K.A.L.	PROJECT KA031		





Based on output from the Canadian Global Climate Model.
Note that estimated temperature change for the Mackenzie Delta region is in the range of 5 to 10°C compared to observations over the last 30 years, while precipitation is expected to decrease slightly. However, precipitation estimates are generally not as reliable as those for temperature.

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Temperature and Precipitation Scenarios for the Northern Hemisphere for 2090

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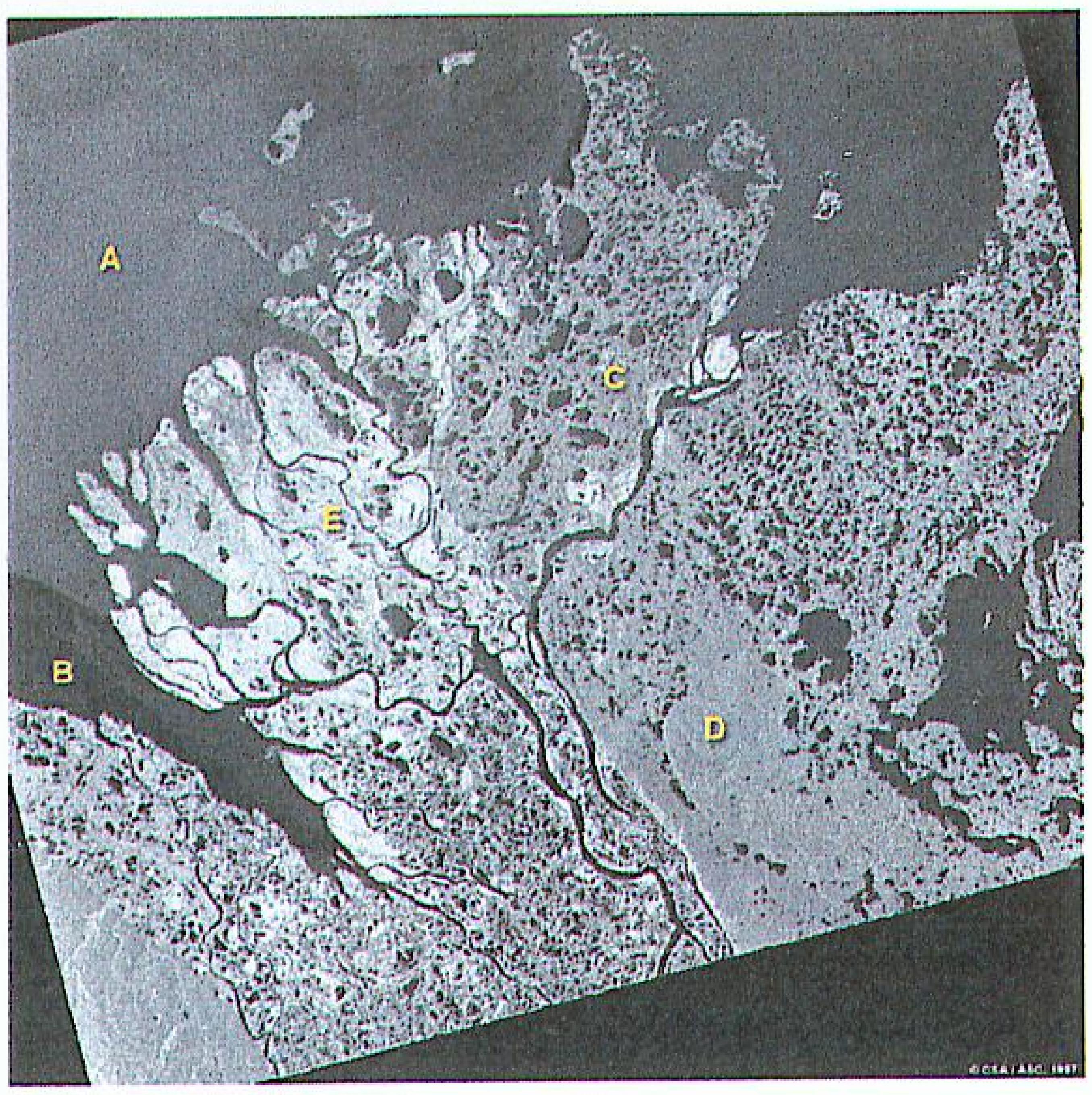
DRAWN L.T.	CHECKED K.A.L.	FIGURE NO. 5-3	REV 1
REVISED K.A.L.	PROJECT KA031		



The Tuktoyaktuk Peninusula, Richards Island, and the outer Mackenzie Delta have an extremely high concentration of tundra lakes.

In addition, the area is underlain by high concentrations of ground ice.

The combination of climate change, lakes, and high concentrations of ground ice, may result in an increase in the rate of drainage of permafrost dammed lakes.

Further research is needed to better understand the impact of climate change on lake drainage, and the implications to the ecosystem and to the infrastructure related to natural gas development.

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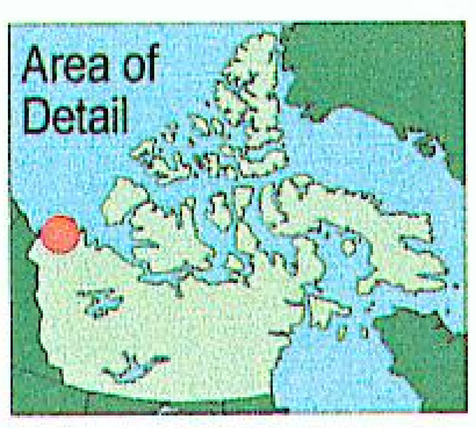
Photographs of the Mackenzie Delta Area



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REVISED K.A.L.	PROJECT KA031	5-4		1

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Aerial Photograph of the Mackenzie Delta

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Acknowledgements:
Photograph by Rick Lauzon

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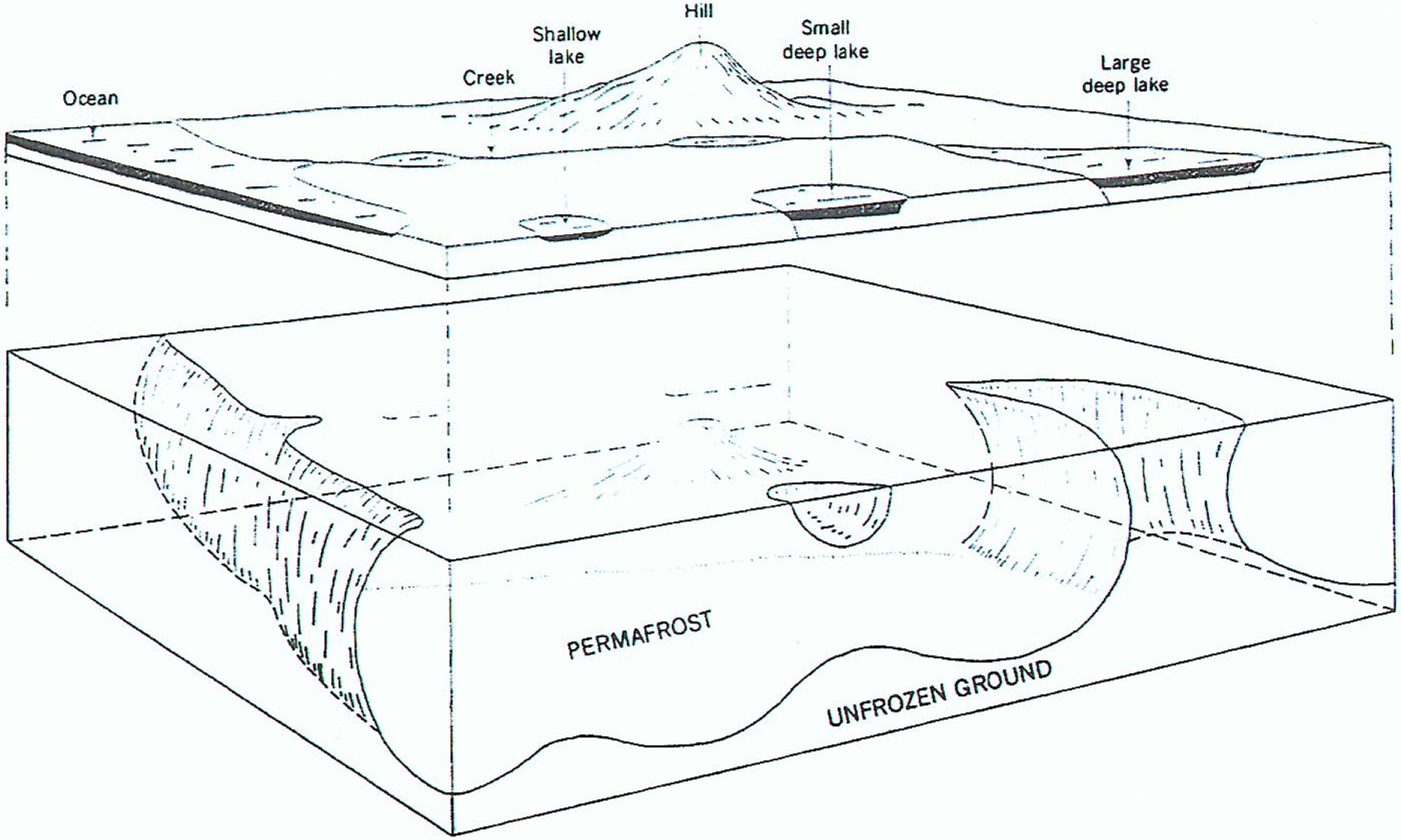
DRAWN L.T.	CHECKED K.A.L.	FIGURE NO. 6-1		REV 1
REVIEWED R.L.	PROJECT KA031			



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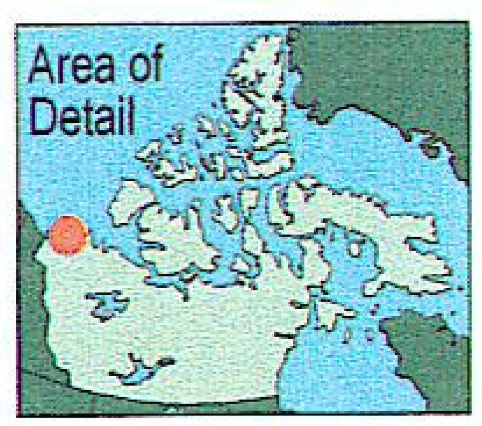
Schematic Representation Showing the Effect of Surface Features on the Distribution of Permafrost in the Continuous Permafrost Zone



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Lachenbruch, Brewer, Greene and Marshall (1962).

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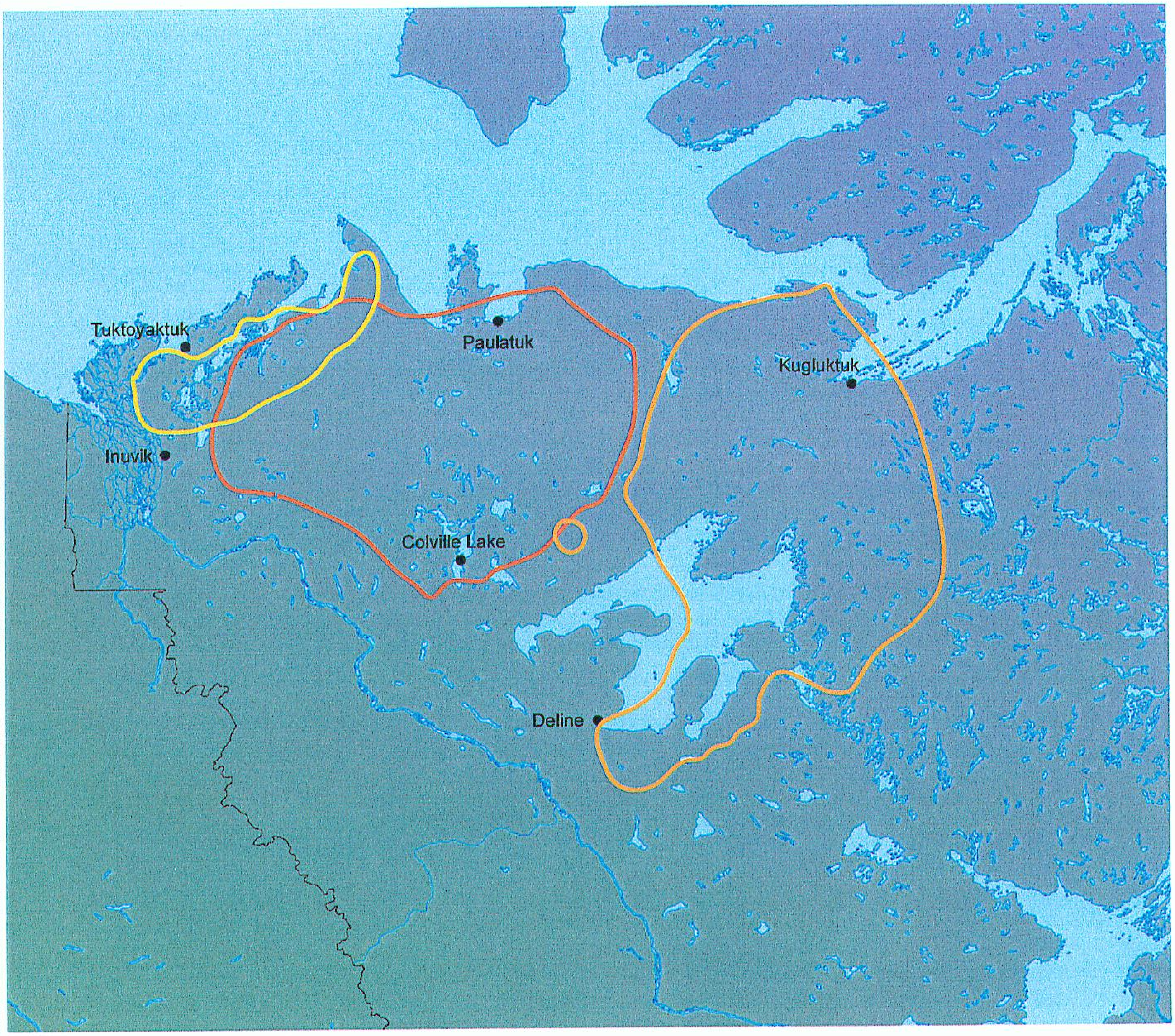
REVIEWED K.A.L.	PROJECT KA031		



LEGEND

Caribou Herd

- Cape Bathurst
- Bluenose-West
- Bluenose-East

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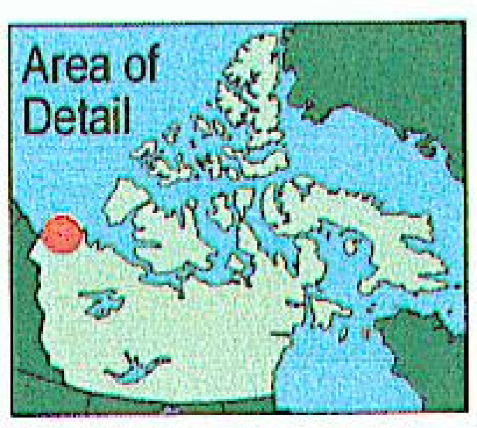
Ranges of the Cape Bathurst, Bluenose-West, and Bluenose-East Barren-ground Caribou Herds



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DRAWN L.T.	CHECKED K.A.L.	FIGURE NO. 8-1	REV 1
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