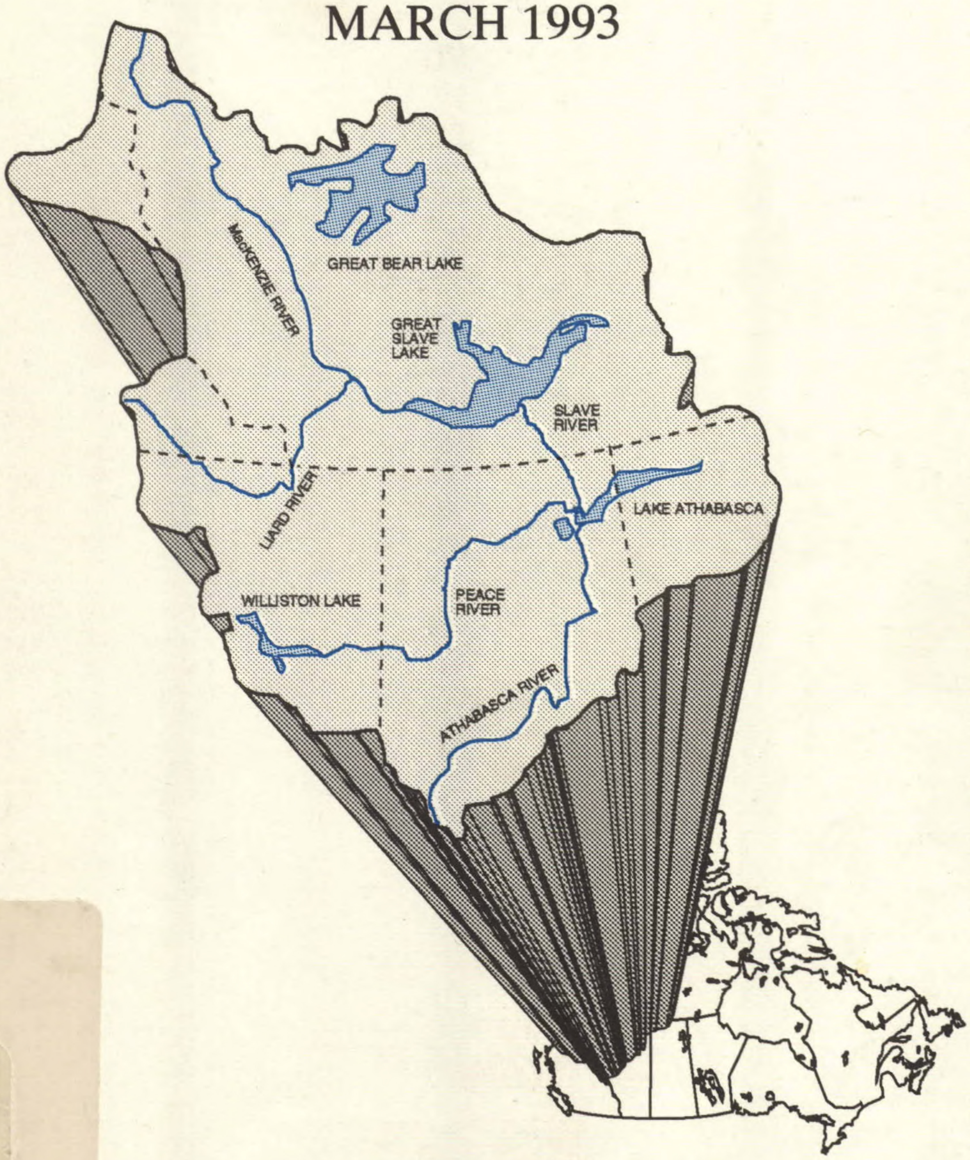
MBIS
Mackenzie Basin Impact Study

INTERIM REPORT #1
MARCH 1993



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Mackenzie Basin Impact Study

Interim Report #1

Stewart J. Cohen, Editor
Canadian Climate Centre
Downsview, Ontario

Environment Canada Environnement Canada

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A Note From The Project Leader

The Mackenzie Basin Impact Study (MBIS) is a six-year effort to assess the potential implications of a warmer climate for a region bounded by the watershed of the Mackenzie. This region includes northeast British Columbia, northern Alberta, northwest Saskatchewan, the Mackenzie Valley within the Northwest Territories, and portions of southwest and northern Yukon Territory.

MBIS is supported by the Government of Canada's Green Plan, and contributions of funds and expertise from other government agencies, universities, the private sector and native organizations (listed in Acknowledgements and List of Authors). Since 1990, when the first draft of the MBIS proposal was approved by the Canadian Climate Centre, we have sought to include regional expertise in the planning and the research. We are indeed fortunate that many researchers with northern experience have agreed to participate in this study.

Interim Report #1 is a compilation of information on issues, scenarios, methods and work in progress. It is intended to serve as an initial reference document for both MBIS participants and others interested in this topic. The Main Report focusses on issues, a brief history of the project, and methods used to produce an integrated assessment. The Appendix provides more details on methods, and also contains background information on the Mackenzie Basin, such as vegetation and climate.

The Executive Summary from this report will be reproduced in Issue #2 of the MBIS Newsletter. This summary will also be available in French from Environment Canada, Edmonton.

The opinions expressed in this report are those of the authors and not necessarily those of Environment Canada.

Stewart J. Cohen
Canadian Climate Centre
Atmospheric Environment Service
Environment Canada
31 March 1993

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Many individuals contributed to this report, and the Appendix attached to it, as indicated in the List of Authors. Two figures within the report, 3.1 and 4.5, were produced by Steve Lonergan and Richard DiFrancesco. Figure captions and credits for those in the Appendix are indicated in the List of Figures. The work of this large group of researchers from many different backgrounds is sincerely appreciated.

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31 March 1993

TABLE OF CONTENTS

Executive Summary 1
Introduction And Objectives 1
Unique Features Of The MBIS 1
Scenarios And Uncertainties 1
MBIS Interagency Working Committee Established 1
Policy Targets Identified 1
Integrated Assessment 1
Highlights Of Results To Date 2
The Next Phase Of The MBIS 2

Main Report

1. Background And Objectives 3
1.1 Introduction 3
1.2 Objectives 6

2. Identification of Policy Issues 8
2.1 A First Attempt at Integration 8
2.1.1 Interjurisdictional Water Management 9
2.1.2 Sustainability of Native Lifestyles 9
2.1.3 Economic Development Opportunities 10
2.1.4 Buildings, Transportation and Infrastructure 10
2.1.5 Limitation Strategies 10
2.1.6 Sustainability of Ecosystems 11
2.2 Linkages with Study Activities-A Second Integration Exercise 11

3. Methodology For Integrated Assessment 14
3.1 Methodological Approach 14
3.2 Resource Accounting Framework 15
3.3 Integrated Land Assessment Framework 17
3.3.1 Introduction 17
3.3.2 The Conceptual Research Framework 17
3.3.3 Applications of the ILAF in the Mackenzie Basin 21
3.3.4 Expected Results 21
3.4 Role of Traditional Knowledge 22

4. Climate And Human Scenarios 23
4.1 The Role of Scenarios 23
4.2 Climate 24
4.2.1 Baseline Climate 24
4.2.2 Recent Climate Trends 24
4.2.3 Climate Change Scenarios 25
4.2.3.1 GCM-Derived Scenarios 25
4.2.3.2 Composite Scenarios 26
4.3 Population and Economic Growth 28
4.3.1 Introduction 28
4.3.2 Economic Definition of the MBIS Region 29
4.3.3 Economic Growth Scenarios 31

5. The Next Phase Of The MBIS 33

6. Conclusion 34

A14. Baseline Population And Economic Growth Simulation 131
A14.1 Development of the Population Growth Forecasting Model 131
A14.2. Implementation of the Population Model 134
A14.3. Development of a Model for the Evaluation of Economic Growth and Structure Under Various Scenarios 135
A14.4. Development of Basin Scenarios 136
A14.4.1 Scenario #1 -- High Resource Development Scenario 136
A14.4.2 Scenario #2 —Low Resource Development Scenario 138
A14.4.3 Scenario #3 —Low Overall Growth Scenario 138
A14.4.4 Scenario #3A Low Overall Growth Alternate Scenario 139

A15. Methodologies For Integrated Assessment 140
A15.1 Socio-Economic Integration Project 140
A15.1.1 Problem Development 140
A15.1.2 Information System Review 143
A15.1.2.1 Ecological Accounting 144
A15.1.2.2 STRESS 144
A15.1.2.3 Natural Resource Accounting 145
A15.1.3 Models 147
A15.1.4 Conclusion and Future Strategy 149
A15.2 Integrated Land Assessment Framework 151
A15.2.1 Introduction 151
A15.2.2 The Conceptual Research Framework 151
A15.2.2.1 Setting Goals 151
A15.2.2.2 Data Base and Spatial Unit 153
A15.2.2.3 Scenario Design 153
A15.2.3 Study Area, Land Use Activities, and Resource Sectors 154
A15.2.4 Setting Goals, Targets, Priorities, and Thresholds 156
A15.2.5 Data Base for the ILAF Study 156
A15.2.6 Scenario Development for Assessment 159
A15.2.7 The Analytical System for Integrated Impact Study and Policy Analysis 159
A15.2.8 Questions to be Answered 162
A15.2.9 Summary 162

Appendix

A1. Water.....37
A1.1. Hydrology: Hydrologic Regime of the Mackenzie Basin, Potential Modelling Approaches, and Future Research Needs for Addressing Climate Change Issues.....37
A1.1.1 Review of Present Hydrologic Regime of the Mackenzie Basin.....37
A1.1.2 Data Availability and Associated Errors.....40
A1.1.3 Cold Regions Hydrologic Processes.....42
A1.1.4 Hydrologic Models.....43
A1.1.5 Ongoing Hydrologic Studies in the MBIS.....45
A1.1.6 Future Research Needs.....45
A1.2 Peace River Ice Regime.....50
A1.3 Snow Cover.....51
A1.4 Peace River Runoff.....52

A2. Land Resources, Surficial Geology And Natural Hazards.....52
A2.1 Permafrost South of the Beaufort Coastal Zone.....52
A2.2 Land Resources.....59

A3. Sea Ice And Coastal Stability.....59
A3.1 Beaufort Sea Ice.....59
A3.1.1 Climatology and Ice Conditions.....59
A3.1.2 Implications of a Warmer Climate.....63
A3.2 Coastal Erosion and Permafrost Stability.....65

A4. Terrestrial Ecosystems/Biomes.....67
A4.1 Vegetation of the Mackenzie River Basin.....67
A4.1.1 Boreal Ecoclimatic Province.....67
A4.1.2 Cordilleran Ecoclimatic Province.....70
A4.1.3 Subarctic Ecoclimatic Province.....70
A4.1.4 Arctic Ecoclimatic Province.....71
A4.1.5 Possible Impacts of Climatic Warming.....72
A4.2 Wetland vegetation and the carbon cycle.....73
A4.3 Wildlife.....74
A4.3.1 Wildlife Response to Forest Burns in the Mackenzie Valley and its Relevance to Global Warming.....74
A4.3.2 Effects of global warming on the biology and management of.....76
A4.3.3 Migratory Arctic-Breeding Geese.....82
A4.3.4 Mackenzie Delta Shorebirds.....83

A5. Freshwater Ecosystems.....84
A5.1 Fish species in the MacKenzie Basin......84
A5.2. Invertebrates.....84

A6. Settlements.....85
A6.1 Overview of Activities.....85
A6.2 Community Adjustment to Extreme Geophysical Phenomena in the Northern Regions of Canada.....86
A6.2.1 Background to the Research.....86
A6.2.2 Rationale for a Northern Research Context.....86
A6.2.3 Natural Hazards in Northern Canada.....87
A6.2.4 Research Objectives.....88
A6.2.5 The Major Themes of Investigation.....88
A6.2.6 Development of a Qualitative Research Approach.....89
A6.2.7 Tentative Observations on Natural Hazards in Northern Canada.....90

A6.2.7.1 Emergency Preparedness Yesterday and Today 91
A6.2.7.2 Local Disaster Response to Natural Hazards 92
A6.2.7.3 The Nature of External Influence 92
A6.2.8 Recommended Actions 93
A6.2.9 Direction of Continuing Research 94
A6.2.9.1 Focus on Three Case Studies 95
A6.2.9.2 Addressing the Influence of Internal and External Factors 95
A6.2.9.3 Schedule to Completion 95

A7. Energy And Mines 97

A8. Transportation And Infrastructure 98

A9. Agriculture 99

A10. Tourism 100

A11. Forest Sector 105
A11.1 Present Status 105
A11.2 Integrated Forest Sector Data Base 105
A11.3 Species Dynamics 105
A11.4 Growth and Yield 105
A11.5 Disturbance Factors - Fire and Pest Outbreaks 106
A11.5.1 Forest Fire Archive 106
A11.6 Wood Supply and Economic Analysis 106
A11.7 Operations 107
A11.8 Protected Areas of the Mackenzie Basin 107
A11.9 List of Participants 107

A12. Canadian Defence Policy And Operations 108
A12.1 The Canadian Defence Mission in Northern Canada 108
A12.2 Air Operations 109
A12.3 Marine Operations 109
A12.4 Land Operations 110
A12.4.1 Permafrost 110
A12.4.2 Tree line and Ecozones 111
A12.5 Summary 111

A13. Methodology For Development Of Climate Change Scenarios 112
A13.1 The Role of Scenarios 112
A13.2 Baseline Climate 112
A13.3 Recent Climate Change 119
A13.4 Climate Change Scenarios 119
A13.4.1 GCM Derived Scenarios 120
A13.4.1.1 GCM Simulations of the Mackenzie Basin 120
A13.4.1.2 Equilibrium Scenarios 120
A13.4.1.3 Transient Scenarios 122
A13.4.2 Composite Scenarios 123
A13.4.2.1 Northern Mackenzie 124
A13.4.2.2 Mackenzie Valley 124
A13.4.2.3 Southern Mackenzie 124

List of Figures

2.1. Vertical Integration Matrix obtained from results of MBIS Integration Workshop 1. 12
2.2. Horizontal Integration Matrix obtained from MBIS Integration Workshop 2. 13
3.1. Resource Accounting Framework..........16
3.2. Integrated Land Assessment Framework..........18
3.3. Possible types of public responses to climate change (modified from Warrick et al., 1988)...20
3.4. Five critical zones within the MBIS region..........21
4.1. Sample output for baseline climate data set: January temperature..........24
4.2. Mackenzie Basin average annual temperature departures, 1895-1991 (Source: J. Reycraft, CCC)..........25
4.3. Sample output for scenario data set derived from Canadian Climate Centre GCM: January temperature. 26
4.4. MBIS Climate Scenario Comparison..........27
4.5. Map of Census Divisions for the MBIS region..........30
A2.1. Profile along the Mackenzie River showing average annual ground temperature for the present and the profile for a hypothetical warming of about 3°C (Source: P. Egginton, GSC)..........53
A2.2. Distribution of landslides in Mackenzie Valley and adjacent mountainous areas (Source: J. Aylesworth, GSC)..........55
A2.3. Thaw depth at three locations in the Mackenzie Valley over the next 50 years under a linear increase in temperature of 5°C for the Mackenzie Delta and 4.2°C for Norman Wells and Fort Simpson (Source: M. Burgess, GSC)..........58
A3.1. Mean annual sea ice motion, taken from Thorndike and Colony (1982)..........59
A3.2. Limit of ice edge for Canadian Beaufort Sea, based on 100% of ice of any kind..........60
A3.3. Maximum extent of landfast ice from 1977 to 1980 (EIS, 1982; Spedding, 1979)..........61
A3.4. The different ice regimes in the southern Beaufort Sea (EIS, 1982; Kovacs and Mellor, 1974)..........62
A3.5. Average annual temperature across the zone in contact with winter sea ice along the Beaufort Sea coast. This plot of reconstructions using differing climates can be used to predict ground temperature distributions offshore from retreating coasts or on newly formed land. 65
A4.1. Approximate boundaries of the ecoclimatic regions of the Mackenzie River Basin (Intergovernmental Seminar 1972 and Ecoclimatic Regions of Canada)..........68
A4.2. Distribution of wetlands in the Mackenzie River Basin. Source: National Wetlands Working Group (1986), *Canada's Wetlands*. Map Folio. Energy Mines and Resources Canada and Environment Canada, Ottawa. 69
A4.3. The relationship between air temperature and mosquitoe harassment index with predicted increase in average harassment under a 2° and 4° C increase in summer temperature. Adapted from Nixon (1991)..........78
A4.4. The relationship between snow depth and percent of day spent eating and cratering and predicted changes in these percentages under a 30% and 50% increase in winter snowfall. Data from Russell et al (1992b)..........79
A4.5. Simulated changes in fall cow weight under varying snowmelt periods for normal, bad winter and bad winter/bad insects scenarios..........80
A6.1 Societal Characteristics..........90
A13.1 Location of climate stations and additional grid point data..........112
A13.2 Baseline and scenario grid point locations..........117
A13.3 1951-80 mean January temperature..........117
A13.4 1951-80 mean total January precipitation..........118
A13.5 Annual temperature departures in the Mackenzie Basin (Source: J. Reycraft, CCC)..........119
A13.6 CCC scenario: mean January temperature..........121
A13.7 CCC scenario: mean total January precipitation..........121
A13.8 Locations of the composite divisions..........122
A13.9 MBIS Climate Scenario Comparison..........130

A14.1 NWT population projections ... 132
A14.2 Yukon population projections ... 132
A14.3 British Columbia population projections ... 133
A14.4 Alberta population projections ... 133
A14.5 Saskatchewan population projections ... 134
A15.1 An ecological accounting system. Source: Adapted from Hannon et al., 1991 ... 143
A15.2 Research framework ... 152
A15.3 Climatic change and public responses. Source: Adapted from Warrick et al., 1988 ... 154
A15.4 Mackenzie Basin critical regions ... 155
A15.5 Structure of the computer based analytical system ... 157

List of Tables

1.1 MBIS working committee ... 4
1.2 MBIS sources of funding and contributions ... 5
4.1 Sample output for composite scenario: Temperature for Northern Mackenzie ... 27
A1.1 Major subbasins, lakes and deltas in the Mackenzie Basin ... 37
A1.2 Monthly and annual discharge for the Mackenzie River at Arctic Red River ... 39
A4.1 The 15 seasons in the annual cycle of the Porcupine Caribou herd ... 77
A13.1 Climate station information ... 113
A13.2 Estimated and actual 1951-80 normals at Barkersville ... 116
A13.3 GISS transient scenario: temperature for regions shown in Figure 13.8 ... 125
A13.4 GISS transient scenario: precipitation for regions shown in Figure 13.8 ... 126
A13.5 Composite table for Northern Mackenzie ... 127
A13.6 Composite table for Mackenzie Valley ... 128
A13.7 Composite table for Southern Mackenzie ... 129
A15.1 Format of a central account ... 145
A15.2 Land bases and land use activities ... 151
A15.3 The GP model of the ILAF system ... 161

List of Authors

The editor gratefully acknowledges the contributions of various authors to this report, as indicated below by chapter:

1 & 2	Stewart Cohen, Canadian Climate Centre
3.1	Stewart Cohen, Canadian Climate Centre
3.2	Stephen Lonergan, U. of Victoria
3.3	Yongyuan Yin, Canadian Climate Centre
3.4	Stewart Cohen, Canadian Climate Centre
4.1	Stewart Cohen, Canadian Climate Centre
4.2	Jamie Smith, Canadian Climate Centre
4.3	Stephen Lonergan, Richard DiFrancesco, U. of Victoria
5 & 6	Stewart Cohen, Canadian Climate Centre
A1.1	Philip Marsh, Terry Prowse, National Hydrologic Research Institute
A1.2	Dave Andres, Alberta Research Council
A1.3	Barry Goodison, Anne Walker, Canadian Climate Centre
A1.4	W.Q. Chin and Hamed Assaf, B.C. Hydro
A2.1	Paul Egginton, Geological Survey of Canada
A2.2	Mike Brklacich, Carleton U.
A3.1	Tom Agnew, Canadian Climate Centre
A3.2	Paul Egginton, Geological Survey of Canada
A4.1,4.2	Barb Nicholson, Suzanne Bayley, Dale Vitt, Denis Gignac, U. of Alberta; Steve Zoltai, Northern Forestry Centre
A4.3.1	Paul Latour, Renewable Resources, GNWT
A4.3.2	Don Russell, Canadian Wildlife Service
A4.3.3	Abdel Maarouf, Canadian Climate Centre
A4.3.4	Cheri Gratto-Trevor, Canadian Wildlife Service
A5	Harold Welch, Freshwater Institute; David Hamilton, U. of Manitoba
A6.1	Stewart Cohen, Canadian Climate Centre; with Dave Aharonian, U. of Victoria, and John Newton, U. of Toronto
A6.2	John Newton, U. of Toronto
A7,A8	Stewart Cohen, Canadian Climate Centre
A9	Mike Brklacich, Carleton U.
A10	Geoff Wall, Janet Brotton, U. of Waterloo
A11	Ross Benton, Pacific Forestry Centre; with Brian Stocks, Great Lakes Forestry Centre (Section A11.5.1)
A12	Chris Tucker, Department of National Defence
A13	Jamie Smith, Stewart Cohen, Canadian Climate Centre
A14	Stephen Lonergan, Richard DiFrancesco, U. of Victoria
A15.1	Stephen Lonergan, Scott Prudham, U. of Victoria
A15.2	Yongyuan Yin, Stewart Cohen, Canadian Climate Centre

Executive Summary

Introduction And Objectives

The Mackenzie Basin Impact Study (MBIS) is a six-year study supported by the Government of Canada's Green Plan and other sponsors to assess the potential impacts of global warming on the Mackenzie Basin region and its inhabitants. Interim Report No. 1 describes the study framework, structure, organization, methods and data, and identifies participants.

Unique Features Of The MBIS

Geography: The study area is a major watershed, much of it unregulated, which contains many different ecosystems (forest, wetland, delta, etc.) and several important climate-sensitive boundaries including treelines and the southern extent of permafrost.

Methodology: The Mackenzie Basin Impact Study represents one of the first attempts at integrated regional assessment of climatic change.

Science-Policy Linkages: One of the study's goals is to identify policy implications.

Partnerships: Native communities and the energy sector, along with government and academia, are participating in MBIS planning and research activities.

Scenarios And Uncertainties

The MBIS employs scenarios of future warmer climates and changes in population and economic conditions. These are not forecasts and there are uncertainties in the methods used and the data collected, so results must be interpreted with caution.

MBIS Interagency Working Committee Established

This committee, established in 1990, includes representatives from federal, provincial and territorial governments, native communities and the energy industry. It provides advice to the project leader and assists in proposal review and exchange of information. The committee has met five times and reviewed 36 proposals. Of these, 18 studies involving researchers from government, universities and the private sector are receiving at least partial support from the MBIS. Work contributions from 10 other studies are being provided by government departments, universities and B.C. Hydro. These 28 research activities cover a wide range of topics including permafrost, hydrology, sea ice, boreal ecosystems, freshwater fish, wildlife, forestry, agriculture, tourism, community studies and defence.

Policy Targets Identified

Six issues have been identified, five of which are related to adaptation. They are: interjurisdictional water management; sustainability of native lifestyles; economic development opportunities; buildings, transportation and infrastructure; and sustainability of ecosystems. The sixth issue concerns limitation of greenhouse gases (carbon dioxide, methane, etc.). Given the time constraints of this study, it may not be possible to address the knowledge gaps related to limitation.

Integrated Assessment

Because of the complexities associated with studying the potential regional implications of global warming, the MBIS will attempt to combine information from physical, biological and social sciences with indigenous traditional knowledge to produce an integrated assessment. This approach attempts to include all interactions that occur between sectors rather than only focusing on them separately. Two methods are currently being developed: socio-economic integration using a resource accounting framework and an integrated land assessment framework.

Integrated assessment will attempt to address questions related to resource management and land use such as:

1. What are the implications of climatic change for achieving regional resource development objectives? Should governments within the Mackenzie Basin alter their current resource-use policies or plans regarding water resources, resource extraction, forests or fish and other wildlife in anticipation of global warming?

2. Does climatic change increase land-use conflicts among different economic and social sectors? If potential conflicts are identified, how serious might they be and how could compromises be reached?
3. What are the possible trade-offs for alternative public responses to climatic change? Should parks and forests be managed to anticipate change, or to preserve existing conditions? What are the implications for fire control, recreation, tourism and wildlife management?
4. What are the implications of global warming for community management of resources under land claims agreements?

Highlights Of Results To Date

- Four scenarios of warmer climates have been developed. Three were derived from general circulation models (GCMs). The fourth is a composite based on data from the past (instrumental and paleo-ecological records). The GCM-based scenarios for an equivalent doubling of CO_2 (assumed to occur in 2050) show a warming of about five degrees Celsius, while the composite scenario indicates warming of 3°C. All four show increased precipitation for the basin as a whole, but with some decreases over parts of the basin during the summer.
- A population growth model and a multi-region input/output (MRIO) model have been constructed in order to produce four scenarios of population and economic growth for the MBIS region. Projections of total employment over the next 50 years range from a sixfold increase under the high resource growth scenario to a decline under conditions of low growth and a move of government services out of the region. The most likely scenario, however, is one of moderate growth in the resource sector, which would imply roughly a doubling of total regional employment. Similar projections have been made for changes in final demand for goods and services. These scenarios provide a range of economic possibilities that need to be considered in the context of a changing climate.
- A model of Peace River freeze-up has been developed and is ready to be applied to scenarios of climatic warming.
- An inventory of landslides in the Mackenzie Valley has been completed. Preliminary results of thermal modelling show how thaw depth would increase in a hypothetical scenario of warmer temperatures and increased snow depth.
- A preliminary investigation of possible impacts on Beaufort Sea ice found that the open water season would lengthen, the extent of open water would increase, accompanied by increasing wave heights, and maximum ice thickness would decrease.
- Two studies of remote communities were initiated in 1992. The first included field interviews on community responses to high water events in Fort Liard and Aklavik. Interviews were also conducted in Aklavik as part of a study on climate and land-use activities.
- The community of Lutsel k'e (Snowdrift, N.W.T.) has agreed to participate in a study of traditional knowledge of climate. Efforts are underway to seek additional funding for this work.
- A series of interviews on resource management goals was initiated. So far, these have been conducted in the upper Peace River region, Edmonton, Norman Wells, Inuvik and Tuktoyaktuk. The sample size is still too small for analysis, so additional interviews will be held in 1993.

The Next Phase Of The MBIS

An important component of integrated assessment is the construction of databases that provide information on spatial patterns and economic flows within the region. During 1993 and 1994, work will continue on the development of two databases. The first will cover spatial patterns of resources such as soils and forest cover, and the second will focus on central accounts of opening and closing stocks of resources such as timber and fish.

A mid-study workshop is tentatively planned for spring 1994. Preliminary results from the many impact study activities will be discussed. Workshop proceedings will be published as MBIS Interim Report No. 2.

MAIN REPORT

1. Background And Objectives

1.1 Introduction

This story begins in the spring of 1989 at the Canadian Climate Centre's (CCC) Arctic Meteorology Section, now the Arctic Adaptation Division. The debate over global warming and its possible impacts had attracted the attention of scientists, governments and the public, particularly after the drought of 1988 in the North American Great Plains and publication of several papers on record-breaking global temperatures observed during the 1980s. The Intergovernmental Panel on Climate Change (IPCC) began its activities by examining the science of global warming, particularly the simulations of future climate produced by general circulation models (GCMs), and by reviewing what was known about impacts and possible response strategies. Global warming programs were in progress in a number of countries, while the Government of Canada's Green Plan was still only an idea. Though there had been more than 50 global warming impact studies completed in Canada to that time, they were generally single-sector in scope, and southern in interest. Only a handful dealt with northern issues and most of those focused on permafrost, the boreal forest and tundra ecotones, the transition zones which separate one ecosystem from another (French, 1986; Maxwell and Barrie, 1989).

A commitment was made that spring to begin the process of developing a framework for an integrated regional impact assessment of global warming scenarios in the Mackenzie Basin to be called the Mackenzie Basin Impact Study (MBIS). The Mackenzie Basin watershed is the twelfth-largest drainage area in the world, with important natural boundaries which may shift in response to climatic change. These include treelines at the northern and southern extent of the boreal forest as well as the discontinuous and continuous permafrost zones. There are large deltas, wetlands and lakes which provide habitat for many terrestrial and freshwater species of wildlife. This is also the most populated region of Canada's North. Energy development is an important component of the region's economy and there is growing interest in forestry, agriculture and tourism. There is also, however, a strong interest among native people in maintaining their traditional lifestyles. The political landscape is beginning to reflect this through land claims negotiations and devolution of management responsibilities from federal to regional authorities (Bone, 1992).

For an initiative such as the MBIS to succeed as an integrated assessment which could truly make a difference to the debate on global warming in the North, it was felt that the best approach was creation of a multidisciplinary working group from government and non-government organizations with interests in the Mackenzie. This group of working scientists and community representatives would also provide important information on other research programs that could be linked to the Mackenzie Basin study. Study organizers did not want to reinvent the wheel. They also wanted to ensure the participation of Northerners in the planning of this study so stakeholders in the region would also feel a sense of ownership in the results of the MBIS, thereby increasing the likelihood that any recommendations from the impact study would be taken seriously.

The Third Northern Climate Workshop, scheduled for October 17 and 18, 1990 in Yellowknife, was selected as the venue for the organizational meeting of the MBIS, as it would be easier to bring interested parties together if they were already planning to participate in the workshop. As a result, the organizational meeting took place on October 16. This meeting resulted in the formation of the MBIS Interagency Working Committee (WC) and Advisory Group, and agreement on a statement of goals. The working committee originally had 18 members, with seven others agreeing to serve as advisers. The WC has since expanded to 24 people (plus six advisers and one ex-officio member) to reflect a growing awareness of the research and stakeholder interests in this watershed (Table 1.1).

The MBIS group has also grown to include researchers from several universities. These individuals were selected on the basis of proposals submitted to the working committee, which were reviewed at five WC meetings held between 1990 and 1992.

Table 1.1 Mackenzie Basin Impact Study Interagency Team

Project Leader	
Environment Canada/CCC	Stewart Cohen
Core Group	
Environment Canada/CCC	Jamie Smith
Environment Canada/CCC	Yongyuan Yin
Working Committee	
Agriculture Canada	Barry Grace
Alberta Environment	Terry Zdan
Alberta Research Council	Raymond Wong
B.C. Hydro	Bijou Kartha
Dene Cultural Institute	Martha Johnson
Dene Nation	Bill Erasmus
Energy Mines & Res. Canada/GSC	Larry Dyke
Esso Resources	Michael Moir
Environment Canada/AES Regions	Tim Goos
Environment Canada/FEARO	Patrice LeBlanc
Environment Canada/NHRI	Phil Marsh
Fisheries & Oceans Canada/FWI	Ray Hesslein
Forestry Canada/NoFC, PFC	Steve Zoltai, Ross Benton
Gwitch'in Tribal Council	Joe Benoit
Indian & Northern Affairs Canada	Ranjit Soniassy
Indian Association of Alberta	Walter Janvier
Indus. Sc. & Tech. Canada/Tourism	Scott Meis
Inuvialuit Game Council	Bruce Hanbidge
Metis Association	Pat Larocque
National Defence	Chris Tucker
N.W.T./Energy Mines & Petrol. Res.	Cara McCue
N.W.T./Renewable Resources	Steven Matthews, Helmut Epp
YT/Renewable Resources	Alan Parkinson
Advisers	
James Byrne, ex-officio	University of Lethbridge
Henry Cole	Fairbanks, Alaska
Corinne Gray	Inuit Circumpolar Conf.
Lynne Kemper	Alberta Environment
Bob Janes	Glenbow Alberta Institute
Fred Roots	Environment Canada
David Sherstone	Science Institute of N.W.T.
Barry Smit	University of Guelph

Table 1.2. MBIS Research Activities (As of 15 February 1993)

Projects Receiving MBIS Support (Subject, Investigator)

Baseline and Physical:	
Population	S. Lonergan & R. Difrancesco, U. Victoria
Land Cover From Remote Sensing	P. Gong, U. Calgary
Permafrost	L. Dyke, P. Egginton, M. Burgess & Others, GSC
Peace River Ice	D. Andres, ARC
Basin Runoff	R. Soulis, U. Waterloo
Biological:	
Forest-Wetlands Response	S. Bayley, D. Gignac, D. Vitt & B. Nicholson, U. Alberta
Freshwater Fish Sensitivities	B. Welch, FWI, & D. Hamilton, U. Manitoba
Fish Habitat, Lake Athabasca And Great Slave Lake	G. Melville & E. Wheaton, SRC
Wildlife Response To Fire	P. Latour, N.W.T. Renew.Resources
Fire At Treeline	R. Wein, U. Alberta
Mackenzie Delta Shorebirds	S. Gratto-Trevor, CWS
Socio-Economic and Integration:	
Agriculture	M. Brklacich, Carleton/Agr. Can.
Tourism	G. Wall & J. Brotton, U. Waterloo
Forestry	R. Benton, PFC, & Others At B.C. Min. Of Forests, UBC, U. Victoria
Dene Traditional Knowledge (Preproposal)	E. Bielawski, Arctic Inst., & B. Masuzumi, Dene Cultural Institute
Community Adjustment To Floods	J. Newton, U. Toronto
Community Perception Of Climate	D. Aharonian, U. Victoria
Regional Accounting Framework	S. Lonergan & S. Prudham, U. Victoria
Work Contributions	
Climate Data Baseline & Scenarios	J. Smith, CCC, & AES Regions
Peace River Runoff & Bennett Dam Operations	B. Chin & Others, B.C. Hydro
Streamflow Routing	B. Aitken & Others, IWD
Lake Ice, Climate Trends	W. Skinner, CCC
Snow Cover	B. Goodison, A. Walker & Others, CCC
Paleoclimate Data	G. Macdonald, McMaster U., & R. Pienitz, Queen's U.
Land Assessment Framework	Y. Yin, CCC
Beaufort Sea Ice	T. Agnew, CCC, & Others
Implications For Defence	C. Tucker, DND, & Others
Porcupine Caribou	D. Russell, CWS
Migratory Geese	A. Maarouf, CCC
Other Data, Research, Etc.	GSC, Agr. Canada, INAC, IWD, N.W.T. Renew. Res., CCC
Review Of Legislative Framework For Water Management	G. Lewis, IWD

Projects to be Reviewed

Settlement Growth And Development	R. Bone, U. Saskatchewan
Energy Sector	M. Kliman, W. Anderson, McMaster
Non-Renewable Resources	R. Bone, U. Saskatchewan
Implications For Water Management	G. Lewis, IWD

Linkage to be Created with Other Projects

Global Energy And Water Cycle Experiment (GEWEX),
Sustainability Of Alberta Agriculture (U. Of Lethbridge),
Northern River Basins Study (NRBS),
Mackenzie Delta Ecosystem Project (C-Core, Memorial U.)

It was difficult to review these proposals solely on the basis of science since the MBIS required a broad range of research activities, including studies in the physical, biological and social sciences. In order to maintain a good interdisciplinary mix of research activities focusing on the Mackenzie Basin, the WC established a number of criteria, of which the following were of particular importance. The research was required to apply to the study area; be completed within time and resource limitations; be linked with critical regions (Mackenzie Delta, upper Peace River, Mackenzie Valley, Liard River, and northeast Alberta) and to other components of the MBIS; and contain subtasks essential to the impact study.

Out of 36 proposals, 18 have been provided whole or partial support by MBIS funds (Table 1.2). The Green Plan is the largest source of funds; but financial and work contributions have also come from Environment Canada, other government agencies, Esso Resources, B.C. Hydro and the Canadian Climate Program (Table 1.2).

1.2 Objectives

The MBIS is attempting to address the what-if question. What if global warming does occur as projected by general circulation model simulations? What if international emission reduction and afforestation efforts fail to stop the rise in greenhouse gas concentrations?

Since this is a regional scale, socio-economic what-if study, considerable attention has been focused on defining the mission of the MBIS. Scientific uncertainties exist in all aspects of this issue, from the regional climatic data bases and GCMs to our knowledge of cold region hydrological processes, boreal ecosystems and sensitivities of northern communities to climatic variability. Concern has also been expressed regarding the context of climatic change given the myriad of other changes that are likely to take place during the next several decades, including new technology, population growth and political, institutional and economic changes.

At the organizational meeting held in 1990, the following statement of goals was adopted:

"The Mackenzie Basin Impact Study will define the direction and magnitude of regional-scale impacts of global warming scenarios on the physical, biological and human systems of the Mackenzie Basin, using an integrated multidisciplinary approach. The study will also identify regional sensitivities to climate, inter-system linkages, uncertainties, policy implications and research needs. Study results will be published and made available to all interested parties."

The key elements in the above statement are: integrated, multidisciplinary, and policy implications. There is a growing trend in the international scientific community towards multidisciplinary investigations that are more suited to dealing with the complex nature of the global warming issue.

A cutting-edge example is the recently completed study of the U.S. Corn Belt, known as the MINK study (Rosenberg et al., 1991). At national and international levels, large multidisciplinary teams have assembled considerable amounts of information (e.g. Pearman, 1988; Smith and Tirpak, 1989; NZME, 1990; UKCCIRG, 1991; IPCC, 1991). They have helped to raise awareness about the sensitivities and vulnerabilities of various sectors to potential climatic change. But are these integrated assessments? The MINK study comes close. The others are collections of single-sector studies which provide the building blocks for addressing policy concerns but, unless each sectoral study accounts for changes being felt by other sectors or other regions, something important will be missed.

We can no longer pursue studies that assume that everything else remains equal and that a sector will be affected only by climatic change. Government, industry and the public want to know what global warming really means to them and how they should respond. Climatic impact assessment has become a highly visible field. Critics are asking serious questions about the assumptions that are being used. Can we talk about new opportunities for agriculture or forestry without considering potential conflicts with existing land uses and infrastructure? Can we realistically determine the impact of permafrost thaw in the mid-21st century without presenting a vision of the region's transportation and pipeline network? Can we produce information that northerners would consider relevant to their interests without incorporating their knowledge of the land into the study?

The MBIS is responding to these questions in three ways:

1. The MBIS working committee includes representatives from native organizations, regional governments and the private sector.
2. An integration framework has been established in order to provide research targets for single-sector and single-issue research activities.
3. A dialogue between researchers and senior managers from various jurisdictions has been initiated in order to identify policy targets for the study as a whole.

The purpose of this interim report is to identify study issues, describe the framework being used by the MBIS to produce an integrated assessment of global warming and provide information on data, methodologies, uncertainties and future research activities. Chapters 2 through 6 focus on study issues, integration framework and future activities. The sections in the appendix provide details on data and methodologies within each of the main components of the MBIS.

2. Identification of Policy Issues

Why was the Mackenzie Basin Impact Study initiated? Why has it received support from the Government of Canada's Green Plan? Despite the many scientific uncertainties, there is consensus that increases in the concentration of carbon dioxide and other trace gases will lead to a warmer climate. It will take many years before the uncertainties are reduced, so what should be done while the climate modellers continue to work on their models? Although some have taken a wait-and-see approach, it is important to point out that policy making goes on. Land-use plans are drawn, pipelines are designed, land claims and treaty rights are negotiated, afforestation options are considered and water management agreements are established. In addition, we should not forget the ongoing efforts leading up to the United Nations Conference on Environment and Development (UNCED). The conference, which took place in Brazil in June 1992, led to more than 150 nations negotiating global agreements, including a convention on climate change.

What difference would global warming make to resource management decisions being made in the Mackenzie Basin? How would the costs of climate (e.g. flood damage, permafrost thaw, fire) change? Could the potential benefits (e.g. longer growing season, reduced ice cover) improve the economic viability of existing operations and attract new investment? The time scale of these and other economic and policy concerns are of similar length to most scenarios of global warming, but decisions (including status quo) have to be made in the context of information available today, not 20 years from now.

The MBIS and other similar efforts exist because there is a need to provide a regional, human perspective on the global warming black box. There is a bridge that needs to be built between global warming science and regional policy interests, so decision-makers can make informed judgments. There will always be scientific uncertainty, but there must not be an information vacuum. Otherwise, unsubstantiated claims will be made and, in the absence of alternative views, these may be acted upon.

In that spirit, the MBIS formed an integration subcommittee which continues to play an important role in helping the impact study become an interdisciplinary effort that can focus on questions that are important to policy-makers. Subcommittee membership was drawn from participants in each of the study's main components (physical, biological, socio-economic). Besides facilitating information exchange between study participants, the subcommittee has also been looking at integrating science and policy. At the subcommittee's first meeting, it was felt that an integration workshop was needed in order to identify policy targets for the MBIS.

2.1 A First Attempt at Integration

After consultation with the Canadian Climate Centre's Policy, Planning and Liaison Branch and Mr. Jim Bruce, Chair of the Canadian Climate Programme Board, Integration Workshop No. 1 (IW1) was organized. This workshop was held February 25, 1992 at the University of Alberta in Edmonton. Senior managers from six agencies of the federal, Alberta and Northwest Territories governments were invited to participate in a panel discussion and to interact with MBIS participants in smaller discussion groups. Each group included representatives from the panel, stakeholders and researchers from physical, biological and socio-economic disciplines.

The panelists were asked to identify policy concerns related to global warming, in effect establishing targets for study participants. The key element in the success of this exercise was that the choice of panelists was based on the need to represent a broad range of perspectives.

The workshop resulted in the identification of six policy targets:

1. interjurisdictional water management
2. sustainability of native lifestyles
3. economic development opportunities
4. buildings, transportation and infrastructure
5. limitation strategies and
6. sustainability of ecosystems.

With the exception of the fifth target, these represent concerns related to adaptation. In the context of global warming, regional adaptation may involve a wide range of responses, from minor adjustments in operating a dam to a major change in land use. Government, industry and communities have considerable experience in adapting to current conditions, but making commitments based on scenarios of a warmer climate will be impossible without more specific information on what the region may have to adapt to.

The following sections identify those MBIS activities that should contribute information to the assessment of each of these policy areas. Discussion of the study's overall integration framework, which builds on the information provided by these activities, is found in Chapter 3.

2.1.1 Interjurisdictional Water Management

Within the watershed, the governments of Canada, British Columbia, Alberta and Saskatchewan established the Mackenzie River Basin Committee (MRBC) in 1977. The Northwest Territories and the Yukon also had representation on the committee, which had as its primary function the development of a joint water management agreement.

A draft of this agreement is currently under review. Seven bilateral agreements among the various jurisdictions are also being negotiated. These agreements will address transboundary water issues such as minimum flows, flow regulation and water quality. The MRBC has established a set of principles that includes consideration of future needs and the preservation of the integrity of the aquatic ecosystem (Lewis et al., 1991).

How would climate change affect water management? Would average and extreme high and low river flows change? What would happen to sediment load and water quality? What effect would a warmer climate have on the W.A.C. Bennett Dam in British Columbia, pulp mills in British Columbia and Alberta, the deltas, waterfowl, fisheries, transportation and communities?

A number of MBIS activities will focus on water-related matters, particularly the studies within the physical component of the MBIS by Soulis, Chin (B.C. Hydro), Aitken (Inland Waters Directorate), and Andres (see Chapter A1). Water issues, however, are also of concern to the biological and socio-economic components of the MBIS. The study of boreal wetlands by Bayley and colleagues (Chapter A4); freshwater fisheries by Welch and Hamilton, and Melville (Chapter A5); and community response to floods by Newton (Chapter A6) will contribute to this effort. The MBIS will also include a review of water management and relevant legislative frameworks by Lewis, and follow-up work is being proposed for 1994 (see Table 1.2, Chapter A1).

The activities described above do not constitute a complete study of water resources issues. Our knowledge of cold region hydrological processes is limited and the database on water quality is sparse. Two other programs, the Northern River Basins Study, and the Global Energy and Water Cycle Experiment (GEWEX), are currently active in the Mackenzie Basin. We anticipate that the MBIS will be exchanging information with these two programs.

2.1.2 Sustainability of Native Lifestyles

One major concern within the downstream jurisdictions of the Mackenzie Basin is the potential implications of a warmer climate on native communities and traditional lifestyles. For those who see their future as one in which harvesting of country food (hunting, trapping, fishing) continues to play an important part, adapting to a change in climate would require knowledge of how renewable resources might change.

MBIS activities that are relevant to this issue include efforts by the Arctic Institute (Bielawski and Masuzumi) and the University of Victoria (Aharonian) to organize studies of traditional knowledge (see Chapter A6). Impacts on boreal wetlands are being assessed by Bayley and colleagues (Chapter A4). Latour is studying wildlife response to burns and Russell is providing a contributed study on the Porcupine caribou (Chapter A4). Studies on fisheries by Welch and Hamilton, and Melville (Chapter A5), and Newton's work on response to floods (Chapter A6) will also be relevant. A proposal to study community development is presently under review.

Additional insights will be obtained from Yin's Integrated Land Assessment Framework(Chapter 3.3 and A15), which is one of the MBIS integration activities. Of particular importance is the survey of resource management goals, which will be used in the analysis of potential future land-use conflicts.

2.1.3 Economic Development Opportunities

Many see Canada's North as the land of opportunity. The region has abundant fossil fuel resources, minerals and renewable resources (forest products, water, fish and wildlife). The area could also become a more popular tourist destination. A warmer climate could increase the potential for development of agriculture. In scenarios of climate change, how significant could these opportunities become and what would the potential side-effects be on existing land and resource uses? What might happen to the region's settlements, including its native settlements and resource towns? What are the implications for defence policy and operations?

At the time of publication, MBIS participants have initiated studies into: agriculture by Brklacich (Chapter A9), tourism by Wall (Chapter A10), the forest industry by Benton and collaborators (Chapter A11), and defence operations by Tucker (Chapter A12). Proposals to study community development and the energy sector are presently under review (Chapter A6, A7).

These activities are important by themselves, but they will also contribute information to the integration activities of Lonergan (Chapter 3.2, A15) and Yin (Chapter 3.3, A15). The frameworks being developed will provide tools to explore various indirect linkages between climate change and the region's economy.

2.1.4 Buildings, Transportation and Infrastructure

The region is a vast, sparsely-populated land. Buildings, pipelines, offshore energy platforms and other infrastructure have been designed to meet the challenges of a cold climate and its associated landscape features, including permafrost, snow and ice. This combination of climate and population has led to the development of utilidors which provide water services in the larger communities. There is also a unique system of winter roads, an inexpensive transportation link between many northern communities which would otherwise be more isolated. These roads depend on a stable snow and ice cover for three to four months. During summer these communities can only be reached by water or air. The all-season road network is gradually expanding, with a new road to Wrigley to be ready by 1994. Other communities, such as Norman Wells, are still waiting.

If the climate warms, what would happen to permafrost, snow and ice? Some areas are already experiencing erosion, thaw settlement and other landscape changes due to past climatic variations. Could these changes accelerate in the future? Could there also be changes in the annual hydrological cycle which could change the nature of high and low flow events?

Any of the above changes could have implications for the design and maintenance of buildings, onshore and offshore energy platforms, roads and other infrastructure. Within the MBIS, work by the Geological Survey of Canada and collaborators on permafrost (Chapter A2, A3), Agnew and colleagues on sea ice (Chapter A3) and Tucker and colleagues on defence operations (Chapter A12) will provide relevant information. This will add to the activities in hydrology and ice by Andres, Soulis, B.C. Hydro and the Inland Waters Directorate (Chapter A1) already noted in Section 2.1.1 above.

2.1.5 Limitation Strategies

The Framework Convention on Climate Change, a product of the Earth Summit, was signed by the Government of Canada earlier this year. It calls for the eventual stabilization of CO_2 and other trace gas emissions. This would affect emissions originating from transportation, agriculture, energy and other industrial activities. Any regional component of a national limitation strategy would have to account for its current and anticipated future mix of emitters.

What complicates matters in the Mackenzie is the interjurisdictional nature of the watershed and potential changes in sources and sinks of trace gases due to possible changes in the landscape which may result from global warming. The MBIS will include a number of activities focusing on the future of the region's ecosystems (see Section 2.1.6). The studies by Bayley et al. (Chapter A4) and Benton and collaborators (Chapter A11) will provide some indication of how the carbon cycle may be affected by a warmer climate. The MBIS does not include a specific activity focusing on anthropogenic (e.g. industrial) emissions.

This is a particularly difficult issue and we do not expect to provide firm answers within the MBIS program. Other research programs, such as BOREAS and NBIOME, are undertaking more detailed investigations of the carbon cycle in the boreal zone.

2.1.6 Sustainability of Ecosystems

The Mackenzie Basin region includes tundra, boreal forest, wetland, delta, montane, sub-alpine and agricultural ecosystems. Each of these exist because of unique combinations of climatic, site and, in the case of agriculture, human influences. There is paleo-ecological evidence that when climate changed in the past, vegetation responded, particularly in the ecotones which separate one ecosystem from another (e.g. Arctic treeline).

Several wildlife sanctuaries, national and provincial parks have been established within the Mackenzie Basin's boundaries, including Jasper, Wood Buffalo and Nahanni National Parks; the Mackenzie Bison and Kendall Island bird sanctuaries; and the Peel River and Reindeer grazing reserves. Agricultural lands extend throughout the Peace River region of Alberta and British Columbia.

If the climate warms, there could be changes in growing season, hydrology, snow and ice cover, and fire frequency. Ecosystems would be sensitive to these changes, but at what rate? Would the treeline shift northward? Would the boreal forest become much smaller in area(Rizzo and Wiken, 1992)? What would be the implications for forestry operations, park management, fire protection and wildlife management? These concerns overlap with the native lifestyle and economic development issues outlined above.

MBIS activities that are relevant to concerns about ecosystem sustainability include the study on boreal wetlands by Bayley et al. (Chapter A4), lake thermal habitats by Melville (Chapter A5), Mackenzie Delta shorebirds by Gratto-Trevor (Chapter A4), wildlife response to burns by Latour (Chapter A4), fisheries inventory by Welch and Hamilton (Chapter A5) and Arctic treeline fires by Wein et al.

The work by Wein and collaborators, a long-term program which is supported by a number of funding sources including the MBIS, covers several key issues: vegetation recovery after fire; tree establishment of particular species and relationships with levels of fire severity; effects of fire on soils, particularly in ice-rich areas; and vegetation recovery in areas of industrial disturbance (e.g. seismic lines).

The MBIS is fortunate to also be receiving contributions of valuable information on forest fires from Stocks (Section A11.5.1), on migratory geese from Maarouf (Chapter A4) and on the Porcupine caribou herd from Russell (Chapter A4). Traditional knowledge will also be of value (Section 3.4).

2.2 Linkages with Study Activities-A Second Integration Exercise

Integration Workshop No. 2 (IW2) was held December 2 and 3, 1992 in Edmonton. Its purpose was to identify linkages between the various study activities (horizontal integration) as well as the vertical linkages with the policy issues described in Section 2.1. Integration matrices were constructed to illustrate both sets of linkages.

The vertical integration matrix shows the linkages between socio-economic components and policy targets (Figure 2.1). The projects labelled 0 are database and scenario construction activities; 1, 2 and 3 represent physical, biological and social science studies, respectively; and integration modelling activities are listed as 4. The MBIS does not have activities focusing on greenhouse gases (GHG) or transportation, but they are listed to indicate that the MBIS group recognizes their importance and has tried (unsuccessfully) to directly address these concerns (see Chapter 5).

The horizontal integration matrix identifies information needs from other activities within the MBIS (Figure 2.2). At IW2, each investigator was asked to indicate his/her information needs. For example, in order to determine the impact of climatic change on agriculture (3.1), one needs information on scenarios, erosion, land capability, and other land uses from project area 3 and 4 study activities. MBIS participants can also use this matrix to identify data from their activities which may be required by other investigators.

Figure 2.1. Vertical Integration Matrix obtained from results of MBIS Integration Workshop 1.

	Information Source		Policy Issues					
ID	Project	Researcher	P1	P2	P3	P4	P5	P6
0.1	Climate Scenario	Cohen, Smith	X	X	X	X	X	X
0.2	Human Scenario	Lonergan, et al.	X	X	X	X	X	X
0.3	Traditional Know.	Bielawski, Newton, Aharonian	X	X	X			X
0.4	Remote Sensing	Gong, Goodison	X	X	X	X		X
1.1	GHG						X	
1.2	Lake/River Ice	Andres, Skinner	X			X		
1.3	Run Off	Soulis, Chin	X			X		
1.4	Stream Flow	Aitken, et al.	X			X		
1.5	Sea Ice	Agnew, Tucker				X		
1.6	Permafrost, Erosion	Dyke, et al.				X		
1.7	Soil Capability	Brklacich			X			X
2.1	Forest	Benton, et al.					X	X
2.2	Boreal Ecosystem	Bayley, Wein	X	X			X	X
2.3	Fisheries	Melville, Welch	X	X				X
2.4	Wildlife	Latour, G-Trevor, Matthews, Maarouf, Russell		X				X
3.1	Agriculture	Brklacich	X		X	X	X	X
3.2	Forest Sector	Benton, et al.			X	X	X	X
3.3	Tourism	Wall		X	X	X		X
3.4	Transportation			X	X	X		X
3.5	Energy		X	X	X	X	X	X
3.6	Fisheries Sector	Melville		X	X			X
3.7	Water Management	Smith, Cohen, Lewis	X	X	X	X	X	X
3.8	Defence	Tucker			X	X		X
3.9	Settlement	Bielawski, Newton, Aharonian	X	X	X	X		X
4.1	Resource Acc.	Lonergan, et al.			X		X	X
4.2	ILAF	Yin, Cohen	X	X	X	X	X	X

Note: P1: Interjurisdictional Water Management
P2: Sustainability of Native Lifestyles
P3: Economic Development Opportunities
P4: Infrastructure/Transportation
P5: Limitation Strategies
P6: Sustainability of Ecological Systems

Figure 2.2. Horizontal Integration Matrix obtained from MBIS Integration Workshop 2.

	Information	Source	Information Needs																									
ID	Project	Researcher	0.1	0.2	0.3	0.4	1.1	1.2	1.3	1.4	1.5	1.6	1.7	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.1	4.2
0.1	Climate Scenario	Cohen, Smith	X	X	X			X	X,*		X	X	X	X	X	X	X,*,+	X	X	?	X	X			X	X		X
0.2	Human Scenario	Lonergan, et al.		X	X									?	X	X	X,*,+	X	X	?	X	X		X	X	X	X	X
0.3	Traditional Know.	Bielawski(X), Newton(*), Aharonian			X									?	?	?	X,?,+		?	?	X	X		X	?	X	X	X
0.4	Remote Sensing	Gong/Goodison				X			?				?	X	X	?	?,+		?						X			X
1.1	GHG						X																					X
1.2	Lake/River Ice	Andres, Skinner		X	X			X		X	X	X				X					X	X		X	X	X		
1.3	Run Off	Soulis(X), Chin(*)		X	X	X		X	X	X	X				X		*							X		X		X
1.4	Stream Flow	Aitken, et al.		X	X			X		X		X			X	?					X	X		X		X		X
1.5	Sea Ice	Agnew, Tucker	?	X							X	X					*					X			X			
1.6	Permafrost, Erosion	Dyke, et al.		X	X	X			X		X	X	X		X		*	X			X	X		X	X			X
1.7	Soil Capability	Brklacich											X	X				X										X
2.1	Forest	Benton, et al.		?	X	X			X					X	X	?	X,+		X	?					X			X
2.2	Boreal Ecosystem	Bayley, Wein			X	X			X			X		X	X	X	X,*			?				X			X	X
2.3	Fisheries	Melville, Welch		X	X											X				?			X	X				X
2.4	Wildlife	Latour(X), Maarouf, G-Trevor(*), Russell(+)			X	X								?			X			?							?	X
3.1	Agriculture	Brklacich																X	X		X	X		X	X		X	X
3.2	Forest Sector	Benton, et al.		X													X	X	X		X	X			X		X	X
3.3	Tourism	Wall														X	*,+	X		X	X	X		X	X		X	X
3.4	Transportation			X	X													X	X	?	X	X		X	X	X		X
3.5	Energy			X													+		X		X	X		X	X		X	X
3.6	Fisheries Sector	Melville		X	X											X					X	X	X	X			X	X
3.7	Water Management	Smith, Cohen, Lewis			X			X		X					X	X		?			X	X		X		X	X	X
3.8	Defence	Tucker																			X	X			X	X	?	X
3.9	Settlement	Bielawski(X), Newton(*), Aharonian			X,*											X	?,*,?	X	X	?	X	X		X	X	X		X
4.1	Resource Acc.	Lonergan, et al.		X	X								X	X	X	X		X	X	?	X	X		X	X		X	X
4.2	ILAF	Yin, Cohen											X	X		?		X	X	?	X	X		X	X		X	X

Note: ID 0.1-0.4: Baseline and Scenario Conditions
ID 1.1-1.7: Physical System
ID 2.1-2.4: Biological System
ID 3.1-3.9: Socio-Economic System
ID 4.1-4.2: Integrated System

3. Methodology For Integrated Assessment

3.1 Methodological Approach

The integration process that has been evolving within the MBIS is a two-track process involving policy targets and research targets. Vertical integration, the linkage between research and policy, uses policy targets to attract researchers into interdisciplinary subgroups within the MBIS. Integrated assessment models, the integration of outputs from various research activities into one model, serve as research targets by defining their input needs in terms of the potential outputs of the single-sector activities.

The policy targets underscore the need to address basic knowledge gaps at the beginning of the study. One example is sustainability of native lifestyles. For the MBIS to provide a meaningful assessment of this issue, information is needed on water resources, permafrost, ice and snow cover, ecosystems, subsistence activities, possible changes in land capabilities and changes in demand for development of commercial activities in forestry, agriculture and tourism. Traditional knowledge and social impact assessment would be important components of this analysis, including the articulation of goals by native organizations and other stakeholders. Integration modelling activities could not proceed without these inputs and policy targets.

Two new methodologies are being developed to address particular economic and policy concerns while, at the same time, serving as research targets. One is a socio-economic resource accounting framework (see Section 3.2) which would describe the state of the region's economic system by including estimates of natural resource flows into the calculation of economic production. The baseline would include scenarios of population and economic changes which would be assumed to occur in the absence of climatic change (see Section 4.3). Results of single-sector studies such as forestry, agriculture and tourism would be incorporated into the framework so that an estimate of the indirect economic impacts of a number of simultaneous changes could be provided. This represents an important component in the Socio-Economic Integration Project of Lonergan et al., described in Section A15.1.

Complementing the above activity is the development of an integrated land assessment framework, or ILAF, by Yin et al. (Section 3.3, A15.2). This would integrate information from different resource sectors and identify the regional economic and environmental impacts of global warming on resource management in the Mackenzie watershed. The ILAF would incorporate remote sensing imagery into a geographic information system (GIS) to extract data and produce baseline maps of land resources. This portion of the ILAF represents a target for the physical and ecosystem studies, just as the resource accounting framework would be a target for the economic studies. A goal-programming model would also be incorporated into the GIS so that various response options could be examined within the context of a climatic change scenario. The goals would be determined from consultation with regional stakeholders including federal, regional and community-based agencies, the private sector and academia.

Results of the ILAF exercise would be used to examine potential land-use conflicts. In a scenario of warmer climate with a longer growing season, for example, land capability for agriculture may be shown to improve in an area of the Mackenzie Basin that is presently used for traditional hunting and trapping. This potential conflict would be identified within the analysis. The next step would be to search for alternative land-use patterns that would best satisfy the aspirations of both sectors.

The resource accounting and land assessment frameworks overlap somewhat, and we are currently exploring ways to link these activities.

Throughout the various phases of the MBIS, there would also be opportunities for modern science and native traditional knowledge to be integrated into the study. We hope that traditional knowledge could be incorporated into the baseline description of resources, identification of trends and sensitivities, and articulation of resource management goals for the future. This is just a concept so far, but several participants in the MBIS are now working to develop a plan for incorporating traditional knowledge into the study (Section 3.4).

Before proceeding, it is important to remember that any research effort, particularly those involving models, involves the use of assumptions which may limit the scope of the interpretation of results. Just as a scenario is not a forecast, a model may not be a realistic simulation of the real world. In the MBIS scenarios and models are used to help gain insight into several possible futures. It is hoped that readers of this and subsequent MBIS reports will understand the limitations of these methods while, at the same time, recognizing their value.

3.2. Resource Accounting Framework

In a multidisciplinary project like the MBIS, there is a need to link together the various pieces of the puzzle that will be generated through the many impact assessment studies undertaken as part of the project. This is consistent with an identified need to integrate biophysical and socio-economic systems to promote better long-term planning and impact assessment. The difficulty has been in dealing with different metrics with intangible or non-quantifiable values, and in dealing with distinct temporal and spatial frameworks. Climate change impact assessment models have typically used a simple cause and effect framework, ignoring the dynamic aspects of social and biophysical change. A separate component of this study will develop population and economic growth projections that will at least give consideration to the dynamic nature of socio-economic systems in the context of long-term impact assessment. In an attempt to develop a framework to integrate the various types of information being generated by the various subcomponents of the MBIS project, a resource accounting framework will be constructed that will provide a system for both structuring and linking data.

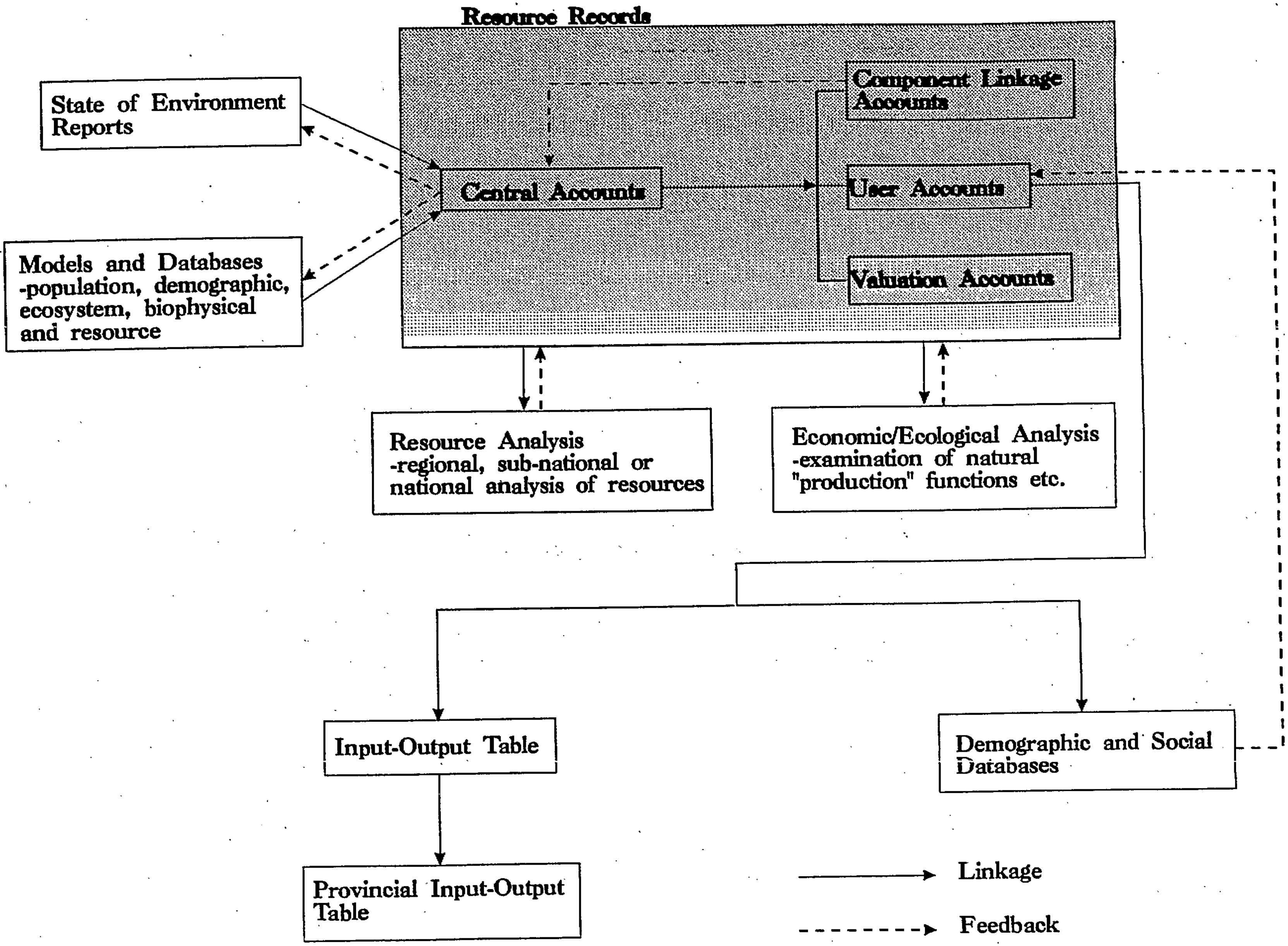
Natural resource accounting is based on two goals. The first is to correct the perceived shortcomings in the United Nations System of Nation Accounts (SNA) and its derivation of income from non-sustainable consumption of natural resources and other environmental services. The second goal is to provide a suitable framework for structuring information, one that might be able to link different sectors and different metrics. The model being developed in this study emphasizes the latter goal by providing an environmental statistical framework that can offer empirical links between natural and social systems. This framework is closely related to ongoing work in state-of-the-environment reporting, ecological input/output analysis and environmental statistical systems. Examples of the latter include Canada's Stress Response Statistical System (STRESS) and the United Nations' Framework for the Development of Environmental Statistics (FDES).

Most of the existing research on natural resource accounting systems has been focused on national level analysis since most of the studies are aimed at redressing the perceived inadequacies in the SNA, as noted above. A regional set of accounts, however, is a more appropriate level for the statistical functions of resource accounting frameworks, since biophysical and socio-economic data are better related at the regional level for purposes of impact assessment. The regional approach will allow for finer spatial resolution of data and may be appropriate for the development of aggregate regional environmental indicators.

The focus of this study will be to design a regional resource accounts model for the Mackenzie River Basin as a means of incorporating the information generated by the various impact assessment studies being conducted as part of the MBIS. The accounts model will consist of separate resource records, each with four types of accounts; central accounts, user accounts, valuation accounts and component linkage accounts. These accounts, and the types of linkages that can be formed from the resource records, are depicted in Figure 3.1.

In brief, the central accounts form the core of each resource record, containing physical measures of opening and closing stocks and health, together with an identification of various flows. The user accounts detail the connections between resources and the economy, both within the region and outside. The types of trade flows built into the economic projections model (described below) are indicative of the types of inter-regional connections possible in the user accounts structure. Valuation accounts consist of monetary estimates of both resource depletion and environmental degradation, as well as the standing stock of economic resources. Lastly, the component linkage accounts allow for exploring the connections between and among the components of the other accounts (within and between accounts).

Figure 3.1. Resource Accounting Framework.



Overall System Linkages

The regional resource accounts model being developed for the MBIS represents a departure from traditional resource accounting. Adopting a regional approach will allow for its use in environmental planning and impact assessment, but the approach also poses a number of data problems. The model is also flexible enough to be reshaped as the amount of information generated by the MBIS increases. As such, it should be viewed as both an environmental statistical framework as well as a model for integration.

Additional discussion on the socio-economic integration project, in which resource accounting will play an important role, is found in Section A15.1.

3.3 Integrated Land Assessment Framework

3.3.1 Introduction

The complex and dynamic nature of the global warming issue requires the development and application of integrated analytical methods to represent functions and interactions of a wide range of components in economic and environmental systems. The analytical tools for studies of separate groups dealing with the physical and biological components of the MBIS are desirable for first- and second-order impact assessments. To provide a picture of global warming impacts for the region as a whole, an integrated impact assessment framework is needed to bring together these first- and second-order impacts and to take into account the interconnections among effects on various sectors of society.

With respect to the above concern, the integrated land assessment framework (ILAF) being developed will provide holistic analysis of projected global warming and policy response in the Mackenzie Basin. In particular, the analytical framework can integrate major results of the individual studies from the physical, biological, and socio-economic components of the MBIS and identify the regional economic and environmental impacts of climatic change. The research framework consists of three distinct techniques: a remote sensing image processing technology, a geographical information system (GIS) and multiple-criteria analysis models. The three analytical systems are linked together to form the ILAF. Application of the ILAF system in the Mackenzie Basin will demonstrate the capability and flexibility of the analytical system for regional impact assessment of climatic change.

3.3.2 The Conceptual Research Framework

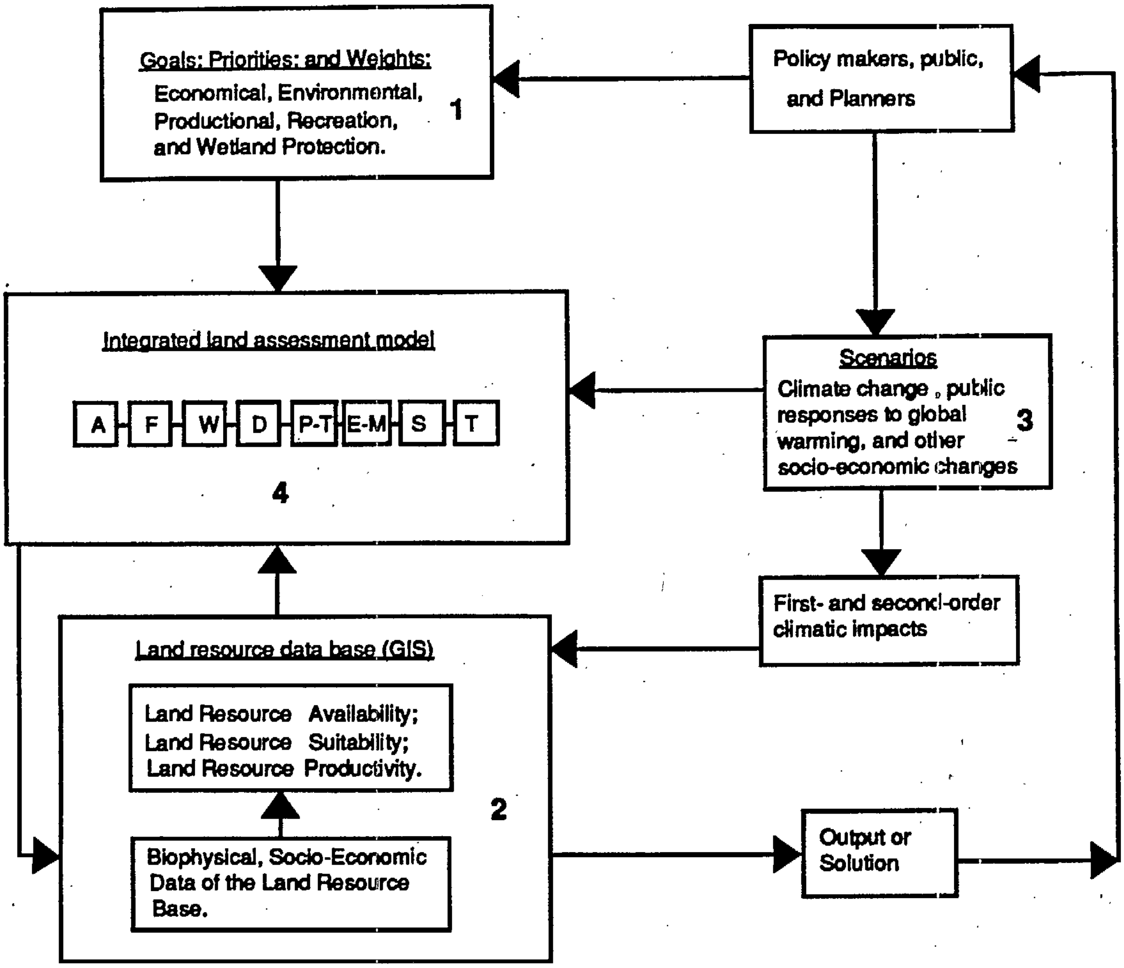
An integrated approach for impact assessment of global warming and its responses possesses certain fundamental characteristics. This study proposes the following set of guidelines, which highlights a group of crucial attributes to be considered in an integrated impact assessment, as criteria in developing analytical methodology. The integrated approach should be able to ensure public participation, be systematic and comprehensive, be multiple- objective and multiple-sector, be able to easily identify trade-offs, and be able to provide more co-ordination in a new modelling research area.

Based on the criteria described above, a conceptual ILAF was developed and its main elements are illustrated in Figure 3.2. The procedures of the analysis are mainly composed of four components: goal setting, a database and spatial unit, scenario development and an assessment system.

Setting Goals

The procedure begins with an identification of goals. In this study, goals are evaluation criteria or standards by which the effects of climatic change and/or the efficiency of alternative adaptation options can be measured. Land resource development goals are diverse, representing the preferences of various interest groups. These goals might include: ensuring adequate resource production to meet future needs; maximizing economic benefits or minimizing costs; and conservation of resources and protection of environmental quality.

Figure 3.2. Integrated Land Assessment Framework.



Research Framework

Note:

A: Agriculture	P-T: Parks-Tourism
F: Forestry	E-M: Energy-Mines
W: Wildlife	S: Settlements
D: Defence	T: Transportation

Database and Spatial Unit

Information is required on the quantity, quality and distribution of the land resource base. Long time-series of data on resource systems is a critical need for this study. Various impact results of the first- and second-order impact analyses of the MBIS will be used as inputs for the integrated impact assessment. In addition, remote sensing processing technology will be used to extract, enhance and classify satellite images and to input the processed information into a geographic information system (GIS). The GIS will also incorporate other existing datasets. The GIS will perform efficient storage, retrieval and manipulation of spatial data.

The Mackenzie Basin has a range of subregions varying in terms of resource availability, suitability and productivity. One important step in the study is to choose a suitable spatial framework to form the basic unit for analysis. Spatial units should be relatively homogeneous with respect to the biophysical, social and economic conditions. However, the spatial scales adopted for climatic impact study are usually larger than scales traditionally used by ecologists and environmental scientists.

Scenario Design

One of the distinctive features of the research framework is the emphasis placed on design of meaningful scenarios representing different climatic change perspectives, future social and economic conditions and response options or policies. These scenarios will be translated into the model's structure to examine their economic and environmental implications. In this study, three types of scenarios will be developed and investigated: climatic change, socio-economic changes such as population and economic growth, and response options.

Scenarios for climatic change and economic growth are presented in A13 and A14. Scenarios discussed here represent possible response options to climatic change. Figure 3.3 shows the possible types of public responses available to deal with global warming. Basically, these responses can be grouped into two categories: adaptation and limitation. The former seeks to lower the negative consequences of global warming. Anticipatory adaptation involves actions taken in advance of projected warming. The latter is aimed at reducing net emissions of greenhouse gases to contain future climatic warming below certain levels. This study is mainly dealing with adaptation options. More detailed discussion on scenario development for the ILAF are presented in Section A15.2.

The Analytical System

The three steps of the research framework have now been conceptually outlined. What remains is an analytical system which will provide mechanisms to integrate biophysical, social and economic factors in several resource sectors. The problem of global warming is so complex that no single presently-available technique can provide the flexibility required for solution. The analytical methods employed for impact study and policy analysis is part of a computer-based spatial decision support system (SDSS). The SDSS can improve the efficiency and effectiveness of the integrated assessment through the use of advanced analytical tools. The analytical system is based on goal-programming and multi-criteria decision-making techniques.

Figure 3.3. Possible types of public responses to climate change (modified from Warrick et al., 1988).

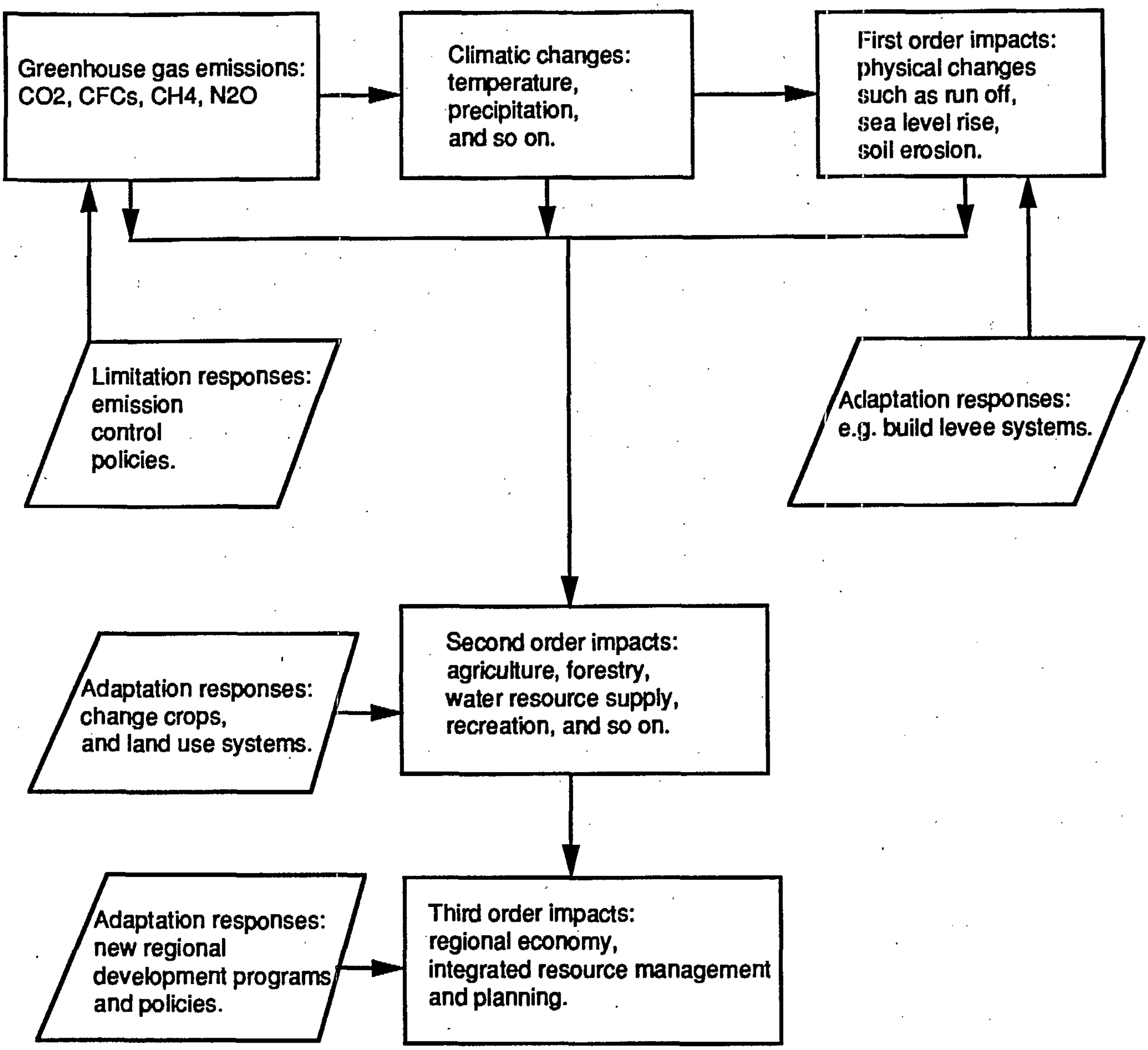
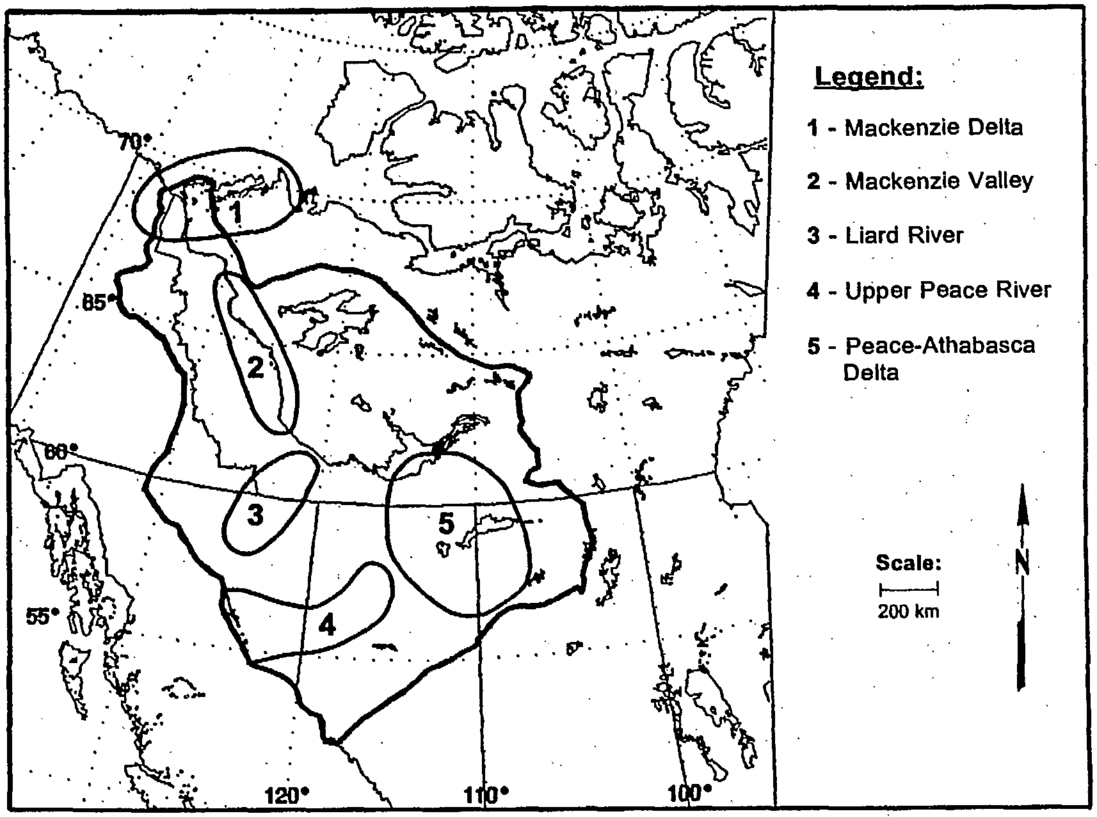


Figure 3.4. Five critical zones within the MBIS region.



3.3.3 Applications of the ILAF in the Mackenzie Basin

The ILAF system is being applied to deal with problems related to climatic change for the Mackenzie Basin. The integrated assessment covers the whole basin but, due to time and resource constraints, the study will focus on five critical zones: Mackenzie Delta-Tuktoyaktuk; Mackenzie River-Fort Good Hope-Norman Wells-Fort Simpson-Hay River; Liard River; Peace River; and Northeast Alberta-Fort McMurray-Peace-Athabasca Delta (Figure 3.4). These were chosen by the MBIS Working Committee.

Detailed discussion on the application of the ILAF in the Basin is presented in Section A15.2. The MBIS is still at early stages of development, so results of other research projects and other important data are still not available to test the conceptual ILAF system.

3.3.4 Expected Results

The integrated assessment seeks to provide answers to some important questions in relation to climatic impact assessment and public response to climatic change. Some broad questions to be examined will be:

1. What are the implications of climatic change for achieving regional resource development objectives? Should governments within the Mackenzie Basin alter their current resource use policies or plans regarding water resources, resource extraction, forests or fish and other wildlife in anticipation of global warming?
2. Does climatic change increase land-use conflicts among different economic and social sectors? If potential conflicts are identified, how serious might they be and how could compromises be reached?
3. What are the possible trade-offs for alternative public responses to climatic change? Should parks and forests be managed to anticipate change, or to preserve existing conditions? What are the implications for fire control, recreation and tourism, and wildlife management?

4. What are the implications of global warming for community management of resources under land claims agreements?

3.4 Role of Traditional Knowledge

In order to explore potential impacts on communities and possible adaptation responses, the MBIS is attempting to bring communities into the research program. One activity already underway is Newton's study of responses in remote communities to extreme events (Section A6.2). The MBIS is also considering a proposal to assess possible future community development patterns and how they may be affected by climate change (Section A6.1).

In addition, the MBIS is very interested in native traditional knowledge and how this might complement the various interdisciplinary efforts of modern scientists working within the MBIS framework. This knowledge is based on observations at the community level which forms the basis of indigenous knowledge about the environment. This knowledge has been passed from generation to generation and provides survival skills to those who wish to maintain a lifestyle that includes country food harvesting. This is important when considering possible adaptation strategies related to a change in climate. The indigenous knowledge base should also be complementary to observations made by modern scientists in their work, particularly since the two sets of observations rarely occur at the same place and time in the vast Canadian North.

Throughout the planning and development of our program during the last two years we have learned that natives place a high value on this knowledge, and their willingness to co-operate in a research project such as the MBIS stems in part from our desire to make them partners, not just objects of study. Since the MBIS has been asked to explore the policy implications of global warming, it is imperative that regional stakeholders, including native communities, be part of this exercise so they will feel a sense of ownership in the results and recommendations. Goals included in the integrated land assessment (Section 3.3, A15.2) should reflect native views related to subsistence economies as well as those of industrial and commercial interests.

Although there is consensus within the study group that traditional knowledge should be part of the MBIS, the group has also learned that the collection and analysis of this information is a slow and difficult process because of the differences in perceptions of science and environment, as well as language. The group is, however, willing to try.

Two activities are presently underway. One is a study in Aklavik, N.W.T. by Dave Aharonian, University of Victoria. He is attempting to describe the community's perceptions of climatic variability and their thoughts about future changes (Section A6). The second is a preliminary consultation with the community of Lutsel k'e (Snowdrift, N.W.T.). The principal investigators, Ellen Bielawski (Arctic Institute of North America) and Barney Masuzumi (Dene Cultural Institute) have obtained an agreement with that community to take part in a survey of traditional Dene knowledge of climate (Section A6). They are now in the process of applying for additional financial support from granting agencies and other potential sponsors. The MBIS cannot support this project on its own.

The study group is hopeful that the activities described here will enable the MBIS to account for community level concerns about climate and its impacts, and to utilize the unique expertise of Northern residents with considerable experience in living in this region. It is felt that if traditional knowledge can be successfully combined with information obtained by the rest of the study group, the MBIS will be able to provide a better product to the stakeholders of the Mackenzie Basin.

4. Climate And Human Scenarios

4.1 The Role of Scenarios

This chapter, and the additional notes provided in the appendix (Chapters A13 and A14), provide an overview of methods being used to develop scenarios of changes in climate, population and economic conditions for the Mackenzie Basin.

Before proceeding with the description of the study's efforts at scenario development, let us first consider the purpose of using scenarios in a study on the potential implications of climate change. The objective of the MBIS is to produce an integrated assessment of the regional implications of global climate change, but there is no consensus on the specific changes in climate that could occur at the regional scale. The magnitude of projected warming differs among the various simulations produced by the general circulation models. Precipitation is expected to increase at high latitudes, but the various GCM simulations produce different spatial patterns, including decreases in precipitation at some locations for some months. Therefore, the group has deliberately chosen to develop three scenarios from three different GCMs so that a range of warming futures would be produced. These are being augmented by a fourth scenario derived from knowledge of past warm periods (see Section 4.2.4). Results of impact studies will be provided for the four scenarios so that uncertainties in the group's knowledge of the region's future climate will be expressed in terms of impacts rather than just temperature or snowfall.

A study of the future, however, also requires consideration of how the region's population and economic structure might change. We therefore need human scenarios so that a more realistic base case can be constructed, against which the scenarios of climate change are compared. The base case would provide an indication of what the economic future of the region could be like without a change in climate. Information for the base case would be obtained from a variety of sources, including surveys conducted by MBIS participants. Some of these will focus on traditional knowledge (see Section 3.4).

The impacts of the four climate change scenarios could then be assessed relative to the future base case and a sense of magnitude of importance could be obtained. For example, it may be that without climate change, commercial forestry operations would be projected to remain south of 60 degrees north for the foreseeable future, but that with a warmer climate, there might be increased activity farther north. Within this scenario there could be a number of indirect spinoff effects such as changes in land use, infrastructure development, employment, community structure, forest fire frequency and changes in wildlife patterns. How important might these spinoff effects be? Could they differ between the four scenarios, and by how much? Could the direction of change differ between the scenarios, or would all four show the same direction of change?

The impacts of scenarios relating to population and economic changes will be more difficult to assess. Scenarios of high and low growth are being developed (Section 4.3, Chapter A14), since there is no consensus on this issue at this time. The application of these may be in a quantitative or qualitative manner depending on the methodology used by each MBIS participant. In studies where local population growth may be important for a calculation, such as to estimate local demand for goods and services (e.g. agriculture,energy and settlements), these scenarios may be used quantitatively. In other cases where these issues are not included as an explicit component of a model (e.g. wildlife), certain assumptions could be made that indirectly account for these scenarios (e.g. hunting pressure).

The scenarios therefore provide an opportunity to explore a range of possible warming futures within the region, without claiming that any of these represent forecasts. There is no way to determine which of these is the best scenario, so there won't be a probability assigned to any particular one. They will provide an indication of the sensitivity of the region, as expressed in various impact models, to the scenarios imposed on them.

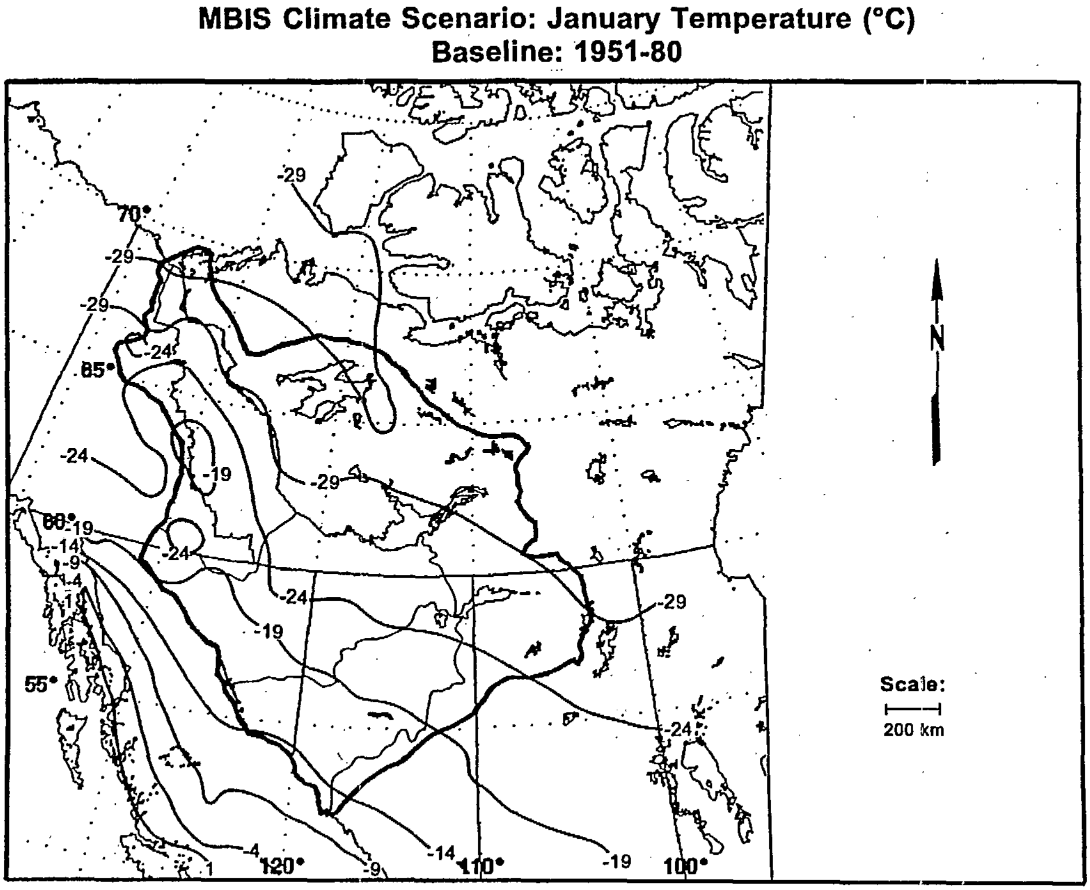
4.2 Climate

One of the main concerns in providing climate data for this large and diverse project is to ensure that all researchers use the same database in order to ensure comparable results. For example, two researchers may begin with identical datasets but by using two different interpolation methods the results may be very different (Cohen, 1990). In order to eliminate this problem it was decided that both the baseline climate and the climate scenarios would be developed at the CCC with the assistance of the Western Region office of the Atmospheric Environment Service (WAES) and be provided in an easily readable form to all MBIS participants.

4.2.1 Baseline Climate

The purpose of this exercise was to develop a baseline climate dataset for the entire Mackenzie Basin. The existing climate database of the region was found to be inadequate. As a result, information was extracted from other sources such as maps and data created using statistical techniques. The resulting maps showed considerable improvement over the original mapping attempts. The improvement was also a result of choosing a more appropriate interpolation routine to be used in the geographic information system (GIS). An example of the Mean January Temperature map is shown in Figure 4.1.

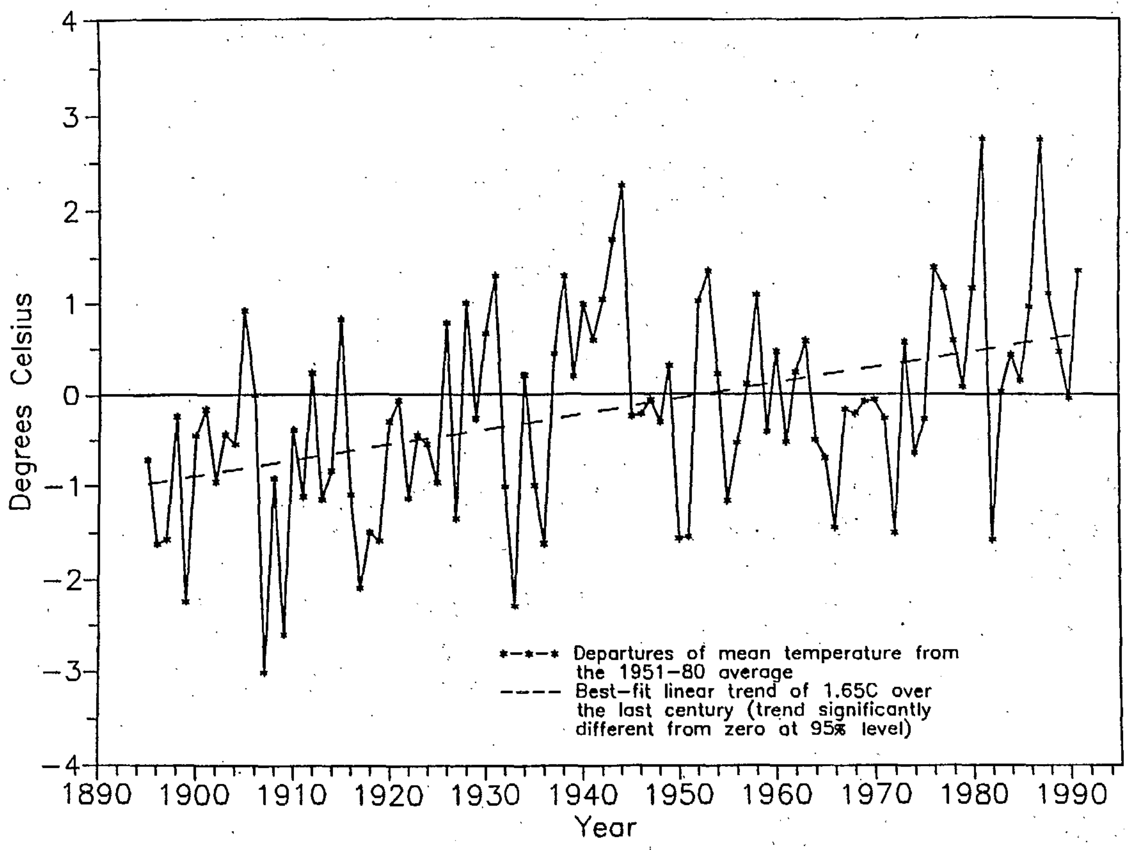
Figure 4.1. Sample output for baseline climate data set: January temperature.



4.2.2 Recent Climate Trends

A corrected dataset was used to determine the most recent temperature trends in the Mackenzie Basin. The average annual temperature departures were plotted (Figure 4.2) and found to be significant with an increase of 1.7 C over the period from 1895 to 1991. This result, however, cannot support any definitive conclusions as to the cause of the trend because the magnitude of increase is within the natural temperature variability over the past 1,000 years.

Figure 4.2. Mackenzie Basin average annual temperature departures, 1895-1991 (Source: J. Reycraft, CCC).



4.2.3 Climate Change Scenarios

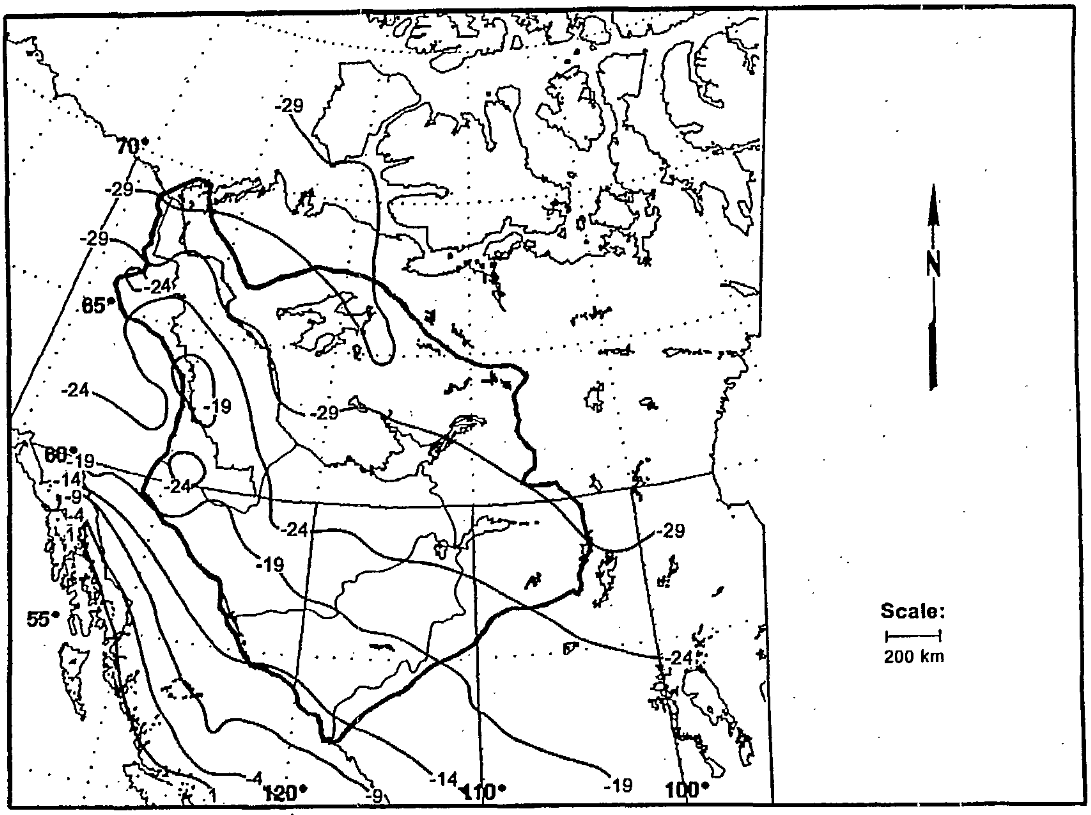
"Scenarios are useful for organizing thinking about what the future may hold. They are not predictions, but sketches of certain key features of the future situation based on plausible extensions of existing trends." (Crosson, 1992; emphasis added). Although this quotation refers to scenarios for U.S. agriculture and technology in the future, it is an appropriate statement to apply to the climate change scenarios which are to be used in this study. Four scenarios of climate change will be used, with three of them based upon general circulation models (GCMs). The GCM-derived scenarios are based upon projected trends in atmospheric carbon dioxide, and not on the global warming trends that have recently been measured (IPCC, 1990). The other scenario is a composite scenario based upon past experiences of climate in the region obtained from instrumental and paleoclimate records. These scenarios should be regarded as possibilities to be used to determine the sensitivity of the socio-economic system in the Mackenzie Basin to plausible climates of the future.

4.2.3.1 GCM-Derived Scenarios

The Intergovernmental Panel on Climate Change suggests that the most developed tool that can be used to predict climate is general circulation models (GCM). Although GCMs do not successfully simulate impact on regional climates, impact scientists have continued to use the GCMs in order to be able to trace the scientific source of their scenarios. In order to compensate for the poor simulation of regional climates by the GCMs, impact scientists have combined climate station data with the GCM data.

Figure 4.3. Sample output for scenario data set derived from Canadian Climate Centre GCM: January temperature.

MBIS Climate Scenario: January Temperature (°C)
Baseline: 1951-80



Three GCM outputs will be used in the MBIS to create scenarios. The first two are based upon equilibrium runs of the GCMs, which represent a stable non-changing point in time under set boundary conditions. The GCMs to be used are the latest General Fluid Dynamics Laboratory model outputs (GFDL R30), and the Canadian Climate Centre (CCC) GCM outputs. The CCC scenario dataset is now available and an example is shown in Figure 4.3. One problem with these scenarios is that each given time is assumed to be representative of a future normal climate. As a result, it does not indicate rates of change in the climate.

The third GCM-based scenario was developed with data from the Goddard Institute for Space Studies (GISS) GCM simulation of a time series. This scenario is based on 100 simulated years from a transient run where the boundary conditions were constantly changing. Data for this scenario will be provided for each decade during the 100 years. A summary of these three scenarios is provided in figure 4.4.

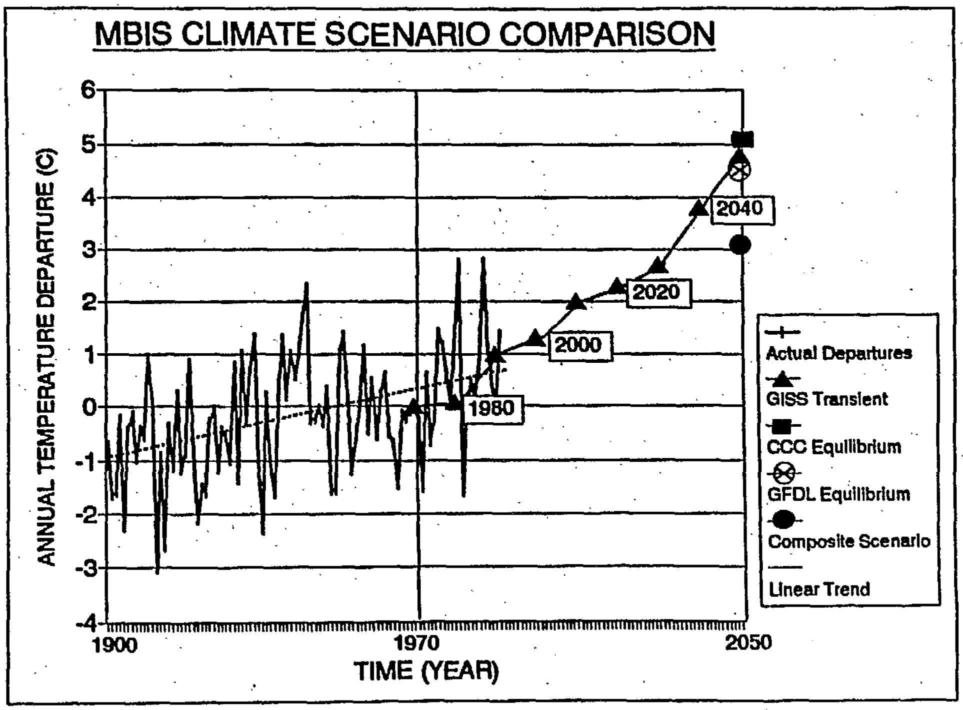
4.2.3.2 Composite Scenarios

In recent studies, researchers have tried to compensate for the large uncertainties surrounding the GCM outputs by developing alternative climate scenarios based upon historical analogues or hypothetical cases. No studies to date have made use of proxy data (paleoclimatic data) or spatial analogues (a real dataset from a warmer location used to simulate climate warming). Many have used hypothetical cases that may have been influenced by knowledge of past climates. The study of the U.S. Corn Belt (MINK Study; Rosenberg et al., 1991) used a scenario based on the 1930s.

Table 4.1 Sample output for composite scenario: Temperature for Northern Mackenzie

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
Inuvik 1951-80 (68.3, 133.5)													
Temp.	-29.6	-28.9	-25.0	-14.3	-0.8	10.1	13.6	10.7	3.1	-8.1	-20.7	-27.2	-9.8
Precip.	17.9	10.5	12.0	14.8	17.6	23.5	33.6	43.6	23.9	33.4	17.9	17.4	266.1
CCC Changes (Grid point)													
Temp.	3.0	6.4	9.2	3.2	4.8	6.7	4.2	2.6	2.0	4.5	6.1	4.9	
Precip.(ratio)	1.00	1.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	2.00	0.67	1.00	
Inuvik under CCC Scenario													
Temp.	-26.6	-22.5	-15.8	-11.1	4.0	16.8	17.8	13.3	5.1	-3.6	-14.6	-20.2	-4.8
Precip.	17.9	10.5	12.0	14.8	17.6	23.5	22.5	43.6	23.9	67.8	12.0	17.4	
Transpositional -				**NONE APPROPRIATE**									
Temp.													
Precip.													
Instrumental Five Warmest Years Average													
Temp.	-25.0	-26.0	-23.1	-10.9	1.8	11.3	15.1	12.2	4.0	-6.9	-20.3	-24.1	-7.7
Paleoclimate - Warm Year													
Temp.				+3.0	+4.0	+5.0	+3.0	+1.0					
Precip.				+10%	+10%	+10%	+10%	+10%					
Composite													
Temp.	4.6	2.9	4.6	3.0	4.0	5.0	3.0	3.0	1.0	0.9	1.2	0.4	3.6
Precip.	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%

Figure 4.4. MBIS Climate Scenario Comparison



In order to develop an alternate climate scenario for the MBIS, an informal meeting was arranged with researchers involved in the development of climate scenarios, climatologists with a knowledge of the instrumental data for the region and researchers familiar with alternate sources of climate data, including paleo-ecologists. The purpose was to develop a composite scenario by merging available instrumental and paleo data.

The results were provided in tabular form for three separate regions of the basin: northern Mackenzie Basin, the Mackenzie Valley, and the southern Mackenzie Basin. Table 4.1 indicates the results for the northern portion of the Mackenzie. Some problems existed with the development of these scenarios. For example, the paleo data were not available in all regions, or in more detail than seasonal time frames; instrumental data records are for relatively short periods; and appropriate spatial analogues may not always be available, since any one of many geographical factors (such as climate controls) may differ significantly from the original site. Overall the composite scenario indicates a 3°C warming (figure 4.4).

4.3 Population and Economic Growth

4.3.1. Introduction

The goal of this component of the MBIS has been to establish a set of economic and population growth scenarios for the study region covering approximately the next 50 years, assuming there will be no noticeable change in the climate of the region. This exercise is important since the region could experience any number of major social and/or economic changes over the time horizon applicable to a gradual climate warming that could influence, or completely mitigate, the expected impacts of climate change. To move beyond a simple cause and effect model of climate change impacts, it is necessary to develop an interactive approach, one that considers socio-economic as well as environmental changes in a region. Such concerns have been apparent in early discussions on the MBIS project, and the attempt in this study was to gain a better understanding of what could happen to the region over the next 50 years irrespective of any climatic alterations.

This report presents the results of a modelling effort aimed at developing population and economic growth scenarios to be used in further impact assessment studies of the Mackenzie Basin along with the climate change scenarios generated through the use of GCMs and other sources. It should be noted, however, that quantitative work on the North is difficult due to the lack of requisite data for the application of more sophisticated and interesting modelling frameworks. A logical approach would have been to design a MBIS-specific, demo-economic econometric model with the linkages between the economic system and the population component made endogenous (i.e. determined within the model). Such a model, however, is unachievable with respect to this project since the necessary data were either not available or available only in fragmented and short time series.

Accordingly, the decision was made to use a full seven-sector, 12-region, multi-region input/output (MRIO) model to carry out the economic scenario work, and to use a population projection model to perform the population forecasts into the next 50 years. The MBIS was defined as an endogenous region, with the other 11 regions being whole or unallocated portions of Canadian provinces and territories. The sectors were defined as follows: primary; manufacturing; construction; transportation, storage, communication, other utilities; wholesale and retail trade; finance, insurance and real estate (or F.I.R.E.); and services. It should also be noted that these two models were in no way integrated and that the application of the various scenarios to this framework yielded only some general impressions as to how the population system may react under various economic scenarios.

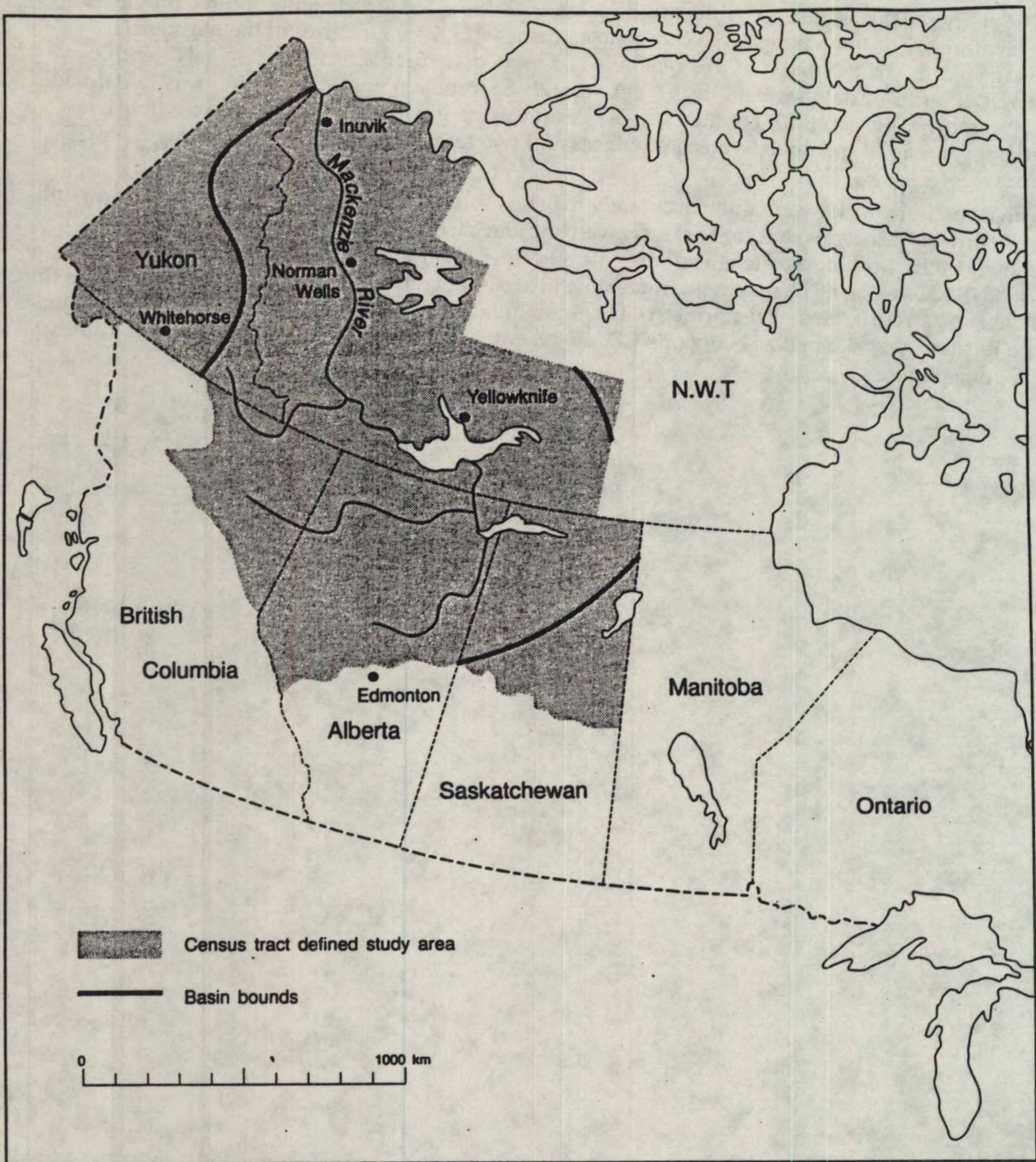
Section 4.3.2 provides a discussion of the methodology used to define the MBIS region via 1986 census divisions. Section 4.3.3 describes the economic growth scenarios. In the appendix, Chapter A14 provides some discussion of the methodology used to build a multiregional population growth projection model for the study area, and a brief description of the methodology used to build the MRIO.

4.3.2 Economic Definition of the MBIS Region

The study region, as defined by the MBIS group, cuts across the jurisdictions of three provinces and two territories. The boundaries were chosen to coincide with the boundaries of the Mackenzie drainage basin. The definition of this region posed immediate problems for any social scientific research in terms of data availability. To get around this problem, the MBIS region was re-defined via 1986 census division (CD) boundaries. The Basin was approximated as closely as possible by overlaying a map of the three western provinces and two territories with a map showing their CD boundaries.

The Basin boundaries were quite accurately matched to the CDs in British Columbia, Alberta and the Northwest Territories, but for Saskatchewan and the Yukon, certain discrepancies had to be tolerated. In the case of Saskatchewan the entire northern half of the province was represented in the 1986 Census as one CD, making it impossible to accurately trace the Basin's boundary through this province. As a result, the entire northern CD was included within the study area. For the Yukon, the entire territory was defined as being one CD, so the entire territory was therefore allocated to the MBIS zone (Figure 4.5).

Figure 4.5. Map of Census Divisions for the MBIS region.



4.3.3 Economic Growth Scenarios

The scenarios used in this study represent the opinions of various experts regarding probable developments in the MBIS region based on a consideration of past trends, existing economic advantage, current trends and consideration of contemporary international forces which may act to shape the region's growth over the next half century or so. A considerable amount of time was spent discussing present conditions and future possibilities for the North with government officials, private companies and the public with respect to both demographic and economic trends.

It is important to keep in mind that a scenario does not represent a prediction. It is just one of many possible situations which is being used to illuminate key linkages and interrelationships which may provide an understanding of the inherent vulnerability, or lack thereof, of a current state of affairs. This analysis proceeds on these grounds, and although current wisdom may consider one or more of our scenarios as being unlikely, they are still useful in that they aid in the delineation of limits. This was the primary goal.

Economic trends were summarized by using four scenarios. The MRIO model contains seven sectors (Section 4.3.1), and the scenarios were constructed by directly altering the output of these sectors (which, in turn, causes changes in the output of other sectors). The first two scenarios were based on growth in activities in the primary resource sector, which presently accounts for approximately 28 per cent of total employment in the Mackenzie Basin. The second two were constructed with the assumptions of a stagnating resource sector and a decline in the service industry.

Each of the scenarios is discussed in more detail in Chapter A14. The scenarios and their regional implications are briefly described below:

Scenario No. 1: High Resource Development (HRD)

The HRD scenario was meant to show what the region could experience if the world prices for oil and gas were to make a high level of exploitation of Mackenzie reserves viable, or if government regional development policies were to have a similar effect. Under this scenario, growth in several resource sectors in the Basin, combined with infrastructural developments, led to a three per cent a year (325 per cent over 50 years) increase in the real output of the MBIS primary sector (sector No. 1). This is the only impact driving the HRD scenario.

Scenario No. 2: Low Resource Development (LRD)

The LRD scenario was designed to reflect a moderate rate of growth in the primary sector combined with separately stimulated moderate rates of growth in the construction sector (sector No. 3) and in the service sector (sector No. 7), reflecting a moderate but optimistic economic environment in the region. The final form of this scenario took the form of a 0.5 per cent a year (28 per cent over 50 years) increase in the output of the primary sector, and a 0.1 per cent a year (5 per cent over 50 years) increase in the output of the construction and service sectors.

Scenario No. 3: Low Overall Growth (LOG)

The LOG scenario was characterized by stagnating output from the region's principal economic base (sectors No. 1 through 4) combined with a 0.055 per cent a year (30 per cent over 50 years) decline in the output of the trade (sector No. 5), F.I.R.E. (sector No. 6) and service (sector No. 7) sectors. This scenario was designed to reflect a generally bleak economic environment combined with a reduction in institutional presence due to a decentralization in government services.

Scenario No. 3-A: Low Overall Growth Alternate (LOG-A)

This fourth scenario was created as an alternative to the previous one due to the fact that the compound impact of the 30 per cent drop in each of sectors No. 5, 6 and 7 was too drastic given the likely gravity of the changes considered under the scenario. Instead, the LOG-A scenario was run with a 30 per cent drop in the trade sector only. This resulted in an indirect reduction of F.I.R.E. and services of a similar magnitude.

These four scenarios provide a range of economic possibilities that should be considered in the context of the projections of climate change in the region. This range is very wide. Analysis of the HRD scenario indicates that, by the middle of the next century, employment in the basin could be six times present levels, with most of this supplied from outside the region. The most likely scenario, however, is LRD, which would imply roughly a doubling of total employment in the region. In both HRD and LRD, the service sector would experience the greatest increase in employment. Under conditions associated with LOG and LOG-A, employment could decline. One of the major uncertainties is with respect to decentralization of government services and the potential impact this may have on the region (particularly if there is little growth in the resource sector). Final demand for goods and services would also experience a wide range of changes under these scenarios, ranging from an increase of 471 per cent (by the middle of the next century) to a decrease of 30 per cent.

A key feature of the Mackenzie Basin regional economy is the strong forward and backward linkages with the rest of the Canadian economy. This means that the region is not isolated and has the same types of linkages as does a province like Ontario. It implies that growth in the MBIS region may have as much to do with rapid growth elsewhere in the economy as it does with the type of impacts considered here. This is important, for it shows that if the region was to experience some fairly significant growth or decline in the future, the task of identifying an economic impact that is attributable to climate change alone may be extremely difficult and may not be a worthwhile endeavor. If, however, the region's economy was to remain stable without any major changes for the better or worse (e.g. LRD, LOG-A), the impact of climate change may be very significant, since it may be the one factor to knock this system out of a fairly stable equilibrium situation and no matter how stagnant that position is, any relatively sudden removal of that state could have very substantial socio-economic ramifications for the region.

An important methodological limitation must also be mentioned. The computed impacts on output have been made without any consideration of whether or not those output levels are feasible, given the availability and quality of capital in the sectors of the MBIS region and in the Canadian economy overall. To properly look at these types of questions, a temporal dimension would have to be added. For example, if there is a tremendous latent supply of capital in the region, the response of sectors may be instantaneous but the employment impacts may lead to little in-migration (and hence population change) as any new jobs will be taken by currently unemployed individuals located in the region. The results reported here have been made on the implicit assumption that excess capacity exists and that the current labour force is relatively unspecialized, meaning that any dramatic increase in the demand for specialized labour would lead to in-migration.

5. The Next Phase Of The MBIS

The integration of different types of information into any regional assessment, including this study, requires the development of new partnerships between disciplines, jurisdictions and cultures. The MBIS is an example that could be applied to many other regions. What MBIS participants (and spectators) have in common is an interest in a place. Within the context of the global village, places maintain their uniqueness because of their history and geography. Regions have always adapted to environmental conditions in their own way, and this attribute should be considered in any regional assessment of global warming. If the MBIS and other integrated impact studies are going to be taken seriously by governments and other stakeholders, these studies should not be planned by outside experts alone. Regional experts and stakeholders should be involved in these assessments, from the earliest planning stages to their conclusion.

The MBIS is now concluding its second year of activity. Most of the pieces are in place though there remain some gaps, particularly in issues related to energy and infrastructure. New research proposals on these topics are presently being reviewed (see Chapters 2, A6, A7). At this time, there are no specific activities underway relating to greenhouse gas emissions or transportation. It is expected, however, that transportation will be partially addressed within the energy and settlements components (Chapters A6, A7). Given the considerable uncertainties associated with projecting future biological and industrial emissions, it is unlikely that the MBIS will be able to answer questions related to limitation (Section 2.1).

There is also a need to ensure the orderly transfer of information between various study participants (the horizontal integration challenge). A mid-study workshop, planned for spring 1994, as well as smaller informal meetings should facilitate this vital exchange of information.

MBIS Interim Report No. 2 is scheduled for publication in late 1994. Its purpose is to provide tentative results of work in progress. There will also be two or three issues of the MBIS Newsletter published during 1993 and 1994. These will be available from Environment Canada in Edmonton.

6. Conclusion

With the exception of the limitation strategies issue, the MBIS is expected to meet its long-term goals of defining the regional impacts of scenarios involving climatic change and identifying regional sensitivities, linkages, uncertainties, policy implications and research needs. The MBIS is attempting to provide an integrated assessment of the regional implications of global warming on the five policy concerns related to adaptation. There are uncertainties and limitations with this exercise and we do not promise to forecast the future.

Integrated regional assessment does provide an important and valuable opportunity to examine the unique physical, ecological and social attributes of regions and how they may be affected by a change in climate. These attributes play important roles in the economic and political mechanism that would influence the development of strategies for adapting to climatic variability and change. If a small number of important issues can be identified, as they were in our vertical integration workshop, the assessment should become a manageable and productive research endeavor which will enable the MBIS to bring the global warming issue closer to the Basin and its stakeholders. It is hoped that stakeholder participation in the MBIS will give them a sense of ownership in the study's results and recommendations for action.

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APPENDICES

APPENDIX

A1. Water

A1.1. Hydrology: Hydrologic Regime of the Mackenzie Basin, Potential Modelling Approaches, and Future Research Needs for Addressing Climate Change Issues

P. Marsh and T. Prowse, National Hydrologic Research Institute

"Of all the elements of the Arctic environment, the hydrology is one of the most pervasive in its influence, one of the most complex, and perhaps the least known"

University Corporation for Atmospheric Research (1988)

The hydrological conditions within a drainage basin are of fundamental importance and must be considered in any integrated assessment of the impact of climate change. A complication in predicting the impact of climate change on the hydrological system is that the hydrology is greatly affected by the interactions with numerous physical and biological components of the system. Unfortunately, however, these interactions are not well understood in northern areas, and our ability to model them is poorly developed. In addition, such problems are exacerbated when dealing with macro-scale systems such as the Mackenzie basin.

The purpose of this section is to briefly: (1) review existing information on the hydrology of the Mackenzie Basin, (2) outline the existing hydrological data base and significant errors with these data, (3) describe the dominant processes controlling these hydrological conditions, (4) examine existing hydrological models and the limitations of these models, (5) describe hydrological studies currently underway in the MBIS, and (6) discuss research needs required to address the question of the impact of climate change on the hydrology of the Mackenzie basin.

Table A1.1: Major subbasins, lakes and deltas in the Mackenzie Basin (Mackenzie River Basin Committee (1981a).

SUBBASINS	Area (km^2)	LAKES	Area (km^2)
Lake Athabasca	307,000	Lake Athabasca	7,987
Peace River	302,000	Great Bear Lake	30,963
Great Slave Lake	380,000	Great Slave Lake	26,829
Liard River	277,000	**DELTAS**	**Area (km^2)**
Great Bear River	158,000	Peace-Athabasca Delta	6,070
Mackenzie River	363,000	Slave River Delta	310
Total	1,787,000	Mackenzie River Delta	12,000

A1.1.1 Review of Present Hydrologic Regime of the Mackenzie Basin

The Mackenzie is one of the great river basins of the world, ranking tenth largest by drainage area, twelfth by sediment discharge, and fifteenth by mean annual discharge (Milliman and Meade, 1983). It is the fourth largest river, and largest North American river basin emptying into the Arctic Ocean (Milliman and Meade, 1983), with an area of $1.787*10^6$ km^2 or almost 20% of the total Canadian land mass. The Mackenzie Basin is composed of six major sub-basins (Table A1.1), three major lakes (Table A1.1) and three major deltas (Table A1.1). Of these sub-basins only the Peace River is regulated to a significant degree, but the entire basin has significant hydroelectric potential (Mackenzie River Basin Committee, 1981a). The hydrologic regime of these basins is influenced by the major physiographic regions (Western Cordillera, Interior Plain, Precambrian Shield and Arctic Coastal Plain), permafrost which covers a significant portion of the basin, and vegetation which varies from boreal forest to arctic and alpine tundra.

Basin Water Balance

The water balance of the Mackenzie Basin is given by

$$(1) \qquad R = P - E \pm \Delta S$$

where R is runoff, P is precipitation, E is evaporation and sublimation, and ΔS is the change in storage. On an annual basis, it is usually assumed that ΔS is equal to zero. Annual values for each component in equation 1 can be approximated from existing data sets. However, due to limitations in the existing data and significant errors in these, no published studies have calculated the water balance at shorter time steps. In addition, the spatial variations in these components are not well known, and as a result the following discussion will focus solely on the annual water balance of the Mackenzie Basin, and will not provide data for major sub-basins or for shorter time periods.

Precipitation

Precipitation ranges from less than 300 mm/yr in the northwestern sections of the Mackenzie Basin, to between 300 to 400 mm/yr in the extreme southern sections of the basin, to as high as 1600 mm/yr in the Cordillera. The mean annual precipitation for the entire Mackenzie Basin is approximately 410 mm/yr (Canada, Fisheries and Environment, 1978). A significant portion of the annual precipitation falls as snow, varying from 32% at Edson, Alberta to 57% at Inuvik. Storage of a large portion of the annual precipitation for between 5 and 8 months of the year is therefore an important component of the water cycle of the basin. Thus, snowmelt runoff during the spring dominates the basin hydrograph.

Evaporation

Regional evaporation for the Mackenzie Basin has been estimated from evaporation pan data (Canada, Fisheries and Environment, 1978) and from the complementary relationship (Morton, 1983a,1983b). The applicability of both techniques to northern environments has only undergone limited testing.

Estimated open water evaporation from ponds, shallow lakes, and reservoirs varies from between 500 and 600 mm/yr in the southern portions of the Mackenzie Basin, to less than 200 mm/yr in the northern sections of the basin (Canada, Fisheries and Environment, 1978; Morton, 1983b). Estimates of regional evapotranspiration for the Mackenzie Basin vary between 350 and 400 mm/yr in the south, to 100 mm/yr in the north (Canada, Fisheries and Environment, 1978; Morton, 1983a). Total evaporation calculated as the residual of the water balance for the Mackenzie basin is 237 mm/yr, or approximately 58% of the total precipitation input to the basin.

Runoff

Runoff varies from less than 100 mm/yr in the southern portions of the Mackenzie basin, to 100 to 200 mm/yr in the northern portions of the basin, to over 1000 mm/yr in the southern cordillera (Canada, Fisheries and Environment, 1978). Total discharge from the Mackenzie Basin can be estimated from separate measurements for the Mackenzie and Peel Rivers. Mean annual values for an approximately 20 year period are 9,088 and 692 m^3/s respectively (Canada, Environment Canada, 1990), for a combined total of approximately 9,780 m^3/s or 308 km^3/yr. Mean annual runoff per unit area is therefore 173 mm/yr, or approximately 42% of total precipitation input to the basin.

Storage

On an annual basis it is often assumed that changes in storage are zero. However, that is not always the case and long term fluctuations in groundwater, lake, and glacial storage can occur. For example, the major impact of glaciers is to store water during cold and/or wet periods, and to release water during warm periods. The magnitude of annual or seasonal changes in storage in the Mackenzie Basin is not known.

Seasonal variations in runoff

Although the annual water balance provides important information on the regime of the Mackenzie Basin, the seasonal variations in flow are probably more important to the wildlife and economic use of the basin. Church (1974) described four regime types which are common in northern Canada, and which are typical for the permafrost and mountainous sections of the Mackenzie Basin. These include:

1. Arctic-nival regimes: In areas of continuous permafrost the spring snowmelt dominates the annual hydrograph, and runoff from summer rain is generally small since precipitation is low in magnitude. Winter streamflow is usually very low or non-existent due to limited groundwater contribution. Such regimes are only found in the coldest, northern and north-eastern sections of the Mackenzie Basin. In the pre-cambrian shield areas, significant lake storage may result in continued flow during the winter.
2. Sub-Arctic nival regimes: are also dominated by spring snowmelt, but summer rainstorms may produce floods similar in size to the spring snowmelt peak flows (Watt, et. al, 1989; MacKay et al., 1973). With the occurrence of discontinuous permafrost, groundwater contributions increase, and winter flow may be larger. Such regimes are typical of much of the pre-cambrium shield, interior plains, and cordilleran rivers of the Mackenzie Basin.
3. Muskeg regimes: occur where drainage is poor due to low relief or the existence of an impermeable substrate. Muskeg streams are characterized by a large water-retaining capacity, and therefore significant flow attenuation. These regimes are typical of the Interior plains where 25 to 75% of the area is covered by wetlands (Brunskill, 1986). Permafrost may play a significant role in controlling the distribution of wetlands.
4. Proglacial streams: in these streams, snowmelt runoff is important, but instead of a brief spring peak, flow increases throughout the snowmelt period and then continues to increase as meltwater is contributed from higher sections of the glacier dominated basin. Within the Mackenzie Basin, proglacial streams are limited to the higher areas of the Western Cordillera. Little information is available on the percentage of total flow which is contributed from glacial streams in the Mackenzie basin.

Table A1.2: Monthly and annual discharge for the Mackenzie River at Arctic Red River. The basin area at this point is $1.66*10^6$ km^2

Month	Minimum, m^3/s	Mean, m^3/s (mm)	Maximum, m^3/s
January	2170	3,676 (5.9)	5,240
February	2610	3,490 (5.1)	4,470
March	2290	3,220 (5.2)	4,360
April	2040	3,259 (5.1)	4,930
May	2100	12,834 (20.7)	34,000
June	11,900	21,102 (32.9)	31,800
July	9,850	17,986 (29.0)	32,100
August	7,870	14,141 (22.8)	28,000
September	7,730	19,400 (30.3)	11,439
October	3,620	9,205 (14.9)	12,500
November	1,730	4,929 (7.7)	12,400
December	1,680	3,551 (5.7)	5,180
Year	1,680	9,088 (172.7)	34,000

The Mackenzie River integrates the runoff of the above described runoff regimes from the major sub-basins in the Mackenzie basin. The resulting regime of the Mackenzie River would best be described as Sub-Arctic nival, with a dominant spring flood (with maximum flows up to 34,000 m^3/s or 3.7 times the mean annual flow), significant summer peaks due to rainfall runoff (up to 32,100 m^3/s or 3.5 times the mean annual flow), and discharge which continues throughout the winter (with minimum flows of 3,220 km^3/s, or 0.4 times the mean annual flow) (see Table A1.2 for monthly minimum, mean, and maximum flows). Although a major tributary of the Mackenzie River (the Peace River) is regulated, this has no significant impact on the flow of the Mackenzie River. However, it has resulted in a slight shift in the annual hydrograph, raising average flow during low flow months, and lowering summer and fall flows (Wiens, 1991).

River ice covers

In the northern portions of the basin the channels begin to freeze over in October, with a complete ice cover forming by January in all portions of the basin. Since few measurements are made during the winter, the traditional view has been that flow gradually declines from freeze-up to the spring melt period. However, more recent work has demonstrated that the lowest flows may occur during freeze-up, due to the large increase in channel storage as a result of increased stage, in response to the higher roughness of ice covered channels (Gray and Prowse, 1992).

Since the Mackenzie and many of it's main tributaries, flow in a northerly direction from areas of relative warmth to a colder environment, melt tends to progress in a downstream direction. The resulting flood wave often progresses downstream more rapidly than the melt conditions, and the flood wave encounters thick, resistant ice covers, resulting in the development of very large ice jams (eg. Andres and Doyle, 1984; Prowse, 1986). These ice jams are responsible for exceptionally high water levels, and result in the flooding of numerous towns (Kriwoken, 1983). The environmental effect of river ice is not well known (Gridley and Prowse, 1993; Scrimgeour, et al., in press). Ice jams also make it impossible to measure discharge during what is often the major flood event of the year.

Hydrologic regime of deltas in the Mackenzie Basin

The hydrologic regime of the Peace-Athabasca delta has been changed significantly by the Bennett Dam on the Peace River. Simulations of natural and regulated water levels in the delta (Farley and Cheng, 1986) have demonstrated that peak water levels in the delta have been significantly lower than what would have occurred under natural conditions. This has resulted in infrequent flooding of the perched lake basins in the delta, and has had significant impacts on the delta ecosystem (Peace-Athabasca Delta Implementation Committee, 1987).

The Slave River Delta is much smaller than the Peace-Athabasca delta (Table A1.1), and its hydrologic regime is considerably simpler. The majority of flow occurs through a single channel, and as in the Peace-Athabasca delta periodic flooding is critical to depositions of nutrient rich sediments, and recharging water levels in the delta (Mackenzie River Basin Committee, 1981b).

The Mackenzie River Delta, is the largest and most complex of the deltas in the Mackenzie Basin. Its hydrologic regime is dominated by the Mackenzie River, but the Peel River also has significant impacts. Water levels are controlled primarily by Mackenzie and Peel River discharge to the delta, growth of river ice, ice breakup, and changes in sea level (Marsh and Schmidt, 1993). The resulting variations in channel water levels control the flooding of approximately 25,000 delta lakes (Marsh and Hey, 1989). Since these delta lakes tend to have a negative water balance between flooding events (Marsh, 1991), any changes in the hydrologic regime of the Mackenzie Basin could have significant environmental impacts (Marsh and Ommanney, 1991).

A1.1.2 Data Availability and Associated Errors

There are a number of data bases of interest to hydrologists working in the Mackenzie Basin. Unfortunately, however, they are plagued by significant errors. The following briefly outlines the available data, and typical errors. A more complete description of the data bases available in the northern sections of the Mackenzie basin are found in Prowse (1991).

Precipitation

Problems include the significant undercatch of snowfall due to wind and the large number of trace events (Goodison and Louie, 1985), the low density of weather stations, and spatial variability of precipitation in mountainous areas. Numerous studies (i.e. Woo et al., 1983) have shown that measured snowfall in northern regions may be 2 to 3 times larger than measured. However, the magnitude of undercatch has not been clearly demonstrated in the Mackenzie. It is generally believed that rainfall estimates are significantly better than those of snowfall. However, the small number of weather stations in mountainous and northern sections of the Mackenzie basin is still a significant problem.

Snowcover

Snow course data is available from a large number of stations in the Mackenzie Basin. Because of the large spatial variation in snow cover and the extreme size of the Mackenzie basin, snow courses cannot adequately describe the natural variability.

Runoff

It is often assumed to be the "known" value in many water balance studies, but in fact its magnitude is poorly known. The number of stations in the Mackenzie basin is similar to that recommended by the World Meteorological Organization (1981). However, the predominance of smaller basins within this watershed makes this less than adequate. Significant errors in the data base occur because of: shifting stage/discharge rating curves, measurement of flow beneath ice covers, and the occurrence of ice jams during peak discharge events. A discussion of errors involved in measuring discharge in ice covered rivers is available in Pelletier (1988), Rosenberg and Pentland (1966), and Gray and Prowse (1992).

Evaporation

Existing data is limited to evaporation pan data available from a number of AES weather stations in the Mackenzie Delta.

Water storage

There is little data on the changes in water storage within the Mackenzie basin. While there is data on large lake storage, there is little or no data available on storage changes in small lakes, main river channels or soil systems.

Cumulative Data Errors

Unfortunately, it is very difficult to determine the magnitude of the errors involved in each of the water balance components listed above. However, as Hare and Hay (1971) discussed, there are serious anomalies in the large-scale water balance over northern Canada due to errors in the precipitation and runoff databases. As Haas (1991) demonstrates, even though significantly more data is available since Hare and Hay's study, these anomalies have still not been solved. For example, Haas (1991) found that estimated change in basin storage was unsuccessful without adjusting precipitation by 14 to 100% (Haas, 1991). It is clear that the existing data bases are not sufficient for accurately describing the basic hydrologic regime of the Mackenzie Basin.

Although these problems are common in many areas, they are exacerbated in the Mackenzie because of the extreme weather conditions, the general lack of roads, the widely spaced weather and runoff stations, and problems due to ice and snow. Such difficulties are significantly worse in the northern (i.e. north of 60°N) than in the southern portions of the basin. The only way to practically overcome many of these problems is to utilize remote sensing techniques. Unfortunately, these are also of limited use in the Mackenzie basin because of poor spatial and temporal resolution, low repeat cycles, cloud cover and the lack of appropriate algorithms to convert the data to the necessary geophysical parameters. One exception may be the use of satellite microwave data. This technique is beginning to address the issue of spatial variation in snow cover water equivalent, but there are significant problems due to the effect of forest cover (Goodison et al., 1990), and lake covered area. Future advances in algorithms will likely result in accurate, near real-time data on snowcover water-equivalent for the Mackenzie Basin. Other data problems cannot be overcome with any existing airborne or space craft remote sensing techniques. The most obvious of these is the determination of runoff.

A1.1.3 Cold Regions Hydrologic Processes

Due to its size and great spatial variability, the hydrology of the Mackenzie Basin is extremely complicated and is of course controlled by many hydrological processes. Unlike many temperate basins, however, its regime is dominated by cold regions hydrological processes, where cold regions are defined as those areas where snow and ice dominates the annual hydrologic cycle. An understanding of these processes, and their inclusion into hydrological models is required to predict the impact of climate change on the hydrological regime of the Mackenzie Basin. The following discussion will focus on the impact of these processes on the water balance components described in equation 1.

Sublimation, Evaporation, and Evapo-transpiration

The direct transfer of precipitation back to the atmosphere plays a significant role in limiting the availability of water for runoff. Traditional studies have addressed the role of evaporation and evapo-transpiration of liquid water and have assumed that sublimation during the winter is negligible. Recent studies, however, have shown that in certain environments this is not the case. In fact, it is essential that runoff models account for these processes.

The interception of snow by trees and the subsequent sublimation of this snow plays an important role in controlling the amount of snow stored on the ground. In dense coniferous canopies, this process can result in up to 40% of the snow sublimating, while in open or deciduous forests it may be less than 10% (Pomeroy and Gray, in press). In addition, snow may be entrained into the atmosphere during high-wind events, re-distributing the snow on the ground and resulting in considerable sublimation. For example, at the northern edge of the prairies, sublimation may remove up to 40% of the snowfall (Pomeroy and Gray, in press), again limiting the amount of snow available for runoff. Blowing snow controls the snow cover distribution, with a highly variable cover in open tundra environments, and a more uniform distribution in forests. Such variations in snow cover have important implications to snowpack energy balance, and snowmelt runoff. Sublimation may also occur directly from the snow surface (Male and Granger, 1981). It is highly likely that such sublimation plays an important role during foehn events on the eastern edge of the cordillera, as it does in the foothills of the Rocky Mountains in southern Alberta (Golding, 1978).

Although evaporation is ubiquitous, there are important aspects of evaporation in cold regions which need to be addressed. These include the effect of a variety of unique land surface and vegetation types, including boreal forest, non-transpiring lichen surfaces, tundra, wetlands, and lake rich environments where the lakes are ice covered for a significant portion of the year. In addition the effect of permafrost and the resulting large soil heat fluxes must be included. For example, during summer, significant amounts of energy may be used for warming the permafrost instead of for evaporation or warming the surface and overlying air.

Snowmelt Runoff

The distribution and temperature of permafrost has a significant effect on snowmelt runoff in northern regions. For example, cold snowcovers behave very differently than "warm" snowcovers. This is due to the extensive refreezing which occurs within and at the base of the snow cover as a result of the cold snow temperatures and the heat flux from the snow to the underlying soil. In temperate areas these processes are often ignored because it is small in magnitude, but in permafrost areas, soil heat flux is a major factor delaying and even limiting snowmelt runoff. Snow melt infiltration into frozen soils also plays an important role in controlling runoff. Variations in active layer properties, primarily maximum thickness, temperature, and soil moisture play an important role in controlling snow melt infiltration. For example, depending on soil moisture at freezeup, snowmelt infiltration varies from zero to greater than the entire snowpack water equivalent. In addition, soil temperature controls the portion of the frozen soil infiltration that re-freezes and will not be available for immediate runoff.

Snow and Ice Storage

While stored on the ground, the snowcover undergoes changes in density, grain size, and optical properties. The rates and processes controlling these changes are temperature dependent, and therefore the physical properties of snow covers in cold regions is different than those of temperate snow covers. For example, in cold snow covers thick layers of depth hoar, a very weak low density snow, develop. An improved understanding of these processes is required for determining changes in albedo, in analyzing remote sensing data, and for modelling snow and soil temperatures, and therefore snowmelt runoff.

An important aspect of alpine glaciers is the storage and release of precipitation over both annual and decadal time periods. Improved modelling techniques for determining the mass balance and runoff from glaciers is required. An important complication is determining the lag due to the refreezing of meltwater within the glacier, and the storage of water within the sub-glacier drainage systems. The importance of modelling these processes in the Mackenzie Basin is not well known due to the lack of data on the relative importance of glaciers to the Mackenzie system.

Changes in permafrost may be very important over long time periods. In areas of ice rich permafrost, permafrost melting can result in the release of large quantities of water, with major impact on basin water balance. Many small lakes and tundra ponds exist only because of the existence of permafrost which blocks subsurface flow. Changes in permafrost could result in lake drainage, with consequences to peak flows, basin storage, and ecosystem processes.

A1.1.4 Hydrologic Models

Modelling Approaches

Numerous hydrologic models have been developed for both water resource and research applications. These models are of three basic types: stochastic, deterministic, and parametric. Each has advantages and disadvantages, and is appropriate for use in certain circumstances. The use of hydrologic models for climate change predictions has requirements which are very different than those for which most hydrologic models were originally developed. For example, climate change studies often require modelling larger basins than those of interest in water resource studies, and must be able to handle significant changes in basin conditions, including vegetation and permafrost. Few existing hydrologic models are able to simulate these conditions with high accuracy. The following discussion briefly describes the major types of existing hydrologic models, their limitations, and ability to predict the impact of climate change on the hydrology of major river basins.

Stochastic models rely on a relationship between inputs and outputs, with little or no regard for the intervening processes. Such models may be used for predicting flows in areas where the only data are precipitation inputs and stream discharge. Attempts have been made to regionalize these stochastic models, in order to use them outside of the basin in which they were calibrated, but they must still be within a narrow range of conditions. Since climate change may result in drastic changes to vegetation and permafrost, stochastic models have limited utility for predicting the impact of climate change.

Parametric models use a variety of parameterization schemes to convert precipitation or snowmelt into streamflow. These parameters may or may not be physically based, and as a result, parametric models often require calibration on existing data sets. If the parameters are not physically meaningful, it is inappropriate to use these models outside the range for which they were calibrated. As a result, they should not be used for climate change prediction. However, if the parameterization schemes are physically based, then these models may work satisfactorily for climate change prediction.

The third class of models are deterministic in nature. These models rely on a complete understanding of the physical processes responsible for routing precipitation or snowmelt to streamflow. These have traditionally been used for research purposes, and due to their physical base, may be best suited to climate change studies. However, they require a vast amount of data, and at present are suitable for only small catchments, not meso-scale basins.

It is apparent from the above discussion, that few if any of the existing hydrologic models are suitable for climate change predictions of major drainage basins. It is often argued that parametric models are sufficient for climate change predictions since they perform adequately for predicting current streamflow, and in fact often perform better than deterministic models. However, since their parameterization schemes often do not include all of the important processes, this does not necessarily mean that parametric models are better suited for climate change prediction. In fact, parametric models often can not be transferred from basin to basin without recalibrating. It is likely that under a new climate, with resulting changes in vegetation and permafrost, basin conditions will be "outside" of the normal range for which the model was calibrated. As a result, parametric models may not be appropriate for climate change studies. There is an urgent need for models which are physically based, or have physically based parameterization routines that do not require calibrating.

An additional problem with both parametric and deterministic hydrologic models is that they are only applicable to small basins, with areas of up to a few tens of thousand km^2. There has been some larger scale work done, but this generally relies on simple regression models, or parametric models suitable for small basins, with a flow routing component to handle routing the flow down channel. There are no existing models which are applicable to a basin as large as Mackenzie. For the Mackenzie basin, operational forecasting is made for small sections of the basin, and flow routing models are available for sections of the main channels (ie. Mackenzie River Basin Committee, 1981a) and for the Peace-Athabasca and Mackenzie River Deltas (Sydor et al., 1989), but there is no existing hydrologic model for the entire basin. Development of such a model would be a major undertaking.

As a result of these problems, there are numerous ongoing studies to develop appropriate models to predict the effect of climate change on the hydrologic regime of major drainage basins. This is in fact one of the goals of the Global Water and Energy Cycle Experiment (GEWEX). A few of the approaches being considered for macro-scale hydrologic modelling include:

1. The use of GCM outputs directly. Kuhl and Miller (1992), for example, used the GISS GCM to model discharge from a number of large river basins around the world. In general they found that for high-latitude rivers, the "amplitude of the annual cycle of model-generated runoff is too large and the spring peak is too large". This was also true for the Mackenzie Basin, with the model overpredicting spring melt runoff and the predicted annual runoff was more than twice the observed.
2. The use of physically based catchment scale models, using aerially averaged effective parameters to develop a macro-scale model. One approach to estimating these parameters is the "probability distributed principle operating on sub-grid scales" (Moore et al.;1991).
3. Kite et al. (in press) described a hierarchical approach for connecting a series of hydrological models to atmospheric general circulation models. The hydrological models use a "grouped response unit" to link process parameters to land cover, basin topography and the areal extent of climatological phenomena at a variety of scales. This approach may allow the inclusion of "the physics of catchment hydrology" (Kite et al., in press) into macro-scale hydrological models. However, although each of the hydrological models required for the Hierarchical model is currently running, the models have not yet been linked.

Data Requirements

In order to run models for predicting the effect of climate change on the hydrology of the Mackenzie Basin, it is important to first run and test models with existing data. The data problems described earlier must be addressed before using existing data for both model input and for testing model predictions. For climate change studies, it is necessary to use GCM scenarios. However, as Stuart and Judge (1991) suggested "current state-of-the art GCM's are incapable of accurately modelling the present-day special climate of the Mackenzie Valley, and any impact studies that use grid-point values of projected temperature and/or precipitation from these models will incur large errors". Even if appropriate macro-scale hydrologic models existed, it would therefore be very difficult to determine the correct input data for modelling the discharge of the Mackenzie Basin under a different climate scenario.

A1.1.5 Ongoing Hydrologic Studies in the MBIS

At the present time there are 2 ongoing hydrological studies in the MBIS: (1) Climate change and the hydrology of the Mackenzie River Basin by R. Soulis, and (2) Modelling the impacts of climate change on the ice regime of the Peace River by D. Andres. The following summary of each study is based on the study proposal outlines submitted by each principal investigator:

Climate change and the hydrology of the Mackenzie River Basin (P.I. is R. Soulis)

This study proposes to use the square grid technique developed by Solomon (1968) for the assessment of hydroelectric potential and hydrometric network design (Solomon et al., 1991), in order to assess the impact of climate change on the water resources of the Mackenzie Basin. This technique uses the water balance equation and an iterative process to interpolate measured temperature, precipitation, and runoff fields for all grid squares in the basin. During the iterative process, measured runoff is used to scale the measured precipitation in order to achieve as much consistency as possible between the various fields. A natural storage reservoir model is then used to account for changes in storage and groundwater discharge. When calculating the impact of climate change, new average values of precipitation and temperature are input, and then the base case regression equations are used to calculate the new values of runoff at points of interest.

This study would be carried out in 3 phases, of which only funding for the first phase has been applied. Phase I proposes to "establish the project data base including physiographic, meteorologic and hydrometric data. Station cross-correlations and first iteration regional [regression] equations will be used to identify anomalous station data. Preliminary regional [regression] equations for demonstration purposes will be developed ignoring both anomalous data and regulated streamflow".

It is expected that this study will provide an improved understanding of the existing hydrologic conditions in the Mackenzie Basin by carrying out a water balance study of the basin, and will clearly demonstrate errors in the existing data bases.

It is proposed that outputs of the study by R. Soulis will be used by Inland Waters Directorate in Regina to simulate changes in water levels for open water conditions in the Peace-Athabasca Delta.

Modelling the ice regime of the Peace River (P.I. is D. Andres)

The primary objective of this study is to "model the ice cover development for a variety of climatic scenarios, including the current normal climate and the anticipated climate resulting from climate change, for a given set of operating conditions of the Bennett Dam". The model to be used in this study was developed to simulate the formation of ice on large regulated rivers in northern Alberta. This model was calibrated on the Peace River, and testing has shown that it can simulate the upstream progression of the ice cover. Since ice cover formation is dependent on both the meteorologic conditions and outflows from the Bennett Dam, climate change will affect ice cover due to changes in climate and the impact on power demand.

This study proposes three phases to the work: Phase I will improve model calibration by carrying out field work to better define parameters in the model, Phase II will define the relationship between power demands, climatic conditions, and discharge from the Bennett Dam, and Phase III will forecast the future ice cover regime of the Peace River for climate change scenarios.

Additional discussion is provided by D. Andres in Section A1.2.

A1.1.6 Future Research Needs

As noted in the above sections, there are great limitations in our understanding of the current hydrologic conditions in the Mackenzie Basin and our ability to model these conditions. For example, it is currently impossible to determine the mean annual water balance of the basin with great accuracy. In fact, only very crude estimates can be made depending on position in the basin, and the scale of interest. In addition, current model limitations make it impossible to predict the effect of climate change with great confidence.

In order to address climate change issues with sufficient confidence, it is necessary to make significant improvements in our current state of knowledge. In order to achieve this we must carry out detailed processes studies, and develop improved hydrological models which are more physically realistic and which incorporate the results of process studies. In addition, since the atmospheric and hydrologic systems interact with each other at large scales, it is essential to link surface hydrology models with atmospheric models. Such dramatic improvements will only occur with long term studies. However, since there is a need to provide more timely answers to the climate change questions, it is necessary to also develop short term studies. Both short and long term studies must have well defined goals and objectives, and the relative reliability of their results must be clearly defined so that unrealistic expectations are not raised. Since short term studies must rely on existing techniques, such studies must be aware of the failings in current modelling techniques which are ultimately hampered by cumulative errors and a lack of basic understanding.

Currently there are two studies of the Mackenzie Basin underway or in the early stages of development. The Mackenzie Basin Impact Study is a shorter term study, which must rely on existing data bases and modelling techniques, while the Canadian GEWEX Programmes study of the Mackenzie Basin will depend on the development of new data collections systems, new process studies to develop physically based parameterization routines, and the implementation of entirely new modelling approaches.

Mackenzie Basin Impact Study

Given the short duration of the MBIS, and the need to provide timely inputs to other components of the MBIS, the following programme is required:

1. Comprehensive Analysis of the hydrologic regime of the Mackenzie Basin: given the poor understanding of the hydrologic regime of the Mackenzie Basin, there is a need for a comprehensive analysis of the present hydrologic regime. Without such an improved understanding of the "current" regime it is meaningless to make predictions of future changes. Such an analysis should carry out a detailed water balance of the major sub-basins of the Mackenzie Basin in order to determine the magnitudes of the inputs and outputs, and the relative importance of various sub-basins to the total Mackenzie flow. Such an analysis would also clearly demonstrate inconsistencies in the existing data bases. This analysis would require the development of a comprehensive data base including data on: topography, snow and ice covers, river discharge, precipitation, air temperature, wind and radiation.
2. Modelling studies: in order to make predictions of the impact of climate change on the hydrological regime of the Mackenzie basin there is a need for a carefully co-ordinated series of modelling studies carried out on basins of various scales. These modelling studies should be integrated with process studies to ensure that important cold regions processes are included in the models. Study basins should cover a range of scales from small basins of the order of 100 km^2, to larger basins up to tens of thousands of km^2. These studies should rely on existing models, but it is essential that they be able to account for changes in vegetation and permafrost. Models selected for use should be physically based parametric models that require minimal calibration. If calibration is required, model testing should be not be carried out on the basins which were used for calibration. The basins selected for study should represent the range of hydrologic regimes typical for the Mackenzie Basin, and the major physiographic, vegetation, and permafrost regimes in the Mackenzie. Using results from such a modelling study, the MBIS would be able to address important regional scale issues. However, the limitations of the model predictions should be clearly addressed.

Canadian GEWEX Program

The Global Energy and Water Cycle Experiment (GEWEX) is a core program of the World Climate Research Programme, sponsored by the World Meteorological Organization and the International Council of Scientific Unions. The scientific objectives of GEWEX are: (1) to determine the hydrological cycle and energy fluxes by means of global measurements of observable atmospheric and surface properties, (2) to model the global hydrological cycle and its impacts on the atmosphere and ocean, and (3) to develop the ability to predict the variations of global and regional hydrological processes and water resources, and their response to environmental change. During the last two years, the Canadian scientific community has been developing a Canadian GEWEX Programme, with the primary objective "to contribute to the international GEWEX Programme in areas of special Canadian interest and expertise and to contribute towards the better understanding and prediction of changes to Canada's water resources arising from climatic change" (Canadian GEWEX Science Committee, 1991).

As outlined by the Canadian GEWEX Science Committee, the long term goal of the Canadian GEWEX Program is to "*Develop the ability to model the water and energy balance of the Canadian*

Arctic basin on scales of approximately 100 km and 1 month". One of the activities which will lead to the achievement of this goal is the Mackenzie GEWEX Study (MAGS) (Canadian GEWEX Science Committee, 1991). This study, which is still in the early stages of development, will (a) augment the existing measurement systems at key locations in the Mackenzie basin to provide long time series of data for use in validating major basin scale hydrological models, (b) carry out selected process studies of the ice, permafrost, and other unique processes of the Mackenzie Basin, leading to improved parameterization for hydrological and related atmospheric models, (c) carry out a major hydrological and related atmospheric modelling program on large river basins, resulting in models that can be tested on the Mackenzie River, and (d) develop a comprehensive data base required for validating new models.

These activities will be carried out during Phase I of GEWEX between now and the launch of the Earth Observing Satellites (EOS) early in the next century. Phase II of GEWEX will be the global data collection period, and will entail the testing of macro-scale hydrologic models integrated with Global Climate Models (GCM's). A major achievement of the Canadian GEWEX Programme will be to provide models that will predict the impact of climate change on the water resources of the Mackenzie basin. Although such models will likely have improved accuracy compared to the models which will be available over the next few years, they will not be fully operational until early in the next century, and as a result will not be available for use in the MBIS.

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continued on page 48

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A1.2 Peace River Ice Regime

Dave Andres, Alberta Research Council

If climate change becomes reality, a significant number of changes will occur in the Mackenzie River Basin. The increased temperatures may lead to a reduction in the extent of permafrost, changes in the patterns of the natural vegetation, a reduction in the stability of frozen slopes, and a redistribution of runoff over the entire year. This will lead to significant changes in the lifestyle of the residents of the area. One important consideration is the effect that climate change will have on the ice regime of the Peace River.

This is important because the Peace River is one of the main tributaries of the Mackenzie River and the river plays a major role in defining the water resource-related constraints in northeastern British Columbia and northwestern Alberta. Because the river is normally ice-affected for about seven months of the year (in one reach or another between the Bennett Dam and the Slave River) and the ice regime is largely a function of both the climate and the way in the Bennett Dam is operated, subtle changes in the temperature regime may have dramatic effects on the ice regime. This could have implications on the winter transportation network, because ice bridges provide the only access across the river at many locations; on water quality, because the ice cover dramatically reduces reaeration at the air/water interface; on water levels in the Athabasca Delta, because ice-related floods are a major factor in maintaining high water levels in the delta; and on the microclimate of some areas of the Peace River valley, because it is possible that a ice cover may not form in some areas.

The study into the effect of climate change on the ice regime of the Peace River is being carried out in three phases, over a three year time frame, with the final report quantifying the impacts of the changed climate regime on the time and duration of freeze-up. Phase I addresses the description, fine tuning, and verification of a freeze-up model that was developed by the Alberta Research Council for the Peace River. This part of the work is focussed on improving the ice generation algorithms and evaluating the procedure by which the border ice growth is calculated. This phase includes a field program to observe the growth of the border ice and to quantify the development of the frazil pans on the river surface. The latter process is important in identifying the role that the floating ice has on the reduction in the ice generation via the heat exchange across the air/water interface.

Phase II will focus on quantifying the boundary and initial conditions to be used in the model. One component of this phase will be to identify the criteria for bridging or lodgement on the Peace River near its confluence with the Slave River. A model describing the lodgement process will be developed and calibrated against the recorded dates on which the ice cover first formed at Peace Point. Another component of this phase will be to assess the effects that the expected changes in the climate regime may have on the way in which Lake Williston is managed by BC Hydro. Because the ice regime is sensitive to both the climate and the river flows, which in turn are a function of the energy requirements within BC Hydro's grid, an evaluation of the effects of the change in the climate on the expected operation of Lake Williston will be undertaken. Much of this will be provided by BC Hydro as part of another study and the results will only be summarized in this phase. The final component of Phase II will identify what the changed temperature regime will be and identify the years on record which most closely reflect the temperature regime. This will serve as an analogue for the changed condition and support the extrapolation that will be made with the model.

Finally, Phase III will document the scenarios which will be predicted by applying the freeze-up model of the changed climate conditions. Recommendations will be made regarding the severity of the impact of the climate change and suggestions will be made to mitigate some of the potentially damaging effects.

The report which describes the work carried out in Phase I has been completed. This report provides:

1. a description of the study area and the relevant ice processes which dominate on the river,
2. a description of the model which was developed to quantify and predict freeze-up on the river,
3. a reassessment of the process of ice generation on the river, including a summary of the data collected to better define an algorithm to compute the rate of ice generation in the presence of flowing ice, and

4. a verification of the border ice growth algorithm.

A field program to measure the longitudinal distribution of surface ice was undertaken to develop a technique to calculate the effects of surface ice on the reduction in the rate of ice production. The rate of formation of the surface ice could be represented by formulating a linear relationship between the vertical flux of suspended frazil and the concentration of suspended frazil. This produced a second order differential equation which relates the surface ice concentration at any location along the river to two parameters - the thickness of the ice floe and the vertical transport velocity. From calibration it was found that the measured surface concentration could be reproduced by setting the floe thickness and the vertical transport velocity to 0.35 m and 0.00002 m/s, respectfully. It should be noted that these parameters are appropriate only for the Peace River and further work would be required to generalize them for other situations.

The field work also provided the first quantitative estimates of the border ice growth rates. It was found that border ice is not a highly significant phenomenum and at most, it only grows to about 15% of the width of the open water channel. Furthermore, the model that was developed from Newbury's data on the Nelson River proved adequate in simulating the growth of the border ice without any further calibration of modification.

With the completion of Phase I, the revised freeze-up model is now ready to be applied to the work in Phase II. The model will be run to identify the appropriate lodgement criteria (start of the development of the annual ice cover) upstream of the Slave River such that the downstream boundary and initial conditions can be stipulated on the basis of the flows in the river and the meteorological conditions. In addition, Phase II will evaluate the effects that climate change will have on the operation of the Bennett Dam and outflow scenario will be developed. Finally, the changed climate will be compared to the historical records to identify which years can serve as analogues for the changed condition.

Phase III will follow in 1993/94.

A1.3 Snow Cover

Barry Goodison and Anne Walker, Canadian Climate Centre

This activity focusses on the use of passive microwave satellite data for snow cover determination in Canadian regions. Algorithms to determine snow water equivalent have already been developed for the Prairie region (south of the boreal forest). During 1990/91, collaborative work was initiated with INAC's Water Resources Division in Yellowknife in order to investigate the application of these current algorithms to the Northwest Territories. Validation and testing of the algorithms continued during 1991/92 and has been extended into 1992/93.

During 1992/93, research has begun regarding the development of a snow water equivalent algorithm for forested areas in western Canada, including the NWT. This effort involves a need for better understanding of the variability of forest species and snow cover. Green Plan funds (outside of MBIS) have been used to support field snow surveys that were conducted in April 1992 by the University of Waterloo in the Mackenzie Valley near Fort Simpson. In May 1992, similar surveys were conducted (with Green Plan support) on Ellesmere Island by McMaster University in order to better understand snow cover variability in the high Arctic region. Both surveys provide essential ground support for the development of passive microwave snow cover algorithms in the northern regions of Canada (Walker and Goodison, 1992).

For further information, please contact either Dr. Barry Goodison (416-739-4345) or Anne Walker (416-739-4357) of the Special Projects Division, Climate Research Branch, Canadian Climate Centre.

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A1.4 Peace River Runoff

W.Q. Chin and Hamed Assaf, B.C. Hydro

B.C. Hydro (BCH) is supporting MBIS by carrying out runoff simulation studies to assess the effects of global warming on runoff conditions in the Williston Reservoir watershed of the Peace River Basin in B.C. A conceptual-type watershed model is being used to simulate snowmelt runoff, rainfall runoff, baseflow and evapotranspiration. The input data needed to run the model are based on daily temperature and precipitation estimates at six nodes surrounding the watershed. These estimates were developed at the Canadian Climate Centre and provided to BCH by MBIS. The estimates include a baseline scenario to represent the climate under current atmospheric level of CO_2 and a global warming scenario using two different GCM models to represent future climate under two times the current level of CO_2. The output from the BCH studies may be useful to other research groups in MBIS to assess possible impacts of global warming on water management, ice cover formation, vegetation, fisheries, wildlife, wetlands and other water related activities.

Some of the important limitations to this runoff study should be underlined. The GCM models were developed to simulate the large scale features of climate. These models do not perform very well for simulating mesoscale topographically-induced climatic features found in the Williston basin or elsewhere in B.C. and were not intended for this purpose. Furthermore, the watershed model that is being used in this study is calibrated on existing data sets for the Williston basin with the assumption that the ecology of the region remains unchanged with global warming. New and improved watershed models based on land cover classifications are being developed and tested that may be more appropriate in global warming studies to account for changes in vegetation, erosion and sedimentation characteristics, and changes in distribution of glaciers and permafrost together with their feedback effects on evapotranspiration, infiltration and hydraulic conductivity rates in the watershed. On the other hand, even if appropriate models were now available for such studies, little or no definitive information is known at the present time about the ecology and related conditions that would occur under the two times CO_2 global warming scenario.

Because of the large uncertainties of both the GCM outputs and the impact on future changes in the ecological system, the current study should be considered only as a first phase of an exploratory study to gain some insight into the potential impacts of global warming on runoff in the Williston watershed. As improved watershed models become operational, sensitivity studies can and will be carried out to assess impacts on runoff by varying the ecological changes for any specific climate change scenario.

A2. Land Resources, Surficial Geology And Natural Hazards

A2.1 Permafrost South of the Beaufort Coastal Zone

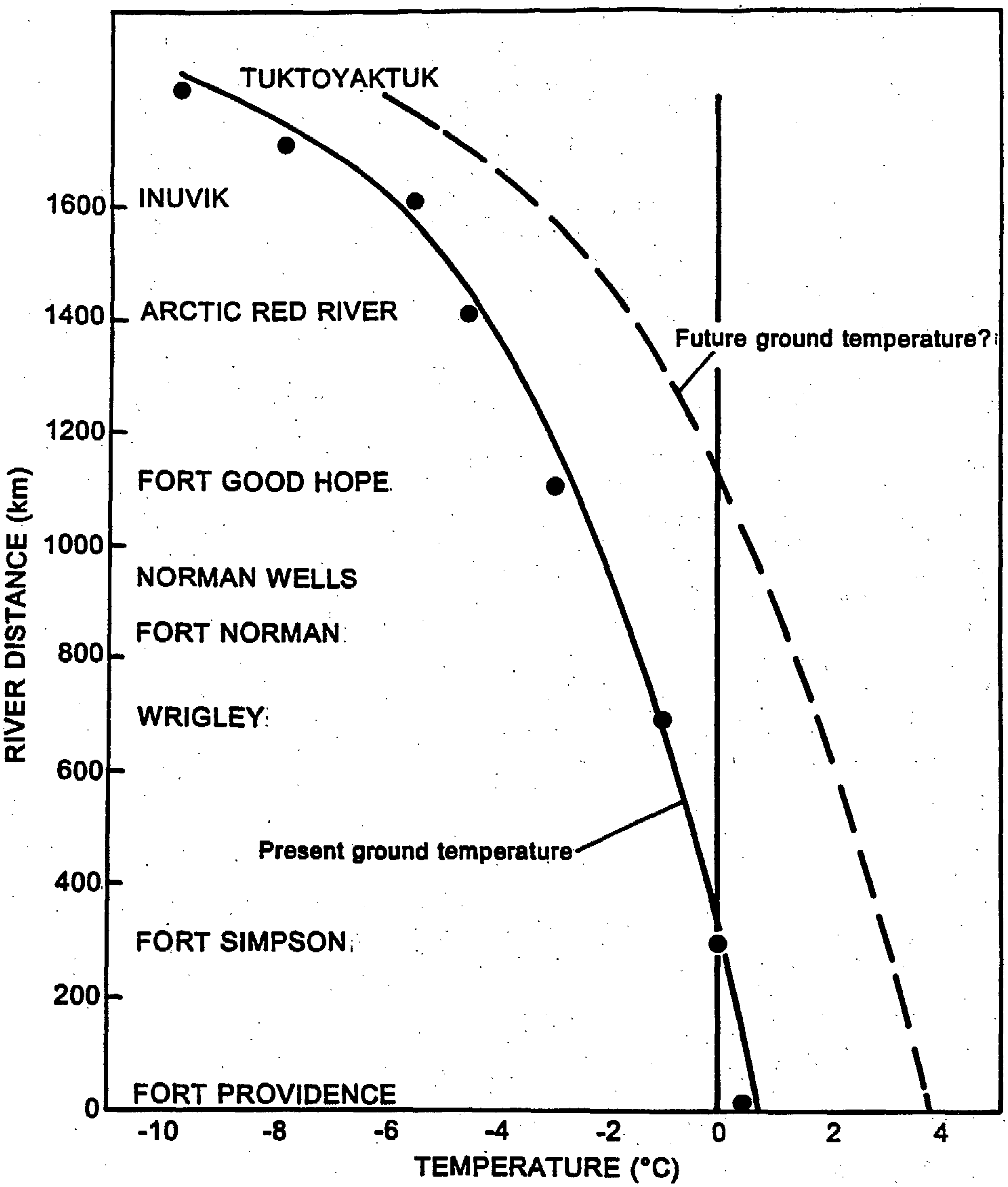
Paul Egginton et al., Geological Survey of Canada

Background

Green Plan research in the Mackenzie Valley Climate Change Observatory is essentially directed toward predicting the impact of air temperature increase on the distribution of permafrost and the processes associated with its degradation. This section concerns permafrost within the Mackenzie Valley and other interior areas, south of the Beaufort Sea. The unique problems of offshore and nearshore permafrost is discussed in Section A3.2.

The most significant changes in permafrost are expected where ice-rich unindurated sediments exist. Melting of the ice will induce subsidence and may initiate slope failures. Changes in permafrost distribution and initiation or enhancement of processes causing soil deformation or failure will undoubtedly have some economic impact because of the importance of these processes in determining the suitability of sites for any kind of building or transportation facility.

Figure A2.1. Profile along the Mackenzie River showing average annual ground temperature for the present and the profile for a hypothetical warming of about 3 °C (Source: P. Egginton, GSC).



As an illustration of the sort of data required to make predictions of process response, Figure A2.1 gives an approximate average annual ground temperature profile at present along the Mackenzie Valley from Great Slave Lake to Tuktoyaktuk. These temperatures are the essential control on the distribution of icebonded permafrost and any change in them will induce changes in active layer thickness and permafrost boundaries. In order to interpret the significance of temperature changes, the properties and conditions of terrain that control thermal response must be known. This is a complex problem because it depends on the various factors that control the transfer of heat to the ground. Vegetation, standing water, and snow cover all influence this heat transfer. These conditions will themselves be influenced by changes in air temperature. To determine the response to hypothetical temperature changes, such as that illustrated by the dashed line in Figure A2.1, it will be necessary to know the efficiency of air to ground heat transfer. It will also be necessary to know the ice content of the ground so that subsidence and changes in strength can be predicted, depending on how much and how quickly this ice melts.

Available Information

A research effort enabling the prediction of heat transfer across the ground surface is impractical because of the complexity of the process. Instead, the approach to the problem of thermal and geomorphic process response is being made by assembling existing information from a variety of sources.

Ground temperature records are available at several locations along the Norman Wells Pipeline between Norman Wells and northern Alberta. These records are being supplemented by the continuing establishment of temperature cables between Norman Wells and the Mackenzie Delta. These records, combined with Atmospheric Environment Service air temperature and snow depth data, as well as the categorization of recording sites with respect to vegetation, provides a means of establishing an empirical relationship between air and ground temperature.

Prediction of processes controlled by thawing of ground ice will rely on ground ice contents recorded in the Mackenzie Valley Geotechnical Data Base. This is a compilation of borehole data collected during site investigations for pipeline and road corridors. It includes logs of geologic materials, water and ice contents, and engineering properties. Surficial geologic mapping at a scale of 1:250,000 has been underway for the last several years and will be complete for the entire Mackenzie Valley within two years. The combination of the Geotechnical Data Base with this mapping will allow surficial units to be characterized in terms of ice content.

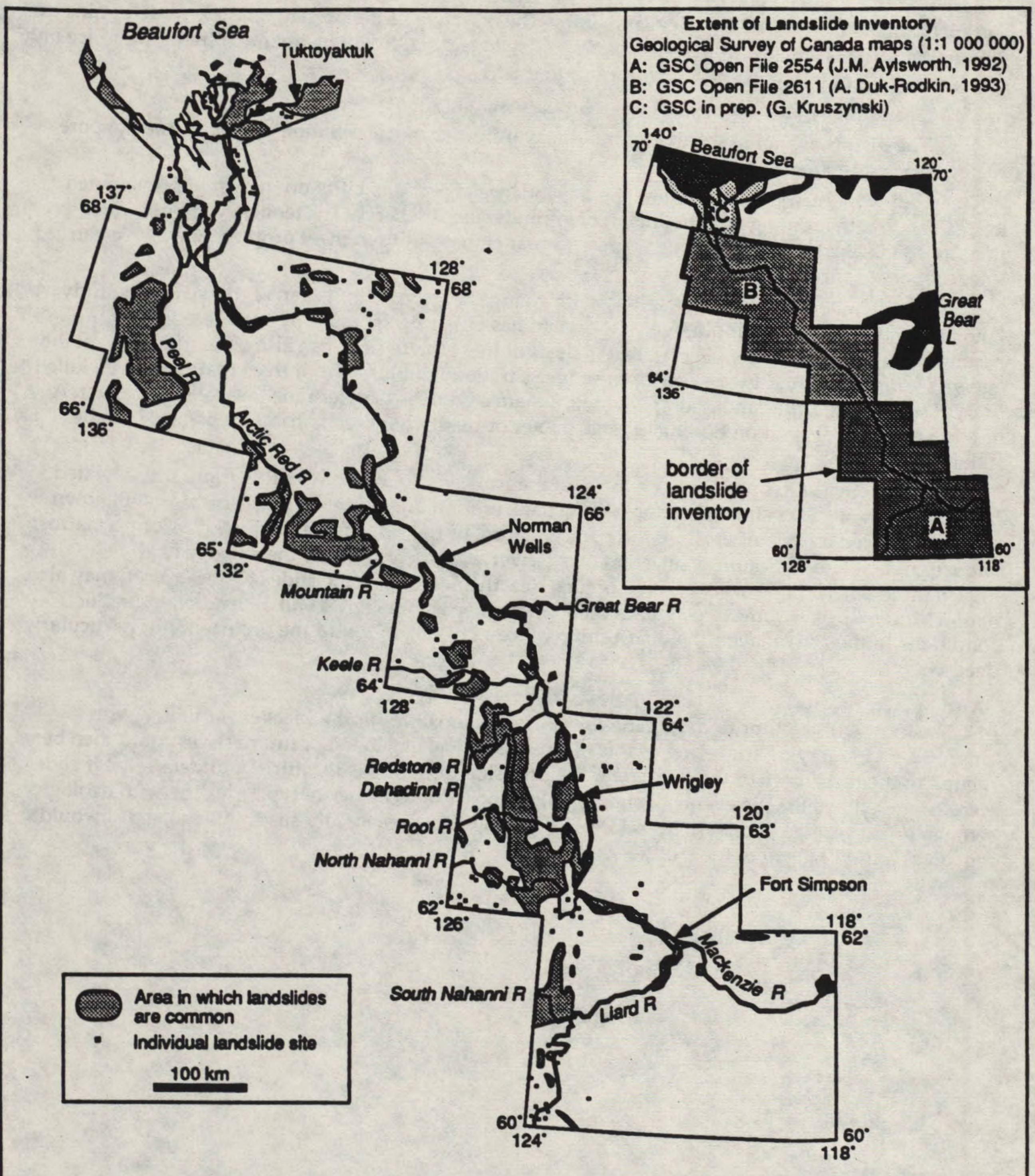
ISSUE: Slope Stability and Climate

Landslides, both as slides and flows, are common in the Mackenzie Valley. River erosion, failure-prone sediments, and thawing ice-rich ground all seem to have some relationship to the occurrence of slides. They take many forms, from active layer detachment slides to thick rotational failures where a block of sediment has moved along a curved failure surface. Because the role of the Mackenzie Valley as a transportation corridor is likely to gain importance, the ability to accurately assess the stability of slopes will also gain importance. Because of the probable link between ice-rich ground and slope failures, the implication of a warming climate for slope stability must also be determined.

Completed tasks

As part of the Geological Survey of Canada's Green Plan research, an inventory of landslides in the Mackenzie Valley has been completed. This inventory includes the mapping, on a scale of 1:1,000,000, of all known slides within a corridor extending about 100 km to either side of the Mackenzie River (Figure A2.2). It also includes a tabulation of slide characteristics: location, size, mode of failure, material, state of activity, and estimate of age. The inventory provides a basis for determining associations between landslides and hypothesized controls such as geologic material, relationship to river channels, and slope aspect. These maps, along with an analysis of the slide characteristics and association with particular materials, will be released as a GSC open file report by the end of the 1992/93 fiscal year. It provides the starting point for a field investigation into slide triggering events and mechanisms causing instability.

Figure A2.2. Distribution of landslides in Mackenzie Valley and adjacent mountainous areas (Source: J. Aylesworth, GSC).



Distribution of landslides in Mackenzie valley and adjacent mountainous areas.
This map is a generalization of a detailed inventory presently available as preliminary maps on open file at 1:1 000 000 scale (see inset). The Geological Survey of Canada intends to release the final inventory within a GSC Paper, accompanied by a database giving location, site information, elevation, dimensions, aspect, mechanism of failure, sediment or rock type, age if known, and other information.

GSC

Field work on mechanisms and triggering events

Presently there is no comprehensive understanding of the factors controlling the occurrence and initiation of these slides. Between 1992 and 1994, field studies are planned to investigate the timing and mechanism of Mackenzie Valley landslides. The objective of the present study is to determine the sensitivity of the sediments in the Mackenzie Valley to sliding. It will be assumed that ground ice and the distribution of permafrost is important in that :

1. Ground ice holds a potential for creating instability.
2. The distribution of ice-bonded ground may influence the distribution and magnitude of pore water pressures.

The study will attempt to determine the dependence of slope stability on thawing of ice bonded permafrost and the routing or impediment of groundwater discharge. The tendency of pore water pressures to be increased, depending on year to year climate and sediment properties, will form an integral part of this study.

The correspondence of past landsliding with changes in climate is also an objective of this study. A landslide can be dated by finding vegetation that has either been buried by the slide or has accumulated as peat on the slide surface. Analysis of tree growth rings can also be used to suggest the age of a surface exposed by a slide. Alternatively, tree ring patterns from trees that have been killed or overturned by a slide can be compared with unaffected trees to determine the age of the event. All of these methods depend on finding organic matter or trees whose relationship to the slide can be reliably determined.

The most active slides appear to be those in the banks of the Mackenzie River and those related to forest fires. River banks slides are triggered by bank erosion but the actual mechanism is not known. The roles played by rate of erosion, mechanical nature of the slope material, thickness of permafrost and ice content and hydraulic connection of the river with the interior of the slope may all be important in determining where a slide occurs. Reactivation of existing slides by toe erosion may also happen and may have some dependence on flood frequency. Skin flows will depend on hydraulic conditions in the active layer, the distribution of ice-rich horizons, and the occurrence of particularly deep thaws.

Anticipated results

This study will attempt to determine the cause of landslides in the Mackenzie Valley with emphasis on identifying triggering events or processes. The likelihood of future slides could then be related to the recurrence of the triggers. If the precision of dating is insufficient to determine if slides were triggered by climatic events, it should still be possible to associate types of slide with geologic settings or triggering processes. Therefore, delineating areas potentially susceptible to slides would remain as a useful result of the study.

<u>ISSUE: Summer thaw depths.</u>

Since 1990 the installation of an array of active layer thickness recorders has been underway. The array has been established along the Mackenzie River and is now complete between the Mackenzie Delta and Norman Wells. It was continued to Fort Simpson during the summer, 1992. The devices record the maximum depth of thaw in any year. They are extremely simple in operation, consisting essentially of an ice-filled tube extending into permafrost. Coloured beads resting on the ice-water interface fall with the thaw and become frozen in the position of the deepest thaw when freeze-back commences.

The intent is to have records in locations representing the complete range of vegetation covers in the Mackenzie Valley. In the short term, the relationship of active layer thickness to vegetation density and height as well as climatic gradient along the Mackenzie Valley can be determined. In the long term, active layer thickness changes can be compared with temperature and precipitation records to gain a direct measure of the influence of changing climate on active layer thickness. The recorders will therefore provide direct indications of the significance of changing climate on permafrost condition.

Anticipated Results

Measured sensitivity of active layer thickness to yearly climate changes will be used to infer response of the active layer to longer anticipated climate changes.

<u>ISSUE: Ground Temperatures</u>

Ground temperatures from within the zone of annual temperature change have been systematically recorded at 23 locations in the Mackenzie Valley since 1984. These recording sites are located along the Norman Wells Pipeline between Norman Wells and northern Alberta. The measurements are being taken to determine the influence of the pipeline right-of-way on ground temperatures. Right-of-way sites are complemented with measurement sites off the right-of-way, providing a ground temperature record that is representative of natural vegetation.

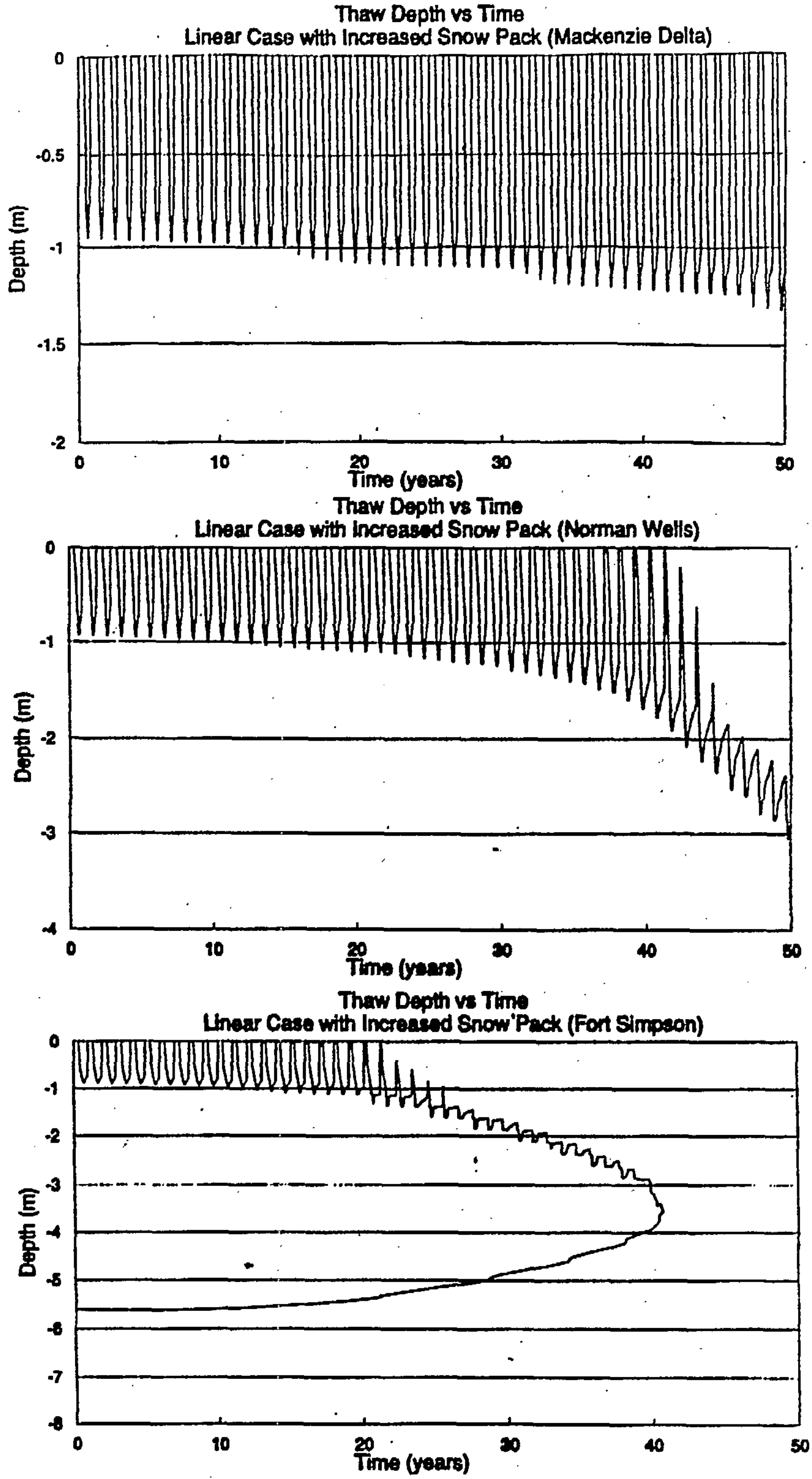
These temperature measurements offer a primary means of monitoring the effect of changing air temperatures and snow cover on permafrost distribution and stability. They will be of primary importance in improving the accuracy of temperature distribution profiles such as Figure A2.1. If ground temperatures can be characterized with respect to vegetation and can be compared with yearly changes in air temperature and snow cover, a direct means for predicting impact of climate change is available.

Anticipated Results

Measured responses of active layer thickness and ground temperature to yearly changes in climate will form the primary basis for developing predictions of long term changes in permafrost distribution and temperature. These analyses will necessarily apply only to specific sites of measurement at first. As more ground temperature and surface climate data becomes available, it will ultimately be possible to plot zones of permafrost sensitivity to climate change. This analysis will require input from climate change models and its accuracy will depend upon how thoroughly the relationship of ground temperature to environmental factors is understood.

Preliminary results of thermal modelling for three locations in the Mackenzie Valley (Mackenzie Delta, Norman Wells, and Fort Simpson) are shown in Figure A2.3. This diagram shows the increase in thaw depth that would occur for a linear increase in average annual temperature and increase in snow depth over the next 50 years. The increase in temperature is assumed to be 5.0°C for the Mackenzie Delta and 4.2°C for both Norman Wells and Fort Simpson. Snow depth increases were assumed to be 10% over the 1951-1980 averaging period.

Figure A2.3. Thaw depth at three locations in the Mackenzie Valley over the next 50 years under a linear increase in temperature of 5 °C for the Mackenzie Delta and 4.2 °C for Norman Wells and Fort Simpson (Source: M. Burgess, GSC).



A2.2 Land Resources

Mike Brklacich, Carleton University

Phase I of the agricultural component of the MBIS will provide land-related information. The required tasks will be completed during the 1993 calendar year and land-related data should be available in late 1993. The land resource potential assessments will be conducted relative to baseline and altered climates.

The CLI rating scheme has been used extensively to rate lands for agriculture, but has proven to be less than dependable in northern climates. The major problems with the CLI under northern conditions is that it does not adequately consider the impacts extended daylengths and mid-season non-killing frosts.

A new land rating scheme designed for application at more northerly latitudes will be used. Preliminary tests in the Yukon provide encouraging results although the approach is currently being refined. Three components comprise the system (soils, climate and landscape), with each component being treated on an equivalent basis in the overall rating. Ratings are based on a 0 to 100 point continuous ratio scale, but these will be aggregated into 7 classes similar to CLI ratings, with Class 1 representing the highest capability and Class 7 repesenting the lowest capability.

No new data collection exercises will be undertaken. The required soils and landscape data will be drawn, and if required inferred, from existing soil surveys and from the recently completed Generalized Soil Landscape Maps for northern Alberta, northern British Columbia and the Northwest Territories. Baseline climatic and climatic change data will be provided by the Atmospheric Environment Service.

A3. Sea Ice And Coastal Stability

A3.1 Beaufort Sea Ice

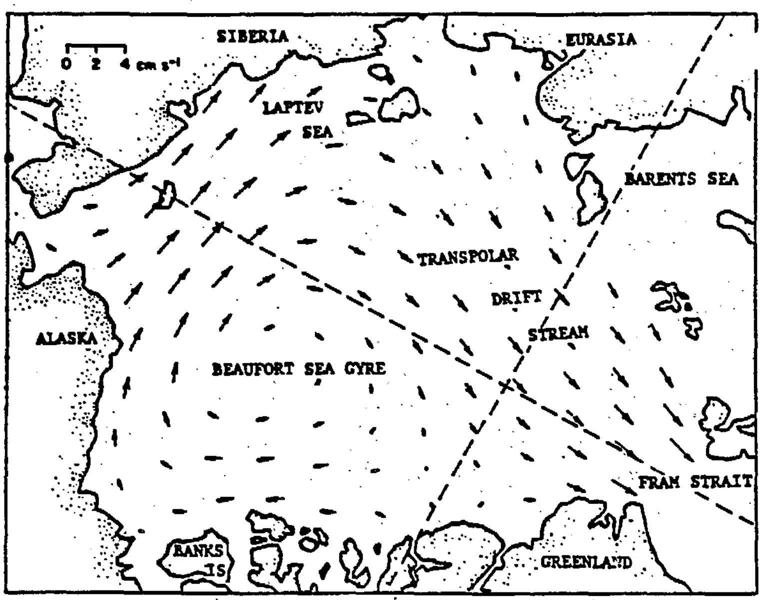
Tom Agnew, Canadian Climate Centre

A3.1.1 Climatology and Ice Conditions

Introduction

Sea-ice is an integral part of the global climate system (Parkinson, 1989) especially in its capacity to act as major planetary heat sink at the poles and as a thermal and moisture barrier between the Arctic Ocean and atmosphere. The sea ice over the Arctic Basin is also under continuous motion caused by atmospheric circulation and ocean forcing. The mean motion is shown in Figure A3.1. This motion creates cracks or leads in some areas (allowing the formation of new ice) while buckling the ice in other areas creating thick ridged ice. The result is a mixture of ice of different thicknesses and different types and is usually referred to as "pack ice". Of particular note in Figure A3.1 is the clockwise motion of the pack ice in the Canada Basin referred to as the Beaufort Sea Gyre. The variability in the extent, intensity,

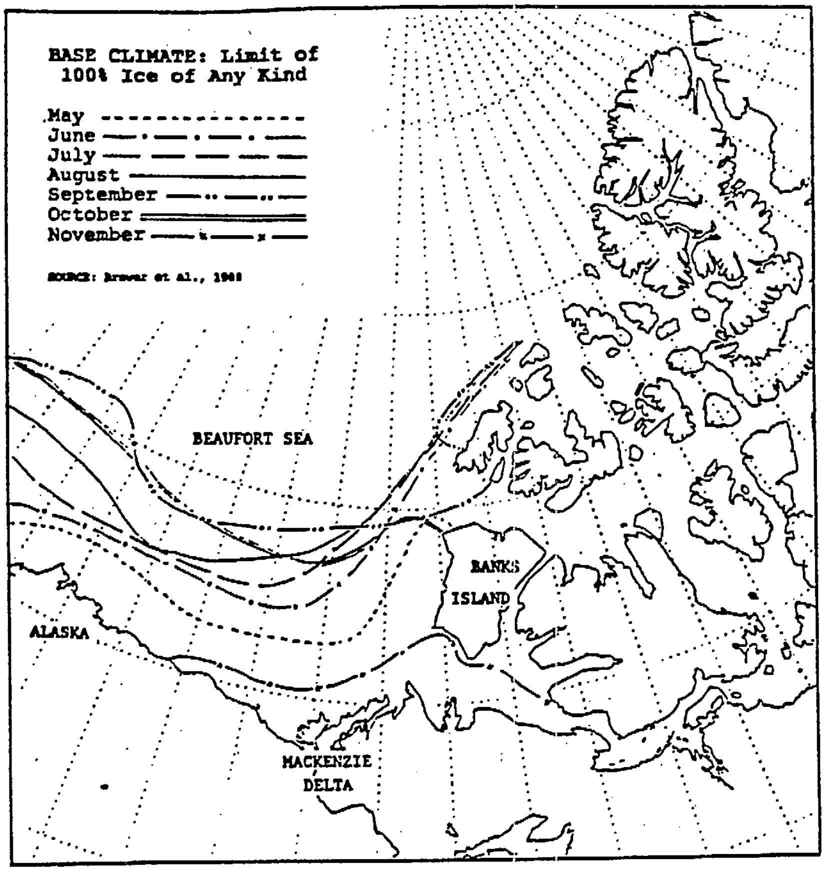
Figure A3.1. Mean annual sea ice motion, taken from Thorndike and Colony (1982).



and even reversal of this Gyre affects sea ice conditions in the coastal regions of the Canadian Beaufort especially the invasion of multiyear ice in summer. Changes in the Gyre are to a large extent atmosphere forced and can cause considerable deterioration and opening of the pack ice.

On a regional scale, sea ice cover plays a different role by exerting very strong control over ocean-atmosphere interactions (e.g. Johnson, 1990). These interactions result from: (a) ice/water albedo contrasts; (b) different thermodynamic effects on the atmosphere and oceans associated with ice; (c) associated changes in moisture flux, cloud cover and cyclogenesis; and (d) the varying and different time scales and lag times associated with atmospheric and oceanographic processes.

Figure A3.2. Limit of ice edge for Canadian Beaufort Sea, based on 100% of ice of any kind.



Seasonal Ice Conditions in the Southern Beaufort

The mean monthly position of the ice edge is shown in Figure A3.2. In the summer, the southern Beaufort Sea is generally ice free from the shore to the pack ice which generally lies about 150 km offshore. In October, ice starts to form in the shallow, fresh water, coastal regions as the temperature drops and by the end of October the entire area is usually covered by thin (0 to 30 cm) ice. As the winter continues, the ice thickens and consolidates.

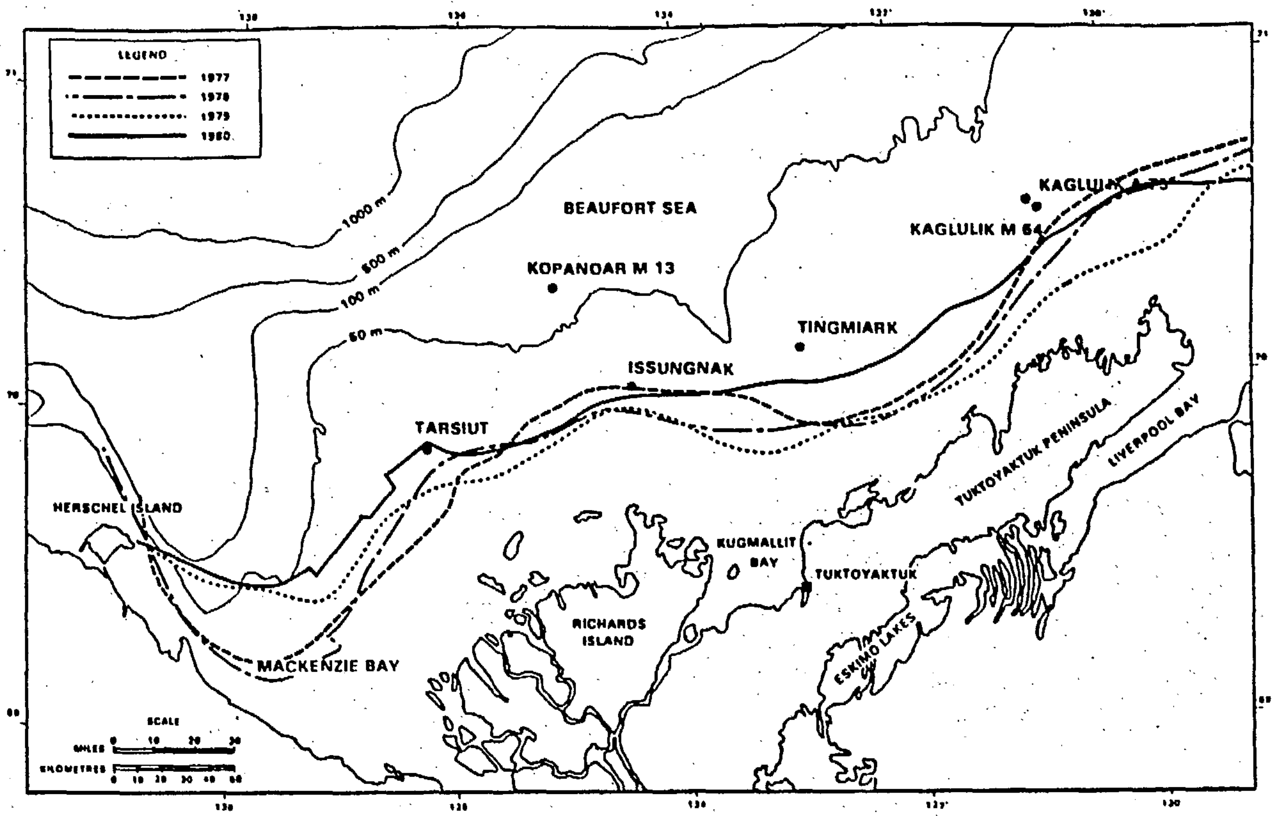
Ice nearshore attaches itself to the shoreline and grounds out in the shallow water to form "landfast" ice. As the ice thickens, the landfast ice extends further from shore until December or January when it reaches its maximum extent, (see Figure A3.3).

By early January, the landfast ice is at its furthest extent approximately the 20 m isobath. The landfast ice is generally stabilized by a shear ridge which delineates its outer edge. The floating pack ice beyond the landfast ice remains unattached to this shear ridge (due to tidal action) and moves freely offshore.

The region of the shear ridge at the outer edge of the fast ice is known as the "shear zone" and this region is very active throughout the winter. Ice cover in this region may vary from open water to 10/10 and from thin to thick ice; up to 900 ridges per month greater than 2 metres thick may pass over a particular location (Pilkington et al., 1991). Figure A3.4 shows the different ice regimes in the southern Beaufort Sea in winter; the landfast ice close to shore, the shear zone and seasonal pack ice zone, and the permanent polar pack beyond.

In late May the ice stops growing and in early June it starts to deteriorate and melt due to the combined action of 24 hours of sunlight and above-freezing air temperatures. The warmer Mackenzie River water melts the fast ice around the river's many tributaries and the adjacent shoreline, and offshore winds blow the pack ice offshore. Slowly the landfast ice deteriorates and moves offshore, the last pieces dispersing by mid-July.

Figure A3.3. Maximum extent of landfast ice from 1977 to 1980 (EIS. 1982; Spedding, 1979).



Oceanographic Processes

The most recent study of the freshwater and heat budget of the southern Beaufort Sea (Fissel and Melling, 1990) suggest that in summer 70% of the freshwater originates from Mackenzie River discharge with the remainder from melting ice. The heat budget is dominated by radiation and exchange with the atmosphere. Both freshwater and heat content of the ocean in the area can vary considerable from year to year and is related to the extent of open water.

Extreme Ice Conditions

In a typical "good" summer, the southern Beaufort Sea is ice-free between the shore and the pack ice, which lies at about 72.5 degrees N latitude, from early August to late September. In "bad" years, the early summer easterly winds do not occur and the pack and landfast ice does not move offshore but remain in the southern Beaufort Sea and slowly melt. The recurrence interval of bad years appears to be 9 or 10 years, (e.g. 1964, 1974, 1983). Some years the ice clears only to return from either the north or west, driven by autumn storms. During these events, multi-year old ice may enter the region and ground in the shallow waters to form the start of the landfast ice.

These extreme ice features can cause serious damage to fixed offshore structures. Such features may be ice islands which originate in the ice shelves on the north shore of Ellesmere Island (Jefferies and Wright, 1987), multi-year hummock fields, which are believed to originate on the western edges of the Arctic Islands, and old thick multi-year floes, which can form any where within the pack ice. Such features may be up to 40 (plus) m thick. The open water summer season varies from 0 to 125 days at typical southern Beaufort Sea well sites.

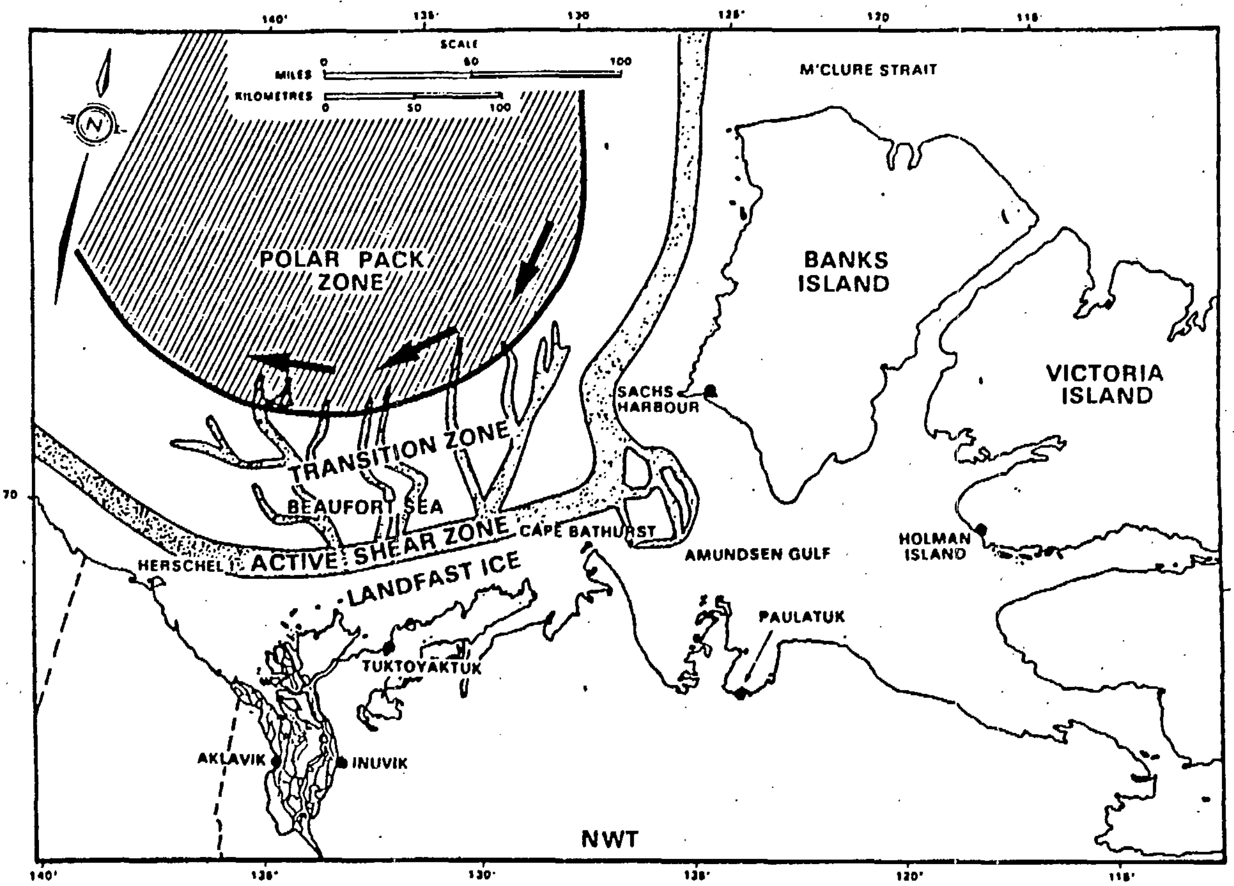
Ice Scour

When deep ice features are driven into shallow water they scour the sea floor. The majority and deepest scours are at the 20 to 25 m water depth (Hnatiuk and Wright, 1983). At these water depths there are in excess of 10 scours/km and the average depth is 1 to 2 m, but this may range up to 5 m. Sea bottom equipment - pipelines, feeder lines, cables, well heads, etc. - must be set below the seabed to protect them from scour.

A bibliography for ice scour is provided in ESRF (Environmental Studies Revolving Fund; 1986). Reports on scour interpretation and implication for offshore operations are provided in workshops proceedings edited by Canada Oil and Gas Lands Administration (COGLA; 1990), and references cited therein.

Strudel scours may also occur in the Mackenzie Delta in the spring, when the Mackenzie River floods over the ice, pours down through melt holes and cracks in the ice and excavates the seabed. In the U.S. Beaufort Sea, strudel scours up to 10 m diameter and 4 m deep have been observed (Reimnitz et al., 1974). None has been observed to date in the Mackenzie Bay area but the potential is there (Pilkington, 1987) and deep flooding on the ice in Mackenzie Bay has been observed.

Figure A3.4. The different ice regimes in the southern Beaufort Sea (EIS, 1982; Kovacs and Mellor, 1974).



A3.1.2 Implications of a Warmer Climate

Impacts on the Beaufort Sea Ice Regime

A global warming trend could result in dramatic changes to the sea ice cover in marginal ice covered seas such as the Canadian Beaufort Sea Coastal zone. Such changes could have a considerable impact on the wave climatology in the area and coastal erosion. These changes would clearly affect the operation and design activities of the oil and gas industry operating in the Beaufort Sea area.

An exploratory study, funded in part by the Panel on Energy Research and Development (PERD), was done to examine possible impacts of global warming on the Beaufort Sea ice regime and implications for the Offshore Petroleum industry (McGillivray, 1992). The study found that in a doubled CO_2 climate: a) the open water season would increase from current average of 60 days to approximately 150 days with an increase in the extent of open water of from 150 - 200 km to 500 - 800 km; b) the maximum ice thickness would decreased by 50 to 75 %; c) significant wave height during the open water season would increase from 16 to 40%.

In terms of Petroleum industry impacts, the general reduction in ice thickness and increase in open water season will have positive impacts in terms of reduced cost for design and operation; however, increased wave height and period and increased coastal erosion will have negative impacts. The study included a half-day workshop with industry representatives. The general consensus from the Petroleum Industry was that the opportunities to reduce costs in design could not be realized because of the conservative approach that the industry must take in its planning and because design of structures would have to incorporate present environmental conditions as well as possible future conditions.

The following recommendations are made for the future study of climate change and its impacts in the Beaufort Sea region:

(a) Efforts should be made to identify and understand the feedback linkages between the atmosphere, cryosphere and ocean in particular albedo, cloud, baroclinicity, oceanic circulation, salinity and the thermal inertia of the system. There is a need to study the thresholds and intensity of these individual processes and the net effect of several of these processes acting in concert.

(b) From a better understanding of these feedbacks, higher spatial and temporal resolution in a GCM can be developed leading to better estimates of changes in storn frequency and intensity under a future warm climate. A denser network of data points would also aid in defining areas of pack ice recession.

(c) From a planning point of view, the transitional period between present and future climates should be investigated, particularly in terms of climate variability and its impact on offshore operations. This can best be done when next generation transient response models are available.

(d) As the confidence and quality of climate change scenarios improves several new studies should be initiated including: - application of more sophisticated sea-ice models (including advection) to investigate the impact of warming trends on the Beaufort sea-ice regime; - application of wave climate models to investigate the deep and shallow water wave regime as well as the problem of coastal erosion and permafrost melt near the coast; - application of storm surge models to investigate how sea level rise would impact coastal areas.

(e) It is also recommended that the dialogue between industry and the research community continue so that pragmatic problems are addressed in climate change studies.

Factors affecting coastal stability

Changes in the following parameters should be considered in evaluation of impacts on coastal stability due to warmer climate:

- the length of the open water season and the extent of open water;
- wind forcing on the upper ocean layers and the associated current regime;
- the sea-ice regime (e.g. summer ice intrusions,thickness of first- and multi-year ice, frequency and thickness of ice islands;
- short (storm surge and seiche) and long term changes insea level which will affect the low lying areas of the Beaufort coastline, particularly in the Mackenzie Delta;
- the synoptic systems (e.g. frequency, duration andintensity of storms) and the position of the storm tracks;
- the deep and shallow water wave climate which will be affected by changes in both the fetch (controlled by the dynamic ice edge) and wind conditions;
- the permafrost regime and runoff characteristics of the catchment areas draining into the Beaufort Sea.

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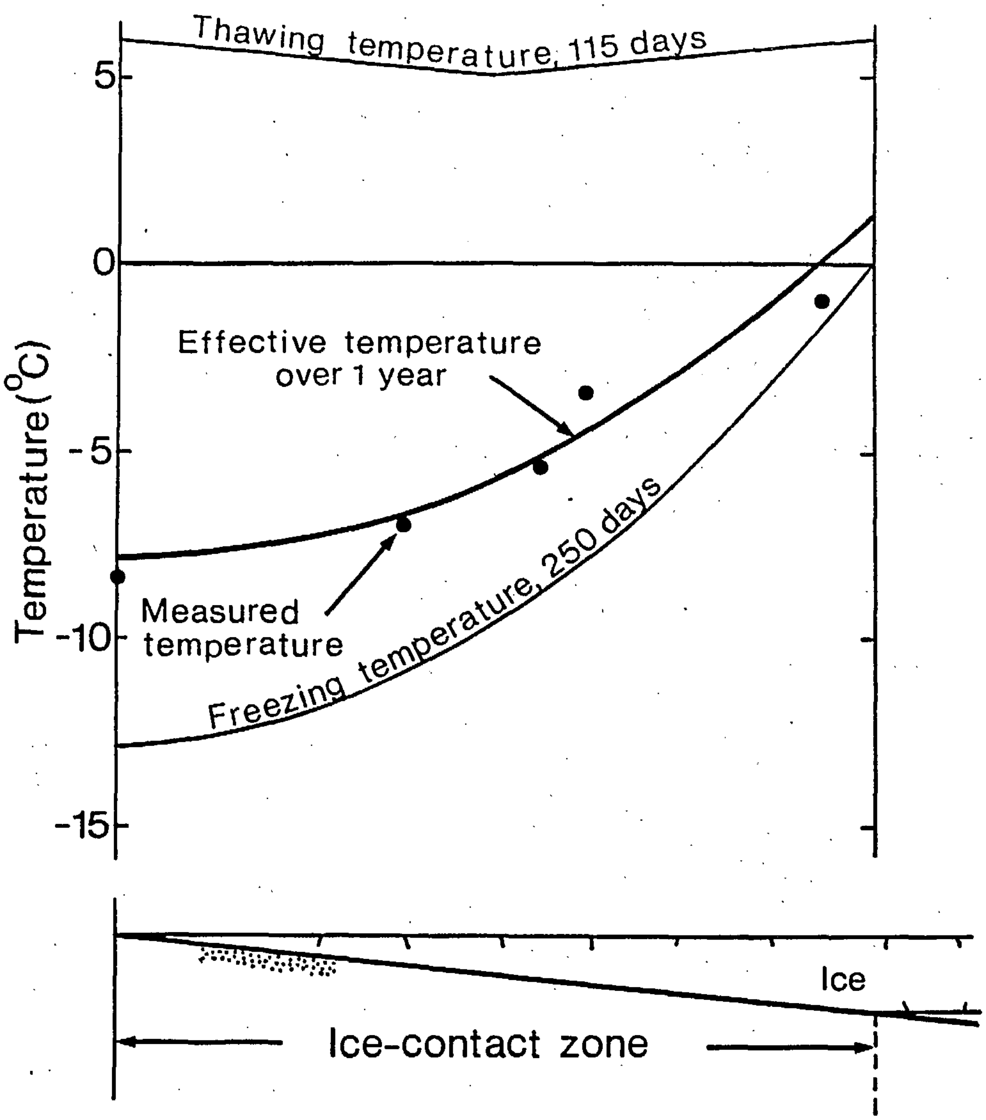
A3.2 Coastal Erosion and Permafrost Stability

Paul Egginton et al., Geological Survey of Canada

In the vicinity of North Head, Richards Island, permafrost is undergoing a variety of modifications in response to coastal erosion, sediment redistribution, and lake filling. Borehole transects, additional thermal data from jet drilling and sea water temperature measurements as well as additional ground temperature studies have resulted in a detailed understanding of permafrost distribution and temperature adjustment beneath waters bordering the generally eroding uplands of northern Richards Island.

A3.5. Average annual temperature across the zone in contact with winter sea ice along the Beaufort Sea coast. This plot of reconstructions using differing climates can be used to predict ground temperature distributions offshore from retreating coasts or on newly formed land.



Completed tasks

For this area a method for predicting the depth to the thawing surface has been developed. It is based on the reduction in the freezing index at the seafloor caused as the thickness of sea ice in contact with the seafloor increases. It is also necessary to know the thermal history of the seawater during the unfrozen interval. The temperature of the sub-seafloor is thus a function of sea ice thickness and thermal history during the open water season (Figure A3.5). The application of this approach accurately predicts the depth of thaw to 500 m offshore along the Geological Survey of Canada retreating coast borehole transect at North Head. Beyond this distance boreholes did not extend into ice bonded sediments.

Several ground temperature cables in the spit and associated sediment platform that extends eastward form North Head were supplemented by three cables placed during the spring, 1990. These three cables are intended to identify any thermal adjustment that may still be occurring following the breaching and filling of tundra lakes. All of these records will serve to determine if areas exist were ground temperatures are still adjusting to recent opportunities for permafrost re-aggradation.

Extension of thermal modelling into the Mackenzie Delta

On the basis of the success in predicting the progress of thaw in the North Head area, summer field work in 1990 and 1991 has been used to extend ground temperature studies westward into the modern delta. The combination of sediment deposition and reworking in a very shallow environment is likely to result in a different distribution of permafrost and ground temperature compared with that adjacent to the older upland terrain to the east. Channel migrations, coastal erosion, and growth or disappearance of distributary mouth bars are processes in this environment that will likely affect ground temperatures. The fact that much of this change occurs in water depths less than the maximum ice thickness suggests that the modelling approach used at North Head can be applied in the modern delta.

The following series of events could produce a large change in ground temperature at a given location at the delta front:

1. Local coastal retreat transfers a point from a well established, vegetated island to an adjacent distributary channel.
2. Retreat continues or the channel migrates, either case resulting in redeposition and shallowing.
3. A subaerial bar forms, eventually becoming vegetated.

Warm, ice-bonded permafrost on the well established island would thaw, then re-aggrade rapidly once the water had shallowed sufficiently to bring the seafloor into contact with winter sea ice. With subaerial exposure, the ground temperature would be considerably below that for the original vegetated site. However, it would warm as the bar became a vegetated island. This cycle probably causes the most extreme temperature variation that could occur at the delta front. Locations matching the physical description of all the stages of the cycle are well represented. It is the rate at which one stage is progressing to the next which will determine the actual ground temperature at any location.

Anticipated applications of thermal modelling

The difference between expected equilibrium ground temperatures and observed temperatures at the delta front is being used to determine how rapidly sedimentary environments are changing. This modelling depends on the assumption that the present yearly temperature histories for given environments don't change. However, if different thermal histories are available, then changes in ground temperatures or changes in the distribution of permafrost can be predicted. The behaviour of the Mackenzie River is the single most important factor controlling ground temperatures. The duration and temperature of the summer heat pulse and the depth in the Beaufort Sea to which this reaches controls the rate of seafloor thawing along much of the retreating Beaufort coast. Changes in the thermal behaviour of the river would also cause changes in the present distribution of permafrost in the delta apart from those due to the dynamics of the fluvial environment. Once the present thermal regime has been linked to present ground temperatures, it will be possible to extend the modelling to predict the response of ground temperatures to other thermal histories controlled by the Mackenzie River.

A4. Terrestrial Ecosystems/Biomes

A4.1 Vegetation of the Mackenzie River Basin

Barbara Nicholson[1], S. E. Bayley[1], S. Zoltai[2], D. H. Vitt[1], and D. Gignac[1]
[1] *U. of Alberta*
[2] *Northern Forestry Centre*

The drainage basin of the Mackenzie River stretches some 2400 kms from southwest of Edmonton to the arctic coastline and encompasses 3,600,000 sq. Km. A diverse flora exists within the drainage basin and the basin is dominated by the Boreal and Subarctic Ecoclimatic Provinces (Ecoregions Working Group 1989). The vegetation of the Mackenzie is primarily Boreal forest in the south and Subarctic woodlands in the north (Figure A4.1). On the western boundary of the basin the higher elevations of the mountains create a complex mosaic of vegetation types which are normally tree dominated. On the eastern side of the basin the subarctic woodlands and zone of continuous permafrost extends much further south than in the western portion of the drainage basin. The eastern portion of the basin is underlain by the Precambrian shield with minimal soil. This portion also has numerous lakes, which are far less common in the western and southern portions of the basin. Peatland areas of the Mackenzie River Basin have not been mapped in detail, although peatlands are numerous in both the Boreal and Subarctic Ecoclimatic Provinces (Figure A4.2). The Alberta peatlands have been classified and mapped in great detail (1: 1,000,000) and our data show that the peatlands of Alberta cover 13,774 x 10^3 hectares of which 12% are permafrost bogs, 16% are bogs, 32% are poor fens, and 40% are rich fens. The majority of Alberta peatlands occur in the Mackenzie River Basin. Here we summarize the terrestrial and wetland vegetation of the Mackenzie River Basin.

A4.1.1 Boreal Ecoclimatic Province

The Boreal forest predominates in the southern portion of the drainage basin. The Boreal forest is characterized by closed canopy forests of northern tree species. In this region of Canada the Boreal forest is subdivided into three regions; Subhumid Low Boreal, Subhumid Mid-boreal, and Subhumid High Boreal.

The most southerly region, the Subhumid Low Boreal, is dominated by deciduous forests of trembling aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*) (Ecoregions Working Group 1989). Dry sandy sites are dominated by open stands of jack pine (*Pinus banksiana*). Peatlands in this area are generally restricted to basin fens and bogs. Fens are often *Larix laricina* dominated with a variety of bryophytes. *Picea mariana* bogs contain an understory of *Ledum groenlandicum, Sphagnum fuscum, Sphagnum magellanicum,* and *Sphagnum angustifolium. Typha* marshes commonly surround shallow open-water bodies which can be fringed with *Salix* and *Calmagrostis canadensis.*

In the Mid-Boreal ecoclimatic region *Picea glauca, Picea mariana* and *Abies balsamea* become more predominant, particularly as secondary successional species (Ecoregions Working Group 1989). *Pinus banksiana* and *Picea mariana* still dominate in well drained upland soils. Wetlands become restricted to fens and bogs dominated by bryophytes, along with open stunted stands of *Larix laricina* and *Picea mariana*. Patterned fens are common along with permafrost peat plateaus and basin bogs (Zoltai et al. 1988).

Subhumid High Boreal forests are characterized by forests of *Abies balsamea, Picea glauca, Picea mariana, Populus tremuloides,* and *Betula papyrifera* (Ecoregions Working Group 1989). In the areas surrounding the Hay and Peace Rivers there are northward extensions of the mixedwood forest which are dominated by *Populus tremuloides* (Parkes 1973). The Subhumid High Boreal extends considerably northwards along the Mackenzie River Valley (Fig. A4.1). Here on the alluvial flats bordering the Mackenzie River *Picea glauca* and *Populus tremuloides* grow, along with *Betula papyrifera* occupying old leeves (Parkes 1973). At higher elevations above the floodplain, pines and aspen can be found growing on well-drained soils, while *Picea glauca, Picea mariana* and *Betula papyrifera* are found on average soils (Crampton 1973). Normal understory flora consists of *Pleurozium schreberi, Cladonia alpestris, Cornus canadensis, Maianthemum canadense, Epilolobium angustifolium, Rosa acicularis, Cornus stolonifera, Rubus pubescens, Calamagrostis canadensis,* and *Ptilium crista-castrensis*. In this area peat plateaus and sloping shallow peatlands (veneer bogs) are more common than the fens (Zoltai et al. 1988).

Figure A4.1. Approximate boundaries of the ecoclimatic regions of the Mackenzie River Basin (Intergovernmental Seminar 1972 and Ecoclimatic Regions of Canada).

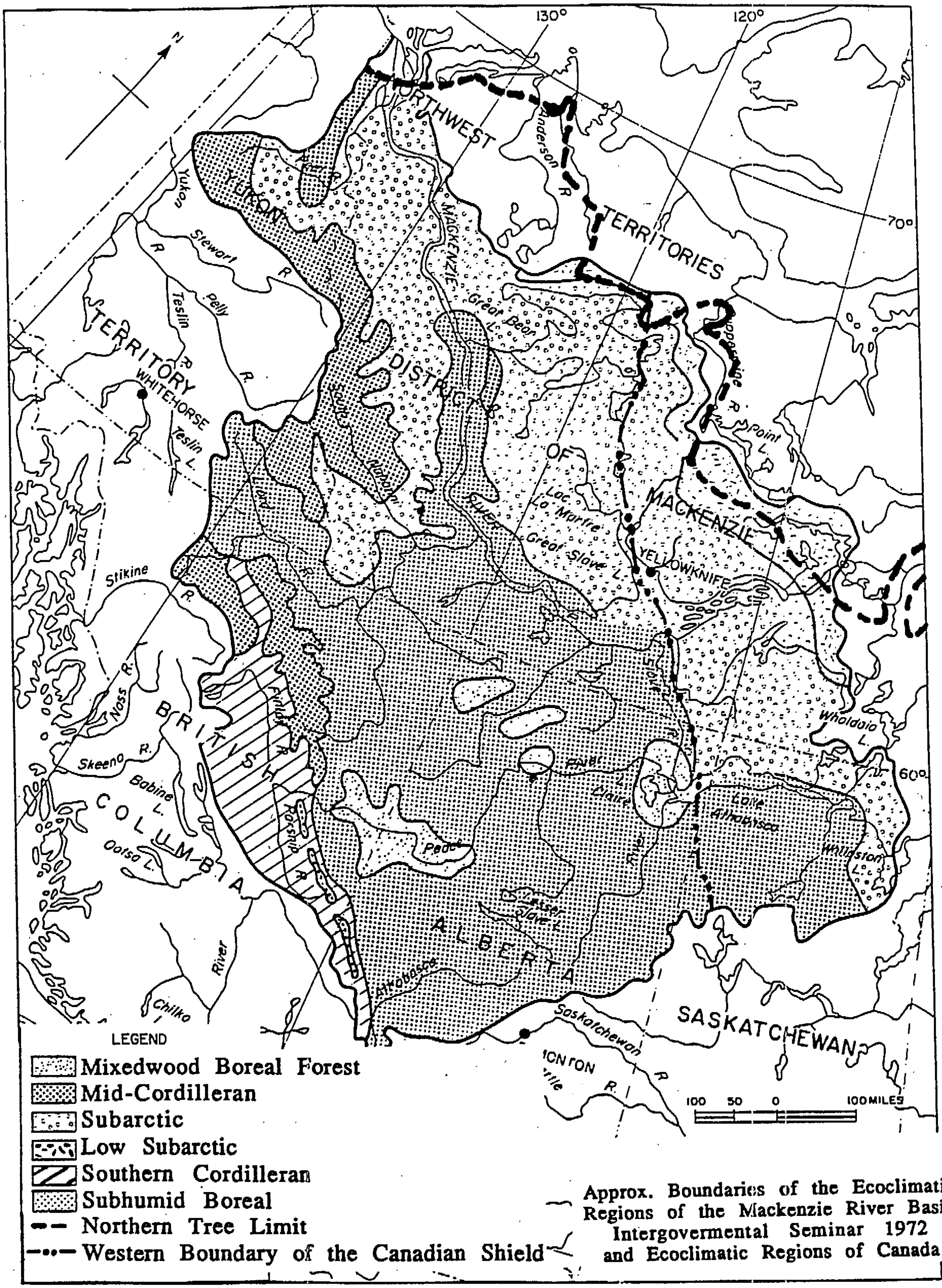
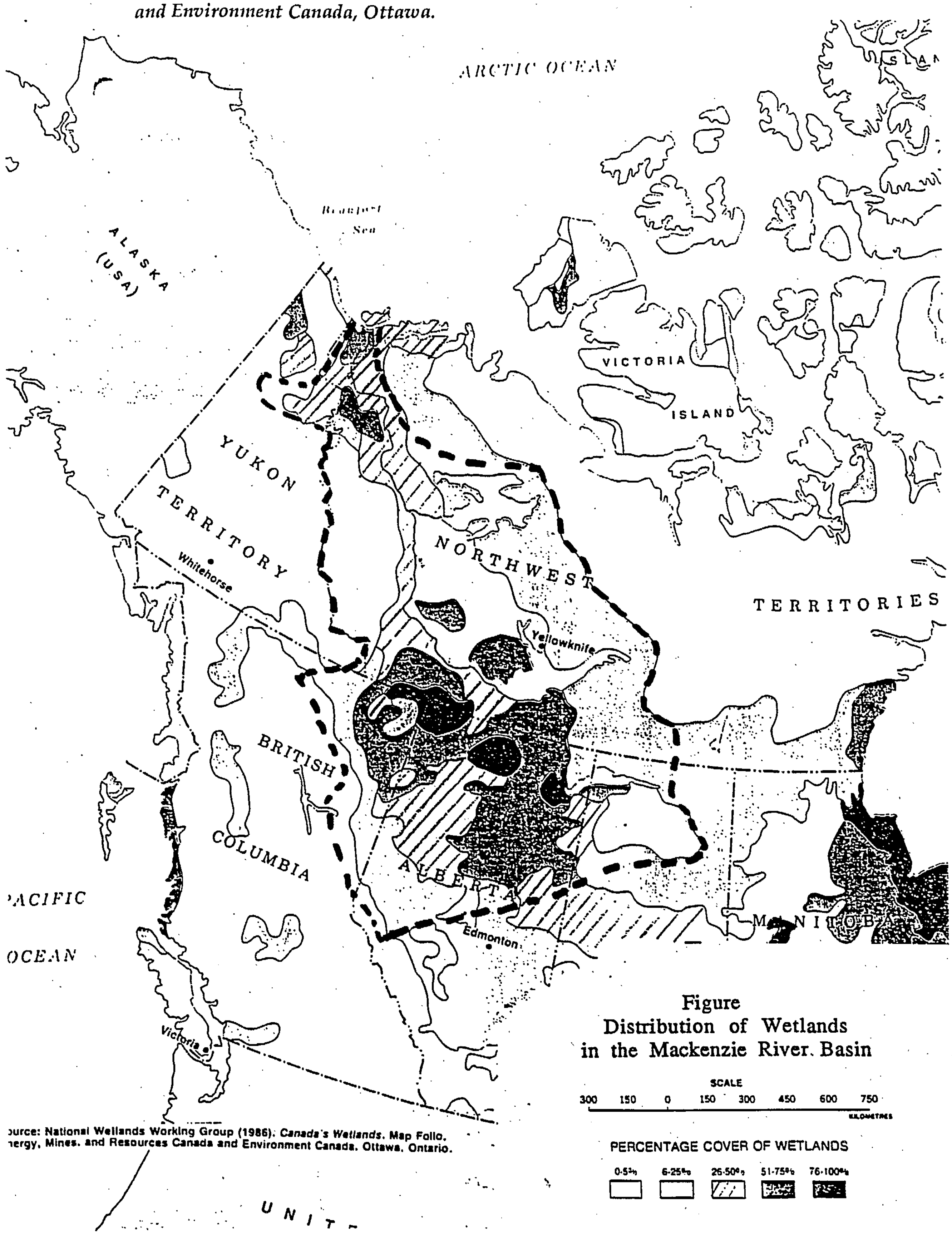


Figure A4.2. Distribution of wetlands in the Mackenzie River Basin. Source: National Wetlands Working Group (1986), Canada's Wetlands. *Map Folio. Energy Mines and Resources Canada and Environment Canada, Ottawa.*



The presence of permafrost affects the vegetation cover in the Subhumid High Boreal region. Crampton (1973) arranged vegetation types of the upper and central Mackenzie Valley into land systems based on the presence or absence of near-surface permafrost. In this area, well drained upland soils with near-surface permafrost are dominated by *Picea glauca, Picea mariana,* and lichens. Seasonally waterlogged soils without near-surface permafrost contain *Picea mariana, Larix laricina, Betula papyrifera, Betula glandulosa, Populus balsamifera, Salix,* ericaceous shrubs, *Sphagnum fuscum, Sphagnum rubellum, Carex,* and *Eriophorum.* Seasonally waterlogged lands having near-surface permafrost have a 'marbloid' appearance due to a increase in the amount of lichens. Open stands of *Picea mariana* occur on these sites with ground covers of lichen, ericaceous shrubs, *Ledum, Empetrum,* shrubby cinquefoil, dwarf birch, and *Salix.*

Peat plateaus have sparse Picea mariana cover with Betula papyrifera and Pinus. Ledum grows profusely along with Vaccinum vitis-idaea, Potentilla fruticosa, and Rubus chamaemorus. Collapse scar fens contain Sphagnum squarrosum and Equisetum. Slopes in this region are lineated with a sub-parallel drainage pattern consisting of runnels located from 50-600 yards apart. Picea mariana grows in the runnels. Lower slopes are wet with Sphagnum, Carex, Betula, and Salix dominating the areas in between the runnels, whereas upper slopes are dry having lichen, Ledum, Betula, Empetrum, Vaccinum vitis-idaea, and shrubby cinquefoil between the runnels.

On the western fringes of the Subhumid High Boreal, such as the upper Liard region, lodgepole pine (*Pinus contorta*) can be found on the upper plateaus with *Picea glauca* and *Populus tremuloides,* while *Abies balsamea* occurs with *Picea glauca, Pinus contorta,* and *Populus tremuloides* nearer the treeline (Parkes 1973).

A4.1.2 Cordilleran Ecoclimatic Province

According to the Ecoclimatic classification scheme, the Cordilleran Ecoclimatic Province has been subdivided into Southern, Mid, and Northern regions as well as Boreal, Subalpine, and Alpine reflecting an altitudinal as well as an longitudinal gradient.

The Boreal Southern Cordilleran Ecoclimatic Region contains mixed forests of *Populus tremuloides, Populus balsamifera, Betula papyrifera, Pinus contorta, Picea glauca, Picea mariana* and *Abies balsamea* (Ecoregion Working Group 1989). On dry sites open stands of *Pinus contorta* and *Populus tremuloides* occur. Poorly drained depressions contain *Larix laricina* and *Picea mariana.*

The Subalpine Southern Cordilleran Ecoclimatic Region has closed canopies of *Pinus contorta, Picea engelmannii,* and *Abies lasiocarpa* (Ecoregions Working Group 1989). Typical understory species are *Vaccinium scoparium, Pyrola,* bryophytes, and *Rhododendron.* Alpine areas contain *Cassiope* and *Phyllodoce, Salix, Carex, Dryas,* and *Kobresia* (Ecoregions Working Group 1989).

In the Boreal Mid-Cordilleran Ecoclimate Region closed canopies of *Pinus contorta* predominate with an understory of *Alnus, Vaccinum, Rosa,* low growing herbs, and dwarf evergreen shrubs (Ecoregions Working Group 1989). Climax vegetation is considered to be *Picea glauca* X *engelmannii* with *Picea mariana* and feathermosses. Dry sites support *Pinus contorta, Vaccinium, Arctostaphylos,* and lichens. Poorly drained sites contain *Picea mariana, Picea glauca, Ledum, Equisetum,* and bryophytes.

Subalpine Northern Cordilleran Ecoclimatic Regions have a scattered cover of stunted *Picea glauca, Pinus contorta* and *Abies lasiocarpa.* Shrub birch, willow, mosses and lichens abound between the stunted trees. Lower elevations also contain *Empetrum, Vaccinum, Alnus,* and *Ledum groenlandicum.* Mid and low slopes are dominated by *Picea mariana, Ledum, Eriophorum, Carex,* bryophytes, and lichens. Drier sites may support *Populus tremuloides, Populus balsamifera, Pinus contorta, Arctostaphylos,* Gramineae, bryophytes and lichens.

A4.1.3 Subarctic Ecoclimatic Province

Just north of Yellowknife, the black spruce canopy thins out, forming the woodlands of the Low Subarctic Ecoclimatic Region. Understory vegetation is dominated by dwarf birch, *Ledum groenlandicum, Alnus crispa, Salix, Shepherdia canadensis* and *Hylocomium splendens. Betula papyrifera* can be abundant following fires.

Dry sites are dominated by open stands of *Picea glauca* and *Betula papyrifera* with *Arctostaphylos, Vaccinium vitis-idaea, Ledum groenlandicum, Cornus canadensis, Pyrola, Cladina arbuscula, Hylocomium splendens,* and *Pleurozium schreberi.* In warm protected areas, *Picea glauca,* *Betula papyrifera* and *Populus tremuloides* can occur. Imperfectly and poorly drained soils have pure stands of *Picea mariana* or mixed forests of *Picea glauca, Picea mariana* and occasionally *Larix* and *Populus balsamifera* (Lavkulich et al. 1972). The moderate shrub cover consists of *Ledum groenlandicum, Rosa acicularis, Vaccinium uliginosum, Betula glandulosa,* and *Potentilla fruticosa.* Ground cover species are *Arctostaphylos, Petasites palmatus, Equisetum scirpoides, Pyrola, Vaccinium vitis-idaea, Cladina arbuscula, Cladina alpestris, Cladina rangiferina, Hylocomium splendens, Tomenthypnum nitens, Ptilium crista-castrensis, Aulacomnium palustre* and the occasional *Sphagnum* hummock.

Peat plateaus and fens are the common wetlands in the area (Zoltai et al. 1988). Peat plateaus have stunted open *Picea mariana* cover with *Betula glandulosa, Myrica gale, Ledum palustre, Ledum groenlandicum, Andromeda polifolia, Vaccinium vitis-idaea, Empetrum nigrum, Rubus chamaemorus, Arctostaphylos rubra, Smilacina trifoliata,* and *Drosera rotundifolia* (Lavkulich et al. 1972). *Sphagnum* mounds also contain *Cladina rangiferina, Cladina arbuscula, Cetraria cucullata, Polytrichum strictum,* and *Dicranum undulatum*. Fens are much rarer than bogs in this area. Vegetation in the fens is dominated by *Carex* and *Eriophorum* with scattered *Sphagnum* hummocks. Shrubs and herbs identifed in this area were; *Betula glandulosa, Myrica gale, Ledum palustre, Ledum groenlandicum, Chamaedaphne calyculata, Kalmia polifolia, Andromeda polifolia, Drosera rotundifolia,* and *Tofieldia* (Lavkulich et al. 1972).

In the High Subarctic Ecoclimatic Region the well drained sites support stunted and very open stands of *Picea mariana,* with occasional *Larix laricina.* The ground is covered with nearly continuous lichen carpet, composed of *Cladina mitis, C. alpestris, C . rangiferina, Cetraria nivalis,* and *C. cucullata*. Low shrubs of *Betula glandulosa* and *Ledum palustre* are also frequent. Dry sites will support open stands of *Picea glauca, Vaccinium vitis-idaea, Arctostaphylos,* dwarf birch, moss and lichens. Tundra patches occur with increasing frequency as the tree line is approached, supporting *Alnus crispa, Salix Richardsonii* and *Betula glandulosa* shrubs, herbs and mosses. *Picea glauca* is often the treeline species, growing with *Salix* and *Betula* shrubs. *Populus balsamifera, Picea glauca* and *Betula papyrifera* grow in river valleys or on south facing slopes.

Characteristic wetlands for this area are polygonal peat plateau bogs and basin fens (Zoltai et al. 1988). The vegetation of polygonal peat plateau bogs is dominated by lichens (*Cladina mitis, Cladina rangiferina, Cetraria cucullata, Cetraria nivalis,* and *Alectoria ochroleuca*). In the wet trenches, *Betula glandulosa, Ledum palustre, Rubus chamaemorus, Sphagnum fuscum,* and individuals of *Picea mariana* can be found. Subarctic fens are dominated in the wetter areas by *Carex, Scirpus hudsonianus, Scheuchzeria palustris, Rhychospora alba, Carex limosa and Eriophorum vaginatum,* with *Drepanocladus, Scorpidium, Campylium, Tomenthypnum nitens,* and *Pohlia.* Shrubs and trees are usually absent or restricted to channel margins where drainage is slightly better (Zoltai et al. 1988). Floodplain marshes usually contain *Equisetum fluviatile,* with some *Salix alaxensis* and the moss *Leptobryum pyriforme*. In riverine swamps *Salix alaxensis* grows to 3-4 m with a complete ground cover of *Equisetum arvense*. Also found in these areas are *Hedysarum alpinum, Aster sibiricus, Campylium stellatum,* and *Leptobryum pyriforme* (Zoltai et al. 1988). Thermokarst lakes often contain *Carex aquatilis, Juncus, Lemna trisulca, Equisetum fluvatile, Menyanthes trifoliata, Hippuris vulgaris, Potamogeton richardsonii, P. foliosus, Myriophyllum,* and *Nuphar polysepalum.*

A4.1.4 Arctic Ecoclimatic Province

In the Low Arctic Ecoclimatic Region, which is only a small portion of the Mackenzie River Valley, tundra vegetation consists of dwarf birch, *Salix, Ledum palustre, Dryas,* and *Vaccinium* occurs (Ecoclimatic Working Group 1989). Corns (1972) identified 6 major community types for the eastern Mackenzie Delta Region and the Arctic Islands. The most extensive community he identifies is a Dwarf Shrub-Heath community comprised of *Betula nana, Salix glauca, Salix pulchra, Ledum palustre, Vaccinum vitis-idaea, Empetrum nigrum,* and *Lupinus arcticus*. Within this community he identifies two additional subgroups based on the increasing occurrence of *Salix*.

In the second vegetation community, Dwarf Shrub-Heath vegetation merges with *Eriophorum, vaginatum, Carex bigelowii, Andromeda polifolia, Chamaedaphne calyculata, Rubus chamaemorus,* and *Tofieldia pusilla* to form a Herb-Dwarf Shrub-Heath community. Subgroups of this community are a sedge-cottongrass-heath community, raised center polygons, lichen heaths, and gravel deposits. The raised polygons are characterized by raised centers covered by *Ledum palustre, Betula* *glandulosa, Salix, Arctostaphylos rubra, Empetrum nigrum, Vaccinium vitis-idaea, Rubus chamaemorus, Poa, Cetraria cucullata, C. nivalis* and *Alectoria*. Ice wedge depressions contain *Ledum palustre, Vaccinium uliginosum, Chamaedaphne calyculata, Carex bigelowii, Andromeda polifolia, Arctophila fulva, Carex aquatilis,* and *Eriophorum angustifolium*. Extremely wet sites may also contain *Caltha palustris, Hippuris vulgaris,* and *Ranunculus*. Gravel deposits occupy only 3 % of the low arctic landscape but have high diversity. Common species are *Betula nana, Saxifraga tricuspidata,* and *Arctostaphylos rubra*. Rare species are *Populus tremuloides* and *Cnidium cnidiifolium*.

Herb communities are found in flat, poorly drained areas. These are commonly low center polygons, thermokarst lakes, and wet facing banks of the Mackenzie River. Low center polygons usually contain *Carex rariflora, Rubus chamaemorus, Tofieldia pusilla, Eriophorum, Salix, Drepanocladus uncinatus, D. revolvens,* and *Calliergon giganteum*. Shoulders of the polygons are better drained and support *Betula glandulosa, Empetrum nigrum, Ledum palustre, Poa alpina, Carex, Cetraria cucullata,* and *Sphagnum*. The shores of thermokarst lakes often have *Eriophorum angustifolium, E. Scheuchzeri, Lemna trisulca, Caltha palustris, Carex aquatilis, C. saxatilis, Arctophila fulva , Ranunculus aquatilis, Potentilla palustris.* and *Drepanocladus revolvens.* Peaty mats surrounding the pools consists of *Tomenthynum nitens, Aulacomnium palustre, Hypnum bambergeri, Philonotis fontana, Campylium arcticum, Carex saxatilis, Eriophorum scheuchzeri, Juncus biglumis, Pedicularis arctica,* and *Saxifraga hirculus*. Only a few vascular species are found along the banks of the Mackenzie River. Major species include; *Artemesia frigida, Calamagrostis purpurascens, Pulsatilla patens,* and *Artemisia tilesii*.

A tall shrub vegetation community type is restricted to river channels, stream channels and lake shores. It is comprised of *Salix lanata, Salix alaxensis, Alnus crispa, Carex aquatilis, Calamagrostis candensis, Equisetum arvense, Eriophorum angustifolium, Arctagrostis latifolia, Hedysarum alpinum,* and *Parnassia palustris*. Less flooded areas also contain *Vaccinium uliginosum, Pyrola grandiflora* and *Pyrola secunda*.

On gentle slopes and places where snow accumulates a medium shrub community can be found. In these moist habitats *Betula nana, Alnus crispa, Ledum palustre, Vaccinium uliginosum, Cassiope tetragona, Andromeda polifolia, Eriophorum, Carex, Pinguicula villosa,* and *Sphagnum* can be found.

The most widespread wetlands in the Low Arctic are the low center polygon fens and bogs, along with peat mound bogs and horizontal fens with peat cushions (Tarnocai and Zoltai 1988). Marshes are common along the coast and deltas, and thermokarst lakes are a common feature in the tundra landscape. Peat mounds are the arctic variety of palsas. These are small peat-covered mounds that rise up to 1 meter above the surrounding fen. The better drained surfaces support *Sphagnum fuscum, Rubus chamaemorus, Ledum palustre, Andromeda polifolia, Vaccinium uliginosum, Vaccinium vitis-idaea, Betula glandulosum, Dicranum elongatum, Polytrichum strictum,* and *Ichmadophila ericetorum* (Tarnocai and Zoltai 1988). Fens in this region do not contain any vascular herbaceous species nor lichens. Occasionally scattered individuals of *Salix arctica* can be found. Dominant species are *Carex aquatilis, Carex chordorrhiza, Carex membranacea, Eriophorum angustifolium, Eriophorum vaginatum, Drepanocladus aduncus, Drepanocladus fluitans,* and *Scorpidium scorpioides* (Tarnocai and Zoltai 1988).

A4.1.5 Possible Impacts of Climatic Warming

Climatic warming is expected to have severe effects upon the ecosystems of the northern boreal forest, including increases in intensity and frequency of fire, increased forest growth on good sites and reduction in soil moisture and runoff to lakes and rivers. The joint Canada/U.S. program called BOREAS (Boreal Ecosystem-Atmosphere Study) is addressing global change and biosphere-atmosphere interactions in the boreal forest biome. While some of the study sites are outside the Mackenzie River Basin, this program will aid our understanding of the boreal forest ecosystem within the Mackenzie River Basin. Wetland ecosystems which we are studying as part of the MBIS are possibly the best "indicator" ecosystems because they are extremely sensitive to climate change. Wetland species respond to the alteration of water tables by even a few centimetres. The most sensitive ecosystems include northern permafrost wetlands, wetlands in the discontinuous permafrost and wetlands at the boundary of the prairie and boreal forest.

A4.2 Wetland vegetation and the carbon cycle

The wetland vegetation in the ecoclimatic zones is described in detail above. Wetlands can be separated into several types (marsh, swamp, fen, and bog) based on hydrology, temperature and vegetation. Bogs and fens, characterized by accumulations of peat, are restricted to an area north of the prairie grassland zone and generally mark the boundary between boreal forest and the aspen parkland in the southern part of the Mackenzie River Basin. Any northward expansion of the grasslands into the boreal forest, as a result of increased temperatures, will be marked first by changes in these peatland ecosystems. Changes in wetland vegetation wil be evident long before actual grassland expansion or forest change becomes detectable. Subtle changes in the presence, absence, or abundance of wetland plant species that are sensitive to fluctuations in the water table and in the water chemistry (resulting from changes in the water table), offer an early warning indicator of large scale climate related changes. We are documenting these biotic responses as part of the MBIS.

Simplistic extrapolations of higher temperature into northern regions will not result in an accurate prediction of the ecosystems that would be developed. Changes in water levels, chemical changes and fires will alter the species response and will institute major shifts in ecosystems.

Our studies of the historical record of boreal wetlands (peat deposits) has dispelled the belief that wetlands originated at the end of the glaciation, nearly 10,000 years ago. We have shown that wetlands of the northern prairies disappeared during the hypsithermal, 6,000 years ago, when temperatures averaged only one degree C warmer than in the 20th century. We have also shown that our present wetlands originated after that period throughout much of the prairies. At the same time, most prairie lakes were probably dry. For example, the bottom of the present Lake Manitoba, one of the largest lakes in western Canada, is known to have been a grassland 6,000 years ago. The climatic changes predicted now are much larger than those that occurred 6,000 years ago. Obviously, this would have serious consequences for wetlands as well as other biological communities. The detailed models of wetlands we have developed as part of the MBIS are based on both contemporary and historical reconstructions (from lake and wetland sediments) of how biological communities respond to heat and to drought, and will permit us to avoid simplistic extrapolations of temperature.

Peatlands are common in the northern boreal region of the Mackenzie Basin (40% of the area in northern Alberta) and play an important role in the carbon cycle in these areas. Northern peatlands are major reservoirs of carbon in the northern hemisphere. In Canada, the average peat depth is over 2.2 metres with apporximately 50% of the peat made up of carbon. Peatlands are also one of the most important natural emitters of methane to the atmosphere. As temperatures increase and wter levels drop, decomposing peatlands may add to the concentrations of carbon dioxide and methane in the atmosphere. The large amounts of carbon stored in peat deposits are a result of slow decomposition rates caused by anaerobic conditions produced by high water levels. Permafrost formation also contributes to the build up of peat deposits. Lowering water levels and melting of the permafrost as a result of global warming would increase decomposition of the peat and would release carbon dioxide into the atmosphere. It is difficult to make accurate predictions about the amount of carbon dioxide and methane that would be contributed by the northern boreal peatlands to the atmosphere as a result of global climate warming.

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A4.3 Wildlife

A4.3.1 Wildlife Response to Forest Burns in the Mackenzie Valley and its Relevance to Global Warming

Paul Latour, GNWT/Renewable Resources, Norman Wells

<u>Issue</u>

Wildlife will remain an important element in the cultures and economies of northern peoples. In the Mackenzie Valley, the sale of pelts from furbearing animals is the major income in many families, and they depend almost exclusively on moose and caribou for red meat.

Forest fires and the amount of suppression effort that should be devoted toward them is a contentious issue in the Northwest Territories. Among some wildlife users, fire is perceived as deleterious to wildlife and, over the very short-term, that is unarguably so. However, fire is now considered to be the driving force behind major change and rejuvenation of the boreal forest. Many wildlife species in the boreal forest, including most of direct importance to humans, are thought to benefit directly from the mosaic of regenerative stages that results from regular burning. To date, however, little data have been collected on the effects of forest fire on northern wildlife.

One prediction of global warming caused by the accumulation of greenhouse gases is that the frequency and extent of fires in the boreal forest will increase substantially. Because of the lack of background data, it is difficult to predict any effects of increased fire activity on wildlife. Better predictive capabilities will be required so that both government and communities can better know, and plan for, the impacts of fire in the future.

This study will rely on several projects within the MBIS to provide various forest fire scenarios based on climate change, and to provide data on vegetation responses to climate change. These models and data will be used when attempting to predict wildlife response to forest burns.

Research Hypothesis

1. Furbearers (primarily marten and lynx), although initially decimated by forest fire, will occupy a burned area within 5 years post-burn in the Sahtu District.
2. Moose will occupy burns (at least seasonally) within 2 years post-burn while caribou avoid burns up to 50 years post-burn in the Sahtu District.
3. Species diversity and biomass of small mammals are greatest during the early stages of vegetation succession within burns in the Sahtu District.

Methodology

Burns 2, 5, 15 and 22 years old have been selected as representing a cross-section of regenerative stages of burned forest in the Sahtu District. Selection was done using already available fire history maps.

1. Each burn will be described by means of remote sensing, initial aerial truthing of identified vegetation associations, then ground truthing of these vegetation associations. Vegetation coverage and horizontal density as well as density and size of fallen and standing dead timber will be determined using standard sampling plot methods.
2. Relative abundance of small mammals will be determined by means of standard snap-trapping techniques.
3. Relative abundance of furbearers and ungulates in each burn will be determined by aerial track counts along randomly located 2 km transects flown by helicopter in March and April of each year.

Results To Date

1. The vegetation associations within 4 of the 5 burns have been identified from remote sensing. These associations were aerial truthed in August 1990 and then ground truthed in August 1991. Truthing indicated that the initial classifications from the remote sensing data were accurate in each of the 4 burns. The fifth burn may have to be abandoned because of the difficult terrain and boundary confusion with earlier burns in the area.
2. Aerial track counts in each of the 4 burns were conducted in March 1991, March 1992, and April 1992. This data has not yet been analysed.
3. Further sampling of vegetation associations within each burn is required and was conducted in August 1992.
4. Small mammal trapping was conducted in each burn in August 1992.

Future Work

1. Aerial track counts in each of the 4 burns will be done in March 1993 and again in April 1993.
2. From December 1992 to March 1993 the observer error associated with the aerial track counts will be determined. Ground counts of furbearer and ungulate tracks will be made along established snowmobile transects. Immediately afterwards, an aerial count or tracks along these same transects will be conducted. The procedure will be repeated at least monthly during the above period.

Integrating Results

The results of this study will be integrated with various models of forest fire frequency, size, and behaviour which are in turn dependent on the climate scenarios based on CO_2 accumulation in the atmosphere. Since it is not clear to what extent these models will be generated by present MBIS projects, we may have to consider already existing models for the final reporting and summarizing of this study.

Forest fire models are based on hypothesized responses of climate to continued CO_2 accumulation which lends uncertainty to predicting effects on animal populations. Furthermore, there is the inherent variability in response by animal populations to large habitat changes, including those induced by fire. This study is already indicating the variability between fires of different ages and possible inter-year variability within any one fire due, perhaps in part, to the natural cyclicity of animal populations. To add further complexity, the wildlife response to fire documented in this study reflects a fire regime that has resulted in a particular, and relatively stable, forest mosaic. The possibility exists that wildlife might respond quite differently to a sudden disruption of this mosaic, caused by accelerated fire activity over the next 20-50 years. Given all these factors, it may be difficult to build meaningful wildlife-fire scenarios even with the results of the present study in hand. These comments are intended solely as a cautionary note, however, at this early stage of this study and the MBIS.

A4.3.2 Effects of global warming on the biology and management of the porcupine caribou herd

Don E. Russell, Canadian Wildlife Service, Whitehorse

***This paper has also appeared in Proceedings of Symposium on the Impacts of Climate Change on Resource Management of the North, May 12-14, 1992, Whitehorse, Yukon (Editor: Geoff Wall). The Proceedings are available from Atmospheric Environment Service, Edmonton.*

Introduction

The Porcupine caribou herd is a large migratory herd of Grant's caribou (*Rangifer tarandus granti*) that moves from winter ranges in the taiga to calving and summering grounds north of treeline. The herd has been increasing over the last two decades and now numbers close to 200,000 animals. Its importance to the culture and economy of northern native communities in NWT, Yukon and Alaska has resulted in considerable research and management directed to this resource. Periodic development proposals and activities have resulted in an almost unbroken record of movements and distribution for 20 years (Russell et al. 1992a). Concurrent to monitoring, research on the herd from all jurisdictions within its range has resulted in an extensive database that can be used as a model for other large caribou herds in the north. In this paper I apply our knowledge about the Porcupine Herd to assess the implications of global climate change on their biology and management.

Abiotics and caribou energetics

Although we have divided the year into 15 season for the herd (Russell et al 1992b; Table A4.1), the majority of a caribou's energetic year is "driven" by three phenomenon; spring snowmelt, summer insects and winter snowfall.

The calving grounds of all large migratory herds appears to be the most consistently utilized habitat within their annual cycle. At the time of calving (June 1-4) caribou are normally on a poor he animals are still on the Alaska coastal plains and use the 3 kilometre strip along the coast, with the cool onshore winds ensuring reduced insect activity. In mid July, the nursery bands enter the Yukon and travel to the northern Richardson Mountains, where the cool temperatures and high humidities ensure reduced harassment and abundant vegetation (Russell et al 1992b).

By early October the first permanent snow begins to accumulate. Our work on the winter range indicates that snow depth has a profound effect of feeding times and the energy expended obtaining food from under the snow (Russell et al 1992b). During deep snow, animals increase lying times and reduce feeding times, as an energetic tradeoff between energy input and energy output. In winter, two regions are occupied during normal to deep snow years; the Richardson Mountains and the Ogilvie/Hart basins. The Richardson Mountains have shallow snow depths in normal winters due to the chronically high winds in the area, resulting in redistribution of the snow. The Ogilvie/Hart basins lie in the snow shadow of weather systems from the Gulf of Alaska and Bering Sea. In years of low snowfall, the lichen-rich Whitestone/Eagle are almost universally used.

The year-to-year abundance of mosquitoes is probably a function of moist, warm springs, however day-to-day activity of both groups of insects is largely dictated by wind and temperature profiles (Nixon 1991). During days of intense harassment, the animals greatly reduce the amount of time spent feeding and lying, while standing, walking and running times are increased. Habitats occupied tend to contain low plant biomass (Russell et al 1992b). During the early insect season, the animals are still on the Alaska coastal plains and use the 3 kilometre strip along the coast, with the cool onshore winds ensuring reduced insect activity. In mid July, the nursery bands enter the Yukon and travel to the northern Richardson Mountains, where the cool temperatures and high humidities ensure reduced harassment and abundant vegetation (Russell et al 1992b).

Table A4.1 The 15 seasons in the annual life cycle of the Porcupine Caribou Herd.

Effects of Climate Change on caribou energetics

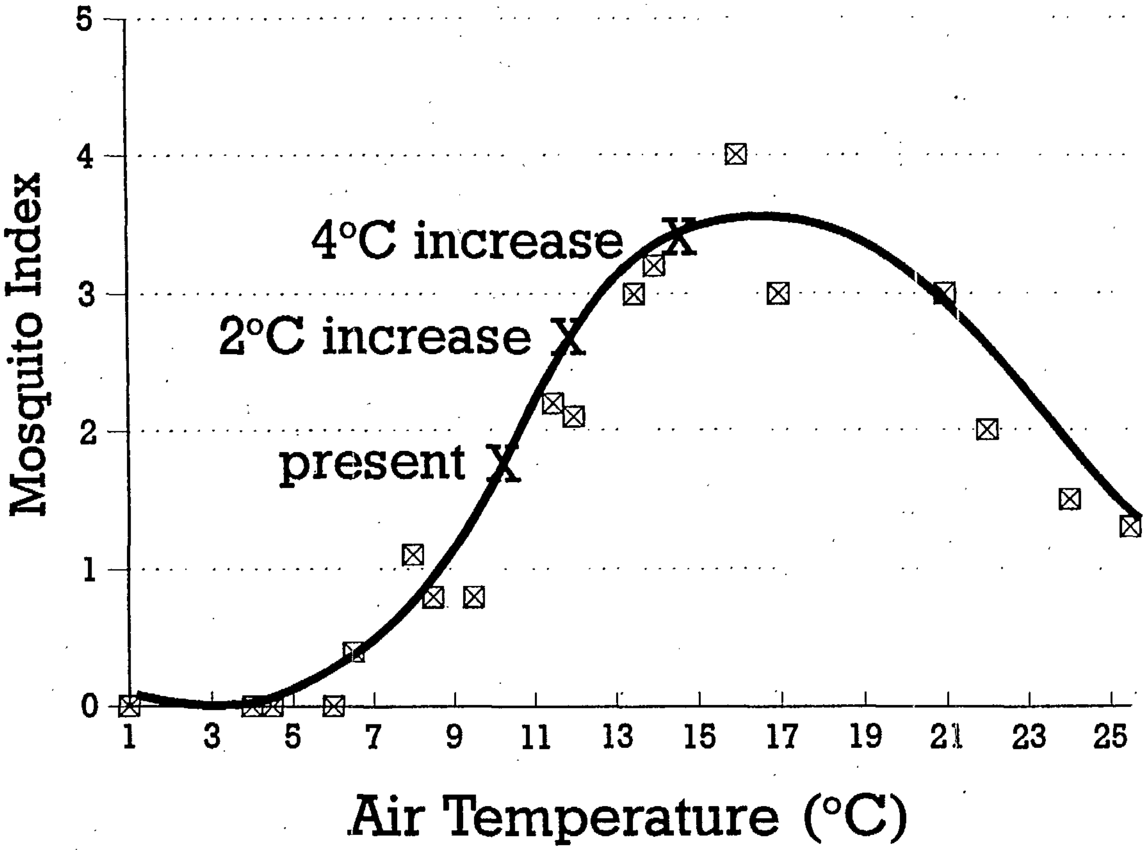
Season	Dates	Characteristics
Rut	8 - 31 October	snow but melting
Late fall	1 - 30 November	beginning of winter snow cover
Early winter	1 December -10 January	snow cover shallow; shortest daylength very cold
Mid Winter	11 January - 20 February	snow cover increasing; very cold
Late winter	21 February - 31 March	snow cover peaking; longer daylength
Spring	1 - 30 April	snow cover decreasing
Spring mign.	1-19 May	80 - 100% snow cover; snow rotting; animals move north of treeline
Pre - calving	20 - 31 May	10 - 50% snow cover, disappearing rapidly; cottongrass in bud
Calving	1 - 10 June	0 - 10% snow cover; cottongrass in full flower; willow leaves in bud
Post - calving	11 - 20 June	cottongrass past flowering; willow leaves unfolding
Movement	21 - 30 June	willow in leaf; biomass increasing rapidly
Early summer	1 - 15 July	biomass peaking; mosquitoes peaking
Mid summer	16 July - 8 August	biomass at peak; mosquitoes past peak; oestrid flies peaking
Late summer	9 August - 7 September	vascular forage quality declining
Fall migration	8 September - 7 October	early snow storms

For discussions in this paper, I have assumed a climate change scenario for the arctic as outlined in French (1986). From this workshop, participants predicted a 2 - 4 week earlier period of snowmelt, a 2 - 4 °C increase in summer temperature, and a 30 - 50% increase in winter snowfall.

Early snowmelt could potentially be beneficial to caribou by eliminating or drastically shortening the period that the animals are on poor spring range after moving north of treeline (and thus into habitats of low lichen biomass). However, the timing of the burst of highly digestible nutrients and minerals is critical to meet the demands of peak lactation. Therefore, although beneficial early in spring, early snowmelt could prove detrimental by mid June when energy and nutrient requirements are greater than at any other time of year. As well, if spring temperatures increase, the period between first flush and plant senescence will shorten, and animals will not be able to take advantage of early plant phenology for as long into the summer.

To avoid this energetic disadvantage, caribou may calve north of their present calving ground, an area where snow melts approximately ten days later. The other option is for the pregnant females to switch to an earlier calving date. Although flexibility in calving date may be possible, dramatic shifts are unlikely because mating is temporally controlled by photoperiod (Skogland 1989).

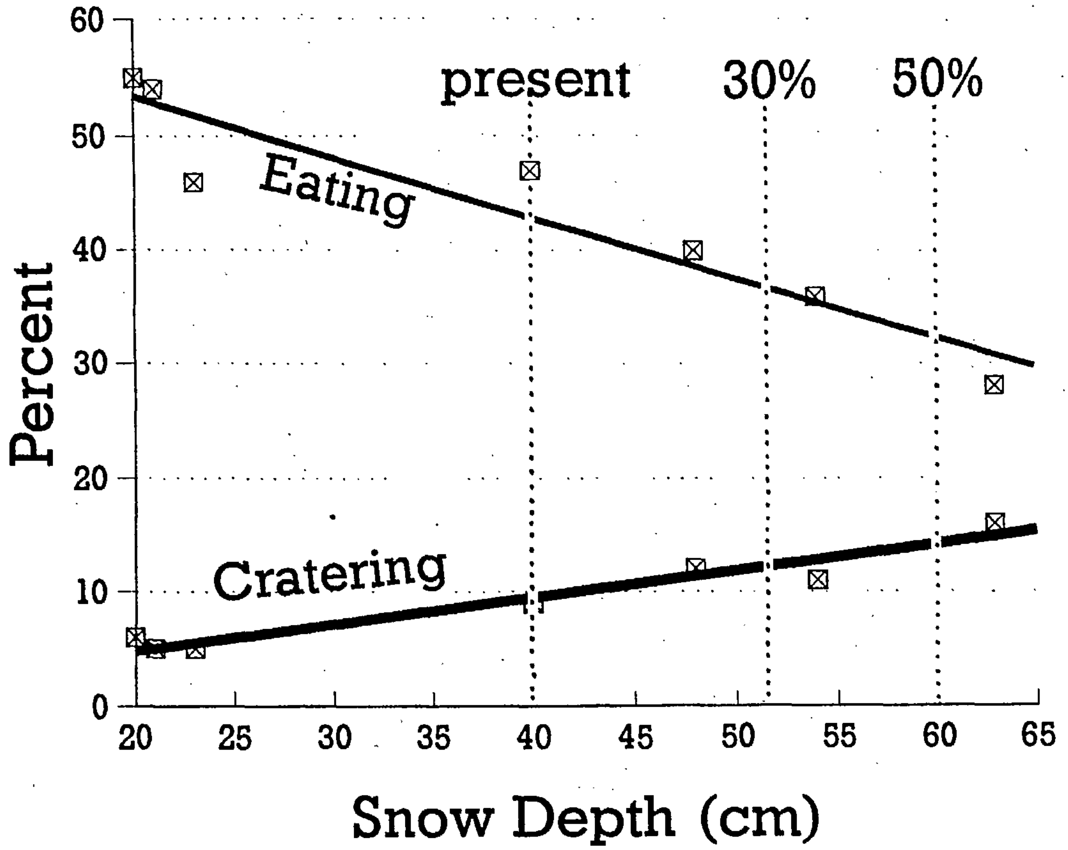
Figure A4.3. The relationship between air temperature and mosquitoe harassment index with predicted increase in average harassment under a 2 ° and 4 ° C increase in summer temperature. Adapted from Nixon (1991).



Mosquito activity is not linearly related to summer air temperature, rather activity peaks at about 18°C and declines at higher temperatures. Unfortunately, a 2 - 4 degree increase would result in an almost linear increase in harassment based on our field observations during insect season (Figure A4.3). This increase in harassment can be translated into a 7% decrease in feeding (37% - 30%; Russell et al 1992b). Relief from insects would theoretically become a more common strategy and thus the importance of insect relief areas would increase.

A 30 - 50% increase in winter snowfall would result in a 5% increase in cratering time (9% - 14%) and a 11% decrease in feeding time (43% - 32%; Figure A4.4). We would predict, as with insect season, a tendency to rely more on areas of low snow (Richardson Mountains and Ogilvie/Hart basins) and consequently reduce use of areas that, although high in lichen biomass, tend to have deeper snow accumulation (Eagle / Whitestone).

Figure A4.4. The relationship between snow depth and percent of day spent eating and cratering and predicted changes in these percentages under a 30% and 50% increase in winter snowfall. Data from Russell et al 1992b).



Energetics Model

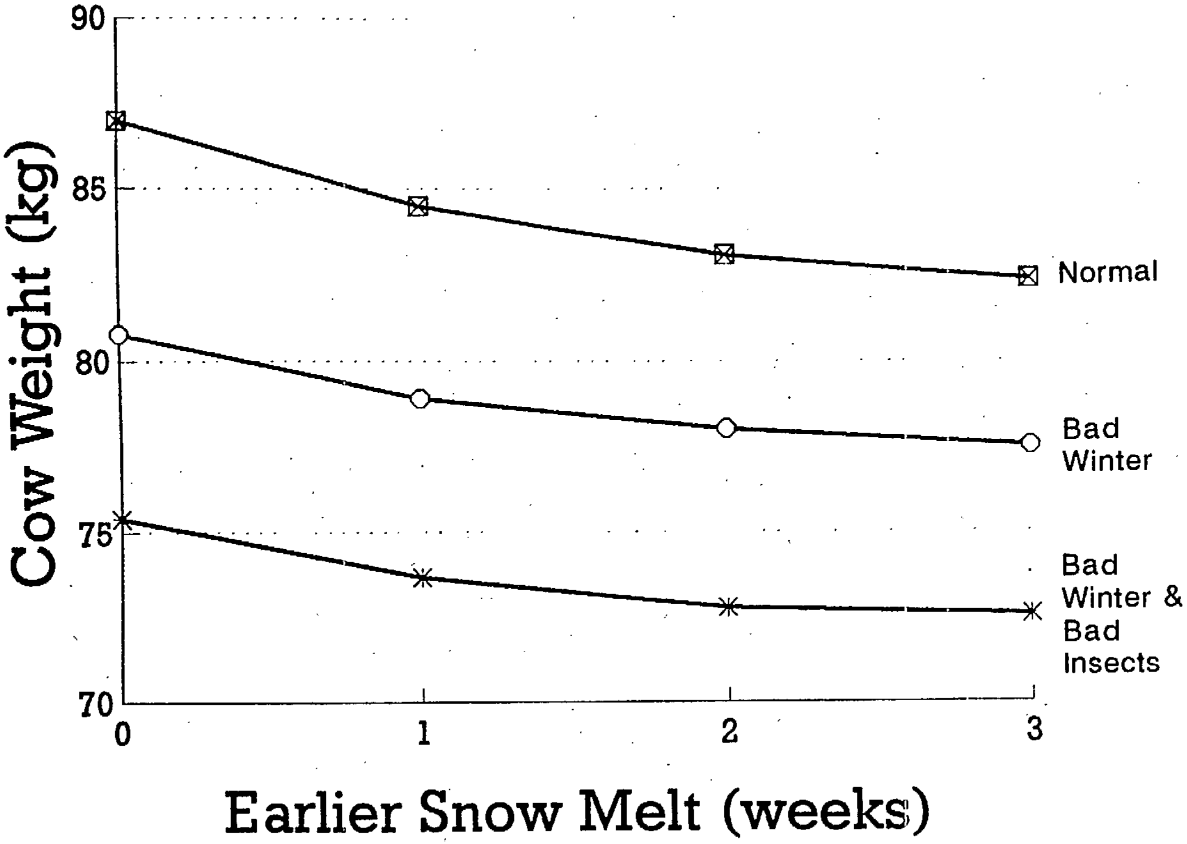
Combining our knowledge of the herds' range ecology and generalized caribou energetics, we have constructed an energetics model (Kremsater 1991) that can examine the results of good and bad winters or insect seasons on weight change of productive adult females (Russell 1991; White 1991) and explore the implications of petroleum development within the herd's calving grounds (Fancy 1991).

Briefly the model is divided into two components; an energy intake submodel and an energy allocation or growth submodel. The energy intake submodel has two parts; first it calculates food intake in specific environments, then it simulates functioning of the rumen and digestive kinetics to predict metabolizable energy from forage intake. The growth section computes the energy status of the female caribou on a daily timestep. The calculations it uses can be grouped into three categories: (1) energetic requirements of maintenance activity, (2) energetic requirements of gestation and lactation, and (3) energetic requirements of growth and fattening.

We can apply the model to examine the implications of climate change on the herd. The model is empirically driven by activity budgets, diet, phenological and nutrient components of vegetation, interpolated between 15 seasons (Table A4.1).

Output from the model is presented for three scenarios; (1) early spring (0 to 3 weeks), (2) early spring combined with deep winter snow and (3) early spring combined with both deep snow and high insect harassment. Total fall body weight can vary from 87 kg to 72 kg (Figure A4.5) and total fat weight varies from 9.2 kg to 5.8 kg.

Figure A4.5. Simulated changes in fall cow weight under varying snowmelt periods for normal, bad winter and bad winter/bad insects scenarios.



The impact of such weight changes can be dramatic to the productivity of the herd. Two theories are presently being tested relating female body condition during the fall rut to subsequent pregnancy and birth rate. Cameron et al (1992) demonstrated a strong relationship between fall maternal body weight and parturition rate, while Crete et al (1991) postulates a threshold effect with total fat weight, with females requiring a minimum of seven kg of body fat to conceive in the fall. From Cameron et al's (1992) logistic regression we would predict a 40% decline in parturition rate from the best to worst case scenario, while following Crete et al's (1991) findings we would conclude that our "simulated female" would fail to conceive regardless of early spring melt, if the females was subjected to both a bad insect year and deep winter snow, or would be at the "conception threshold" in years of deep snow and two to three weeks earlier snowmelt.

Impact of climate change on present management decisions

Clearly such a relatively simple treatment should serve only as a warning that these future scenarios add another factor we must consider when making present management decisions. These decisions are now being made in the area of habitat management, population management and in setting research priorities.

The disposition of sensitive habitats is an important issue on both sides of the international border. Probably the most controversial discussion is the leasing of a portion of the Arctic National Wildlife Refuge for oil exploration and development (the "1002" lands). The southeastern portion of the 1002 lands has been identified as critical core calving habitat for the Porcupine Caribou Herd (Garner and Reynolds 1986), with the remaining area of 1002 receiving extensive use after calving until mid to late July. Given the tendency of the herd to calve in regions of melting snow, we would predict that with earlier average snowmelt, the present core area would expand to include areas to the north incorporating a higher percentage of 1002 lands. In fact, we have ample evidence of this northward calving shift in years of early snowmelt. Present arguments for preserving the 1002 lands are focused on the historic use of the core calving grounds. This area may be of less relative importance to the herd in 40 years and the area to the north may be the key to the long term viability of the herd.

We would also predict post-calving nursery bands would be more dependant on the coastline of the 1002 area for insect relief in July. The present concern over port facilities and east/west pipelines hindering the herd's free access to the coast would become a much stronger argument by considering the implications of future climate change.

In Canada, insect relief areas in the northern Richardson Mountains have been identified as important habitat. Over the next few years long term decisions on the fate of this region will be decided largely through the North Slope Conservation and Management Plan and the Yukon Land Claims process. Presently all lands north of the Porcupine River in Canada are under a Federal Order-in-Council moratorium for exploration and development. The challenge in the next few years is to put in place sufficient protection for key wildlife habitat, so that orderly development can proceed if the moratorium is lifted. The herd's greater dependence on the northern Richardsons with increasing frequency of insect harassment underlines the importance of these decisions. A similar argument can be made for adequate protection of the shallow snow regions in winter (Ogilvie/Hart basin and Richardson Mountains).

Over the last decade the herd has enjoyed a modest annual increase in numbers, our "simulated" female tells us that a decline in pregnancy rates and thus the carrying capacity of the range may occur. We are fortunate that the "political environment" of the herd has evolved to deal with a declining resource. Structures are now in place in Canada (Porcupine Caribou Management Board) to potentially address the allocation of a declining harvestable surplus, although the Board has never had to deal with the issue. The International Porcupine Caribou Board has also initiated discussion on how to address the international aspects of possible quotas. The only missing structure is an Alaskan counterpart to the Porcupine Caribou Management Board, necessary to accept and implement harvest restrictions in the U. S.

Our knowledge about the Porcupine herd and its range requirements is more complete than any other Rangifer in North America and probably the world. Management agencies in both countries can utilize this baseline knowledge to develop a research monitoring program that will intensively address the impacts of climate change on the range and the caribou.

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A4.3.3 Migratory Arctic-Breeding Geese

Abdel Maarouf, Canadian Climate Centre

Migratory geese inhabiting Canada are intermediate in size and neck length between swans and ducks. The sexes are coloured alike and they are much better walkers than ducks and feed more often on land. They accumulate reserves on their southern wintering grounds then migrate to the Arctic where they arrive with substantial reserves remaining. Individual females lay different number of eggs according to how much fat they arrive with, deriving the necessary nutrients and energy from their reserves, then continuing to draw on the remaining reserves through incubation, until snowmelt exposes fresh vegetation. Availability of food is controlled in part by climatic factors during the previous summer. Delayed thaws, low temperature and heavy summer precipitation contribute to low breeding success.

Some species of the Arctic-breeding goose are currently undergoing population expansion and may become pests causing conflict with man. This is due, at least in part, to a reduction in human persecution and disturbance, although changes in farming procedures on the birds' migration routes and on their wintering areas have also contributed. The four types most commonly found in the Mackenzie District are:

1. Canada Goose: This is the wild goose frontier to most Canadians. The majority of people see it in its spring or autumn migration as the big birds fly swiftly in V-formation. Despite heavy hunting it has managed to increase its numbers substantially in recent years and has certainly profited from grain and grass fields across North America.

   It breeds over vast, ecologically varied areas in both treeless and forested country varying from prairies and plains in the Arctic to mountains. It nests on the ground near water and forages on berrybearing tundra.

   The young fly south in autumn with their parents and do not separate from them until they return in the spring to the nesting grounds. Migrating flocks often comprise several families. It winters from southern Canada south to northern Mexico and the Gulf coast of the United States.

2. Snow Goose: It breeds and nests in loose colonies of various sizes in the Arctic. The ground nest is a mass of mosses or other tundra vegetation lined with down. It migrates spring and autumn through British Columbia, Alberta, Saskatchewan, Manitoba and Ontario. It winters mainly from southern British Columbia south to California; along the Gulf coast from Mexico and Texas to western Florida; on the Atlantic coast, New Jersey to South Carolina. In migration, it avoids forested habitat and stops on fresh- or saltwater marshes, lakes, wet fields, grain fields and sandbars.

3. Brant: This small goose is primarily a saltwater bird. It breeds in maritime areas throughout the Arctic and nests in loose colonies or singly. The ground nest is well lined with down. The foundation varies from a mere hollow in the ground to a mound of mosses and lichens.

   The wintering range of Brant in coastal areas is closely tied to the distribution of eelgrass, which comprises most of their diet. The wintering distribution of these geese changes according to the availability of eelgrass. In Canada, it winters mainly on the coast of British Columbia, and rarely in extreme southern Ontario and the Maritimes. In the United States, it winters along the Pacific Coast in California and along the Atlantic Coast from Massachusetts to North Carolina.

   It does not fly in the familiar V-pattern of its near relative, the Canada Goose, but in long wavering lines or formationless flocks. Brant like company and usually are seen in groups. Spring migration is late, and in the Maritimes, many Brant linger at favourite feeding places until the first week in June.

4. Greater White-fronted Goose: It breeds in the arctic tundra on edges of lakes, grassy flats, valleys, islands and deltas of streams. It often nests gregariously. The nest is on the ground and made of mosses, grasses or tundra rubbish, lined with down and feathers.

   It is a spring and autumn transient in Manitoba, Saskatchewan, Alberta and British Columbia. It appears rarely during migration east of the Prairie Provinces. It winters occasionally in southwestern British Columbia, but mainly in southern United States south to Mexico.

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A4.3.4 Mackenzie Delta Shorebirds

C. Gratto-Trevor
Canadian Wildlife Service, Saskatoon

Fieldwork (determination of priority habitat and invertebrate food), literature searches, and correspondance with experts in the fields of arctic botany, invertebrate zoology, hydrology and climate change will be used to examine potential effects of climate change on populations of shorebirds breeding in the outer Mackenzie Delta, NWT.

Of the 40 species of shorebirds (sandpipers and plovers) breeding regularly in Canada, 65% (26 species) breed almost exclusively in the arctic or subarctic. Shorebirds are an important component of tundra ecosystems, serving as major predators of small invertebrates, and prey of many avian and mammalian predators such as hawks, owls and weasels. Particularly in years when densities of small mammals such as mice and voles are low (about every three years), shorebirds' egg and young are an alternate source of food for arctic foxes and other predators. Since most species are asssociated with wetland areas, shorebirds are an excellent indicator group for modelling the effects of climate change on wildlife populations.

The outer Mackenzie Delta area itself is an extremely important region for many species of shorebirds. At least 15 species of shorebirds are known to breed there, including the entire western Canadian populations of Long-billed Dowitchers, Whimbrel, Stilt Sandpipers and Hudsonian Godwit. It may also be the last breeding area of the Eskimo Curlew.

A5. Freshwater Ecosystems

H. Welch and D. Hamilton
Freshwater Institute and University of Manitoba

A5.1 Fish species in the MacKenzie Basin.

The Problem: Climate change will result in changing environmental conditions for lake communities in the MacKenzie drainage basin, and it is likely that in some cases the existing fish and invertebrate communities will no longer be those most adapted to the altered conditions, resulting in reduced yield to man from those systems. We can also assume that post-glacial invasion of lakes by all potential species has also been incomplete, such that optimal communities have not been established everywhere. Rather than wait for natural invasions to "catch up" to rapidly changing conditions, a process which takes millenia as evidenced by invasions following the Wisconsin glaciation, we suggest that man can act proactively to establish suitable fish and invertebrate communities in lakes whose fauna is no longer suited to the changed conditions.

The Process: There is no detailed comprehensive compilation of fish distributions in the MacKenzie drainage basin. We have extracted data from about 200 literature references, and are currently compiling information from the "gray literature", consisting primarily of environmental impact reports for nonrenewable resource extraction projects. A data base has been constructed that includes fish species present, habitat, food, water chemistry, basin morphometry, and temperature for each lake. We are investigating the best method to use for projecting geographic distribution from the data set.

Our next step will be to determine key environmental requirements for each fish species, which will entail more search through the literature. After that we should be able to make predictions as to the common fish communities now existing in the MacKenzie drainage basin, what their habitat requirements are, how closely those requirements match "optional" requirements according to our literature compilations, and what communities might be more suitable (ie. more productive to man) given certain scenarios for climate change. Presumably the final step would be the experimental introduction of a better adapted community to a small lake whose existing community is not well adapted, but such an experimental demonstration of the usefulness of the research is not planned within the time frame of the current project.

The project by Melville and Wheaton on thermal habitats and yields in lakes Great Slave and Athabasca is complementary to our own work, since we will be concentrating on smaller systems. Nonetheless there is no reason that more suitable fish communities might not be considered for those lakes as well. Their study will also provide a useful benchmark for our own work, because they will probably obtain better data and scenarios for temperature change in Athabasca and Great Slave than we are likely to find for any of the smaller lakes.

A5.2. Invertebrates

A separate data base has been developed similar to the fish database, and will similarly be used to plot geographic distributions as well as relationships between invertebrate prey and fish distributions. Other comments made regarding fish above also apply to invertebrates. We believe that all important members of the fish and invertebrate communities must be considered in this analysis, not just, say, the important commercial species. On the other hand, microzooplankton, phytoplankton, and Chironomidae are widely distributed, relatively mobile, and are often present in numbers too low to find in routine limnological sampling but nonetheless may become dominant as conditions within the lake change. Therefore we are concentrating only on the larger macroinvertebrates such as amphipods and crayfish.

A6. Settlements

Stewart Cohen, Canadian Climate Centre; with Dave Aharonian, U. Victoria, and John Newton, U. of Toronto

If climate change does occur, impacts on the physical and biological environments of the Mackenzie Basin would be felt by the people who live and work there. A number of policy concerns listed in Chapter 2 relates directly to settlements, particularly sustainability of native lifestyles and economic development opportunities.

A6.1 Overview of Activities

Bone (1992) has compiled a considerable data base on northern settlements. He indicates that the Mackenzie Basin has a population of approximately 150,000, mostly south of the 60th parallel (also, see Section A14). Almost all live in organized settlements or reserves with populations generally under 1,000. Few communities are larger than 10,000 (e.g. Fort McMurray, Yellowknife). Bone has identified three types of settlements: a) regional centres, b) resource towns, and c) native settlements. The urban population has been growing because of in-migration, movement of people from the land to former trading posts, and a high rate of natural increase in native communities.

How will climatic change affect the pace of urban growth and northern development? Could it lead to a restructuring of the geography of settlements in the Mackenzie Basin? Could it affect services within these communities?

One activity partially supported by MBIS is a study on community adjustment to extreme geophysical phenomena by John Newton, University of Toronto. The focus is on the perception of natural hazards (such as flooding, forest fires, etc.) by residents of remote communities, and how this influences communities' preparation for such events. Do northern communities' responses differ from those of southern communities? What is the role of technological change in the response of native settlements to natural hazards?

This research will employ surveys of remote communities, site observations, and discussions with governments, native organizations, the private sector, academia and international disaster research organizations. Some field work has already been completed in Aklavik and Fort Liard, as well as Attawapiskat, Ontario. In 1992, Aklavik and Fort Liard experienced severe flooding during the spring break-up, and Attawapiskat was evacuated in anticipation of a flood event. Additional information is provided in Section A6.2, below.

A second activity focussing on communities is a study by Dave Aharonian, University of Victoria, on how residents of a native settlement, Aklavik, perceive climate and climate change. The intent is to show how current land use activities, and the historical development of the community, are regulated by climate. Given these influences, Aharonian would suggest how future climate scenarios might impact the land-based activities in the community.

Interviews were conducted in Aklavik during August and September, 1992, with the support of the Aklavik Indian Band, Aklavik Regional Corporation and the Hamlet of Aklavik. Information was collected from interviews with 78 people, including elders, active hunters and trappers, non-natives and women. They provided considerable information on the the state of the present climate, but were not particularly interested in climate change. Land use patterns were documented, particularly hunting, fishing and trapping. The seasonal nature of these activities over time has led to further investigation of the timing of break-up and freeze-up, as well as variations in the extent of flooding.

The two projects described above provide a look at native perceptions of current environmental conditions. MBIS is also supporting preliminary activities that could lead to the development of a third project which would aim to provide information about past conditions when the climate was warmer. Traditional knowledge based on oral histories could complement evidence and interpretations from paleoecology (Sections 4.2, A13) and current ecological observations (Sections A4, A5).

At the time of printing, Eileen Bielawski (Arctic Institute of North America) and Barney Masuzumi (Dene Cultural Institute) have undertaken discussions with the community of Lutsel k'e (Snowdrift), located on the southeastern shore of Great Slave Lake. This community has agreed to participate in a survey of its elders in their language. This type of study, described as Participatory Action Research, requires considerable time and is expensive, so the proponents are now seeking additional sources of support.

MBIS is also considering a proposal to determine the potential effects of global warming on settlement growth and development over the next several decades. The proponent, Robert Bone (University of Saskatchewan), would compare possible settlement changes under current climate conditions with those that could occur if the climate becomes warmer. Changes in resource development and transportation would be important factors, so the proposal includes consideration of these (see Sections A7, A8).

A6.2 Community Adjustment to Extreme Geophysical Phenomena in the Northern Regions of Canada

John Newton, University of Toronto

A6.2.1 Background to the Research

Understanding how remote communities cope with extreme natural hazards is essential for maintaining the viability of these communities. It is commonly believed that most communities in Canada's north are ill-equipped to respond effectively to a disaster, having few of the skills and resources possessed by communities in the densely settled parts of the country. The sustainability of the over 350 remote communities in Canada is dependent on the complex integration of traditional techniques and modern technologies. A better understanding of these coping mechanisms (O'Riordan 1986) can minimize vulnerability and enhance adjustment to potential shifts in weather patterns throughout the north. Evidence obtained from studying the human-environment interaction between the people of these remote communities and extreme geophysical phenomena (Hewitt 1983; Mitchell 1990), such as floods, could be crucial to their continued existence and safety.

The research investigates whether these isolated communities adjust due to previous experience and advance preparations, structural control programmes, or deeply rooted social cohesion. In the event of a flood or forest fire the ability of the community to respond effectively may depend, not only on preparation, but also on community leadership and cooperative action (Mitchell 1990; Hewitt 1983; White 1964).

A6.2.2 Rationale for a Northern Research Context

If one accepts that these northern communities, and other similar settlements worldwide, are in transition from a strictly traditional society to a new condition incorporating characteristics of a modern society (Bone 1992), then how has this change influenced their ability to cope with natural hazards? Have traditional coping mechanisms been eroded or augmented by the influence of modern society? This research opens these questions to scrutiny through detailed investigations in three communities and argue tentatively that coping with natural hazards outside the protective mantle of institutional structures can have a positive bearing on the sustainability of communities in both northern and southern Canada. Beyond the continental land mass the question of sustainability is intimately entwined with Canada's claim to sovereignty over the northern islands and the Northwest Passage (Jackson 1992). This issue remains unresolved making continued habitation a crucial issue.

Given the difficulty of addressing community level response to natural hazards within heavily populated urban centres, where the socio-economic environment can inhibit community action, this research has elected to focus on isolated communities. By looking at more remote, isolated communities not embedded in the extensive supportive infrastructure of an urban environment, attitudes and mechanisms that influence social actions and responses can be simplified. A shift in the level of institutional arrangements, such as a reduction in police, fire and medical services, may allow the issues and interconnections between communities and natural hazards to be revealed more clearly (Wisner et al. 1977). In today's individualist urban environment few people experience the implications of disasters, being buffered from this reality by an incredibly complex system of attitudes, values and responsible government agencies. Only through establishing a research environment where these constraints are minimized may some possible links between hazards and society be productively investigated.

Most northern residents are aboriginal with ancestors predating Columbus, Cartier and Champlain, and a connectedness to their land unknown to all but a few white southern Canadians (Sutherland 1991). Again, this cultural heritage provides an understanding of the integrated nature of people, animals and land (Marsh 1864; O'Riordan 1989) rarely available to urban dwellers whose lives are embedded in the culture of science and technology. Remote communities possibly exhibit unique social and cultural conditions which allow investigations of hazards and the communities they threaten, to be fruitfully explored. Through such a perspective this research will assess the specific issue of flooding and the issues of human coping mechanisms, sustainability and related government policy (See Visvidar and Burton 1974 for an earlier policy perspective) for northern communities. Of potential value to southern municipalities are insights now too obscured by culturalization and institutional structures to be identified and studied in urban environments but which can be tentatively addressed through the operationalization of this research.

A6.2.3 Natural Hazards in Northern Canada

Not all northern communities are subject to flooding even though there are undoubtably similarities in the coping mechanisms required for fires or severe weather. Attention is therefore drawn to small isolated communities located on rivers, lakes and oceans for historic, cultural or political reasons where the potential for flooding exists (Kirwoken 1983; 1988). These settlements tend to range in size from less than 50 to over 2,000 people with portions of the population living on and actively using the surrounding land base for substantial periods of the year (Berger 1988). Life in these communities is strongly influenced by the annual cycles of country food supplies (Brody 1981; 1987).

Predominant among the hazards of living in these isolated communities are flooding, forest fires and severe winter storms. Avalanches are common to the mountainous areas of the northwest and earthquakes have been recorded in the western arctic. The focus of this research is flooding, more specifically spring flooding on northern rivers. Where large volumes of meltwater and river ice pushing northward towards frozen bays and channels. Here, for commercial and political reasons, communities were located for trade and access to local resources, creating at numerous sites the conditions for disaster. To underline the reality of this situation, in May of 1986 the community of Winisk, Ontario was swept away in a matter of minutes by a torrent of ice and water, killing two people. And yet these communities survive, and prosper.

To survive under these conditions adaptation becomes a way of life developed through experience of the annual cycle and guided by oral histories. While perhaps true at some time in the past, the vision of complete self-sufficiency is rare today as the technologies, policies and culture of modern society have become an integral part of life in the north. Snowmobiles have replaced dog teams and though traditional hunting and trapping tools and methods are still employed the rifle is the basic instrument used to collect country food. People and environment are inseparable in the north, they are one. The land is named after the people and the people have often taken their names from the land and the products of the land. To begin to assess the impact of natural hazards on remote communities one must first understand the people, how they live, what their values are and how they perceive what are commonly called natural hazards.

A6.2.4 Research Objectives

As studies of the appropriate use of emergency preparedness principles and disaster response activities are rare in remote communities, this research aims to enhance awareness and to provide a basis for the development of relevant policies and implementation procedures for emergency preparedness, by governmental agencies and local populations. These actions could prove essential should projected climate changes in northern Canada be realized. Among the impacts envisioned, current climate modelling projects increased winter precipitation, potentially leading to acute flooding, and drier summers which could increase the hazard of forest fires (Cohen 1991). Understanding the relationship between people and the natural environment under these conditions will be critical to the implementation of appropriate action plans by local and central agencies.

The proposed research grows out of a history of interdisciplinary risk and disaster research at the University of Toronto (Burton et al. 1968; Hewit and Burton 1971) and a recent body of literature that vigorously debates the theories and findings proposed in some of the earlier studies. It is upon this foundation and discussion that my research builds. My research questions address the general weakness of the dominant structural approach to disaster mitigation, following a more behaviourial approach to understanding how *communities* cope with geophysical disasters (Burton et al. 1968; Hewitt 1983). Only through an interdisciplinary approach spanning environmental geography, engineering (watershed hydrology, river morphology and ice jamming), sociology (community structure and social relationships), and anthropology (traditional skills, knowledge and lifestyle) can one truly begin to move towards a more holistic understanding. This is the route I am following based upon personal and professional experience in three of these fields.

Through this approach I hope to provide a needed understanding of community level response to natural hazards in a cross-cultural setting (Sutlive et al. 1986). How is the internal/external balance of influences shifting within these communities? And are these adjustments and changes making the population more, or less vulnerable? Understanding these issues will, I feel, be essential to the development of locally sensitive development and emergency policies for remote northern communities and could prove a valuable contribution to improving current urban policies.

Of equal importance are the implications of hazard research on the complex issue of self-reliance, or sustainability in today's jargon, for northern and southern Canadian communities. Through addressing the role of social relationships in coping with disasters this research pinpoints the critical topic in the current discourse on sustainability. In this manner, I would argue, my research has the potential to contribute to the theory of adjustment to natural hazards and sustainability as well as practical aspects of disaster response and preparation.

A6.2.5 The Major Themes of Investigation

Within the communities whose societal characteristics straddle traditional and modern attitudes and ideas this research addresses whether experience in these remote, isolated communities corroborates, extends or rejects previous research on human adjustment to natural hazards (Mitchell 1990). It will be argued that response to natural hazards at a community level has been neglected and could be a key factor in the continued existence of remote northern communities. Of equal importance the pivotal role of community-based activities in providing a foundation for the social sustainability of northern communities is considered.

To investigate this research theme the following are a few of the questions that have been investigated through an inductive process of field discussions with community leaders, residents and local agency officials (ie. religious, health, educational).

- How do residents of northern communities perceive natural hazards? As potential disasters, temporary inconveniences or part of everyday life?
- What influences this perception of natural hazards? Personal experience? Oral histories? Faith in physical or institutional protection?
- Given this perception what influences how the community copes with a natural disaster? Preparation? Level of resources? Social structure? Characteristics of the event?
- In what ways do northern communities differ from southern communities and how do these differences increase or decrease their ability to cope with natural hazards?

- Can traditional hazard coping skills and modern technologies be successfully transferred to the benefit of both northern and southern communities? Are such transfers appropriate and will they be accepted?

To address these questions, within the complexity of a cross-cultural context, will require an understanding of how remote communities prepare for disasters and what characteristics of the community, or the hazard, influences the type and level of preparedness. Of specific interest will be any evidence of enhanced ability to cope with one event due to experience with another event, whether similar or not. And will modern adjustments and preparedness techniques work or merely destroy traditional skills leaving communities potentially more vulnerable?

Among these sub-themes lies the relationship of the community to its immediate environment and how this relationship is influenced by social and technological changes. Technologies such as televisions, snowmobiles, telephones and computers have certainly changed life in northern communities and may well influence their ability to cope with natural hazards. While not being investigated directly the influence of specific technologies is acknowledged.

Coping ability does not rest solely within the innate characteristics of the residents, their family, religious or community groups but is also dependent on the degree of local *emergency preparedness* and the direct and indirect *influence of state agencies*. These two areas of investigation constitute secondary research themes which complement and expand the focus of the primary theme providing depth and additional relevance.

Implicit in the consideration of coping mechanisms is the role of the state both in influencing the structure of 'normal life' and responding to actual disasters. Do government actions complement and support local coping efforts or does state intervention destabilize traditional community-based response to natural hazards? To what extent does state involvement at the preventative stage incorporate local knowledge and skills? Or do preparatory efforts largely depend on material and procedures developed for use in southern communities where cultures and physical conditions differ? With limited, and shrinking capital resources and operations staff, the responsible state agencies might find such a transfer of existing policies and training materials an extremely attractive option. The specific needs of remote northern communities must be clearly outlined if state policies are to be developed in response to the actual situations and not a general perception of need based on southern models. Answers to these concerns will be critical to the development of emergency response policies that can successfully meld local experience and southern knowledge.

A6.2.6 Development of a Qualitative Research Approach

The research has been operationalized in three stages, each growing out of the former and directed to probe the issues to a greater depth. Stage 1 collected basic policy and procedural information from relevant government agencies across Canada. In Stage 2 information on experience with natural disaster in remote communities has been solicited through personal discussions and from existing records. Based upon this information Stage 3 involved intensive field research in the communities of Attawapiskat, Ontario, Fort Liard, NWT and Aklavik, NWT. Each of these communities has experienced flooding and faced the threat to varying degrees again, in the spring of 1992. The research approach is qualitative drawing heavily on the experience and knowledge of residents and local officials (Kirby and McKenna 1989).

The field research involved discussions with elders and community leaders, local agency officials (ie education, religion, health) and residents, based upon an interview guide highlighting crucial research questions (Jones 1985a-b). The field research was timed to correspond to spring break-up when local concern and activity are high. In Fort Liard and Aklavik the potential for event observation was realized as both communities experienced flooding. Attawapiskat was evacuated as a precautionary measure after my departure. The opportunity to observe local preparation and response to these events augmented the information collected and served to corroborate the historic data obtained from residents. In this manner my research focus has moved from the broad governmental perspective to the reality of community experience with natural hazards.

As a possible framework to address the current transitional condition of northern communities a descriptive typology composed of a series of theoretical poles representing the extreme conditions of traditional and modern societies is proposed (Figure A6.1). For each pair of terms each community, whether southern of northern, will sit at some intermediate point on the continuum. This point can be approximated by considering how each factor influences the ability of a community to cope with a natural hazard. While each community and hazard combination will likely exhibit differences some general trends may emerge. Mapping these influences for northern and southern communities shows a tendency towards the left for the former and to the right for the later. Deviation of the line towards the opposite extreme for a specific characteristic would acknowledge the influence of that society. Does this influence help or hinder the ability of the community to respond to a natural hazard? The detailed community studies can assist in beginning to answer such questions. Such a framework can provide a better understanding of the context within which researchers work, and in so doing assist them with their research.

Figure A6.1 Societal Characteristics

Traditional Society						Modern Society
Community Reliance		*†		◊	•	State Reliance
Knowledge Embedded In Experience	*†◊			•		Knowledge Separated From Experience
Oral Tradition	◊		*	†	•	Written Format
Needs Driven		◊	*	†	•	Wants Driven
Traditional Technology		◊	*	†	•	Modern Technology
Community		◊ *		†	•	Individual
Cohesive			◊ *	†	•	Fragmented
Cooperation	*	◊	†	•		Competition
Informal	◊	*†			•	Formal
Holistic		◊ *	†		•	Systemic

* = Aklavik † = Fort Liard
• = Toronto ◊ = Attawapiskat

A6.2.7 Tentative Observations on Natural Hazards in Northern Canada

Initially a number of questions were asked about remote communities in Canada's north and the impact of natural hazards, such as flooding, on these communities. Are some remote communities better able to cope with the impact of natural hazards than others? How are the impacts of extreme natural events such as flooding mitigated? Do communities that cope exhibit similar characteristics? Is the ability to cope embedded in cultural traditions or the result of conscious efforts to minimize risk and anticipate needs in the event of a disaster? These questions provided the starting point for this research sparking interest by colleagues, government agencies and research organizations in an area to which minimal attention had been given. Many more questions arose during the investigation, to which answers were rarely available, or to which only tentative explanations could be deduced from the field experience and collected information.

A few of these questions are noted here. Does family structure, specifically single parent family units, influence community response? Does the annual cycle of obtaining "country food", such as the spring hunt for geese or muskrat also function as a built-in protective action? And what is the social impact of flooding, does break-up seriously disrupt everyday life or is it perhaps an integral part of the annual cycle? Further crucial questions relating to preparedness and response will be answered in the larger study currently in process. For example, are remote communities better prepared due to previous experience and advance preparations, or due to traditional practices that have emphasised a sensitivity to, and intimate knowledge of, the natural environment? And in the event of a flood, will the ability of the community to respond effectively depend, not only on preparation, but also on community leadership and social cohesion?

The questions are numerous, the situations are real, as shown by the 1992 break-up, and the answers are few, and tentative. To attempt firm answers is unrealistic, both from an academic and a practical perspective, but tentative conclusions can, and should be drawn to illuminate this area of investigation and provide a direction for communities, government agencies and other researchers to follow. At this stage in the research tentative answers, based upon the field research, can be given to questions in each of the three primary areas of investigation while other questions as outlined above will require further analysis.

Based upon research between July 1991 and June 1992 and field investigations in the communities of Aklavik, N.W.T., Attawapiskat, Ontario and Fort Liard, N.W.T. during the winter and spring of 1992, the following tentative findings are presented in the areas of *emergency preparedness, disaster response* and *state influence*. Please note the very recent acquisition of this information and thus the more intuitive rather than formal analysis that forms the basis of these findings. A more comprehensive analysis will be undertaken during the coming year and be presented in the forthcoming dissertation, which is the ultimate academic objective of this work.

A6.2.7.1 Emergency Preparedness Yesterday and Today

Tying a boat or canoe to one's dwelling appears to be an almost universal preparation for spring break-up. Boats wintered on river banks will be moved closer to home as a means of escape and to prevent the boat from being washed away by the spring meltwater and river ice. Each year boats, and the occasional snowmobile, are lost in this manner due to negligence, or possibly as a means of disposal. Personal preparation for spring break-up also includes having a supply of food on hand and the necessary equipment for camping on the land. As elders and patients are generally the first to be evacuated they are advised to keep a small bag of essentials packed. For some this is routine practice when they notice snow melting and the warmth of the spring sun. Another common preparatory activity is to raise belonging off the floor to prevent damage due to water and silt. Snowmobiles and sleds are often placed on wood piles, porches or trailers. Within houses residents will move furniture and belongings to upper floors, other houses or central reception centres. Levels of individual preparedness vary substantially due to perceived risk and the value assigned to material possessions.

Community level preparedness is as equally diverse as personal actions. Early preparation does not appear to be a human trait though notices explaining the meaning of sirens were posted throughout Fort Liard well in advance of break-up. The first meeting of the local emergency operations committee often occurred as water approached the top-of-bank. Activities then took on a reactive character responding to the level of water and condition of ice both in the immediate vicinity of the community and on the river or delta in general.

In the case of Liard, experience with the 1989 flood certainly influenced the personal and community actions taken during the spring of 1992, whereas in Aklavik the 1982 flood seemed to have less direct influence on actions in 1992. Three factors may account for this difference. First, the shorter the time *between* events the stronger the influence. Over a longer period, such as the 10 years in Aklavik, many of the leaders have changed, houses have been raised and the nature of the community may have altered. Thus, experience with past floods as an influence on coping appears to drop off sharply with the passage of time. One to four years could be said to significantly influence community coping, while five to eight years will likely exert some influence, and for events over nine years apart the influence will be minimal. Second, the severity of the event must be considered. A catastrophe will be well remembered, a brush with danger glorified and forgotten, or distorted over time. Attitude will be a third important factor. If floods are considered "everyday" type events preparation will be minimal, with response geared to events as they develop rather than taking preparatory action. Communities following this route exhibit confidence in their own abilities to survive. Such attitudes were prominent throughout Aklavik.

A6.2.7.2 Local Disaster Response to Natural Hazards

With 32% of the families in Attawapiskat having a single female as the head of the household the ability to follow traditional responses to flooding is severely threatened. Hunting has not been a traditional female pursuit among the Cree and other Algonquin and Athapaskan indians. Thus rarely have these skills been developed nor, more importantly for disaster response, has the specialized equipment, such as boats, tents and other camping essentials, been acquired. This is not to say that these families could not survive if equipment was available and circumstances dictated the need for action, but rather that such a response to a flood is not their natural first choice as is more likely the case with nuclear families. Illegitimate children bear no obvious stigma in Attawapiskat being accepted throuhout the community. Uncles and grandfathers will, to some extent, fulfil the role of a father, especially where daughters return to their parents' home. Widespread occurrence of single parent families was not found in either Fort Liard or Aklavik where informants indicated a strong resistance to separation and divorce, with illegitimacy being rare.

Communities such as Attawapiskat therefore require organized evacuation procedures and the implementation of an evacuation plan based largely on external assistance. The precautionary evacuation in May 1992, in moving 421 people to southern reception centres, supports this observation. Each community must be assessed on not only the condition of its family structure but also on the role women take in the specific culture. Where hunting, living and moving on the land are an integral part of the culture, external assistance may not be required to the same extent as in Attawapiskat.

Viewed from the local perspective, response to a flood might be considered part of everyday life for this time in the annual cycle of events. Spring is when break-up occurs, when winter equipment such as snowmobiles and sleds are put away and boats and motors are brought out. Going hunting by snowmobile, pulling a boat and returning with the snowmobile in the boat is in keeping with the sudden change in seasons break-up brings. In the Mackenzie Delta, the period prior to break-up until June 15th is muskrat season traditionally taking people to their camps for extended periods. The spring goose hunt along the James Bay coast provides a similar impetus for the Cree to leave their communities in search of a valuable source of country food. Not only do these activities make dealing with changing ice and water conditions a natural part of life but they also remove people from the flood risk area in the community. This is not to say that they will not have to contend with adverse conditions while on the land but such conditions *are part of life on the land* and thus expected and taken in stride. Stories of nights spent in boats or on hastily constructed stages are common on both the James Bay coast and the Mackenzie Delta. Flood waters are not to be feared but respected.

In Fort Liard, the opening of the Liard Highway in 1984 caused many changes in activities and perceptions. Still isolated by urban standards, Liard no longer relied on the air connection to the outside world during break-up. The increased availability of easy escape has bred an individualism in Liard not found in other communities visited. In response to a flood, people could, and did, simply leave town by road for their camps or to visit friends or family in Nelson, B.C. While viewed by some residents as deserting the community during a time of crisis, these actions are merely one form of response, not unlike leaving the community for the spring hunt. However, widespread departure can weaken the response capability of the community shifting greater responsibility to fewer people.

Response is also a function of perceived risk. In Liard where a portion of the community is on higher ground, the degree of concern is reduced even if the seriousness of the event is acknowledged. It is those directly affected who live with the imminent threat of disaster and feel the full psychological impact. Within a few hundred metres, one family lives in a highly disruptive state while another proceeds normally, aware of the general risk but oblivious to the mental impact to those directly at risk. Understanding these differences can help account for the dramatic range of behaviours that often accompany events such as flooding.

A6.2.7.3 The Nature of External Influence

State influence can range from advice, through guidance to active participation. The approach taken will depend on numerous factors, some relating to the nature of the event and others dependent upon the abilities of residents. Where a strong local government can mobilize a response team from the community, outside help will remain on standby providing advice, information and moral support. In the spring of 1992 this appeared to be the state role throughout the Mackenzie Basin in the N.W.T. In contrast, government agencies were actively involved in Attawapiskat from the time a potential hazard was perceived, taking a key role as a participant on the emergency response committee in the community.

Throughout Canada, state organizations at the provincial\territorial and federal levels are mandated to provide services to communities. Due to remoteness and limited budgets, isolated settlements continue to receive less attention than urban centres though agencies are beginning to work with Indian and Northern Affairs Canada (INAC) with respect to First Nation communities. Other isolated settlements are generally left to their own devices though assistance will be provided if residents cannot cope.

The legislative difference, from the perspective of an isolated settlement, between the Territories and the Provinces is worthy of note. While the actual legislation is similar, the relationship between the centre of power and the periphery varies within provinces and differs substantially from the situation in the Territories. Contrary to what one might expect, the psychological distance between the centres of power and isolated settlements is greater in the Provinces than in the Territories. A policy in the Territories applies to all communities whereas in the provinces more attention is directed to the populated south rather than the sparsely populated northern regions of the Provinces. More specifically, INAC plays a larger role in the affairs of northern native communities in Provinces than in the Territories where all departments of the Territorial Government serve every community. Territorial communities are closer to the mainstream of decision-making thus developing political and administrative skills essential to the successful management of not only natural hazards but other technologically based tragedies. This reality deserves special attention, underlining the failure of generic solutions, whether to natural hazards or social issues, in isolated northern communities.

Building standards in Aklavik now require buildings to be built on piles primarily as a result of the permafrost in this region. However, by also requiring a minimum height above the projected 100-year flood level, new buildings are also less susceptible to flood waters. Ice could still be a problem should large flows enter the community, however trees along river banks form barriers to ice flow. For older houses, Housing Authorities and individuals have raised buildings on wooden cribs to provide protection from flood waters. Many Aklavik homes damaged in 1982 were dry in 1992 minimizing the need for local evacuation to only a few families.

A6.2.8 Recommended Actions

To assist isolated communities in the northern region of Canada to prepare and respond to natural hazards such as flooding, and to provide a basic decision-making structure to respond to technologically-based emergencies, the following recommended actions are suggested. These actions will also be of value to government organizations responsible for the development and implementation of emergency preparedness and response policies. Incorporating these suggestions will reinforce existing policies, improve the delivery of programs and allow managers to guide rather than control the evolution of community-based response networks.

These suggestions should be considered tentative, based on initial perceptions rather than detailed analysis and not taken to be a panacea for the difficulties of serving a remote audience with tools designed for urban settings:

- An up-to-date Emergency Response Plan should be in the hands of all members of the emergency response team. The Plan should be designed to move beyond a list of contacts and generic responsibilities to include specific activities and locally sensitive information. To be of value the plan should be updated on an annual basis and approved by the local governing bodies.
- A formal emergency response team meeting should be held at least one (1) month before break-up is anticipated.
- The estimated break-up period should be noted on the calenders of all local and senior level governments to avoid events being planned in the community and to ensure key team members are available during the break-up period.
- Condition of response equipment, such as radios, batteries, water level gauges, etc. should be checked and if necessary repaired or replaced prior to April 1st of each year.
- Sources of temporary response equipment such as tents, sleeping bags, primus stoves and fuel, etc. should be confirmed annually after the meeting mentioned above.

- Clear communication in writing and by radio should provide residents with the meaning of warning signals and suggest appropriate actions.
- Set decision points for actions such as warnings or evacuation but maintain flexibility as conditions change.
- To maximize the cooperation of all residents actively involve all local jurisdictions in the emergency response team.
- Ensure volunteers and staff receive food and hot beverages while on flood watch. When tired the chance of secondary emergencies (eg. vehicle accidents) increases.
- Provide rest and sleep periods for all participants to ensure the ability to respond to an escalation if the event is present.
- Establish permanent water depth gauges at monitoring locations so that critical levels can be preset.
- Have backup radios, spare batteries and sufficient battery chargers to maintain the viability of the communications network throughout the event.
- Make sure the crisis is fully over before relaxing vigilance. Water levels during spring break-up can rise and fall rapidly.
- Complement local expertise by training a few key community members in the art of emergency preparedness and disaster response. Provide opportunities for generic approaches to be modified to suit local conditions.

A6.2.9 Direction of Continuing Research

The work presented in this paper represents the beginnings of the study of natural hazards in the remote regions of Canada. Covering the research design, field investigations and discussing tentative findings this study raises many important issues in the preceding pages. Ongoing work directed towards the completion of a doctoral dissertation will move the analysis forward substantially shedding further light on the coping mechanisms of northern communities and our ability to understand how their needs can be best served. Much remains to be done in the coming year and yet much of interest will only be touched on. First, a few comments on the work anticipated and then some remarks on the work that will likely remain unaddressed despite inclinations to pursue these avenues of research.

Information from the twelve provinces and territories and the 108 field interviews (77% taped) requires formal review and evaluation to add support to the tentative findings mentioned above and to address the themes of coping, preparedness and state influence more thoroughly. The subjects of river morphology and the dynamics of ice formation and ice jamming deserve attention as does a comparative analysis of the similarities and differences in the annual cycles of each community visited.

The anthropological side of the research themes could be explored in greater detail as the unique cultural heritage of the Mackenzie Delta provides a complexity rarely found in the north. How do two cultures coexist and will co-management of Aklavik Settlement Lands prove workable in light of a long history of intermarriage between Loucheax and Inuit? To the south in Fort Liard, the influence of the road connection on the community and how this has affected its ability to cope with natural hazards and economic diversity is a subject worthy of investigation. Another area of study would be a historical investigation of the evolution of the communities from dispersed camps to established communities. The current work will address this subject to a limited extent but research into the role of camps and how they influence today's communities would also be of value to further our understanding of the strength and resiliency of northern communities. Superimposed on these issues is the current movement towards greater independence and ultimately self-government at regional, tribal and even community levels. The politics of native self-government lies just below the surface of many of the issues addressed by this work and yet is a major subject demanding specific attention. Further research into the implications of self-government for emergency preparedness and disaster response in northern communities would be a valuable and timely addition to our limited knowledge in this area and be complementary to the focus of this study.

A6.2.9.1 Focus on Three Case Studies

From the beginning of this undertaking, I have reiterated the importance of hearing the views, attitudes and ideas of the residents in remote northern communities. It is these people who are exposed to the fury and destruction of the ice and water. What do they think? What do these events look like through their eyes? How do they cope? I have spoken to some of these people, listened to their stories, walked in their communities and in a small way experienced similar threats. But their views have not been told. This is the work at hand, to focus on the three case studies, ponder the research questions and see what answers I can extract from their responses.

I will first look at each case study community independently as each is different, representing a unique set of characteristics to which only a few communities in each region will bear any resemblance. As clear an understanding as the information will allow is essential at a local level, outside the complexities of cultural and physical differences. Only upon a firm understanding in each of the three communities can more general observations and findings be tentatively made. The recommended actions presented in the preceding chapter represent a step in this direction based upon my personal experience in the study communities rather than a detailed analysis and synthesis of the interviews conducted in each community. More comprehensive investigation of the collected material will hopefully support these preliminary observations and identify other actions that also warrant attention.

A6.2.9.2 Addressing the Influence of Internal and External Factors

Wherever a natural disaster, or for that matter any catastrophe, occurs there will be two responses, both before and after the event. Locally there may have been preparation and there was undoubtably some immediate response. Further from the centre of the event in district, regional or national capitals other people, unaffected directly by the disaster, but nonetheless responsible due to their delegated authority in these areas, are responding. For each event the balance of activity between these two sets of actors, one internal, the other external, will vary dramatically. Factors such as magnitude, damage, skills and resources will influence the mix of internal and external actions needed to successfully mitigate the impact of the event. Timing will be crucial to minimizing the impact, reflecting the extent of preparation and the speed of response.

Understanding the mix of internal and external actions and the physical, political, economic and cultural factors that influence the mix represents a central challenge of this research. In crisis the interface between traditional and modern societies becomes dynamic, functioning at a speed which magnifies the differences, highlights the strengths and underlines the deficiencies of trying to cope with a disaster in an isolated community. In more peaceful times, the inconsistencies are not seen. They are lost in the hypothetical nature of the discussion, minimized by the lack of urgency. Stress can bring the best out in people. It can also highlight the weaknesses in organizations whether informally, or formally structured and working at a local, or agency level.

In the analysis and synthesis of the collected information from communities and government agencies, careful consideration will be given to the roles and responsibilities of internal, local groups and external, generally governmental agencies. It is here, I believe, in the interaction between these groups, that disasters can be dealt with successfully or escalate uncontrollably. Maximizing the former and minimizing the later should be the primary objective of all involved.

A6.2.9.3 Schedule to Completion

The nature of research, and especially the analytical phases, makes the prediction of timing problematic. Research by its very nature is iterative causing new questions to arise in order to provide tentative answers to outwardly simple questions. Stemming this tide and yet concluding with reasonably supported findings is a challenge faced by all researchers. Thus, I hesitate to be firm about completion dates as much of the formal analysis is yet to be done. Nonetheless I would hope to have a completed draft available for review by my committee towards the end of March 1993. Depending on how the draft is received, the final dissertation could be competed as soon as the late spring and at the latest in the fall of 1993.

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A7. Energy And Mines

Stewart Cohen, Canadian Climate Centre

A warming of the region's climate would lead to a series of changes to the physical and biological environment. These, in turn, could affect the commercial viability of energy and mineral extraction activities by altering the factors determining production and transportation costs.

Sections 2.2 and A1 included reference to the project by Andres on modelling Peace River ice formation as a function of the hydrologic effects of climate and the operation of the Bennett Dam, which is a hydroelectric facility within the BChydro system. A change in climate would affect runoff in the Peace River subbasin upstream of the Dam, and would also affect demand for electricity to provide heating and cooling to residential and commercial customers, most of whom are located outside the Mackenzie. This project represents an important challenge, since the linkage between climate and ice (and subsequently, ice jam floods in the city of Peace River and the Peace-Athabasca Delta) includes external forces which are not necessarily related to conditions within the watershed.

Section A3 provides some preliminary results of a study by Agnew and others on the implications of changes in sea ice on offshore energy exploration in the Beaufort Sea. This study was funded by the Panel on Energy Research and Development (PERD). Scenarios of a warmer climate inevitably include a reduction in sea ice. This could benefit the energy industry by reducing the costs of winter operations, but on the other hand, there may be an increased likelihood of storm surges during the longer open water season. There are indications that this scenario could actually increase the overall costs of operating in the Beaufort since the energy industry would have to account for the new summer hazard while still protecting its operations during the winter.

MBIS is also considering two proposals: a) Robert Bone's study of non-renewable resources, which is linked to his proposal on settlements (see Section A6), and b) William Anderson's and Mel Kliman's (McMaster Institute for Energy Studies) study of the energy sector.

The first proposal would provide detailed analyses for specific cases: Norman Wells oil and pipeline, Delta-Beaufort oil and gas, Fort McMurray heavy oil, Tumbler Ridge coal and Cluff Lake uranium mine. The cases would address operations (including transportation) and maintenance costs, and how these might be affected by a changing climate. Permafrost thaw and ice reductions could have substantial implications, as would prices, transportation (see Section A8) and secondary effects on settlements (Section A6).

The second proposal would be an economic analysis of the energy sector, including electricity, and how supply and demand would be affected by potential changes in climate, prices and infrastructure. The focus of the research on oil and gas would be on the effects of climate change on the costs of exploration and exploitation, including transportation, labour and drilling, so as to determine the minimum international energy prices necessary to make production feasible under various climatic scenarios. The electricity component would be examined for any possible changes in a) hydroelectric potential due to changes in streamflow at various sites, b) thermal generation resulting from a spinoff of climate-induced changes in oil and gas development, and c) the potential to develop decentralized electricity generation facilities, such as low head hydro and wind generation, both of which would be sensitive to climate change. The overall economic analysis would be linked with the Input-Output model of the Mackenzie Basin's economy currently being developed for MBIS (Section 3.2, A15.1).

A8. Transportation And Infrastructure

Stewart Cohen, Canadian Climate Centre

Changes in permafrost, snow cover and ice conditions could affect the design, operation and maintenance of winter roads, pipelines, shipping facilities and service systems (e.g. utilidors) in settlements. This is one of the main policy concerns described in Section 2 of the main report.

MBIS is compiling information on current conditions and potential climate-induced changes. Activities focussing on permafrost and sea ice have been described in Sections A2 and A3, while hydrology, snow cover, river ice and lake ice are discussed in Section A1. We are also continuing to receive updates on current permafrost and terrain conditions along the Norman Wells pipeline, courtesy of K.L. MacInnes of Indian and Northern Affairs Canada, Yellowknife. The most recent report, dated November 1991, includes contributions by researchers from several federal and territorial agencies, and universities. This data base will be available for MBIS activities addressing transportation and infrastructure.

There is considerable overlap between this issue and energy-related activities because much of the investment in transportation and infrastructure originates from the need to provide facilities for energy exploration, extraction and delivery to market within and outside the region. Studies on Beaufort Sea offshore oil exploration (Chapter A3) and the proposals by Bone, and Anderson and Kliman (Chapters A6, A7) recognize this close relationship. In a climate change, however, there is the possibility that other sectors (e.g. forestry, agriculture, tourism) may become more important actors in the regional economy than they are now. MBIS will consider this possibility in the integrated assessment of potential impacts (Chapter 3).

A9. Agriculture

Mike Brklacich, Carleton University

The assessment of the extent to which global climatic change might alter prospects for agriculture in the Mackenzie will be conducted under Phases II and III of the agricultural component of the MBIS. Phase II will focus on the effects of altered climates on yields for selected crops, whereas Phase III will be directed towards evaluating regional development opportunities that might stem from global climatic change and possible socio-economic adjustments in the Basin (see 3.2, A15.1). Results from Phase I (see A2.2) will be used to delineate areas in the Basin that would have a physical potential to support commercial agriculture under existing and altered climatic conditions, and research undertaken for Phase II and III will be limited to these areas. Preliminary assessments of the impacts of global climatic change on agroclimatic properties in the Mackenzie Valley (Brklacich and Tarnocai, 1991) suggest:

1. the northern agroclimatic frontier for agriculture could extend into the upper reaches of the main trunk of the Mackenzie River, but
2. changes in climatic conditions would not significantly enhance agricultural opportunities beyond the upper portions of the Mackenzie Valley.

In other words, it is anticipated that Phases II and III will be directed to the existing agricultural regions in the upper parts of the Mackenzie Basin (i.e. Peace River area) with some preliminary exploration of new opportunities in the areas near Great Slave Lake.

Phase II will utilize the family of crop productivity models available from the Intenational Benchmark Sites Network for Agricultural Technology Transfer (IBSNAT). This work is scheduled to begin in late 1993 with an expected completion date of early 1994.

In addition to information compiled for Phase I activities, completion of Phase II will require additional information on crop varieties, crop growth rates and management practices. Crop trials conducted in northern Alberta should provide most of this information, but it should be expected that this base data will be supplemented with additional information provided by crop production experts familiar with the region.

Phase III will investigate the extent to which global climatic change and changes in other conditions might:

1. expand regional production potential, and
2. alter economic opportunities for selected farm enterprises.

These activities are scheduled for 1995-1996 with preliminary results expected in late 1995.

Methods to perform these sorts of analyses are not yet fully developed, and it is anticipated that Agriculture Canada will participate in the development of appropriate methodologies to gauge the prospects for adaptation to global climatic change in the agricultural sector.

A10. Tourism

Geoff Wall and Janet Brotton, University of Waterloo

Background

The charge to examine the potential implications of climate change for parks and tourism in the Mackenzie basin is daunting. Not only are the magnitude and timing of climate change uncertain, both existing and future climates are likely to vary substantially across the basin. Furthermore, parks have a dual mandate of preservation and use. This dual mandate is also relevant to the broader tourism industry if tourism is to be developed in a sustainable manner and the resources on which it depends are not to be destroyed. The preservation mandate raises fundamental questions concerning what is to be preserved in an era of change. The use mandate raises questions with respect to what activities are currently and in the future likely to be feasible, bearing in mind that different activities have different ties to and different degrees of dependence on climate. The sheer size of the study area suggests that answers to these questions are not likely to be consistent across the basin.

The delimitation of the study area as a watershed has considerable advantages for certain physical investigations, such as those related to hydrology. It is less suitable for the consideration of mobile resources, such as wildlife, which migrate across watershed boundaries. Human activities are seldom restricted to specific watersheds and the boundaries of administrative districts rarely coincide with river basin boundaries. Data on human activities are usually collated on the basis of administrative jurisdictions, and political and management decisions are often made with reference to the same administrative framework. The Mackenzie basin encompasses parts of a number of provinces and territories so that there is great difficulty in acquiring data for the basin as a whole for such data may have been collected using different definitions, for different time periods, and may not be readily aggregated or disaggregated to a basin level. Thus, data acquisition and manipulation constitute a significant challenge.

Elements Of Tourism

At a very basic level, tourism can be viewed as comprising three fundamental components: attractions, transportation, and infrastructure. Although transportation can be viewed as one element of the infrastructure, because of its great importance, it is appropriate to view it separately. All three components are impacted upon by climate.

Attractions

Widely- accepted reasons must exist for tourists to visit an area in any numbers. Although push factors as well as pull factors may be involved, the existence of attractions is necessary to draw visitors in sufficient numbers for a viable tourist industry to be able to operate. In the north, both natural and cultural attractions exist.

The natural resources are used for both consumptive (e.g., hunting and fishing) and non-consumptive (e.g., hiking, photography) activities. Both of these groups of activities are likely to be impacted by climate change. However, a superficial evaluation suggests that the former may be more impacted than the latter. This is because the consumptive activities are more likely to be directed at specific species whose habitat may be modified by climate change whereas the latter are more flexible with respect to resource base provided that the area remains relatively natural and uncongested. Furthermore, consumptive uses may come into conflict and compete with indigenous uses of the same resources, particularly should such resources come into short supply.

The cultural resource is rooted in the lifestyles of the native peoples, both past and present. Such lifestyles, which are already changing, could be further modified by climate change. Insofar as the native peoples become more similar to residents to the south, curiosity in such lifestyles is likely to be diminished. Conversely, there may be increased interest in vestiges of the past among both native and non-native groups. Ongoing discussions concerning land rights and the government of native peoples could have far-reaching implications for all forms of resource use, including tourism.

Transportation

By definition, tourists come from elsewhere so that transportation between origin and destination, and within the destination area are crucial for tourism. It is unlikely that transportation networks will be set up specifically for tourism. Rather, transportation systems may be modified to facilitate the exploitation of other resources and, in such circumstances, tourism often follows closely behind. Should the Arctic Ocean become navigable, the increased accessibility of northern shorelines will have implications for tourism. Paradoxically, the special attractions of the Mackenzie basin derive partially from its remoteness and inaccessibility. Operating seasons may change but it appears that high cost, low density tourism is likely to continue into the forseeable future.

Infrastructure

With the exception of hunting and fishing lodges and other forms of tourism which benefit to some degree from remoteness, many of the comments made above with respect to transportation networks also apply to accommodation and other services. Few structures are likely to be built specifically for tourism. However, building standards for all structures in the north, including those used by tourists, may require amendment in a modified climate.

In summary, the indirect impacts of climate change on parks and tourism may be as significant as the direct impacts. Remoteness and associated high costs, as well as the long dark winter, are likely to be constraints on tourist development, although the former may be of increased interest to a growing ecotourism market in an increasingly modified world, and the latter may capture the curiosity of a specific small market segment.

Given the size of the study area and the many activities involved, to date, emphasis has been placed on scoping the problem. Efforts have been made to collect secondary data on parks and tourism from federal, provincial and territorial agencies; these activities are reported below. At this stage it is likely that a case study approach will be adopted with emphasis placed on: 1. the ski areas on the periphery of the basin; 2. the national parks; 3. hunting and fishing.

Activities To Date

Following two months of research and exploratory work, including one week spent in Edmonton, Alberta, and one spent in Yellowknife, Northwest Territories, a variety of information was obtained, and contacts made. Upon analysis, it can be stated that ten types of information have been collected and reviewed, and will be discussed briefly here. These data are as follows: information regarding characteristics of the Mackenzie basin; the relationship between recreation and climate; general tourism information; information regarding accommodations in the Mackenzie basin; data regarding downhill skiing and ski resorts in the basin; provincial and territorial parks in the area; National Parks in the area; hunting and fishing opportunities in the basin; permafrost in the Canadian North; and climatic data with regards to the basin.

Characteristics of the Mackenzie Basin

The area encompassed by the Mackenzie basin is vast, stretching across three provinces and two territories. Several sources were consulted (for example, Wolforth 1967, Inland Waters Directorate 1973), to obtain information regarding the drainage area of the basin, its population, population density, economic characteristics and development, and resource characteristics of the basin.

The relationship between recreation and climate

The decision to recreate is influenced by climate and weather: people consider the climatic requirements of particular recreational activities before engaging in them. Climate influences the type of activity participated in, the place where the activity occurs, and the duration and intensity of use. The relationship between climate and recreation was explored, as was the methodology employed in devising a system of climate classifications for recreational purposes. In addition, Wall et al. (1985) was consulted, to determine the methodology used in calculating downhill ski season length, and alterations to it if the climate were to change. Crowe (1976) developed climatic classifications of the Northwest Territories for recreation and tourism; these classifications were also examined. Winter and summer recreation-tourism classifications were presented. For the former, the three factors used for the development of the classification are length of day (the sum of the hours of daylight and hours of twilight), mean daily maximum temperature, and mean monthly wind speed. For the latter, the three factors used for the development of the classification are mean daily maximum temperature, monthly frequency of 80 to 100 percent cloud cover, and mean monthly wind speed. Four different winter classifications were developed; these range from excellent capability for recreation and tourism, to highly unsatisfactory capability. In addition, five summer classifications were developed; these also range from excellent capability for recreation and tourism, to highly unsatisfactory capability for recreation and tourism. The potential applicability of the classification is to be explored further.

General tourism information

A large number of documents contain general tourism information regarding the Mackenzie basin. From these, the number of tourists to the basin can be estimated (it is possible to regionalize these data to specific areas), as can the number of people employed in tourism, tourist expenditures, and characteristics of tourists to the Mackenzie basin. Specific visitor surveys were also consulted; these provide a detailed picture of the characteristics and economic impact of visitors to sites in the Mackenzie basin. In particular, the four non-resident travel exit surveys published by Alberta Tourism (1991) provide a great deal of information about the characteristics and impacts of tourists to four tourism zones in Alberta. Thompson's works on tourism in the Northwest Territories are also extensive; these were analyzed, and several types of information (for example, expenditures by tourists, gross revenues from tourism, person-years of employment) were extracted.

Accommodations in the Mackenzie basin

An important component of tourist infrastructure is facilities that accommodate tourists; the number of facilities, and rooms in these facilities, is both an indicator of the value of tourism in a region, and may act to encourage tourist activity in that region. Several sources were analyzed with regard to accommodation facilities in the Mackenzie basin (for example, Hughes 1989, Kinkaide 1990, Thompson 1992); from these, the number of hotel, motel and bed and breakfast facilities, and rooms in each, has been determined. These data have been regionalized for the Northwest Territories, Alberta, and British Columbia.

Downhill skiing and ski resorts

Downhill skiing is a major recreational activity and generator of revenue in the provinces of Alberta and British Columbia. From the literature review and field work, a profile of the Albertan skier is possible; this includes characteristics of and expenditures by skiers in Alberta (Travel Alberta 1984). In addition, information regarding the location, operating season, snowmaking capacity and specific features of ski resorts in British Columbia and Alberta that are within the Mackenzie basin was collected, as provided by Doughty (1991) and Savage and Barry (1985). A proposal of the Canada West Ski Areas Association (1992) is also of value, as it examines the importance of skiing in Alberta and British Columbia (its social aspect, economic impact, and multiplier effect).

Provincial and territorial parks

A large amount of data is collected regarding the provincial parks in Alberta. Alberta Recreation and Parks (1991) contains both individual and party visit statistics, as well as information regarding all provincial parks and provincial recreation areas in Alberta. In contrast, little information is collected regarding the territorial parks in Northwest Territories. While the location, year of establishment, and a description of each park and its facilities are provided, no records are kept concerning the number of visitors. As a result, it is not possible to state with any preciseness what the value of or demand on territorial parks in the Northwest Territories is.

National Parks

A substantial amount of data are available on the three National Parks which fall within the Mackenzie basin study area (Wood Buffalo, Nahanni and Jasper). These include the area encompassed by each Park, the year the Park was established, the activities permitted within each Park, and statistics regarding the number of visitors to each Park per month. In addition, specific surveys of National Park visitors are available (for example, Thompson Economic Consulting Services 1989); from these, it is possible to determine the economic impact of visitors to the National Parks within the Mackenzie basin.

Hunting and fishing

It is evident that revenue and employment provided by hunting and fishing opportunities within the Mackenzie basin are significant. Data are available regarding the number of sport fishing operations in each province and territory within the basin; however, these are not regionalized (Canadian Department of Fisheries and Oceans 1986). A large amount of other information is also available, including the number of fishing and hunting licences sold, and licence sales revenue, for the provinces, territories and National Parks within the basin (Déry and Boulanger 1988). Other information includes the impact of unlicensed anglers in Alberta (Carss 1978), revenue and employment at guide outfitter operations in British Columbia (these data have been regionalized) (DPA Group Inc. 1989), and the status and estimated populations of individual fish and wildlife species in Alberta, and endangered, threatened and rare species (Status of the Fish and Wildlife Resources in Alberta 1984). Thompson has done a great deal of research and reporting on sport fishing and hunting in the Northwest Territories; several information sources are available, and have been analyzed. From them, the number and characteristics of visiting anglers and their expenditures can be determined (Thompson 1986), as can the number and characteristics of big game hunters (Thompson 1988).

Permafrost in the Canadian North

The role of permafrost in the North is significant, as it may cause difficulties in carrying out certain developments, and may restrict the type of development that is possible. Tucker and Judge (1991) discuss the permafrost conditions in the North as they pertain to some aspects of transportation, while Woo et al. (1992) discuss adaptation to permafrost in the North (as it affects flora, fauna, human activities, and transportation networks), assuming a climatic warming.

Climatic data

Because this study is concerned with the possible impacts of climate change for tourism in the Mackenzie basin, it is necessary to determine what type of climatic data exists, and is collected, for points within the basin. The Meteorological Division of the Department of Transport has published monthly records of temperature and precipitation values for 1951 to 1980; these, along with the climate normals (Atmospheric Environment Service 1982) devised from them, have been analyzed, and will be a major source of climatic data once specific weather stations have been chosen. In addition, the offices of Atmospheric Environment Service in Edmonton, Alberta were visited. They were found to have a wealth of information, including avalanche reports containing winter precipitation forecasts for two areas in Alberta. Two maps were also obtained, illustrating the location of climate stations in the province, and snow survey stations.

Conclusion

The social and economic value of tourism in the provinces of Saskatchewan, Alberta and British Columbia, the Yukon territory, and the Northwest Territories, will be evident upon analysis of the relevant information. A more thorough analysis of the information will commence, and a profile of the tourism industry will result. This profile will focus upon downhill skiing, hunting and fishing, and National Parks within the Mackenzie basin.

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A11. Forest Sector

Ross Benton, Pacific Forestry Centre; with
Brian Stocks, Great Lakes Forestry Centre, (Section A11.5.1)

A11.1 Present Status

The size of the study area and the complexity of the forest sector limits the ability to do a detailed analysis of the impacts of climate change on the forest industry in the Mackenzie basin. In order to address this issue, the forest industry component will deal with a case study region within the Mackenzie Basin. The Peace-Liard drainage study area provides an opportunity to investigate the potential impacts on the forest sector in a variety of physioclimatic regimes and the potential to extrapolate results into similar physioclimatic areas throughout the Mackenzie study area.

The Peace-Liard study area is composed of five predominant physiographic regions. These are: the Liard plateau, The Rocky Mountain trench, the Rocky Mountains, the foothills region, and the Alberta plateau. This last region is the largest and most uniform of the regions. Its uniformity and continuance into the prairies provides the opportunity to extrapolate models and results into other areas of the Mackenzie Basin.

A11.2 Integrated Forest Sector Data Base

Much of the current year has been spent in the accumulation and aggregation of the data base required for the various researchers to conduct their individual studies with the goal of developing an integrated forest sector data base. The data base is still under development and is expected to be completed by mid 1993.

When completed, the intention is that the data base will contain information on forest cover, species mix and age, soils, site quality, economic (census) data, pest data, climate, protected areas, topography, drainages, transportation, and other factors important to the understanding of the forest sector.

A11.3 Species Dynamics

There is an expectation that species will migrate as the climate changes with projected global warming. While many factors are involved with species habitation of a given location, it is possible to estimate the potential range of species movement given current knowledge of soil and species limitations and the estimated climate outputs from the GCMs.

The ability of a species to survive or expand will determine potential shifts in the availability of a given resource. It also has implications for the maintenance of biodiversity of a given region or potential ecological reserves and other protected areas.

The species dynamics component of the forest sector study has been initiated this year looking at the relationships between major forest types and current climatic conditions. Present knowledge of species tolerances and site limitations are being used in conjunction with future climatic conditions to estimate large scale changes in forest cover.

A11.4 Growth and Yield

There is potential for marked increases in forest growth due to a longer growing season and the possibility of carbon dioxide fertilization. This component of the study, in conjunction with the species dynamics segment, ultimately drive the wood supply and economic analysis section. This study will provide estimates of the available timber supply based on estimates in changes to the potential growth response of the trees with the changing climatic conditions. Several growth and yield models exist which could be used for this purpose. One such model relates site quality for major species to climatic variables. Assuming that site quality does not rapidly decline, it is possible to compare model outputs using climate parameter values from current and future climate scenarios.

Work on this and the species dynamics component of the study commenced this year with a detailed search of the literature and available data bases.

A11.5 Disturbance Factors - Fire and Pest Outbreaks

Disturbance factors are largely driven by climatic parameters such as temperature, precipitation, and extreme events. This component of the study is intended to address some of the potential impacts on the forests given current knowledge of the relationships between climatic variables and forest pest and fire occurrences.

Forest fire frequency and intensity is projected to increase in areas where the climate becomes warmer and drier. The fire component of the forest sector study deals primarily with the sensitivity of fire frequency and size to climate changes. This study, being conducted by a University of Victoria graduate student, is still in its formative stages and has yet to be completely fleshed out.

The study region suffers from four significant forest pests. Spruce budworm, spruce beetle, and spruce budworm are all present in the study area. Forest tent caterpillar is also a hazard to a more limited extent in the Alberta plateau region.

A study by a University of British Columbia graduate student working in conjunction with researchers from the B.C. Ministry of Forests, is currently underway to investigate the sensitivity of spruce weevil attack to climatic conditions, particularly changes in heat sums during critical insect and vegetation development periods. To date the study concentrates on the Prince George Forest Region of B.C. Field work for this study has been conducted this summer with the analysis of the data collected to be completed by early spring 1993. Extrapolation of the results from this year will be used to estimate impacts in other areas of the Mackenzie Basin.

Further studies being conducted at the Pacific Forestry Centre may provide insights into the cyclical nature of other major forest pests in the study region using time series analysis methods. The results of this study may be used in conjunction with GCM outputs to investigate the potential changes given global warming.

A11.5.1 Forest Fire Archive

Brian Stocks, Great Lakes Forestry Centre

Forestry Canada fire research scientists are currently compiling a GIS-based archive of all fires >200 hectares in size that have occurred across Canada since 1980. This data base will be completed within the next six months and will be updated annually. Although only 2-3% of Canadian forest fires grow larger than 200 hectares, due to aggressive fire management practices, these fires account for approximately 97% of the area burned nationally. Thus, an accurate estimation of the impact of forest fires in Canada can be ascertained from this relatively small sample of fires.

The heaviest concentration of large fires occurs in the boreal forest zones of northern Quebec, Ontario, Manitoba, Saskatchewan, and the Northwest and Yukon Territories, areas where some fires are not actively suppressed, and where fire management policies are modified depending on values at risk, economics, and the natural role of fire in boreal forest ecology. It is anticipated that this data base will be particularly useful to scientists interested in the spatial and temporal distribution of forest fire as a disturbance mechanism in the boreal forests of Canada, relative to topical issues such as carbon balance and global change.

A11.6 Wood Supply and Economic Analysis

The Prince George forest region of British Columbia is the largest of the six forest regions in the province and covers all of the Peace river drainage within the province. This region also produces the largest volume of timber with an annual allowable cut (AAC) of approximately 17.5 million cubic metres. Present estimates of harvest and regeneration show that, given no significant change in the forest resource or its current management, there is more than 160 years supply.

Both hardwoods and softwoods are harvested in the region. The primary forest products from the region is pulp and pulpwood products, particularly from the Alberta plateau portion of the region. Saw logs are also produced but make up a smaller proportion of the overall forest utilization.

Outputs from the growth and yield and stand dynamics components of the study will be used to estimate future wood supply using currently existing models. Forest level wood supply models (such as MUSYC, TRIM, or ATLAS) will be used for the economic study component. Inferences as to economic impact can be derived based on comparisons between model outputs from runs using present day and future estimated wood supply/requirement data. These inferences may be limited, however, in that the impacts of climate change on the world's forests and their related economies may far outweigh subtle changes in smaller regional areas.

Work on the wood supply and economic analysis component of the forest sector study is not slated to start until 1993 when the initial results of the other key components of the study and the overall data base will become available.

A11.7 Operations

While many companies operate within the region, there are a few companies which hold a relatively large proportion of the annual allowable cut. Four companies within the study area are permitted approximately 13% of the total AAC for the Prince George Forest Region, which includes some land area outside the Peace-Liard study area.

Global warming potentially means warmer winters, thus later freeze up and earlier spring breakup conditions. Harvest operations stand to be significantly impacted as much of the harvesting is done in the winter months to allow access to areas that would otherwise be unavailable for use and to limit the environmental impacts. While this issue will not be specifically addressed, an attempt will be made to incorporate estimates of freeze up and break up into estimates of available wood supply.

A11.8 Protected Areas of the Mackenzie Basin

An additional study undertaken with the forest sector component investigates protected areas within the study area. The intent of this component of the project is to examine the implications of global warming on protected areas (reserves) from the standpoint of resource conservation and to stimulate interest in assessing the protected areas network of the Mackenzie Basin. To date, an inventory of the areas protected for ecological, wilderness, recreational, and other purposes has been conducted and summarized.

A11.9 List of Participants

Glen Armstrong, UofA, Faculty of Agriculture and Forestry, regional forest economics modelling and interpretation

Ross Benton, ForCan, Pacific Forestry Centre, coördinator, data base management, forest pest/climate cycles

Isobel Booth, graduate student, UBC, growth and yield, stand dynamics

Phil Comeau, BCMoF, Research Branch, forest cover, growth and yield

George Harper, BCMoF, Research Branch, forest cover, growth and yield

Lisa Kadonaga, graduate student, UVic, fire sensitivity

Val LeMay, UBC, Faculty of Forestry, growth and yield, stand dynamics

Joe Lowe, ForCan, Petawawa National Forestry Institute, national forestry data base

Peter Marshall, UBC, Faculty of Forestry, growth and yield, stand dynamics

Doug Pollard, ForCan, Pacific Forestry Centre, protected areas, issue analysis

Daryl Price, Alberta Forest Service, Alberta forestry data

Brian Sieben, graduate student, UBC, insect sensitivity

Dave Spittlehouse, BCMoF, Research Branch, forest cover, insect sensitivity

Bill White, ForCan, Northern Forestry Centre, forest economics modelling and interpretation

A12. Canadian Defence Policy And Operations

Dr. C.M. Tucker, Directorate of Strategic Analysis
Operational Research and Analysis Establishment,
Department of National Defence, Ottawa,Canada

A12.1 The Canadian Defence Mission in Northern Canada

Some 40% of Canada's landmass is located north of the 60th parallel. This region is surrounded by 2/3 of our coastline and offshore waters, and shares the Arctic Ocean, the world's fourth largest, with seven other countries. It is because of these facts, among others, that the strategic and operational issues related to global climate change as it relates to arctic Canada are of concern to the Department of National Defence (DND). In a policy context, we need to know the security and sovereignty implications of issues such as; the possible melting of sea ice between the Arctic Islands, and the northward shift of forest and tundra. From an operations point-of-view, the practical problems of melting permafrost that underlies about half of Canada's land surface and significantly changed meteorological conditions, will require modifications to existing infrastructure and revised planning for, amongst others, future construction, materiel and exercises.

The Federal Government is obliged by Canada's Constitution, to make adequate provision to defend the country. This obligation must be carried out fairly and prudently in each and every region of Canada. It must also be in consonance with the threats to the well-being of all Canadians. It would be unconscionable, for example, to provide in different parts of Canada different levels of defence against the penetration of similar threats to our security.

The Federal government does not, therefore, have a specific defence policy for each region; rather there is only one policy for Canada. Any differentiation in the implementation of defence policy between regions arises only because of the threat itself.

The threats to the well-being of Canadians, in the North and elsewhere, are quite diffuse and always changing:

a. some threats stem from the military capabilities of our competitors which first manifest themselves on the ocean approaches and borders of Canada. The Arctic is, for example, on the shortest route between Europe and North America. While these threats are currently quite remote, their consequences are too severe to ignore;

b. other threats arise from a desire of foreign groups to take actions that would violate Canadian laws and jurisdiction. Examples are poaching, smuggling and fouling our arctic waters. These threats tend to grow as does the level of economic activities -- nationally and regionally:

c. finally, some harmful events occur unexpectedly within Canada. They may be
   - deliberately instigated such as civil disobedience, riots, and sabotage;
   - inadvertent, such as chemical spills, or
   - the consequence of a natural disaster, such as the loss off public services in an earthquake or forest fire.
   - When their magnitude exceeds the capabilities of the provinces or territories, the Federal government is obliged to help with whatever resources it can muster.

The Mackenzie Basin and adjoining Beaufort Sea study area, as described in earlier chapters of this paper, are of significant interest to DND, and the results from this current multidisciplinary research effort will have implications for other parts of arctic Canada and, in fact, the circumpolar North as a whole.

The political and economic infrastructure of Canada, as in most societies, has developed with an underlying assumption of a variable climatic environment which is stable about a long-term mean. The greenhouse warming of the atmosphere, whatever its magnitude, undermines this assumption, and thus, as well as environmental change, substantial social and economic disruption will also take place. It is anticipated that over the next half century, virtually that period of time since the end of the Second World War, human activities will have substantially altered global climate by enhancing the earth's natural greenhouse effect.

A12.2 Air Operations

Is is reasonable to expect that future meteorological conditions in arctic Canada may be more difficult to deal with from an air operations point-of-view, despite a proposed amelioration, from those existing today. Though there is some disagreement about the range and time frame, a general consensus among climate modellers is that the annual global average temperature will rise from the 1950-80 value of 15.3° C to 16.8-19.8° C by the year 2035, i.e., approximately 0.3° C per decade. In the Arctic, the warming is anticipated to be less than the global average during the summer, perhaps as little as half a degree. However, during the winter a dramatic increase in temperature is expected, as much as 8° C according to the Canadian Climate Model. This would be twice the global average.

Though not entirely conclusive, predictions also hold that there will be increases in precipitation throughout the year; 10-50% in summer and by up to 60% in winter. In essence, given current estimates, we can expect a much warmer, wetter Arctic with far more unsettled meteorological conditions 50 years from now. Coastal areas will be significantly foggier because of increased open water conditions and increased overall moisture. For similar reasons, one can expect increased low stratus cloud cover in summer.

As a result of these changes, the requirements for DND aviation meteorological services are likely to increase in the coming decades. Present DND missions in the North include interception of aircraft and airborne vehicles, surveillance / sovereignty, search and rescue, and tactical and logistical air support for land force exercises. With climatic amelioration, many of these roles could conceivably increase in the future.

New technologies will, therefore, be required to aid forecasting. The areal coverage of weather observations `north of 60' already falls well short of the World Meteorological Office recommended 150 km grid density. To remedy this, automatic weather stations, radar coverage and enhanced satellite surveillance and communications use would need to be considered. There will increasingly be a need for an expanded military meteorological presence in the Arctic.

Research on the effects of changed meteorological conditions as they might influence the North Warning System (NWS) will also need to be considered. Given that existing NWS stations are located in the Mackenzie Basin Study Area, results from this current research project will aid future research and decision making.

A12.3 Marine Operations

Both numerical models and paleoclimatic research concur that sea ice extent and dynamics have not been static over time, nor are they likely to remain so with climatic amelioration over the next century. For the moment this does not give cause for concern. Nevertheless, when contemplating the future, there are significant geopolitical, and military operational / strategic issues that will need to be addressed.

From a geopolitical aspect, Canada may have to contemplate how it intends to defend its 1973 claim to sovereignty over `internal' arctic waters. Under present conditions, whether the Northwest Passage is or is not a `Canadian internal waterway' may be considered by some to be a moot point since it is not, by most standards, navigable. For the majority of the year, transit is blocked by ice in its widest part, Viscount Melville Sound, and it is necessary for vessels to retreat to passage through the Prince of Wales Strait between Banks and Victoria Islands, as happened with the voyages of the supertanker S.S. Manhattan in 1969 and the icebreaker U.S.S. Polar Sea in 1985. On both these occasions there was considerable protest from the Canadian public. With increased economic activity likely to be brought about by an enhanced ice-free shipping season and freer access to natural resources, the level of debate will certainly increase.

The original Manhattan voyage resulted in the enactment of The Canadian Arctic Waters Pollution Act in 1970. The legislation provided for the protection of ocean waters north of 60°N latitude and for a distance of 160 km offshore. Although at the time the Act was opposed by the United States, it has been seen in Canada as good for the environment and for strengthening our sovereignty over arctic internal waters. Obviously, any increase in shipping due to climatic amelioration will put added pressure on DND resources to assist in preserving Canadian interests in this area.

Another aspect of diminished ice cover is that one needs naval vessels capable of operating in ice-infested waters - something that Canada currently does not possess. At the present time, without heavy icebreaker support, which itself is limited, Canada's navy cannot operate in the Arctic Ocean. Even from a commercial viewpoint, only CANARCTIC's ice breaking freighter, M.V. Arctic, is capable of operating virtually year round in ice-covered waters. Consideration will probably be given to our naval operational future in the Arctic and our ability to design and build vessels tailored for that environment.

Similarly, if DND activity increases in arctic waters, because of less severe meteorological conditions and increased commercial shipping in the North, marine forecast speed and accuracy will also need to be bolstered to be better able to predict events such as coastal fogs, ice conditions and sea states, etc.

To better assess DND's future in arctic waters, further scientific research is needed on sea ice extent and dynamics, especially how it relates to global warming. Under the auspices of the Mackenzie Basin Project, DND will fund continued research (Fleming and Semtner, 1991) at Royal Roads Military College to develop a coupled ice-ocean numerical model of the Arctic Ocean. The Beaufort Sea component of this model will be relevant to the near-shore zone of the Mackenzie Basin. The model will be run with a normal atmosphere and a double CO_2 content. There are also strategic aspects to the results of this research. It is important to know how sound propagation will change in arctic water, how thermoclines will shift, circulation patterns will be modified, and ice will ground.

A12.4 Land Operations

A12.4.1 Permafrost

In general, the effects of projected climate warming during the next several decades will deepen the active layer in the Mackenzie Basin and initiate a northward retreat of permafrost. Current expectations are that a 2° C global warming would shift the southern boundary of the climatic zone currently associated with permafrost north and northeast by at least 500-700 km. The southern extent of permafrost will lag behind this, moving only some 25-50 km in the next 40-50 years. The depth of the active layer is expected to increase by one metre during the same time frame. The melting of permafrost would also result in the release of methane and, to a lesser extent, CO_2 from previously frozen biological material and from gas hydrates. The extent to which this will enhance the greenhouse effect is uncertain, but it could be about 1° C by the middle of the next century.

From DND's point-of-view, these events will have a significant operational impact. In practical terms, increased terrain instability would lead to major concerns for the viability of roads, airfields, dams, reservoirs, and other engineered foundations located within affected areas. Deepening of the active layer would subject foundations to continuing deformations as a result of thaw settlement. Decreases in the amount of ground ice present would lead to reductions in the mechanical strength of the associated soil as well as increases in permeability, both of which will have significant consequences for engineering of facilities and overland mobility.

It is possible given the current state of knowledge and design constraints to predict areas that will be particularly susceptible to permafrost degradation. Most of the Forward Operating Locations (FOL) airstrips are located within this zone, though it must be noted that the affected areas are highly dependent on which climate model is chosen as a reference. A recent cooperative study between the Geological Survey of Canada, EMR and Operational Research and Analysis Establishment of DND has mapped subsurface conditions at FOL site in Inuvik with ground penetrating radar (Tucker and Judge, 1991). Zones of massive ground ice were detected below the proposed extensions. It was concluded that in areas slated for construction or modification of drainage patterns, the identification of subsurface permafrost features ahead of events can play an important part in the planning process to avoid future problems. In fact, current engineering at the airport is allowing for some degree of future climate change. It is our intention to continue and extend this site-specific study under the auspices of the Mackenzie Basin Project in order to assess the long-term stability of man-made structures on permafrost.

There are several approaches to designing structures located within permafrost. These include: a) disregard the thermal regime of underlying permafrost and apply conventional techniques of construction from temperate regions; b) thaw permafrost prior to construction; c) allow for thawing during construction, and; d) maintain permafrost in a frozen state. Of these options, a) is a very risky procedure, b) is very expensive and not widely used, and c) is only of benefit for short term construction or where materials are thaw-stable. Option d) is currently used throughout the North by DND.

Another issue related to permafrost integrity that DND may need to analyze is that of overland summer mobility. Although we assume that given our current level of activity in the North there is no mobility problem (since most transport is by air) this situation may not remain as such in the future. In addition, since the existing road network will be especially vulnerable to thaw, perhaps catastrophically, the design parameters of low ground pressure / high mobility vehicles for the Canadian Forces (CF) might profitably be given renewed consideration.

A12.4.2 Tree line and Ecozones

In general, the practical aspects of northern shifting tree lines and ecosystems would only concern DND in so far as they relate to the economic activities of Canadians in the North. It is concluded that migration of tree lines and ecozones will happen with less rapidity than will the disintegration of permafrost, for example. Nevertheless, as southerners find more reasons to populate the Northwest, DND will become involved in appropriate activities in the territory.

There is an aspect of northern migration of the tree line that will directly affect DND, i.e., the increased risk of forest fires. Future climate warming will result in far more dead and diseased trees ready to fuel fires. Forestry officials state that this is one of the most significant aspects of northern climate migration. As the summers of 1990 and 1991 in arctic Canada have shown, forest fires in northern regions where communications and infrastructure are poor, habitually evolve into situations that are profound disasters, partly because of our difficulty in coping with them in sparsely populated areas. DND has as one of its mandates "aid to civil authorities," and as the organization with one of the largest groups of personnel in the North, it is and will continue to be incumbent on the CF to assist in such activities as fire fighting and other environmental disasters. If the risk of severe fire increases over the coming decades, DND policy and logistics may require modification to accommodate the new situation.

A12.5 Summary

The policy aspects of DND operations in the Mackenzie Basin and arctic Canada in general are very much related to global climate change. It may be that in the future the general level of activity in the North by Canadian society will increase as climate becomes more amenable. New possibilities for economic activity will open up and settlements will be created where they are not currently viable. Because it is part of our overall formal societal structure, an enhanced DND presence in parallel with this growth would most likely occur. Despite climatic warming, doing business there will become more, not less, expensive. How much we are prepared to pay for new facilities and for remedial measures on existing infrastructure will require considerable thought, as will our defence policy as it pertains to Canadian sovereignty in the North. The current Mackenzie Basin Impact Study will go a long way towards providing scientific and policy-related answers to questions relevant to our whole future existence in Northern Canada.

References

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Tucker, C.M. and Judge, A.S., 1991. An Assessment of Permafrost Conditions at Three DND Airports in Arctic Canada as They Pertain to Future Planning and Operations. ORAE Report No. R107, Department of National Defence, Ottawa, 40p.

A13. Methodology For Development Of Climate Change Scenarios

Jamie Smith and Stewart Cohen, Canadian Climate Centre

A13.1 The Role of Scenarios

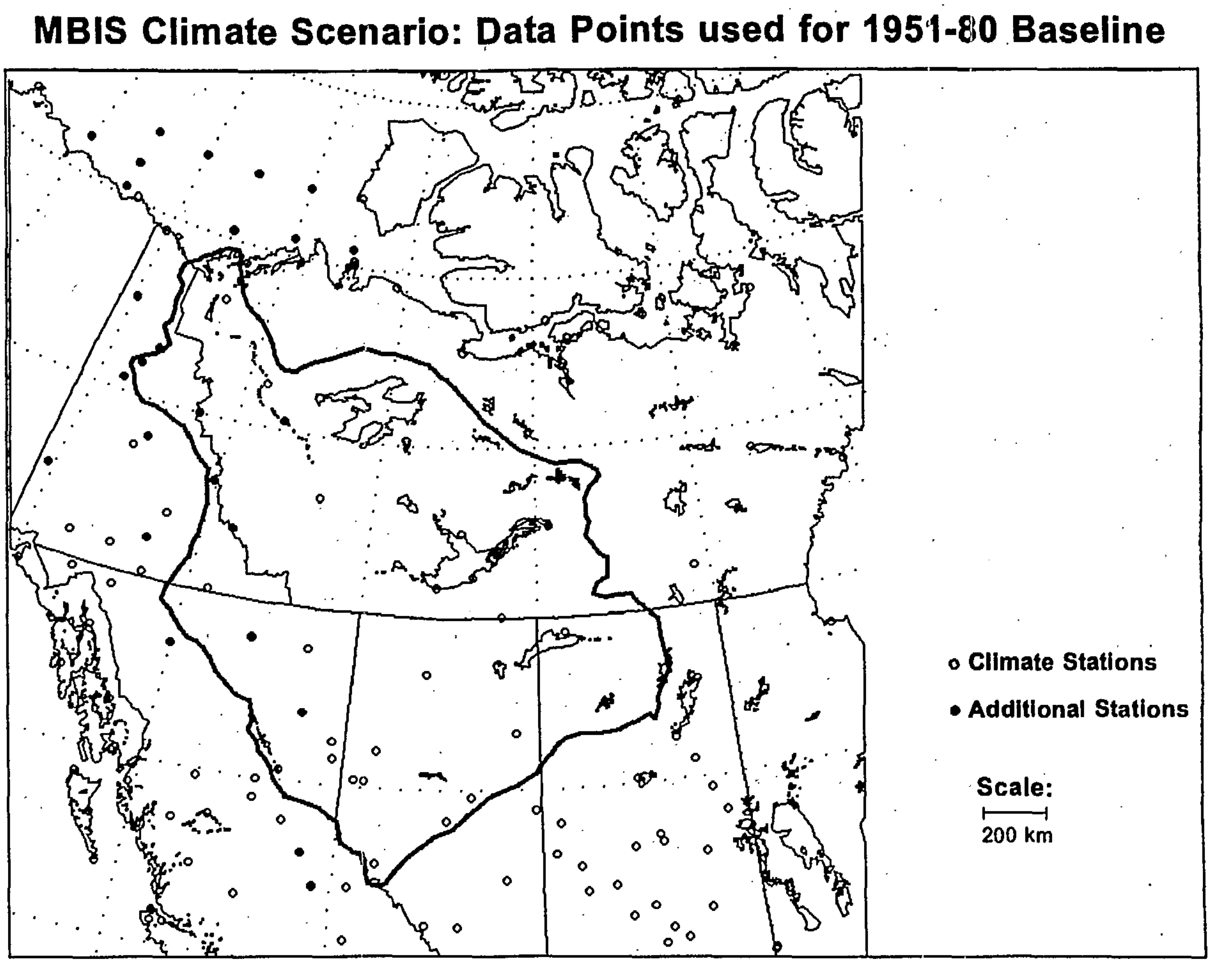
One of the main concerns in providing climate data for this large and diverse project is to ensure that all researchers use the same data base in order to ensure comparable results. For example, two researchers may begin with identical data sets but by using two different interpolation methods the results may be very different (Cohen, 1990). In order to eliminate this problem it was decided that both the baseline climate and the climate scenarios would be developed at CCC, with the assistance of the Western Region of AES (WAES), and provided in an easily readable form to all MBIS participants.

A13.2 Baseline Climate

The purpose of this exercise was to develop a baseline climate data set for the entire Mackenzie Basin. The following criteria were used in order to develop the data base: 1) The data should as accurately as possible represent the average climate of the Mackenzie Basin, and 2) the data set should be provided in a format which could be easily read by the individual users in the study.

The development of an accurate baseline data set is affected by the spatial distribution of the climate stations, and the accuracy of the climate data available. First, all climate station records available at CCC were obtained for British Columbia, Alberta, Saskatchewan, Manitoba, Northwest Territories, and Yukon. This list was reduced to include only the 121 stations with 25 or more years of data during the period 1951-80 (Table A13.1).

Figure A13.1 Location of climate stations and additional grid point data



In examining the remaining primary stations it was found that only five were located above 1000m, with very few located in the Mackenzie Mountains located west of the Mackenzie Valley (Table A13.1, Figure A13.1). An effort was made to develop a set of data points in the Mackenzie Mountains which would improve the representation of this data sparse region. Regression analysis was used to compare five nearby primary stations with high elevation stations established in the late 1960's and 1970's which had a short period of record, in order to develop a statistical relationship between elevation and the monthly climate parameters of temperature and precipitation. The results showed a strong relationship between temperature and elevation, but estimates were found to be less satisfactory (e.g. Barkerville: Table A13.2). By combining these "new" climate stations with the primary stations, climate maps were produced using SPANS GIS and the results were compared with the published maps in the document "Climate of Yukon" (Wahl et al., 1987).

Table A13.1 MBIS Climate Station Information

	Latitude(N)		Longitude(W)		Temperature
Station Name	Degrees	Minutes	Degrees	Minutes	Homogeneity
PRINCE RUPERT BC	54	17	130	23	na
WASECA SASK	53	8	109	24	yes
BELLA COOLA BC	52	22	126	41	na
HAINES JUNCT. YT	60	46	137	35	na
ROSS RIVER A YT	61	58	132	26	na
MULE CREEK BC	59	47	136	36	na
GRAHAM INLET BC	59	36	134	11	na
MACKENZIE A BC	55	18	123	8	na
ARRAS BC	55	44	120	32	na
KALDER LAKE BC	54	58	124	15	na
HOLBERG BC	50	39	127	59	na
BRANDON A MAN	49	55	99	57	no
FORT MCMURAY ALTA	56	39	111	13	na
VICTORIA INT A ALTA	48	39	123	26	yes
TATLAYOKO BC	51	40	124	24	no
KANMANO BC	53	34	127	56	no
BRANDON CDA MAN	49	52	99	59	yes
MORDEN CDA MAN	49	11	98	5	yes
SPRAGUE MAN	49	2	95	38	yes
THE PAS A MAN	53	58	101	6	yes
CHURCHILL A MAN	58	44	94	4	na
BROCHET A MAN	57	53	101	41	yes
FLIN FLON A MAN	54	41	101	41	na
PORT HARDY A BC	50	41	127	22	no
BULL HARBOUR BC	50	55	127	57	na
PACHENA POINT BC	48	43	125	6	no
CAPE ST JAMES BC	51	56	131	1	yes
LANGARA BC	54	15	133	3	no
SANDSPIT A BC	53	15	131	49	no
SMITHERS A BC	54	49	127	11	yes
WISTARIA BC	53	49	126	10	no
FORT ST JAMES BC	54	27	124	15	yes
PRINCE GEORGE BC	53	9	122	41	no
ABBOTSFORD A BC	49	2	122	22	yes
VANCOUVER INT BC	49	11	123	10	no
CRESTON BC	49	6	116	31	no

continued on page 114

FAUQUIER BC	49	52	118	4	no
KASLO BC	49	55	116	55	no
RIVER NORTH A BC	52	9	119	17	na
SALMON ARM 2 BC	50	42	119	17	na
BALDONNEL BC	56	14	120	41	no
DEASE LAKE BC	58	25	130	0	yes
LETHBRIDGE A ALTA	49	38	112	48	no
BANFF ALTA	51	11	115	34	no
JASPER ALTA	52	53	118	4	no
FORT NELSON A BC	58	50	122	35	na
CALGARY INT ALTA	51	7	114	1	no
FORT MACLEOD ALTA	49	43	113	24	na
CAMPSIE ALTA	54	8	114	41	no
BEAVER ALTA	55	12	119	24	yes
FAIRVIEW ALTA	56	4	118	23	no
VERMILION CDAALTA	58	23	116	2	na
GRANDE PRAIRIE ALTA	55	11	118	53	yes
CARLYLE SASK	49	38	102	16	no
ESTEVAN A SASK	49	13	102	58	yes
INDIAN HEAD SASK	50	32	103	40	no
MIDALE SASK	49	24	103	24	yes
NOKOMIS SASK	51	31	105	0	no
REGINA A SASK	50	26	104	40	no
YORKTON A SASK	51	16	102	28	no
ANEROID SASK	49	43	107	18	yes
KLINTONEL SASK	49	41	108	55	yes
BIGGAR SASK	52	4	107	59	no
BATTLEFORD A SASK	52	46	108	15	na
PRINCE ALBERT SASK	53	13	105	41	no
SASKATOON A SASK	52	10	106	41	no
ISLAND FALLS SASK	55	32	102	21	no
WHITESAND DAM SASK	56	14	103	9	na
LOST RIVER SASK	53	17	104	20	na
ALLIANCE ALTA	52	26	111	47	na
COLD LAKE A ALTA	54	25	110	17	no
DAVIDSON SASK	51	16	105	59	no
CHOICELAND SASK	53	30	104	29	yes
HUDSON BAY SASK	52	9	102	24	na
ATHABASCA 2 ALTA	54	49	113	32	yes
CUPAR SASK	50	51	104	16	no
LOON LAKE CDA SASK	54	3	109	6	yes
URANIUM CITY A SASK	59	34	108	29	na
LA RONGE A SASK	55	9	105	16	na
MAYO A YT	63	37	135	52	yes
WATSON LAKE A YT	60	7	128	49	yes
WHITEHORSE A YT	60	43	135	4	na
FORT RELIANCE NWT	62	43	109	10	yes
FORT SMITH A NWT	60	1	111	57	yes
HAY RIVER A NWT	60	50	115	47	yes
NORMAN WELLS A NWT	65	17	126	48	na
YELLOWKNIFE A NWT	62	28	114	27	yes
BAKER LAKE A NWT	64	18	96	5	na
CHESTERFIELD NWT	63	20	90	43	na
RESOLUTE A NWT	74	43	94	59	na
MOULD BAY A NWT	76	14	119	20	na
TESLIN A YT	60	10	132	45	na

COPPERMINE NWT	67	50	115	7	na
GOOD HOPE A NWT	66	16	128	37	no
RESOLUTION A NWT	61	11	113	41	na
WRIGLEY A NWT	63	13	123	26	na
ENNADAI LAKE NWT	61	8	100	54	na
ISACHSEN NWT	78	47	103	32	na
SACHS HARBOUR NWT	72	0	125	16	yes
KOMAKUK BEACH YT	69	35	140	11	na
CAPE PARRY A NWT	70	10	124	41	na
CLINTON POINT NWT	69	35	120	48	na
CONTWOYTO NWT	65	29	110	22	na
INUVIK A NWT	68	18	133	29	no
TUKTOYAKTUK NWT	69	27	133	0	yes
BYRON BAY A NWT	68	45	109	4	na
LIND ISLAND A NWT	68	39	101	44	na
SHEPHERD BAY NWT	68	49	93	26	na
ANCHORAGE INTL AK	61	10	150	1	na
BARROW WSO AP AK	71	18	156	47	na
BARTER ISLAND AK	70	8	143	38	na
KOTZEBUE WSO AK	66	52	162	38	na
JUNEAU WSO A AK	58	22	134	35	na
FAIRBANKS INTL AK	64	49	147	52	na
YAKUTAT AK	59	31	139	40	na
ANNETTE ISLAND AK	55	2	131	34	na
SITKA FAA AP AK	57	4	135	21	na
CORDOVA FAA A AK	60	30	145	30	na
WRANGELL AK	56	28	132	23	na
BETTLES WSO A AK	66	55	151	31	na
GULANKA WSO AK	62	9	145	27	na

Note: AK = Alaska, na = Test results not available, temperature homogeniety = a homogeneous data set has no measurable steps, spikes or trend in the data relative to nearby stations.

Table A13.2: Estimated and Actual 1951-80 Normals at Barkerville

Temperature				
Month	**1951-80***	**Estimated**	**#Points**	**R2**
Jan	-10.7	-11.4	10	.94
Feb	-5.9	-6.3	9	.80
Mar	-4.3	-4.7	9	.84
Apr	0.5	0.4	9	.82
May	5.7	5.4	10	.82
Jun	9.6	9.5	10	.96
Jul	12.1	11.9	9	.76
Aug	11.5	11.5	10	.95
Sep	7.7	7.4	10	.93
Oct	2.8	2.3	9	.75
Nov	-4.1	-4.1	10	.90
Dec	-8.2	-9.2	10	.95

Precipitation				
Month	**1951-80***	**Estimated**	**#Points**	**R2**
Jan	103.0	102.7	10	.63
Feb	85.6	94.7	10	.61
Mar	85.3	80.9	9	.66
Apr	61.8	59.5	9	.81
May	65.9	71.8	9	.83
Jun	89.2	89.6	10	.70
Jul	81.7	62.7	10	.50
Aug	102.3	86.5	9	.83
Sep	85.4	100.2	9	.68
Oct	88.4	82.2	8	.73
Nov	86.6	75.4	7	.68
Dec	108.7	73.8	8	.62

* The 1951-80 calculated normal using 25-29 years of data.

The results showed an improved simulation of the climate of the region from the maps produced without new station data, however more data points were needed in the region. It was suggested by WAES to choose values from the Yukon climate maps in the Mackenzie Mountains to improve the distribution of data points in the region. In the end, 15 "dummy" stations were added to the Mackenzie Mountain Range, and 14 grid points were plotted in the Beaufort Sea from the NOAA Climate Atlas for the Beaufort and Chukchi Sea (Figure A13.1) (Brower et al., 1988).

At Working Committee Meeting Three (WC3) the results of this procedure were presented. It was suggested that by using a different interpolation routine to the one used in SPANS GIS, the maps may be improved. This was accomplished by using the NATCON contouring package available at the CCC. The Shepherd interpolation routine, which uses a weighting function, was found to give the best results. The data set was produced on a large grid of approximately 3800 points encompassing the entire Mackenzie Basin and a portion of the Beaufort Sea (Figure A13.2). This procedure was repeated for 12 months of the year for both temperature and precipitation. Examples of the final maps reproduced in SPANS GIS (linear interpolation routine) using the grid output of NATCON is shown in Figures A13.3, A13.4 for the month of January. (These maps are essentially identical to the original NATCON maps since the grid points are very close together)

Figure A13.2 Baseline and scenario grid point locations

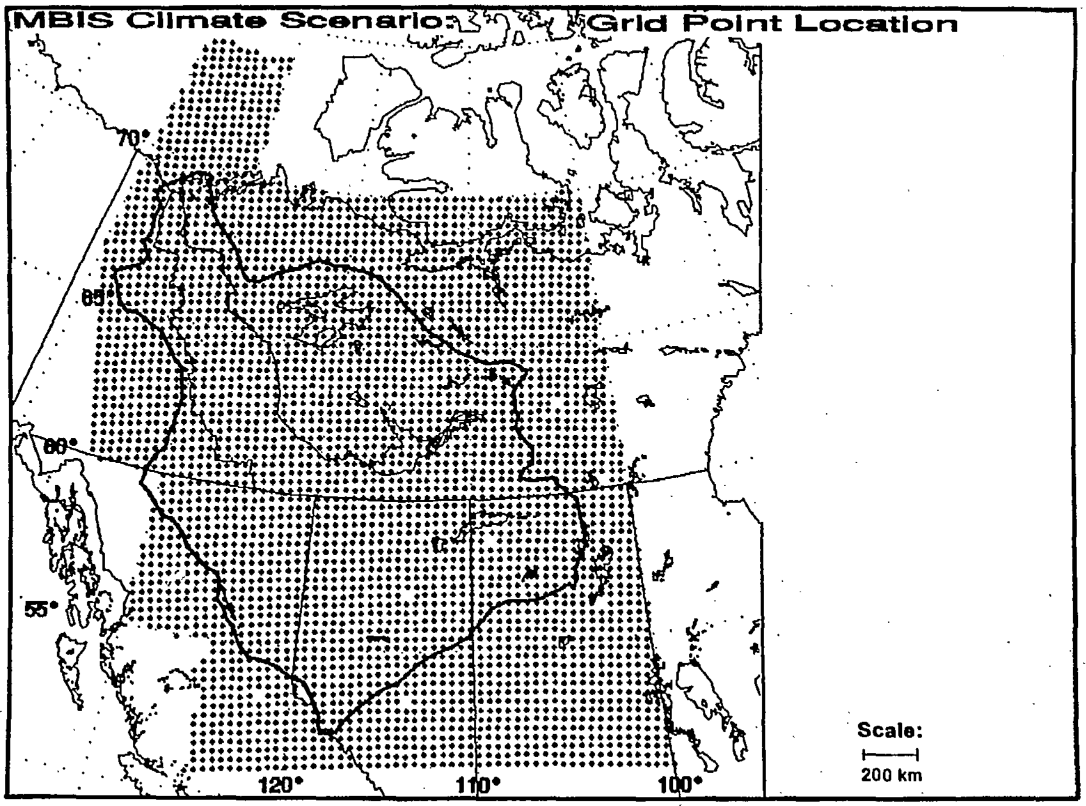


Figure A13.3 1951-80 mean January temperature

MBIS Climate Scenario: January Temperature (°C)
Baseline: 1951-80

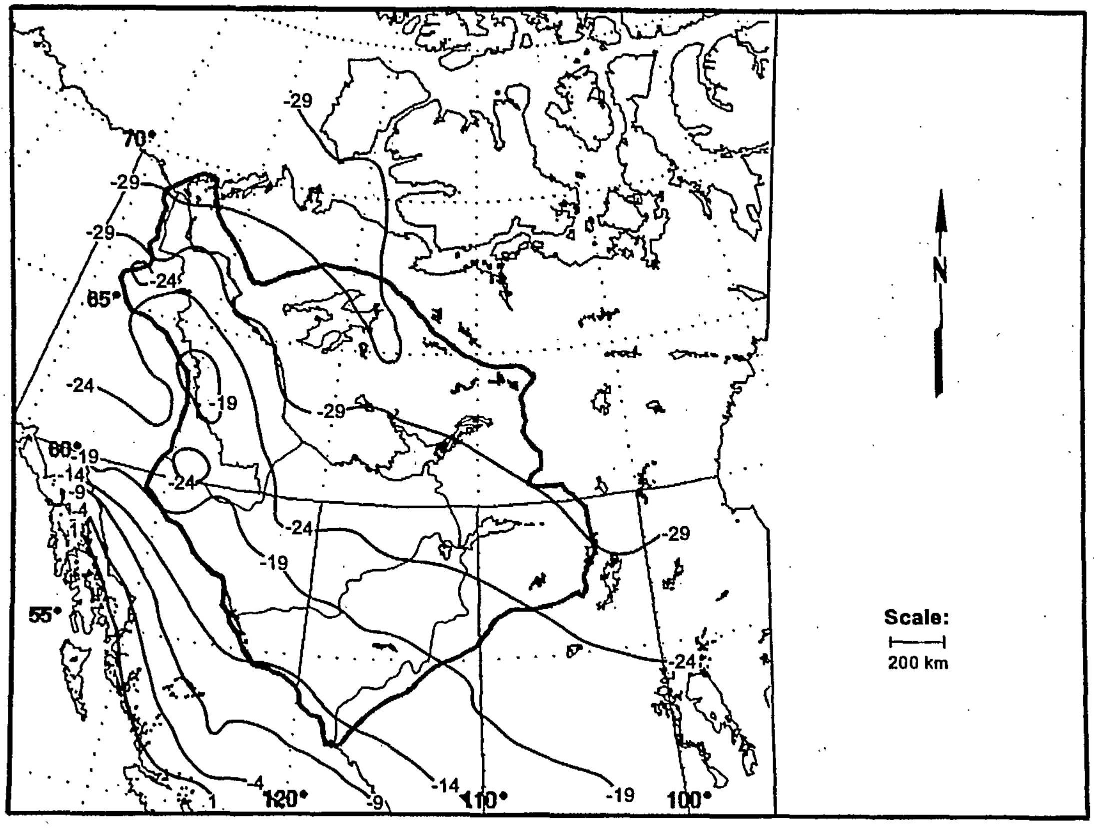
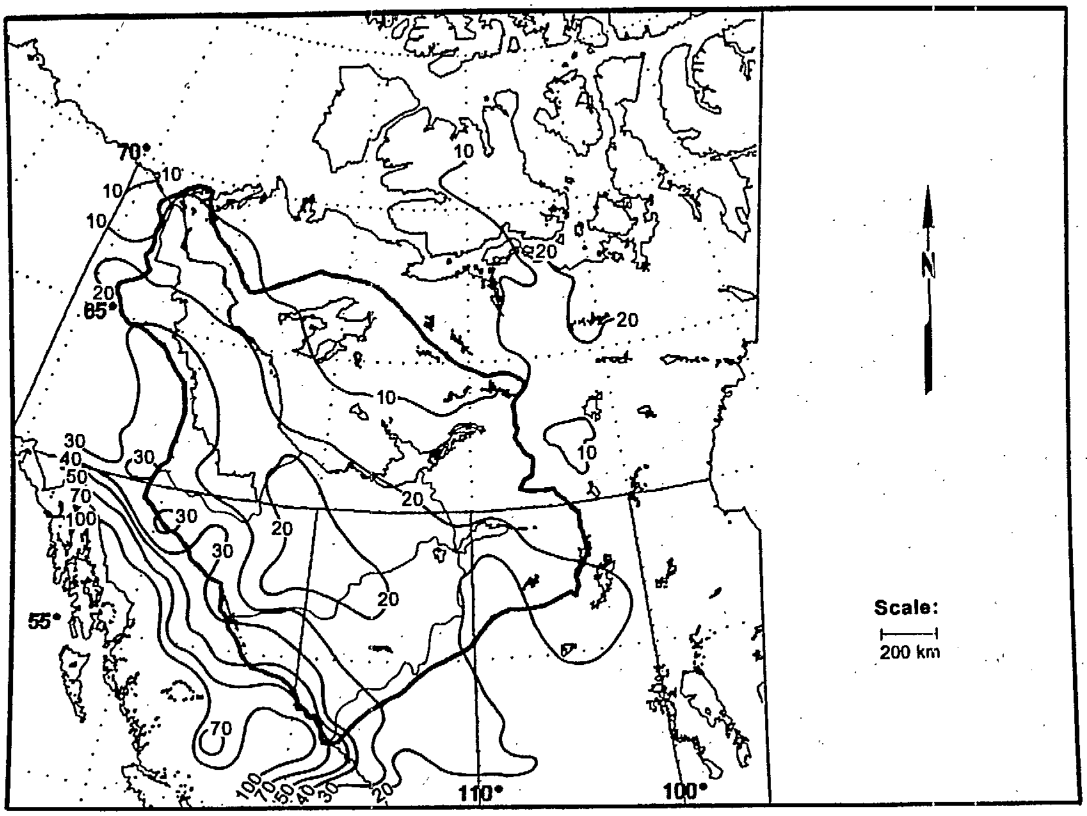


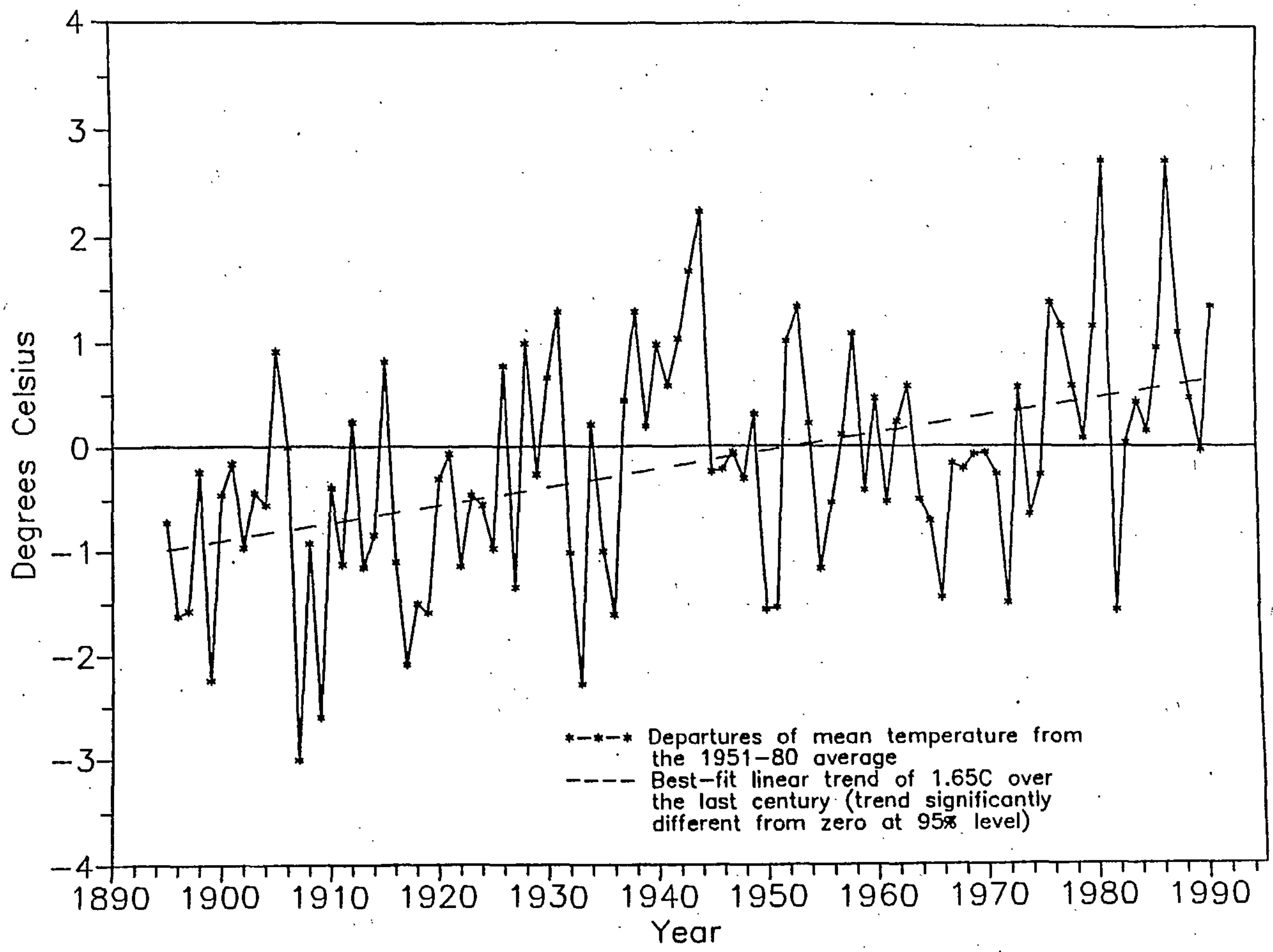
Figure A13.4 1951-80 mean total January precipitation (mm)



The question of data reliability/accuracy for temperature can be answered by completing a homogeneity test which determines if a data set has significantly different trends or steps then the surrounding stations (Gullett et al., 1991). Of the primary stations, 62 were appropriate for testing, and 46% of these were found to be homogeneous during the 1951-80 period (Table A13.1) (Gullett et al., 1991). At present little information is available on the accuracy and reliability of precipitation data for the region. Experiments by Goodison and Metcalfe (1991) have indicated that both large systematic and random errors exist in precipitation data as a result loss due to wind, wetting loss from remnants left in the gauge, evaporation, and trace amounts recorded as zero in the archive. None of these factors are corrected in the Canadian data base. Their experiments in the Prairies suggest an average of 31% underestimated winter precipitation as a result of these factors. Testing of the homogeneity of precipitation time series will not be completed before 1996 (Malone. per. comm., 1992).

The seriousness to the data user of the lack of homogeneity due to trends or steps in the data varies according to its use. For a general discussion of the climate in the Mackenzie Basin, homogeneity may not be an important consideration. However, for use in a fine resolution hydrological model, the problems associated with inhomogeneous data are significant. Calibration of the model may require several years of continuous data which may vary over time, and a station by station evaluation should be considered.

Figure A13.5 Annual temperature departures in the Mackenzie Basin (Source: J. Reycraft, Canadian Climate Centre)



A13.3 Recent Climate Change

The State of the Environment Report (SOE) on temperature change in Canada states that "a statistically significant warming of 1.1° C has taken place in Canada during the period of 1895-1991" (Gullett and Skinner, 1992). This was determined by using a rigorous statistical procedure which was applied to 131 stations located across the country (Gullett et al., 1991).

Sixteen stations of the original 131 were located in the Mackenzie Basin. The annual temperature departures from the 1951-80 normals were plotted (Figure A13.5), and were found to be significant with an increase of 1.7° C over the 1895-1991 period. As in the national case, however, this result cannot support any definitive conclusions as to the cause of the trend because the magnitude of increase is within the natural temperature variability over the past 1000 years.

A13.4 Climate Change Scenarios

"Scenarios are useful for organizing thinking about what the future may hold. They are not predictions, but sketches of certain key features of the future situation based on plausible extensions of existing trends." (Crosson, 1992; emphasis added). Although this quotation was referring to scenarios of U.S. agriculture and technology in the future, it is an appropriate statement to make about the climate change scenarios which are to be used in this study. Four scenarios of climate change will be used, and three of them are based upon General Circulation Models (GCMs). The GCM derived scenarios are based upon projected trends in atmospheric carbon dioxide, not on the global warming trends that have recently been measured (IPCC, 1990). The other scenario is called a "composite scenario" and is based upon past experiences of climate in the region obtained from instrumental and paleo climate records. These scenarios should be regarded as possibilities to be used to determine the sensitivity of the socio-economic system in the Mackenzie Basin to "plausible" climates of the future.

A13.4.1 GCM Derived Scenarios

"The most highly developed tool which we have to predict future climate is known as a general circulation model or GCM. These models are based on the laws of physics and use descriptions in simplified physical terms (called parameterisations) of the smaller-scale processes such as those due to clouds and deep mixing in the ocean. In a climate model an atmospheric component, essentially the same as a weather prediction model, is coupled to a model of the ocean, which can be equally complex.

"Climate forecasts are derived in a different way from weather forecasts. A weather prediction model gives a description of the atmosphere's state up to 10 days or so ahead, starting from a detailed description of an initial state of the atmosphere at a given time. Such forecasts describe the movement and development of large weather systems, though they cannot represent small scale phenomena; for example, individual shower clouds.

"To make a climate forecast, the climate model is first run for a few (simulated) decades. The statistics of the model's output is a description of the model's simulated climate which, if the model is a good one, will bear a close resemblance to the climate of the real atmosphere and ocean. The above exercise is then repeated with increasing concentrations of the greenhouse gases in the model. The differences between the statistics of the two simulations (for example in mean temperature and interannual variability) provide an estimate of the accompanying climate change." (IPCC, 1990)

A13.4.1.1 GCM Simulations of the Mackenzie Basin

Given the global nature of GCMs, they cannot successfully simulate regional climates. Stuart and Judge (1991) examined the ability of three GCM's (Goddard Institute for Space Studies (GISS), General Fluid Dynamics Laboratory (GFDL;1986), and Oregon State University (OSU)) to simulate the present climate of the Mackenzie Valley. As expected, they found the models inadequately reproduced the 1951-80 average climate patterns.

Impact scientists derive scenarios from GCM outputs because these models are the most sophisticated tools currently available for estimating the likely future effects of increases in CO_2 and other trace gases. GCMs are not yet sufficiently realistic to accurately simulate regional climate patterns. What is often done is to use the difference between the $1XCO_2$ ("current" climate, current concentrations of CO_2) and $2XCO_2$ ("future" climate and CO_2) simulations to derive scenarios (Carter et al., 1992). By applying these "anomalies" to a regional climate data set obtained from observation, we attempt to provide a better representation of the region's future climate. This procedure does not, however, eliminate inaccuracy of the GCM simulations. In MBIS, much attention was given to the development of the baseline data in order to ensure a good data base for the development of climate scenarios. Two types of GCM data can be used to develop climate scenarios: equilibrium and transient data.

A13.4.1.2 Equilibrium Scenarios

Equilibrium runs of the models are simulations of global climate based upon a set boundary conditions such as the concentration of atmospheric CO_2. As described above for the purpose of estimating the impact of increased atmospheric CO_2, normally two data sets are created: 1) under pre-industrial levels of CO_2 ($1XCO_2$), and 2) under a possible future level of carbon dioxide double the pre-industrial value ($2XCO_2$). The data sets used in impacts research have generally been monthly averages of 10 or more simulated years under equilibrium conditions. Data are provided for a certain number of grid points over the globe which are spaced according to the resolution of the GCM. The disadvantage of this type of data is that it fails to simulate the rate of change of conditions in the atmosphere over time. As a result, the output gives no indication of changes in climate variables over time. The advantage is that it takes less time and cost to produce the runs, and therefore to determine the impact.

Figure A13.6 CCC scenario: mean January temperature

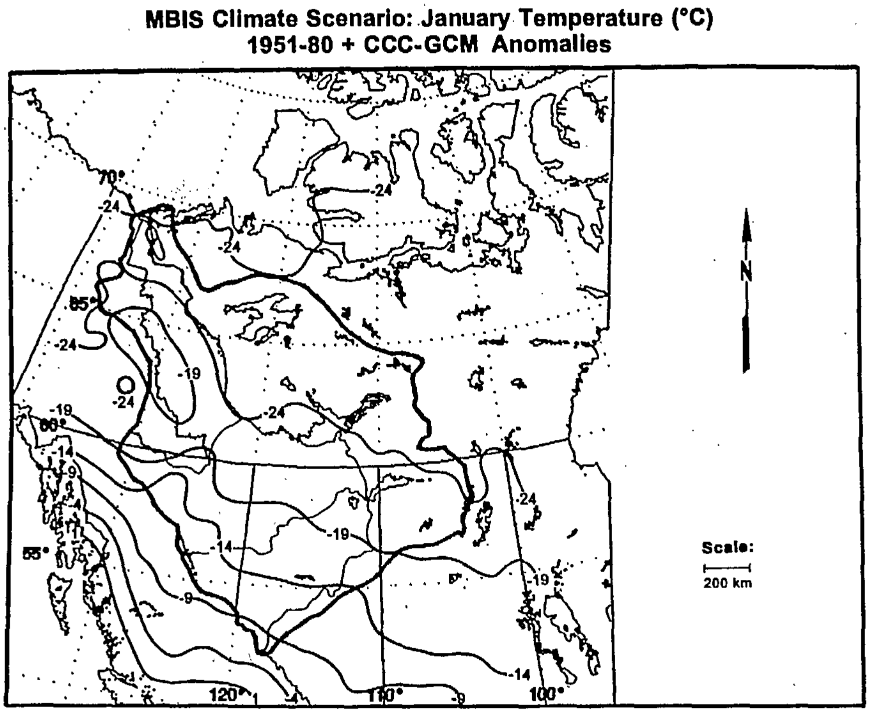


Figure A13.7 CCC scenario: mean total January precipitation

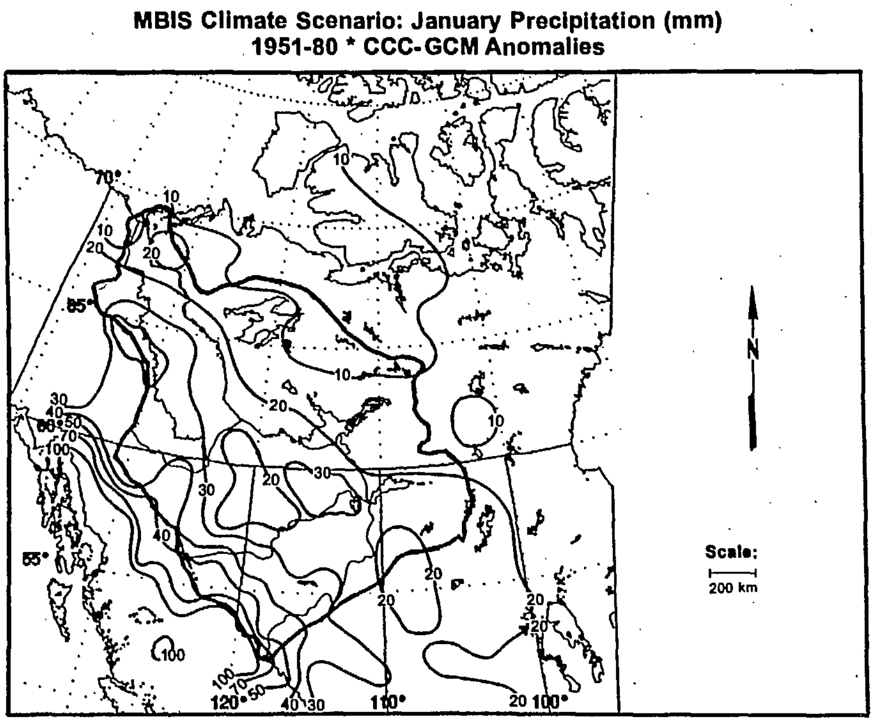
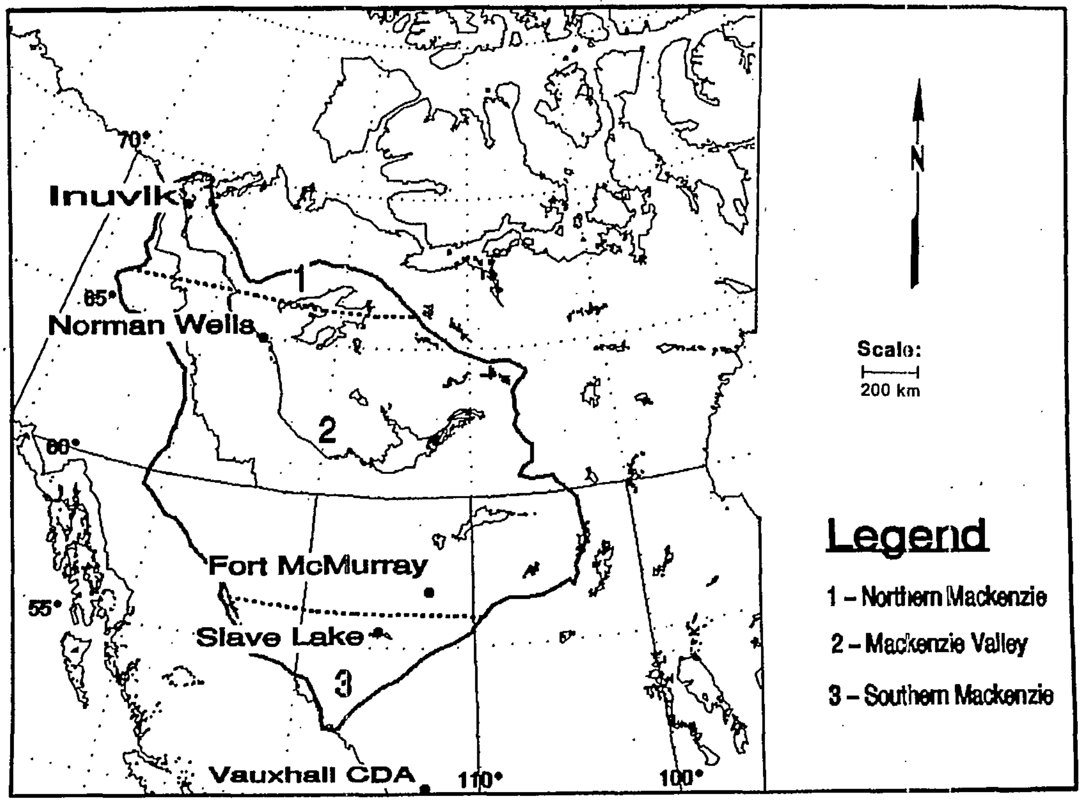


Figure A13.8 Locations of the composite divisions

MBIS Climate Scenario: Composite and Transient Divisions



Three GCMs were identified by the Intergovernmental Panel on Climate Change (IPCC) as the most sophisticated for simulating equilibrium climates: the Canadian Climate Centre (CCC), the United Kingdom Meteorological Office (UKMO), and the General Fluid Dynamics Laboratory R30 (GFDL R30) models (IPCC, 1990). Since the most recent version of the UKMO model was not available, only the GFDL-R30 and the CCC GCMs will be used to derive equilibrium scenarios for MBIS. Some results of the CCC GCM equilibrium derived scenario are presented in Figures A13.6, A13.7. The data used to produce all monthly maps for this scenario are available from CCC, and the GFDL-R30 scenario data will be available in 1993.

A13.4.1.3 Transient Scenarios

Transient runs of the GCMs are based upon changing boundary conditions over time which are an attempt to simulate real time change in the atmosphere (eg. a set rate of change in CO_2 concentration of 1.5% per year). It takes more effort to create transient runs of the GCMs and requires the impact scientist to determine the impact for each designated time period.

The Goddard Institute for Space Studies (GISS) has produced a number of transient runs. The one chosen to be used in MBIS assumes a decrease in the rate of trace gas growth and the addition of volcanic aerosols in 1995 and 2015 (Hansen et al. 1988). Results were compiled by region, using Figure A13.8 as a guide. This map was also used for developing the "composite" scenario (Section A13.4.2 describes the map in more detail).

Results for temperature and precipitation are listed in Tables A13.3 and A13.4 respectively. Mean annual temperature increases by 3.9 to 6.9° C by 2050, with greatest warming in "Northern Mackenzie". Precipitation in 2050 is slightly higher, but there are periods of lower precipitation within the time series.

A13.4.2 Composite Scenarios

Most scenarios of global warming have been derived using the outputs from GCMs. In recent studies, however, researchers have tried to compensate for the large uncertainties surrounding the GCM outputs by developing alternate climate scenarios based upon historical analogues or hypothetical cases. The hypothetical scenarios have represented a range of changes in temperature and precipitation values which have been based upon possible changes created arbitrarily by the researcher, though bounded somewhat by GCM projections. Long term climate records have been used in the development of alternate scenarios in North America (eg. the MINK study), but proxy data (paleoclimatic record) and spatial analogues (a real data set from a warmer location used to simulate climate change) have rarely been used in published climate impact assessments in Canada (e.g. Mooney and Arthur, 1990).

In order to develop an alternate climate scenario for MBIS, an informal meeting was arranged with researchers involved with the development of climate scenarios, climatologists with a knowledge of the instrumental data for the region, and researchers familiar with alternate sources of climate data such as paleoecologists. The purpose was to develop a "composite" scenario by merging available instrumental and paleo data.

Transpositional or spatial analogues were also considered. These analogues are derived by choosing climate data from a station in another region with warmer temperatures to replace the original data in order to simulate a warming. This can be done by using a GCM annual temperature change as a guide to choosing a climate station with a corresponding annual temperature to the GCM scenario. The advantage of this approach is that it allows the climatologist to consider inter-annual variability and extreme values from an existing time series.

The meeting was shared with the two other regional impact studies within the Green Plan. These are concentrating on the Prairies and the Great Lakes-St. Lawrence regions. Attendees at the meeting included: Glen MacDonald, McMaster University; Reinhard Pienitz, Queens University; Frank Quinn, Great Lakes Environmental Research Laboratory; Stan Changnon, Illinois State Water Survey; Elaine Wheaton, Sakatchewan Research Council, and various staff from the Adaptation Branch of the CCC who are familiar with instrumental records.

In the meeting brief presentations were made by the invited experts followed by some discussion and the following is a summary of the sessions:

1. Paleo data are useful in transition zones, but not in the center of ecozones (eg. middle of the boreal forest) where changes in species have varied little over time/space. Paleo data are also labour intensive, and not always available in all areas. The confidence limits of the monthly data estimates by the paleoecologists were approximately ±3°C for temperature, and ±10% in precipitation.
2. Instrumental data are useful in analogue development since the data resolution is good, but, it is a short record and not all variables are always available. For example, temperature and precipitation are not always enough to calculate an accurate water budget. The use of historical analogues are regarded with more respect by policy makers than GCM-derived scenarios because they are based upon observations rather than models.
3. Spatial (or transpositional) analogues are promising, however, there needs to be some criteria set up for choosing the appropriate location before determining the analogue. This may include climate controls, length of record and the nature of the scenario required by the researcher.

A series of tables and graphs were used as a guide for the group to develop the "composite scenarios". For each impact study a number of regions were defined, and a representative station was used from each region along with a CCC GCM grid point as a basis for developing an alternative scenario. An adjusted time series for each station was also provided by the Climate Change Detection Division at the CCC as a reference of climate variability for annual temperature only. The precipitation time series will be available at a later date.

Figure A13.8 shows that the Mackenzie Basin was separated into three regions: 1) Northern Mackenzie (above treeline) represented by the station at Inuvik (68.3°N, 133.5°W), 2) Mackenzie Valley (below treeline) represented by the station at Norman Wells (51.0°N, 114.0°N), and 3) Southern Mackenzie represented by the station at Slave Lake A (55.2°N, 114.8°W). A possible fourth region in the Mackenzie Valley, was eliminated due to lack of data. Overall, the composite is slightly cooler than the GCM - based scenarios (Figure A13.9). De5tails for each region are ?????

A13.4.2.1 Northern Mackenzie

Inuvik station is located in the Mackenzie Delta near the coast. As a result of the location of the station, it was impossible to find an appropriate transpositional analogue because the only other climate station in the Delta was Tuktoyaktuk, which is north of Inuvik. It was suggested to use Tuktoyaktuk as the primary station and Inuvik as the transpositional analogue, however the difference in mean annual temperature between the two stations is only 1.1°C which made Inuvik inappropriate as a transpositional analogue for Tuktoyaktuk. As a result, no transpositional analogue was chosen for Inuvik. Paleoclimatic records indicate summer temperatures. MacDonald suggested that the Delta was approximately 10% wetter in the summer months, and 1-5°C warmer as indicated in Table A13.5. These values were used in the composite scenario, and an average 10% increase in precipitation was used based upon the paleoclimatic evidence. For the spring, summer and fall months the difference between the average of the instrumental record's warmest five years and the 1951-80 mean monthly temperature was used.

A13.4.2.2 Mackenzie Valley

Norman Wells is located in the Mackenzie Valley. Fort McMurray was identified as the transpositional analogue based upon the annual temperature changes projected by the CCC-GCM. Using paleoclimatic data was difficult for this part of the basin because little change in tree species composition has occurred over time. The only conclusion that could be made was that the warmest temperatures experienced in the valley were similar to those changes in the Delta's warm period. It was suggested to assume a linear temperature change for this region based upon the changes suggested for Inuvik as indicated in Table A13.6. A five year average was used to develop the instrumental scenario. As in the Delta region the difference between the instrumental warmest five years' average and the 1951-80 mean monthly temperature was used in the composite scenario for the spring, fall and winter months, and a hypothetical change of +10% was used for precipitation based upon the paleoclimate evidence.

A13.4.2.3 Southern Mackenzie

The southern portion of the Mackenzie overlaps with the Prairies study region where paleoclimate data are more available then in the central Mackenzie. At Slave Lake, winter temperatures were estimated to rise in warm periods up to 3.5°C above present normals, and summer temperatures by 1.0°C (Table A13.7). Precipitation was estimated to be 15% below present normals in the summer months. The transpositional analogue assigned to Slave Lake was Vauxhall CDA, which showed lower precipitation all year except for April, due to the earlier onset of spring. The composite scenario therefore includes an earlier spring with higher precipitation, while -15% to 0% would be assumed for other months. The instrumental analogue was used to develop changes in temperature for the spring and fall months, as in the previous cases.

A full report on this meeting is available from CCC upon request.

Table A13.3 GISS transient scenario: temperature for regions shown in Figure 13.8

Northern Mackenzie Temperature Changes for GISS Transient

Year	January	February	March	April	May	June	July	August	Septembe	October	November	December	Annual
1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980	1.3	0.9	0.2	-1.1	-0.1	0.0	-0.1	0.1	0.9	0.1	1.3	0.0	0.3
1990	1.2	0.0	2.4	1.5	1.5	1.4	0.2	0.4	1.6	1.5	2.1	1.9	1.3
2000	5.5	3.5	2.8	1.7	0.6	1.0	0.7	0.6	2.2	3.0	1.5	1.5	2.0
2010	4.9	5.1	3.4	2.7	1.2	1.8	0.3	0.6	2.2	3.5	4.6	3.0	2.8
2020	5.5	5.4	2.4	2.4	1.2	2.2	0.5	1.2	2.8	5.9	5.4	4.7	3.3
2030	6.9	5.8	5.1	2.8	1.5	2.8	0.2	0.8	2.6	5.1	5.9	5.7	3.8
2040	8.4	10.0	7.1	3.4	2.8	3.2	0.1	1.5	3.7	7.3	9.6	7.0	5.3
2050	11.9	8.9	7.3	5.2	4.3	3.4	0.5	3.0	4.4	9.8	12.8	11.0	6.9

Mackenzie Valley Temperature Changes for GISS Transient

Year	January	February	March	April	May	June	July	August	Septembe	October	November	December	Annual
1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980	1.6	1.9	0.3	-0.0	-0.4	0.1	0.6	-0.1	0.4	0.9	-0.0	-0.7	0.4
1990	3.1	-0.3	1.0	2.0	1.3	0.1	1.1	0.4	1.9	1.3	1.2	1.3	1.2
2000	2.8	0.4	1.2	2.0	1.2	0.4	1.0	-0.4	2.0	1.6	1.8	1.2	1.3
2010	3.3	3.0	1.4	2.7	1.0	0.5	1.5	1.0	2.0	2.4	3.0	1.5	1.9
2020	4.7	3.8	1.2	3.1	1.6	0.7	2.4	1.3	2.0	3.8	3.2	2.7	2.5
2030	5.2	4.0	3.9	3.9	2.1	1.0	2.4	1.5	2.5	3.8	2.9	3.9	3.1
2040	6.4	5.7	3.6	4.4	2.8	1.4	2.8	2.4	3.8	3.7	4.6	4.6	3.9
2050	7.7	5.3	4.4	5.7	3.1	2.6	3.6	3.7	4.0	6.0	6.2	5.9	4.8

Southern Mackenzie Temperature Changes for GISS Transient

Year	January	February	March	April	May	June	July	August	Septembe	October	November	December	Annual
1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980	0.4	1.1	0.2	-0.6	0.5	0.5	1.2	0.9	0.1	-0.1	0.1	-0.5	0.3
1990	0.6	0.7	0.7	0.1	0.3	1.0	1.2	1.3	0.5	1.0	1.6	1.2	0.8
2000	1.2	1.1	1.3	0.6	0.5	0.3	0.9	1.4	1.1	1.1	1.2	1.5	1.0
2010	2.0	1.4	1.2	0.9	0.8	0.8	1.2	1.4	1.1	1.2	1.4	1.6	1.3
2020	3.0	1.5	1.6	1.1	1.2	1.0	1.6	1.6	1.6	2.1	1.5	2.4	1.7
2030	3.5	2.5	3.1	2.2	1.7	1.8	3.0	3.3	3.1	2.4	3.1	3.6	2.8
2040	3.6	3.8	2.9	2.9	2.2	2.4	3.5	3.2	3.1	3.0	3.2	3.3	3.1
2050	4.2	3.5	3.5	3.3	3.2	3.0	3.6	4.2	4.4	4.1	4.6	4.7	3.9

Table A13.4 GISS transient scenario: precipitation for regions shown in Figure 13.8

Northern Mackenzie Precipitation Ratio Adjustments for GISS Transient

Year	January	February	March	April	May	June	July	August	Septembe	October	November	December	Annual
1970	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	1.37	1.01	0.99	1.03	0.97	1.06	1.01	1.14	1.08	0.98	1.15	1.00	1.05
1990	0.83	0.88	1.01	1.11	1.17	1.02	1.23	1.06	1.08	1.09	1.04	1.12	1.05
2000	1.30	1.26	1.17	1.08	0.99	0.97	1.01	1.02	0.94	0.99	0.98	0.99	1.02
2010	0.98	1.08	0.95	1.00	0.93	1.08	0.97	0.99	1.12	1.05	1.05	1.07	1.01
2020	1.01	1.08	0.99	1.05	1.01	1.26	1.10	1.05	0.99	1.11	1.03	1.05	1.05
2030	1.10	0.91	1.19	1.01	1.01	0.88	1.05	0.97	1.03	0.94	1.00	1.07	0.99
2040	1.00	1.19	1.10	1.24	1.20	1.03	1.18	1.15	0.94	1.08	1.19	1.02	1.10
2050	1.07	0.90	0.90	0.92	1.02	1.07	1.09	1.06	1.18	1.18	1.08	1.09	1.05

Mackenzie Valley Precipitation Ratio Adjustments for GISS Transient

Year	January	February	March	April	May	June	July	August	Septembe	October	November	December	Annual
1970	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	1.06	1.13	1.08	1.16	1.18	1.06	1.01	0.95	1.00	1.07	0.85	1.02	1.04
1990	0.99	1.05	0.94	0.89	0.99	1.11	1.07	1.04	1.12	1.04	1.19	1.18	1.03
2000	0.99	0.92	1.16	1.08	1.13	1.03	0.94	0.94	0.96	0.95	1.08	1.01	0.99
2010	1.14	1.00	0.86	1.00	1.05	1.07	1.13	1.16	1.19	1.09	0.94	1.14	1.07
2020	1.01	1.06	1.26	1.18	1.18	1.02	1.05	1.01	0.92	0.98	1.15	0.91	1.04
2030	1.14	0.99	1.09	0.97	1.08	1.00	0.94	1.02	1.12	1.17	0.85	1.04	1.03
2040	0.85	1.27	0.97	1.00	0.96	1.06	1.07	1.06	0.97	0.95	1.16	1.04	1.02
2050	1.02	0.92	0.96	1.08	0.94	1.04	1.02	1.05	1.09	1.12	1.07	1.01	1.02

Southern Mackenzie Precipitation Ratio Adjustments for GISS Transient

Year	January	February	March	April	May	June	July	August	Septembe	October	November	December	Annual
1970	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1980	1.00	0.97	0.97	1.07	0.96	0.97	0.94	0.93	0.86	0.93	0.99	1.08	0.97
1990	1.03	1.10	0.97	0.89	0.96	1.02	0.95	1.13	1.24	1.14	1.10	0.98	1.03
2000	1.12	0.93	1.10	1.29	1.15	1.06	1.10	1.02	1.29	0.94	1.05	1.05	1.05
2010	0.96	1.01	1.06	0.95	0.97	0.98	1.07	1.10	0.94	1.09	0.95	1.13	1.01
2020	1.07	0.98	0.98	1.03	1.01	1.13	1.01	1.19	0.94	0.91	1.04	0.92	1.00
2030	1.04	1.02	1.04	1.06	1.02	0.93	0.88	0.81	1.55	1.00	1.04	1.01	1.00
2040	0.90	1.16	1.06	1.03	1.02	0.99	1.03	1.20	1.12	1.16	0.98	1.09	1.02
2050	1.17	1.03	1.01	0.82	1.11	1.08	1.15	1.10	0.81	1.08	1.09	1.02	1.04

Table A13.5 Composite table for Northern Mackenzie

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
Inuvik 1951-80 (68.3, 133.5)													
Temp.	-29.6	-28.9	-25.0	-14.3	-0.8	10.1	13.6	10.7	3.1	-8.1	-20.7	-27.2	-9.8
Precip.	17.9	10.5	12.0	14.8	17.6	23.5	33.6	43.6	23.9	33.4	17.9	17.4	266.1
CCC Changes (Grid point)													
Temp.	3.0	6.4	9.2	3.2	4.8	6.7	4.2	2.6	2.0	4.5	6.1	4.9	
Precip.(ratio)	1.00	1.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	2.00	0.67	1.00	
Inuvik under CCC Scenario													
Temp.	-26.6	-22.5	-15.8	-11.1	4.0	16.8	17.8	13.3	5.1	-3.6	-14.6	-20.2	-4.8
Precip.	17.9	10.5	12.0	14.8	17.6	23.5	22.5	43.6	23.9	67.8	12.0	17.4	
Transpositional -			**NONE APPROPRIATE**										
Temp.													
Precip.													
Instrumental Five Warmest Years Average													
Temp.	-25.0	-26.0	-23.1	-10.9	1.8	11.3	15.1	12.2	4.0	-6.9	-20.3	-24.1	-7.7
Paleoclimate - Warm Year													
Temp.				+3.0	+4.0	+5.0	+3.0	+1.0					
Precip.				+10%	+10%	+10%	+10%	+10%					
Composite													
Temp.	4.6	2.9	4.6	3.0	4.0	5.0	3.0	3.0	1.0	0.9	1.2	0.4	3.6
Precip.	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%

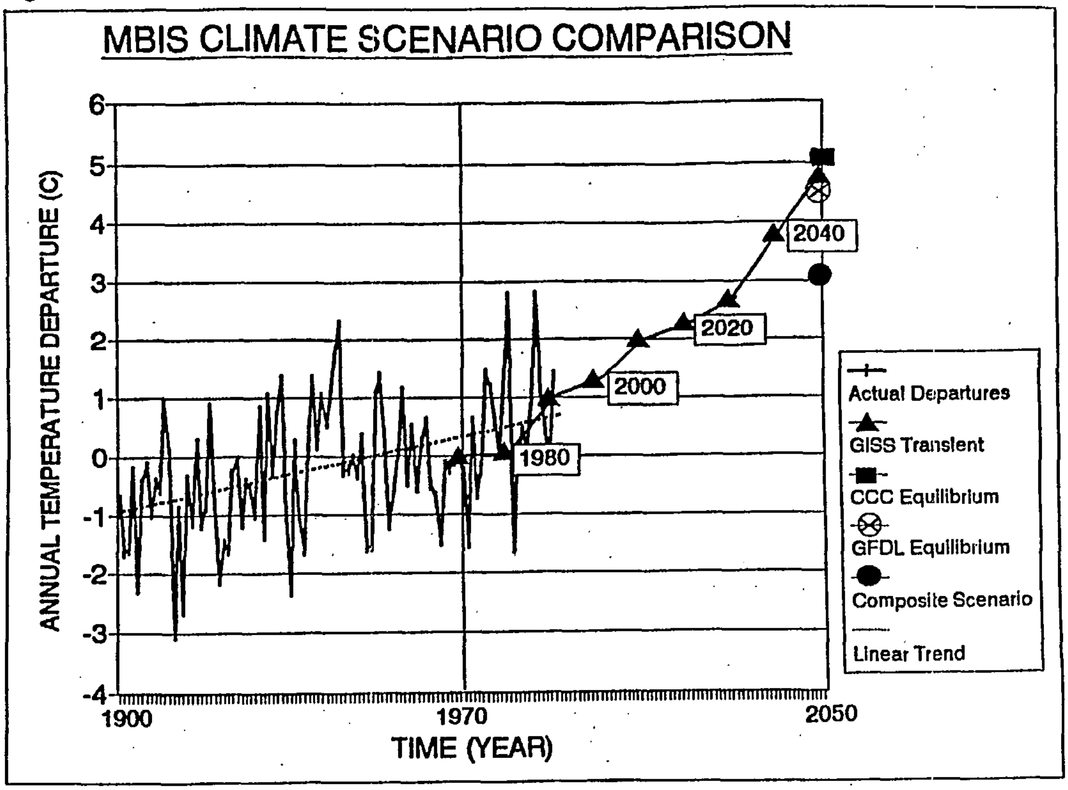
Table A13.6 Composite table for Mackenzie Valley

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
Norman Wells 1951-80 (65.3, 126.8)													
Temp.	-28.9	-26.2	-19.8	-7.2	5.4	14.0	16.3	13.4	6.1	-4.6	-18.2	-26.5	-6.4
Precip.	19.5	16.1	13.9	15.4	17.0	37.0	56.1	58.6	29.3	26.8	20.9	18.8	328.4
CCC Changes (Grid point)													
Temp.	4.3	4.2	5.3	1.2	3.1	4.9	3.1	3.0	3.1	1.5	8.8	5.7	
Precip.(ratio)	2.00	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Norman Wells under CCC Scenario													
Temp.	-24.6	-22.0	-14.5	-6.0	8.5	18.9	19.4	16.4	9.2	-3.1	-9.4	-20.8	-1.5
Precip.	39.0	8.1	7.0	15.4	17.0	37.0	56.1	58.6	29.3	26.8	20.9	18.8	
Transpositional - Fort McMurray (56.7, 111.2)													
Temp.	-21.8	-15.4	-9.2	2.1	9.7	14.0	16.4	14.8	9.0	3.3	-8.2	-17.0	-0.2
Precip.	22.7	18.8	20.7	20.5	36.3	64.1	75.4	76.6	58.5	28.1	25.2	25.0	471.9
Instrumental Five Warmest Years Average													
Temp.	-22.9	-22.5	-16.5	-4.2	7.7	13.2	16.3	13.3	7.8	-1.0	-15.8	-22.4	-3.9
Paleoclimate - Warm Year													
Temp.				+3.0	+4.0	+5.0	+3.0	+1.0					
Precip.				+10%	+10%	+10%	+10%	+10%					
Composite													
Temp.	6.0	3.7	3.3	3.0	4.0	5.0	3.0	3.0	1.0	3.6	2.4	4.1	3.5
Precip.	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	+10%

Table A13.7 Composite table for Southern Mackenzie

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
Slave Lake A 1951-80 (55.2, 114.8)													
Temp.	-18.0	-12.3	-6.9	2.5	9.0	13.3	15.6	14.4	9.0	4.1	-6.3	-14.1	0.9
Precip.	27.4	20.1	21.2	17.5	44.0	82.6	77.5	71.3	49.9	25.3	23.9	27.4	488.1
CCC Changes (Grid point)													
Temp.	4.5	5.0	4.4	2.4	4.6	4.0	3.2	3.3	3.1	2.6	1.5	5.7	
Precip.(ratio)	1.80	1.00	1.50	1.50	1.33	1.00	1.33	1.00	2.00	1.00	1.67	1.33	
Slave Lake A under CCC Scenario													
Temp.	-13.5	-7.3	-2.5	4.9	13.6	17.3	18.8	17.7	12.1	6.7	-4.8	-8.4	4.6
Precip.	49.3	20.1	31.8	26.3	58.5	82.6	103.1	71.3	99.8	25.3	39.9	36.4	
Transpositional - Vauxhall CDA (50.0 , 112.1)													
Temp.	-12.7	-7.4	-3.0	4.9	11.2	15.6	18.6	17.5	12.1	6.9	-1.9	-7.9	4.5
Precip.	20.8	16.0	17.2	32.5	41.4	59.2	31.3	38.5	34.2	13.5	13.0	20.8	338.4
Instrumental Five Warmest Years Average													
Temp.	-14.5	-7.5	-5.7	3.6	9.8	13.6	16.5	15.4	11.9	6.1	-1.8	-8.7	3.3
Paleoclimate - Warm Year													
Temp.	3.5	3.5				1.0	1.0	1.0				3.5	
Precip.						-15%	-15%	-15%					
Composite													
Temp.	3.5	3.5	1.2	1.1	1.0	1.0	1.0	1.0	2.9	2.0	4.5	3.5	2.2
Precip.	-10%	0%	+10%	+10%	0%	-15%	-15%	-15%	0%	0%	-10%	-10%	-2.9%

Figure A13.9 MBIS Climate Scenario Comparison



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A14. Baseline Population And Economic Growth Simulation

Stephen C. Lonergan and Richard J. DiFrancesco, U. of Victoria

A14.1 Development of the Population Growth Forecasting Model

The first step in implementing the first phase of this project involved building a model which would facilitate the assessment of how the region's population dynamics could behave, given current conditions and trends, over the next 50 years. Limited time series data and concerns about going beyond simple curve fitting extrapolation methods meant that a deterministic component approach had to be adopted[1]. The model chosen was taken from Rogers (1985) and was adapted to the situation at hand. Specifically, the component approach involved the decomposition of population change into two constituent parts, the first being natural increase and the second being the net effect of in - and out - migration.

In terms of structure, the model was defined as a system of linear equations where each sub - region comprising the MBIS zone had an equation of the following form associated with it;

(1) $$P_i(t+1) = (1 + b_i - d_i - \sum_{j}^{n} o_{ij}) \bullet P_i(t) = \sum_{j}^{n} o_{ji} \bullet P_j(t)$$

where;

b_i, represents the birth rate of region *i*,

d_i, represents the death rate of region *i*,

o_{ij} represents the out - migration rate from *i* to *j* and,

$P_i(t+1)$ represents region population at time $t+1$.

Equation one shows how region i's population is comprised of two components, the first represents natural increase of i net of all out - migration and the second component (the second product in equation 1) represents all sources of population gain in i from in - migration.

One equation of the type shown in equation 1 was defined for each of the five sub - regions and an additional equation was included for a sixth "rest of Canada" (ROC) region[2]. The inclusion of this sixth region, along with the inclusion of in - migration rates in all other equations showing migration propensities from the ROC region to each of the sub - regions, allowed the multiregional system to be closed. This system of six linear equations was easily transformed into a matrix projection system for the purpose of simulation exercises. The final form of this model was as follows:

(2) $$\Gamma^n \quad \bullet(t) = \quad (t+n)$$

where;

Γ represents the natural increase net of out - migration component,

A represents a column vector of population figures at year t, and

n represents the number of periods being forecast.

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[1]A number of curve fitting exercises were conducted but population data for the sub-regions comprising the MBIS zone was both scarce and unreliable due to numerous CD re-classifications which occurred from one census year to another. In fact, to get a set of time series data on population which was consistent for all subregions meant that a 10 to 12 observation time series had to be used and this was deemed to be far too short for any accurate extrapolation exercise.

[2]It should be noted that all rates were based on provincial rates which were then weighted via population shares to represent sub-regions appropriately as inter-census division migration statistics are not collected. The details behind this weighting scheme are available from the suthors upon request.

Figure A14.1 NWT population projections and yearly percentage Changes: 1986-2038

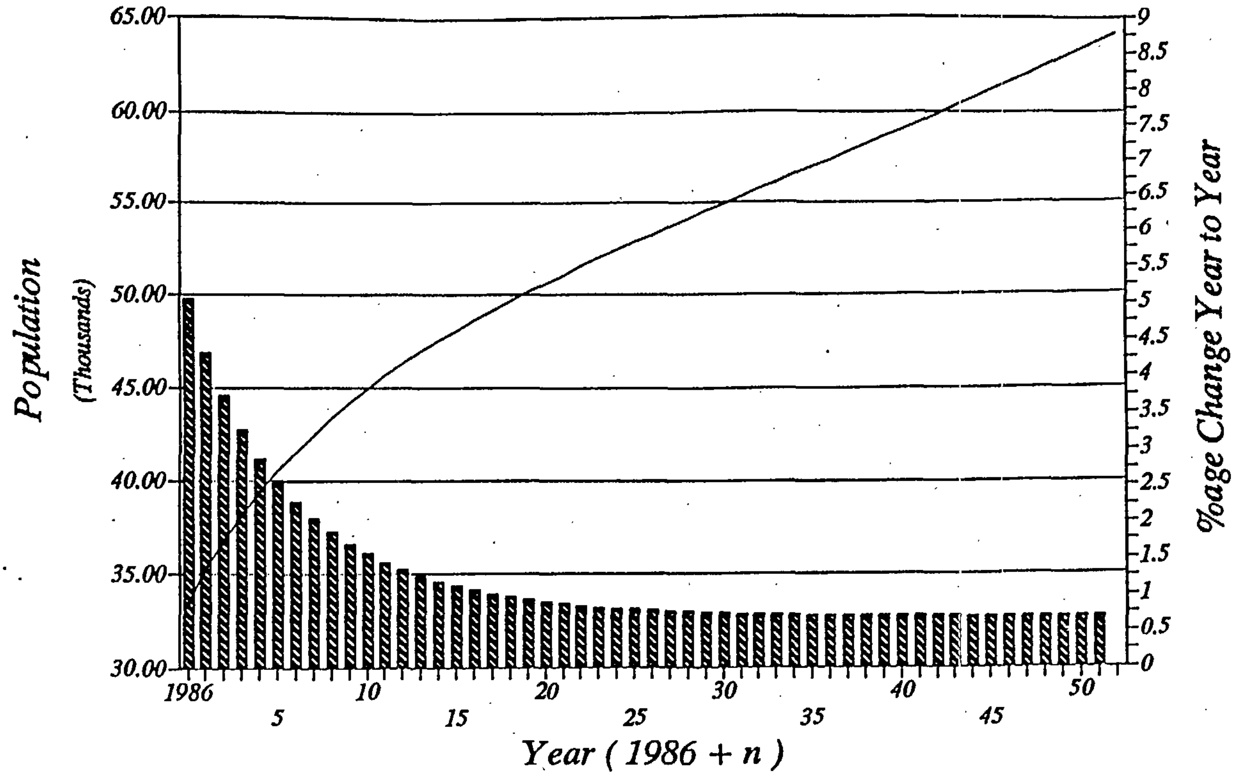


Figure A14.2 Yukon population projections and yearly percentage Changes: 1986-2038

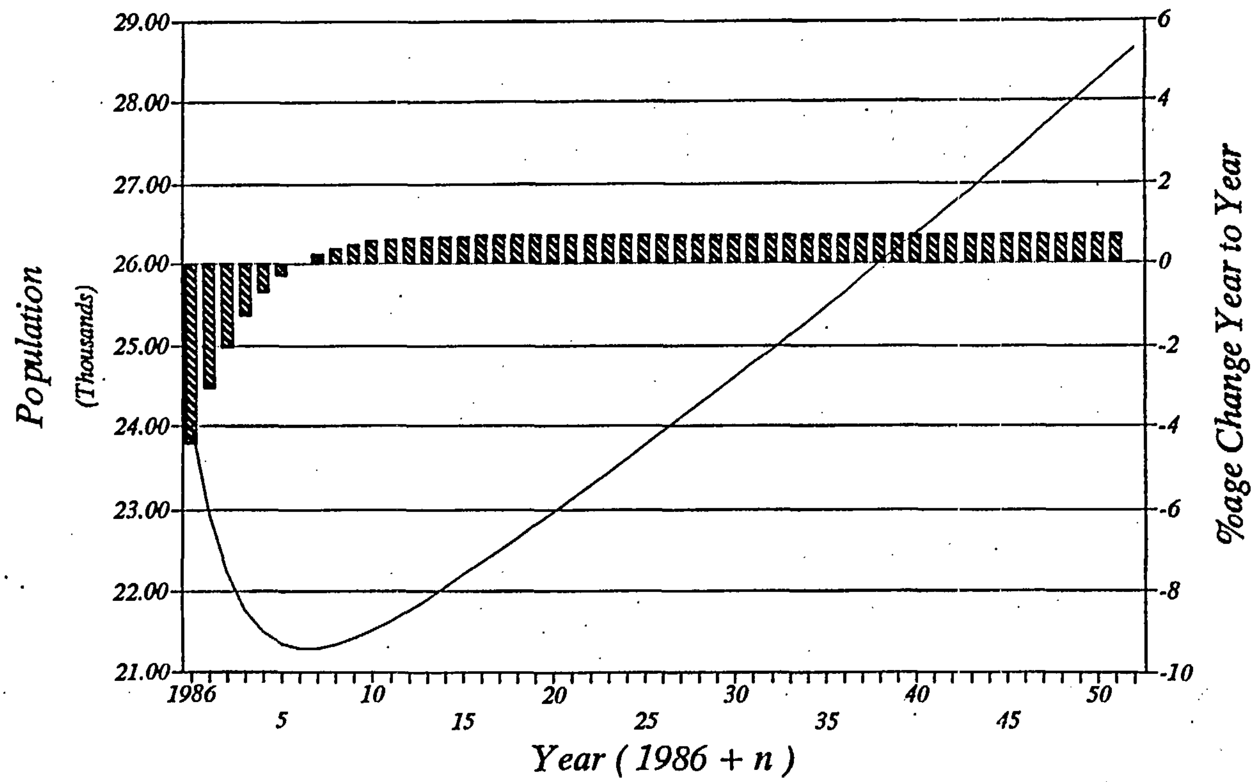


Figure A14.3 British Columbia population projections and yearly percentage Changes: 1986-2038

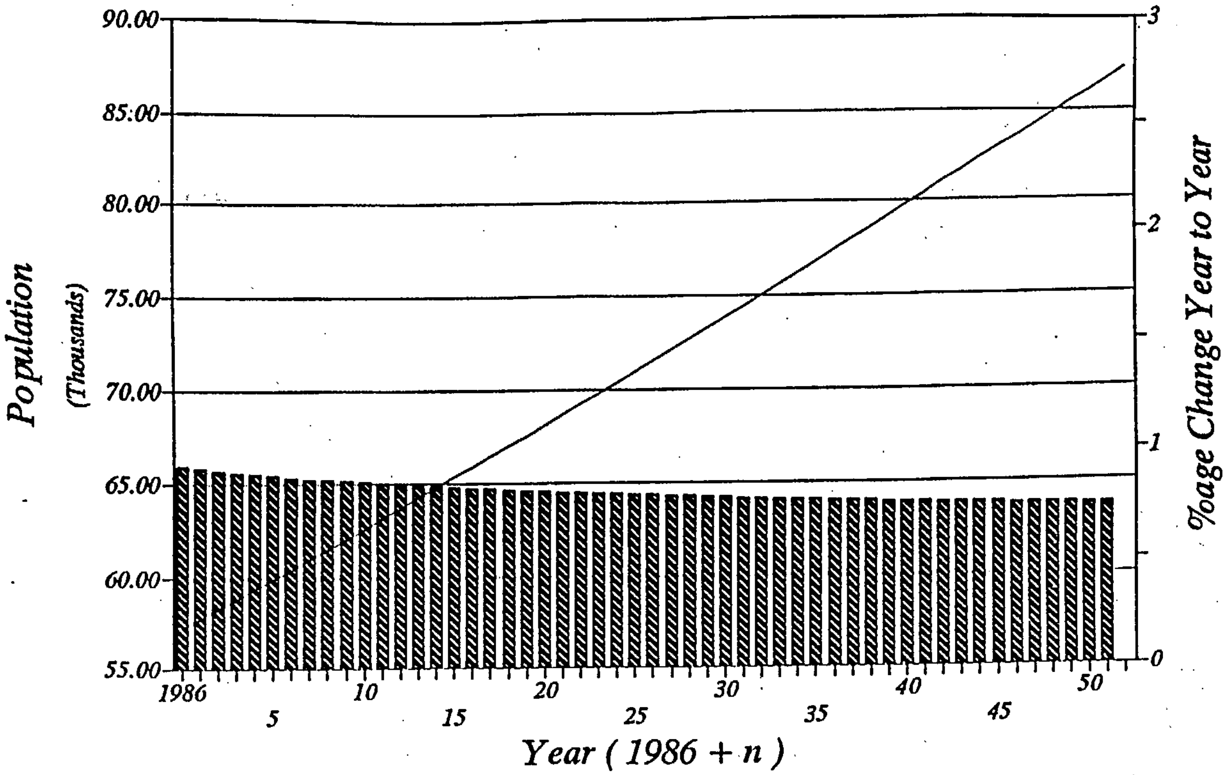


Figure A14.4 Alberta population projections and yearly percentage Changes: 1986-2038

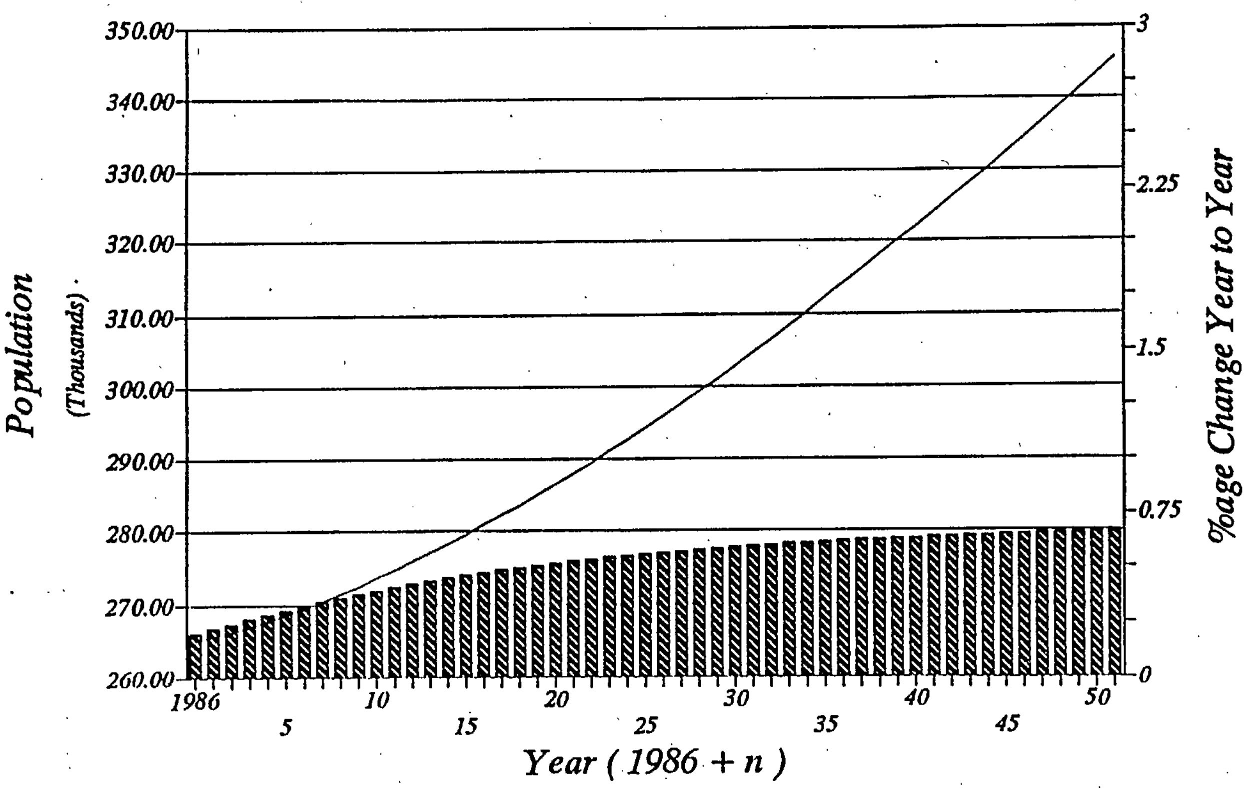
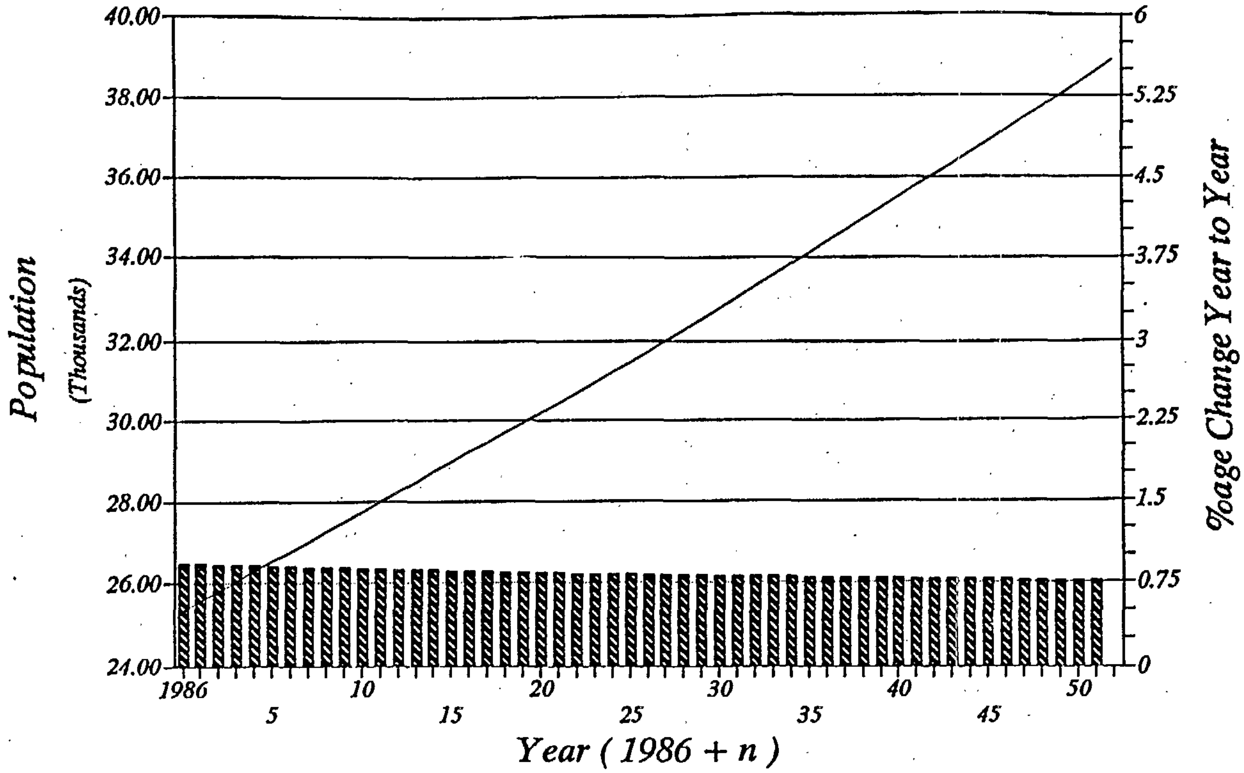


Figure A14.5 Saskatchewan population projections and yearly percentage Changes: 1986-2038



A14.2. Implementation of the Population Model

The matrix of rates (Γ) was assumed to remain unchanged from period to period and successive vectors of period (t+ 1) population figures were computed up to period (t+50). The population projections are shown graphically in Figures A14.1 to A14.5.[1] The intention was to build a model that would lend itself to the evaluation of various development scenarios in terms of population movements and totals. These scenarios will be impressed upon the model by altering specific rates in the Γ matrix of the model. The development of these scenarios represents a significant portion of this project and advice from government officials as well as speculation from informed individuals along with knowledge of proposed long term developments in the region will all be used to generate a few scenarios of how this region's economy could develop over the next 50 years. The 50 year projections shown here were performed more to test the performance of the model than to give population forecasts for this region over the next 50 years. It is important to note that as yet, no consideration has been given to climate change.

[1] When looking at the projections, it is interesting to note that after the first 20 to 25 projected years the year to year change becomes constant. This result is an artifact of this type of model which is easily explained using the theory of Matrix Algebra. As Rogers (1985) noted, in the case of a matrix of non - negative elements, after repeated powering of such a matrix, each element of the higher power matrix will be proportional to the corresponding element of the lower power matrix ($G^{h+1} = AG^h$).

A14.3. Development of a Model for the Evaluation of Economic Growth and Structure Under Various Scenarios

The next component of the first phase involved the building of an economic model which would allow the level of economic activity taking place in this region to be forecast under the same development scenarios used in conjunction with the population model presented above. Two general classes of modelling systems were initially considered; econometric models and input - output models. The former type have the advantage of being stochastic and hence never provide point estimates while the latter type are deterministic in nature and always provide point estimates. The literature on economic forecasting relies heavily on these two basic categories of models and the general consensus is that the former is better for long range forecasting while the latter is better suited to short to medium term use due to a reliance upon a matrix of coefficients which imply an unaltering technological relationship between sectors of an economy and which do not acknowledge the existence of scale effects. Based on this information, the first choice of modelling frameworks was a macro - econometric simultaneous equation model (SEM) where each of the 6 sub - regions defined earlier would have a block of equations and where all sub - regions were joined via trade equations[1]. This type of system however was soon found to be impractical in this situation since many of the necessary variables were not available at the CD level and, what data was available was only available in short and irregular time series. A preliminary reconnaissance of available data sources revealed that, at best, an 11 year time series on a limited set of CD based variables could be obtained for the regions in question. Further examination revealed that even a very simple SEM would run into degrees of freedom difficulties. The decision was made to not investigate the use of Monte Carlo based simulations to generate data sets or to develop elaborate regionalization routines to "boil down" provincial data to the regional level.

The second category of model considered, and subsequently decided upon, was the input - output model. This type of model, while generally not well suited to long range work, was considered to be applicable in this situation for a number of reasons. Firstly, the economy to which the model would be applied was relatively very small and immature and not likely to experience turbulent and far reaching structural change. Secondly, the structural change which could occur would likely occur in a predictable manner[2], and thirdly this modelling framework was also deemed satisfactory due to the fact that our analysis will be based upon the evaluation of different scenarios and, as such, methods may be incorporated to adjust the coefficients of the model accordingly. The use of the input - output model will provide projections of macro - economic activity in the region as well as a detailed picture of the structural relations which may exist under the various scenarios.

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[1] If this approach were feasible, the ideal situation would have been to have the macro - economic equations along with the interregional migration and population stock equations all included in one SEM. The result would be a true multiregional econometric model.

[2] Meaning that structural change would occur in one or all of two major sectors, forestry and energy related sectors.

The specific model built for this purpose is a full Multiregional Input - Output Model (MRIO) with 12 endogenous and interactive regions (10 provinces and 2 territories). The structure of this model is as follows;

(3) $$X = (I - CA)^{-1} \bullet CY$$

where;

X represents a (84X1) gross output vector

A represents a (84X84) block diagonal technical coefficient matrix,

C represents a (84X84) matrix of interregional trade coefficients, and

I represents a (84X84) identity matrix, and

Y represents a (84X1) sectoral final demand vector[1].

The model just described represents a model of the entire Canadian Interprovincial system with the smallest spatial unit defined being a province. To make this system useful for the MBIS, the MBIS region must be "split out" of this larger system and portrayed as an endogenous and interactive component of the larger Canadian system. A regionalization scheme which will allow this region to be "split out" has been nearly completed. This scheme will allow the MBIS region to be included as the 12th region in the system[2]. To perform the regionalization, data has been obtained on employment totals by sector at the CD level and these will be used to compute employment shares which can be used as weights to define a set of transactions tables representative of the MBIS region[3].

A14.4. Development of Basin Scenarios

Four scenarios of economic development have been constructed. These were used as input for the MRIO model calculations of economic output and changes in employment. The following discussion describes these scenarios according to the MRIO model structure, which split the regional economy into 7 sectors.

The sectors were defined as follows: 1) primary, 2) manufacturing, 3) construction, 4) transportation/storage/communication/other utilities, 5) wholesale and retail trade, 6) finance, insurance and real estate (or F.I.R.E.), and 7) services.

A14.4.1 Scenario #1 -- High Resource Development Scenario

The high resource development (HRD) scenario is so named because it is distinguished by expansion beyond business-as-usual in the main primary resource sectors of the Basin. These sectors include Mining, Petroleum and Natural Gas, and Forestry. The scenario is based on the presumption that conditions favouring growth in these sectors will be witnessed over the modelling time horizon, including that global price incentives for such growth exist and/or government intervention at the policy level encourages such growth. One example of the necessary underlying conditions for growth in these sectors is the development of sufficient infrastructure in the North, and in particular the construction of all-season roads connecting Fort Simpson and Wrigley, connecting Wrigley and Arctic Red River and connecting Tuktoyaktuk and Inuvik. The connection of Wrigley and Fort Simpson by an

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[1]The data used to build this model was the 1984 S level Input - Output Accounts which are based upon a 43 commodity by 16 industry accounting structure. The model, once transformed into an industry by industry (square) format represented each province as being composed of 16 sectors supplying 16 sectors. These were aggregated into 7 sectors. Since there are 12 regions in the model there are 12 x 7= 84 rows and 84 columns in the system.

[2]Since the entire Yukon has been included in the MBIS region, the MBIS region was defined as the sum of the allocated portions of BC, ALB, SAS, and the NWT and the entire Yukon. As such, the Yukon's set of rows and columns in the original model will be replaced by the MBIS rows and columns. The dimensions of the system therefore will not change.

[3]This process will be rather time consuming and involved. The lack of detail here should in no way reflect to the reader that this is a trivial exercise but only that all of the details have yet to be finalized.

all-weather road is currently underway and should be completed in the next five years. However, the completion of the all-weather connections between Wrigley and Arctic Red River and between Inuvik and Tuktoyaktuk is both less certain and more significant for the NWT from a developmental standpoint[1].

The HRD scenario is driven by a three per cent annual rate of growth in the real value of total output in the primary sector (sector 1), driven chiefly by the mining, petroleum and natural gas, and forestry sectors of the Basin. The result of this growth is an increase in sectoral output of roughly 325 percent over the model time horizon. Mining output is assumed to be concentrated in the NWT, while petroleum and natural gas output increase in both the NWT and northern Alberta. Forestry output, should it increase at the specified levels, would likely be concentrated outside the Territories, in northern Alberta and British Columbia. Agricultural output and fishing, hunting and trapping output in the Basin are assumed to take place at the business-as-usual rate under all scenarios, based upon consensus opinion that these sectors will continue to be minor players in the Basin's economy. A brief description of the mining, petroleum and forestry sector growth scenarios follows. This information is intended to provide background in support of the HRD and subsequent scenarios.

Mining

The HRD scenario entails rapid growth in the mining sector of the Basin, driven chiefly by increased output in the NWT. This is contrary to current trends in both regions, where the mining sector has shown signs of gradual decline and is also contrary to the current national trend. Capital expenditures in the mining industry over the period from 1984-1992 for the NWT and Alberta do not exhibit any consistent trend, however, capital expenditures are down over the entire period for both regions. This is also true at the national level. Closer examination of the NWT mining sector[2] reveals a steady decline in the number of claims in good standing from 1981 to 1989, and a drop in the total area of claims in good standing from a high of 4,217,000 ha in 1981 to 3,085,000 ha in 1989 (although the latter represents a rebound from a 1986 low of 2 672 000 ha; Outcrop Ltd., 1990). An examination of lead, zinc, gold, silver and copper over the 1980-88 interval reveals that silver and copper production have shown marked declines, with no copper production after 1985. However, lead, zinc and gold production levels have all shown stability or slight growth.

Although the scenario applies to the Basin as a whole, it would be reasonable to expect that growth would be concentrated in the NWT. Alberta's mining sector is relatively small if petroleum is excluded. This seems unlikely to change. If growth is to occur in the mining sector, it is likely to be centred in gold, lead and zinc mining. This is based on examination of capital expenditures in gold exploration (Outcrop Ltd., 1990), on the comparative health of gold and zinc mining, and on the fact that gold and zinc together account for a disproportionate share (usually above 75%) of the total annual value of shipments from the mining industry of the NWT.

Petroleum

The petroleum industry in the North can be characterised as moribund. Information from government sources in both the NWT and Alberta indicates that conditions are not favourable for an imminent growth in petroleum industry production North of 60°N. Crude oil production in the NWT, over the period 1981 to 1990, grew dramatically from below 172,200 cubic metres (c.m.) per year in 1981 to 1,884,500 c.m. per year in 1989. This can be attributable to new production facilities coming into operation in Norman Wells. The trend is not expected to continue. Natural gas production also rose dramatically from 1981 to 1986, peaking at over 518,300,000 c.m., before declining to a 1990 level of 202,300,000 c.m.

Similar trends in expenditures for oil and gas exploration, and new production facilities, respectively, are testimony to pessimistic short term predictions for growth in the petroleum sector of the NWT. In general, the unfavourable global market conditions coupled with the emergence of former

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[1]See RTM Engineering Ltd. 1992. Northwest Territories Alternative Fuels from the Mackenzie Delta Gas Development. Report prepared for the Department of Energy, Mines and Petroleum Resources of the Government of the Northwest Territories.

[2]Examination of the Alberta mining data is potentially misleading given that only the Northern portions of the province are of current interest, yet the data are collected at the provincial level.

Soviet Republics as players on the world market make further development of northern reserves unlikely in the near future.

In the Alberta portion of the Mackenzie Basin, there are currently two major oil sands development projects operating, and a third in the developmental phase. Syncrude and Suncor are currently producing at a rate of 130,000 barrels per day (B/D), and 53,000 B/D, respectively. The newest production facility is OSLO , slated to begin producing at a rate of 77,000 B/D in 1996, although this seems quite speculative at this time.[1] Most information indicates that future development of tar sands is unlikely to extend beyond these three projects while current global conditions prevail. In addition, there is little associated gas in the bitumen deposits of the tar sands. Moreover, Alberta's natural gas reserves are extremely high relative to demand, indicating little urgency in seeking new gas deposits in northern Alberta. This is an additional factor indicating the low probability of large scale natural gas production from Mackenzie Delta deposits in the near future.

Despite the pessimistic outlook in the petroleum industry, large scale expansion of oil and gas development in the basin forms a component of the HRD scenario. This is useful given the volatility of this sector over the past decade and also given our desire to present a spectrum of possible future scenarios. The above information serves as a reminder that scenarios are for demonstrative purposes, and that elements of individual scenarios may run counter to what is believed highly probable.

Forestry

The Forestry sector has not traditionally been a significant factor in the NWT economy. While the NWT does maintain an annual allowable harvest (AAH) over 25 million board feet, cut has rarely exceeded five million board feet. It may be reasonable to expect some limited growth in forestry in the NWT, however it is more likely that growth would be concentrated in northern Alberta and BC, where sectoral infrastructure is in place. For example, Alberta Forestry officials assert that Forestry in their province may well exhibit a shift northward in the near future as completion dates for processing facilities in the region approach.

A14.4.2 Scenario #2 —Low Resource Development Scenario

The Low Resource Development (LRD) scenario is characterised by lower growth estimates for the petroleum industry. This scenario is intended to provide contrast between the HRD scenario and one of more moderate projections of growth in resource development. In addition, this scenario can be compared to the HRD scenario in order to highlight the importance of energy development in the North. Finally, this scenario is in response to expert opinion that rapid and steady growth in the petroleum industry in the Basin is very unlikely. In this scenario, growth in the primary sector is limited to 0.5% per year.

Aside from the drop in energy output forecasts , the LRD scenario differs from the HRD scenario in its projections of output in construction and services (Sectors 3 and 7, respectively). Here, the growth rate in the construction and services sectors is projected to increase at 0.1% per year. This is intended to reflect more moderate economic conditions in the Basin.

A14.4.3 Scenario #3 —Low Overall Growth Scenario

The Low Overall Growth (LOG) scenario is characterised by stagnating output in all groups over the model time horizon, and particularly from the region's economic base sectors (Sectors 1, 2, 3, and 4). The value of these sectors' aggregate output remains constant in real terms over the time horizon of the model. The mining, petroleum and forestry sectors are assumed to cause stagnation in sector 1 output as changes in agriculture and fishing, hunting and trapping sector outputs are assumed constant. Background information on the mining, petroleum and forestry sectors is contained in the discussion of the HRD scenario and requires little further elaboration. In the mining and forestry sectors, indications run somewhat contrary to the LOG scenario, perhaps corresponding most closely with the business-as-usual scenario determined by population projections. However, forecasts of extreme declines in these industries seem less than probable. This may not be so for the petroleum industry, where most indications point to future stagnation or decline. In general, however, it is possible that

[1]Information collected on the Tar Sands is derived from personal communications with Alberta Energy officials and from "OSLO. An Alberta Oil Sands Project. Background Papers." produced jointly by the Alberta and Canadian governments.

the primary resource sectors of the North will decline in real terms over the model time horizon. The LOG scenario serves to show what the implications of stagnation in these sectors might be.

The LOG scenario also includes stagnation in sectors 3 and 4. Decline in the forecasted growth for these sectors relative to the other scenarios is based on the assumption that the road connecting Wrigley and Arctic Red River is not built. In addition, the possible shift of government services out of the region (see below) results in a shrinkage in government investment in infrastructure improvements. Similarly, general diversification serves to channel funds away from the Mackenzie Basin.

Sectors 5-7 experience the actual decline in the LOG scenario. Here, the real value of total output drops by 0.55% annually. This decline is founded upon a scenario of general economic stagnation coupled with the split of the NWT into two autonomous regions. Governments accounted for 29% of all employment in the NWT in 1986 (Outcrop Ltd., 1990). A restructuring of the NWT government thus has significant implications for the economy of the Basin, where territorial offices and services are now concentrated. The net effect of this split is foreseen to imply a significant shift in the services industries out of the Basin.

A14.4.4 Scenario #3A Low Overall Growth Alternate Scenario

Due to the compound impacts of Scenario #3 - which projected a 30% decline over the time horizon of the MBIS study, an alternate scenario was developed, based on a 30% total drop in the trade sector only. This essentially allowed for four separate scenarios for the MBIS: high growth, moderate growth, minor decline and substantial decline. These scenarios were then used to drive the MRIO model as discussed in Section 4.3 of the Main Report.

Additional Sources

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A15. Methodologies For Integrated Assessment

Yongyuan Yin and Stewart Cohen, Canadian Climate Centre,

The potential threat of climatic change pertains to the need for the understanding of the processes and interactions among various biophysical and socio-economic systems. There are still large uncertainties surrounding current estimates of future climatic change and its effects on our society. Substantial gaps in knowledge about the economics and physical science of climatic change hinder the implementation of appropriate policy responses to greenhouse effects (Malone and Corell, 1989; Daly and Cobb, 1989).

The rationale to design methodologies to evaluate the adaptation options or policies to global warming is that research in the natural and social sciences have an important role in developing well designed adaptation strategies because it will provide the information and understanding of processes necessary to develop efficient response options to a changing climate, and better management plans for the sustainability of our life-support-system. It is recognized that the development of sound environmental policies for adaptation depends on the capability of the scientific research community to respond to increasingly specific demands for information from policy makers.

The complex and dynamic nature of the global warming issue requires the development and application of comprehensive and integrated analytical methods to represent functions and interactions of a wide range of components in economic and environmental systems. The analytical tools for studies of separate groups dealing with the physical and biological components of the MBIS are desirable for first- and second-order impact assessments. To provide a picture of global warming impacts for the region as a whole, an integrated impact assessment framework is needed to bring together these first- and second-order impacts of global warming and to take account of the interconnections among effects on various sectors of society.

What follows is a description of two activities concerned with developing methodologies for integrated assessment of the MBIS region: a) Socio-Economic Integration Project, and b) Integrated Land Assessment Framework (ILAF).

A15.1 Socio-Economic Integration Project

Steve Lonergan and Scott Prudham, U. Victoria

The socio-economic integration project is in its initial phases. We have been reviewing the issues which will determine the integration framework design criteria and constraints, as well as examining alternative approaches to integrating the various studies of the MBIS. This paper presents aspects of our progress to date, describes the critical issues, outlines the various impediments which remain, and establishes a strategy for further work. The paper is divided into four sections. The first of these consists of an explanation of the problems that the socio-economic integration project is meant to address. Here we outline our belief that to be comprehensive, the integration framework must address two distinct types of integration. The second provides a discussion of alternative information systems which could be applied to the MBIS for integrative purposes, including the strengths and weaknesses of each in this context. In the third section, we review selected integrated models as they pertain to the MBIS, and discuss the merits and demerits of symbolic modelling. The fourth section synthesises information from the first three and establishes our future strategy. It is important for all study participants to feel empowered to make suggestions and comments in helping to refine the integration methodology.

A15.1.1 Problem Development

The purpose of the integration framework is clear. Impact studies such as the MBIS require not only the investigation of the direct implications of future perturbation on each sector of the study, and an analysis of the associated policy implications, but also the indirect, additive and synergistic impacts of combined effects. These are effects which precipitate from cumulative change as well as from combinations of changes. Studying these effects identifies policy implications which cannot be ascertained in simple cause-and-effect studies.

In order to study such effects, it is important to establish some format to associate the results and even the undertaking of related studies. Five considerations are relevant to the establishment of integration framework design criteria and constraints:

1. *Topics* -different studies characteristically address different topics. This is the defining characteristic of a study such as the MBIS . However, multiple studies may address the same subjects using different methodologies and assumptions.
2. *Information Quality* -the integrity of data is a major concern. However, the exchange of data between studies makes this a particularly sensitive issue.
3. *Dynamics* -the integration framework must conform to the time horizon of the MBIS, and can be either transitory or static.
4. *Spatial Scale* -some studies may focus on different regions at similar levels of resolution. Others may operate at very different spatial resolutions.
5. *Metrics* -a variety of metrics will be used among the various studies. The use of a single metric analytical framework under these circumstances has serious conceptual implications.

An interdisciplinary project like the MBIS by nature addresses a broad spectrum of specific issues. Nevertheless, the integration model must integrate the various studies by facilitating the identification and investigation of linkages. For example, forestry and agriculture studies are linked by potential conflicts in land use. The integration framework will be required to make explicit such links and to contribute to the resolution of contradictions. It is also possible for the same theme to be treated differently by separate studies. For example, two studies may forecast future rates of timber harvest, one based on revenue maximisation in the forest industry, and the other based on harvest at the maximum sustainable yield. Since these forecasts are likely to be dissimilar, the integration framework must include some mechanism for addressing any resulting disparities, even if this entails the simple comparison of results.

Information quality is a particular concern in an interdisciplinary study where data exchange is involved. Studies cooperating independently of the integration framework will have to address this issue for their purposes, however some consideration of information quality as the issue applies to the integration framework is in order, since the framework quality will be determined by the quality of the weakest data source. Systems and standards for describing and maintaining data quality exist, notably in statistical applications where accuracy can be assessed (e.g. significant digits, variation, correlation, etc.), however some of these are specific to the disciplines from which they have emerged (e.g. see Fylese, et. al. 1992). While it is unreasonable at this juncture to expect the design and implementation of a set of standards for describing information quality, individual study participants can further the integration project by providing assessments of information accuracy and reliability. This is true of qualitative as well as quantitative data.

Because climate change is a long term issue, the MBIS has a relatively distant time horizon. This time horizon must be mirrored by the integration framework, calling into question the issue of dynamics. The integration framework will be required to report on present and future relationships across sectors. If these relationships change over time, a highly probable circumstance, then the system will have to incorporate a dynamic component. The nature of this dynamic component is a determinant of the system complexity, since continuous relationships are generally more mathematically and conceptually demanding. At the opposite end of the spectrum is a comparatively static system whose dynamics consist of beginning and ending snapshots of present and future relationships, for example, two sets of input-output style technical coefficients.

As outlined above, the spatial variation of individual studies is a potential impediment to full integration. There are essentially two generic types of variation. The first is locational in that studies will examine various sub-regions of the Basin. This is an issue confronting integration of individual studies if the information and results stemming from the studies cannot be generalised. The second type of variation is in spatial scale. While some studies (e.g. changing fish habitat volumes in Great Bear Lake) address relatively large scale issues which may be difficult to aggregate to the Basin level or even to the level of the five political sub-regions of the Basin, others (e.g. forestry) are comparatively coarse in resolution and may not lend themselves easily to disaggregation. Geocoding data is a first step toward resolving this dilemma, however it is unreasonable to expect fully geocoded socio-economic information.

The fifth major consideration is the choice of metrics for the integration system. The individual studies will employ a variety of metrics in their data sets; integrating these can pose considerable difficulties. Information from the integration projects of the MBIS could and should be a focal point for the marriage of scientific and traditional knowledge. The challenge is essentially twofold. First, the MBIS projects are predominantly quantitative, yet information on traditional knowledge will be largely qualitative. The gap between these needs bridging. Second, by definition, scientists from outside the Basin will share different perspectives and imperatives from those of local people. The essence of a traditional knowledge component is finding common ground. Shaping the integration methodology to suit concerns raised through the traditional knowledge projects will be an ongoing, organic process, about which little can be stated at this point. However, actually combining qualitative data with quantitative data is a special case of the mixed metric problem, to which there are no easy solutions (see Lonergan and Prudham, 1992).

There are essentially two dichotomous choices for integrating information in different metrics. The first is to employ an analytical framework which allows the use of different metrics. Ultimately, any comprehensive integration system must exhibit this characteristic to some degree since no single metric can capture the full range of information that will emerge from the MBIS projects. The goal programming methodology to be employed in the ILAF by Yin and Cohen (Section A15.2) is an example of this approach to integration. The cost of maintaining disparate metrics is that functional relationships are sometimes difficult to compare, reducing the analytical flexibility and power of the system. The alternative extreme is to unify all information possible using a single metric. Monetary and energetic analysis are the options. The advantage of employing a single metric lies in the augmented flexibility and analytical capability of the system, with a particular advantage of monetary analysis being that the results carry broad heuristic power. The costs are mainly associated with the loss of information quality and the special problems of transforming relationships into those meaningful to the system --for example, describing the monetary flows generated by a day of hunting.

Two Types of Integration

Consideration of all factors suggests that, conceptually at least, we need to address two types of integration. The first type of integration addresses the problem of bringing the information from individual studies under an umbrella framework for standardised description and storage. This type of integration must address the problems presented by mixed metrics, spatial scales and themes. It is important to construct a database which will store and present information in standardised fashion if subsequent analysis is to be undertaken and if MBIS individual project results are to be made widely accessible; access to MBIS information bases by Basin residents is a consideration. The second type of integration addresses the central purpose of the integration project; analyzing multi-disciplinary data in order to study the impacts of combined effects. Even though both types of integration may be addressed under a single integration system, it is useful to separate the two conceptually, since the first type is inherently more comprehensive and less restrictive. It is reasonable to expect that more of the MBIS projects can be linked through the assimilation of their diverse information into a common format than can reasonably be addressed in a detailed, multi-disciplinary, analytical context. The majority of our research to date has addressed the first type of integration in order to devise a format for information reporting at IW2. However, some consideration has been given to analytical integration inasmuch as both types of integration may be addressed entirely or in part by a single information system.

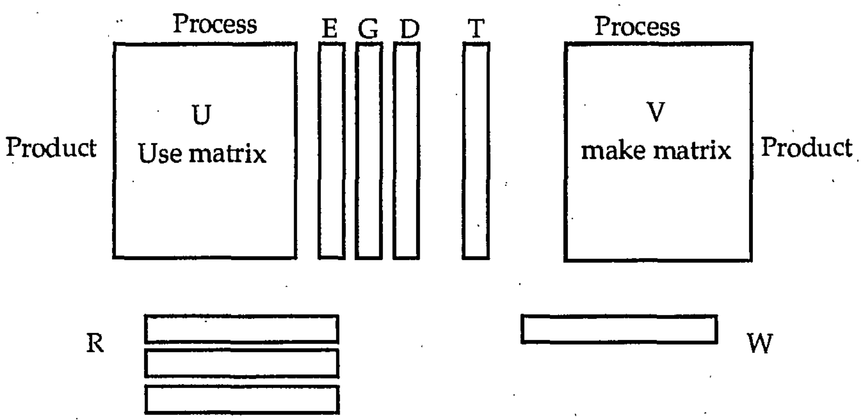
A15.1.2 Information System Review

Information systems have the potential to act as overall umbrella frameworks for integrating information from the various projects. Three such systems are discussed briefly below. These include:

1. The Ecological Accounting System of Hannon and others (Hannon, 1991; Hannon et. al. 1991);
2. The STress Response Environmental Statistical System (STRESS) of Statistics Canada (Rapport and Friend, 1979); and
3. Natural Resource Accounting, primarily the regional design devised at the Centre for Sustainable Regional Development (CSRD -- Prudham and Lonergan, 1992; Prudham, 1992).

Each is given a short conceptual review, assessed in terms of its strengths and weaknesses as an information system, and compared on the basis of its potential extension to analytical work.

Figure A15.1. An Ecological Accounting System Source: Adapted from Hannon et.. al.., 1991



E - Net Export Vector
G - Net Growth Vector
D - Depreciation Vector
T - Total Output Vector
R - Non-Produced Inputs Matrix
W - Waste Heat vector

A15.1.2.1 Ecological Accounting

Figure A15.1 depicts the structure of an ecological accounting system designed by Hannon and others (Hannon, 1991; Hannon et. al., 1991). The system is structurally derivative of a commodity-by-industry input-output model. In the I/O model, flows of economic commodities to economic industries are described in the Use matrix, while the production of commodities by industries is described in the Make matrix. In the ecological accounting system, ecological commodities are shown flowing from ecological processes in a similar Make matrix (V), while the use of ecological products by processes is presented in the Use matrix (U). Vectors **e**, **g** and **d** represent respectively, net export from the system[1], net growth, and net depreciation. Vector **t** records total product output, the matrix R describes the flow of non-produced inputs to the processes of the system, and the vector **w** describes the flow of waste heat from processes. The balance across the accounting system is described in (1).

(1) $$\sum_j U_{ij} + E_i + G_i + D_i = \sum_j V_{ij}, \forall i$$

While the system is based in principle upon I/O methods, there are several points of departure. Notably, the description of ecosystem flows is recorded in mixed units, each appropriate to the measurement at hand. This allows row sums, but renders column sums nonsensical. Only subsequent analysis of flows as intensities in terms of a single non-produced input makes the system fully operational from an analytical standpoint (Hannon et. al. 1991; Costanza and Hannon, 1989). Hannon et. al. (1991) cite the potential for the system to act as a precursor for subsequent analysis as being among its most significant assets. Conceptually, systems such as this are extremely powerful analytically when detailed knowledge of ecological processes is at hand and when all flows can be described in terms of their direct and indirect dependence on a single non-produced input. Once this information is known, the system can be expanded to include ecological flows, ultimately approaching systems such as that described by Daly (1968). The difficulty is that detailed ecological information of this type and scope is extremely rare. In addition, if the linear assumption and the use of average production functions (versus marginal values) are problematic in purely economic applications, they are at least equally so in analytical uses of ecological I/O. However, Hannon et. al. (1991, p100) assert that the precursor to analysis is "...the existence of a consistent data format like the proposed accounting system" much as we have pointed out above. For example, the system format lends itself well to the study of ecosystems using optimization methods over short time horizons.

A15.1.2.2 STRESS

The STress Response Environmental Statistical System is a design for an environmental information database stemming in large part from the failure of previous and contemporary systems. The objective underlying the STRESS is to describe the interplay between human social processes and those of the biotic and abiotic environment in a way that is conceptually sound from public policy and scientific standpoints. The system differs from its precursors and contemporaries in that the spatial definition of statistical areas is prescribed as being at least partially based on ecological criteria, and in that description of environmental statistics is based upon some functional understanding of ecological process, as opposed to the simple division of the environment into air, land, water and noise categories[2] (Rapport and Friend, 1979).

Thematic organisation of environmental statistics is based upon (largely) anthropogenic stresses and associated responses. Stressors are defined as the activities and processes of social and environmental systems which pose threats to environmental quality, human health, species survival, non-renewable resource stocks and human settlements (Rapport and Friend, 1979, p78). These are

[1] The system is defined as an ecosystem whose boundaries are specified by the user (Hannon, 1991)

[2] Biota should really be listed here too, but is not listed in Rapport and Friend (1979).

considered to be the independent variables from which response arises. Stress elements form a sub-class of stressors whose targets are known. Responses are divided into environmental (direct and indirect), and collective and individual responses. Environmental responses are the "...observed effects of stress upon natural and man-made (sic) environments" (p79), while collective and individual responses are human in origin.

There is considerably more structural detail to the STRESS as described by Friend and Rapport (1979) than is presented here. What makes the system of interest for the present discussion is the conceptual appeal underlying the organisation of environmental statistics. In as much as the MBIS is a study aimed at identifying the impacts of a particular stressor (i.e. increased concentrations of atmospheric trace gases), the organisation of information in the integration framework following a similar organisational concept is possible. The association of individual projects in the MBIS would then arise from analysis of particular environmental responses to climate change stress, along with related collective and individual responses. Integration takes place under the STRESS by thematically linking biophysical and socio-economic data, and by identifying groups of related response mechanisms for further study.

While the STRESS is an appealing framework within which to organise data for the MBIS, it is not without its drawbacks. The first of these is inherent to the STRESS and relates to the simplification of environmental perturbations under anthropogenic stress to a near cause-and-effect conception. This does not lend itself well to the analysis of combined and indirect effects. While this weakness could be addressed, it would likely necessitate a revision of the STRESS structure for information storage and reporting. A second important drawback is that the STRESS has no internal analytical capacity. Thus it does not lend itself well to the second type of integration described above.

A15.1.2.3 Natural Resource Accounting

Natural resource accounting is an approach to describing connections between economic and ecological systems in a standardised format. Resource accounting systems balance the objectives of supplying systematic information on the availability and use of natural resources (in physical terms), and of supplementing the macro-economic accounts of the SNA (System of National Accounts) with monetary estimates of resource stocks and flows. The latter objective has been particularly emphasised recently, as attempts are made to calculate the contribution of resource depletion to what has traditionally been considered economic growth (see Repetto et. al., 1989; Foy, 1991; and Solorzano et. al. 1992 for case studies and methodological discussions).

Table A15.1 Format of a central account

Class	Opening Stock	Recruitment	Additions	Harvesting	Other Losses	Closing Stock
A						
A_1						
A_2						
•						
•						
Zn						
Total						

Accounting systems vary considerably in structure and scope, but must all rely on sound baseline biophysical information. A common element of many systems is their use of core physical accounts describing the stocks and aggregate flows of resources, sometimes broken down into sub-classes. The French patrimony system of accounts employs this format in what are called equilibrium accounts, while at the CSRD we use the term central accounts to reflect their pivotal role in constructing the overall system. An example of a central account is provided in Table A15.1. This type of account is the basic building block for each resource. For example, the central account in Table A15.1 could contain the basic statistics on changes in timber stocks in a given period. The individual classes listed down the left column represent species of timber, which can be further broken down by age or economic categories. Columns can be added or deleted in individual cases, but generally describe the processes of aggregate additions and subtractions from resource stocks. An identity across each row in Table A15.1 is described in equation 2,

$$(2) \qquad OS+R+A+H+L+CS$$

where OS is opening stock, R is recruitment, A is additions, H is harvesting, L is loss or adjustment (based on revisions, catastrophic loss or changing economic conditions)[1], and CS is the closing stock. Information specifying user groups as well as the monetary value of resource stocks and flows can be contained in the same account as the baseline information, or can be presented in a number of different types of accounts[2], as is usually the case with more comprehensive resource accounting systems.

The accounting system that we have been working on at the CSRD (Prudham and Lonergan, 1992; Prudham, 1992) deviates from most in that it is regionally oriented. The original framework was designed for application in watershed agglomerations on Vancouver Island. Although there is little about the structure of any resource accounting system that precludes use at a variety of spatial levels, emphasising regional application brings to the fore the issue of regional resource sustainability, facilitates a more coherent biophysical approach and tends to allow the system to be more easily decoupled from national and provincial level economic accounts.

The emphasis of regional applications in our own system makes it well suited for use as an information system for the integration component of the MBIS. Our familiarity with this system adds to its allure. Resource accounts in general are attractive as databases for environmental information because of their familiar structure and conceptual simplicity. Also, resource accounts form a natural bridge between environmental and socio-economic systems by emphasising resource themes. Resource accounts are a first step toward identifying links of the social and economic systems of the Basin with biophysical parameters, since the decision to compile a resource account on a given theme is premised by a recognition of that theme as important to social and economic functioning. An added strength of a resource accounting approach is that no restrictions are placed on the use of multiple metrics in the accounts as long as central accounts are individually unified. It is possible to apply later monetary or energy analysis to groups of resource flows. In general, resource accounts are well suited for subsequent economic analysis --where market or market surrogate values are available-- through the establishment of monetary satellite accounts which can supplement standard economic accounts and macro-indicators. A final strength of the resource accounting approach is that it is structurally compatible with the Ecological Accounting system described above, offering the potential to combine the two.

A resource accounting system is not without its drawbacks. Like the STRESS and the raw transaction matrices of the ecological accounting system, resource accounts in physical units have no internal analytical capability. They are best viewed as pre-cursors to later work. It may be that no system can satisfactorily combine the types of integration we have described; certainly the links

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[1] Depending on data availability, separating these categories are separable in to distinct columns. This Table represents a generic structure for a central account. Revisions to the structure can be quite significant for environmental quality accounts and for ecosystem accounts. See Prudham, 1992.

[2] At the CSRD, for example, our regional accounting system includes user and valuation accounts as well as a facet of the system which allows for the analysis of inter-relationships between resources.

between the two remain to be resolved. An additional shortcoming of a resource accounting framework is that the effort required to supply data for an intricate system may not be warranted. This depends critically on the ultimate objectives we have for the overall integration system, and particularly on the role of the information system as a planning tool for resource and environmental management in the Basin.

A15.1.3 Models

As earlier specified, we have spent the majority of our research effort thus far on problem development and on surveying existing information system designs for the overall integration aspect of the project. We have, however, touched upon some specific models which may be considered for use in more analytical integration. Nearly all of the models we have examined are ecological-economic ones. This is because of several considerations. First, ecological-economic models are by definition interdisciplinary. Second, ecological-economic models address the interface between ecological and economic systems in a formal capacity. Specifically, Braat and van Lierop (1987, p49) give the following definition:

> ...economic-ecological models are those that are capable of assessing the relevant impacts of the socio-economic activities on ecosystems, as well as the relevant effects of the state and development of ecological systems on socio-economic activity. In a structural sense, economic-ecological models are models in which both the economic and ecological phenomena relevant to a particular problem, as well as the relationships between socio-economic activities and ecological processes essential to the problem are included...

The MBIS integration project is served well by this approach to modelling since we seek to assess the interlinkages between biophysical and socio-economic phenomena under climate change. A third consideration is that ecological-economics can be characterised by a world view placing the economy inside the ecosystem. We find this concept appealing as a reference base for integration.

Our review of ecological-economic models has been limited, and has concentrated on two groups of models. The first is characterised by the use of network analysis, where model structures are derivative of the input-output approach. The second is characterised by a more dynamic approach, involving detailed analysis of single or multiple resource systems.

Flow or network analysis incorporating ecosystems was first proposed by Hannon (1973) as a means of modelling ecological energy balances. His system was based on the ecosystem as a set of processes exchanging matter and energy. Since this model, considerable effort has been directed at developing a theoretical basis for dealing with the "mixed units"problem. Single metric analysis of ecosystem flows is usually undertaken using solar input as the ultimate, single non-produced input. All flows are then expressed in terms of their direct and indirect dependence on solar energy (see Costanza and Hannon, 1989).

Costanza and Neill (1984) adopt this idea, but approach the problem using linear programming. A system of equations, represented in matrix notation in equation (3),

$$AX = Y = BX \quad (3)$$

is established on the premise that the intermediate input of all commodities to a process plus final demand must balance the total output of all commodities by that process. A is an mxn matrix of commodity "technical co-efficients" of material exchange, X is an nx1 total activity vector, Y is an mx1 "final demand" vector, and B is a mxn matrix of process specific "technical co-efficients". The authors relax two assumptions about I/O in order to present the problem as a linear programming application, solving the dual problem for shadow prices of final demand in energy units. The two constraints relaxed are (i) the fixed technology assumption, wherein each output is assumed to have a unique technological make-up and (ii) the single commodity output assumption. The LP framework is characterised as:

Primal Problem - Minimize

$$P = EX \quad (4)$$

s.t.

$$(B - A)X \geq Y \quad (5)$$

and

$$X \neq \theta \quad (6)$$

Dual Problem -Maximize

$$P' = eY \quad (7)$$

s.t.

$$e(B - A) \leq E \quad (8)$$

Where:

P is the value of the primary objective function, in this case measured in energy units,
P' is the value of the Dual objective,
B is the mxn matrix of output coefficients,
A is the mxn matrix of input coefficients,
Y is the net export vector (mx1),
E is the vector of primary energy inputs to the system (1xn), and
e is the 1xn vector of commodity energy intensities

Ulanowicz (1991) also uses network analysis to evaluate the shadow values associated with each transaction in the ecosystem.

These systems are useful for describing ecosystem flows in a systematic fashion and are well suited for integrated economic-ecological modelling. In fact, Costanza (1980; Costanza and Herendeen, 1984) has applied embodied energy analysis to economic systems. A commonly cited drawback in ecological applications of network analysis is the immense data requirement. In addition, assumptions of fixed linear relationships can be very restricting.

The second group of models we have touched upon is unified by a more dynamic approach. These models range widely in complexity and scope. The general approach is to specify a set of dynamic equations which model the behaviour of resource systems over time. Two way linkage between economic and ecological parameters adds conceptual depth to the models. Clark (1987) provides a basic example of this type of model as applied to the Antarctic whale industry. The model is a non-linear optimization based upon maximising equation (9) by manipulating Effort (E_t) and Investment (I_t).

$$\int_0^\infty e^{-rt}(pH_t - c_1E_t - c_2I_t)dt \quad (9$$

where r is the discount rate, t is time in years, p is the price of the harvest, H_t is the harvest in year t, c_1 is the cost of effort and c_2 is the cost of investment. Single sector models like these are more useful for management applications (Clark, 1989) than for purposes such as ours. However, the expansion of dynamic models to include multiple sectors begins to approach what we will require from our analytical integration. It is also possible, in theory, to add social variables (see van den Bergh and Nijkamp, 1989). The difficulty with added scope and detail is augmented mathematical complexity, demanding more and more effort per unit of useful output from the model. Also, data availability can be a problem, especially for information that is difficult to quantify (e.g. traditional knowledge). We will continue to review more models of these and other types in concert with our evolving ideas about MBIS integration.

A15.1.4 Conclusion and Future Strategy

As yet we have not settled on a final system for integrating the various components of the MBIS into a meaningful socio-economic information system. We have arrived at a more refined basis upon which to select from a number of options, and have differentiated two types of integration that need to be addressed; one largely entails the design of an information system; the other is more analytical. Options for the information system include Ecological Accounting as described by Hannon et. al. (1991), a modified STRESS, and a natural resource accounting framework similar to the regional system designed at the CSRD (Prudham and Lonergan, 1992; Prudham, 1992). We need to further evaluate the various strengths and weaknesses of these systems, particularly as they apply to the individual studies. We must also give some consideration to the relationship between this integration project and the activities outlined by Yin and Cohen (Section A15.2). There may be areas of potential collaboration and data exchange. This is particularly so if we can forge a relationship between the spatial database that is to be built and the information collected for the overall integration system. While the two integration projects are independent of one another, common themes may emerge (e.g. land use conflicts) which would encourage methodological discussion and data standardisation.

Our recommendation to the MBIS participants is that information be submitted in the form of central accounts as described in Table A15.1. Individual applications of the format will need to be structurally adjusted. We are available for consultation. The advantages of adhering to this format are twofold. First, the structure is flexible and conceptually simple, allowing subsequent alterations to fit specific database requirements. Also, the system structurally reinforces the description of biophysical parameters as resources. Some information will be largely irrelevant in this regard, however difficulties in conforming to the structure of the accounts in reporting information should be a first indicator that the information is not well suited for a socio-economically oriented database. We do encourage all participants to consider all possible connections between their studies and the socio-economic systems of the Basin. We further suggest that participants submit information on user groups for resource flows, material or service in nature. By user groups, we refer to the beneficiaries and controllers of environmental services and material resources. This covers a spectrum of user groups defined by their common relationship to a natural resource, be it an airshed, annual petroleum shipments from the Basin (or sub-region), or the rights of access or tenure to a forestry management unit: broadly, those who use resources. We will work with participants on standardising this information.

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A15.2 Integrated Land Assessment Framework

Yongyuan Yin and Stewart Cohen, Canadian Climate Centre

A15.2.1 Introduction

The overall objective of this research project is to design and apply an integrated land assessment framework (ILAF) which will provide holistic analysis of projected global warming and policy response in the Mackenzie Basin. In particular, the analytical framework will integrate major results of the individual studies from the physical, biological, and socio-economic components of MBIS and identify the regional economic-environmental impacts of climatic change. The research framework will consist of three distinct techniques: a remote sensing image processing technology, a geographical information system (GIS), and multiple criteria analysis models. The three analytical systems are linked together to form the ILAF. Application of the ILAF system in the Mackenzie Basin will demonstrate the capability and flexibility of the analytical system for regional impact assessment of climatic change.

A15.2.2 The Conceptual Research Framework

An integrated approach for impact assessment of global warming and its responses possesses certain fundamental characteristics. According to the major purposes of MBIS, this study proposes the following set of guidelines, which highlights a group of crucial attributes to be considered in an integrated impact assessment, as criteria in developing analytical methodology. The integrated approach should be a) able to ensure public participation, b) systematic and comprehensive, c) multiple objective and multiple sector, d) able to easily identify trade-offs, and e) able to provide more coordination in a new modelling research area.

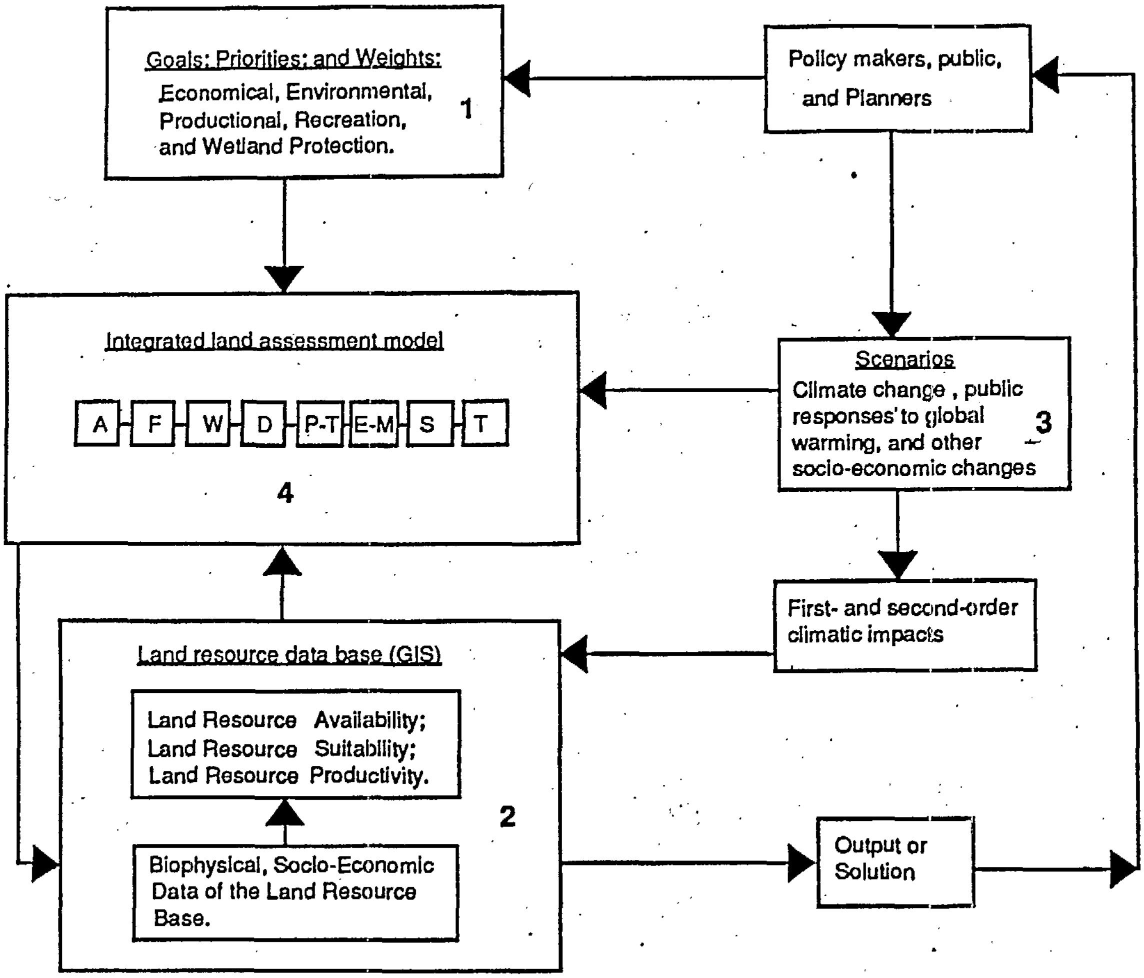
Based on the criteria described above, an integrated research framework is developed for the regional impact assessment of the MBIS. The main elements of the framework are illustrated in Figure A15.2. The procedures of the analysis are mainly composed of four components: goal setting, data base and spatial unit, scenario development, and assessment system.

A15.2.2.1 Setting Goals

The procedure begins with an identification of goals. Land resource development goals are diverse. They represent the preferences of various interest groups. These goals might include: (1) ensuring adequate resource production to meet future needs; (2) maximizing economic benefits or minimizing costs; (3) conservation of resources and protection of environmental quality; and (4) others.

The possible future impacts of projected global warming or response policies must be evaluated by relating various impacts to a number of relevant evaluation criteria. In this study, goals are evaluation criteria or standards by which the effects of climatic change or/and the efficiency of alternative adaptation options can be measured. Goals represent evaluative rules on some dimensions of concerns to interest groups and in turn to the governments who seek response options to global warming through a structured decision making process. With these specific goals, the effects of an adaptation option or a public policy in terms of progression toward or regression from these goals can be examined. In other instances, the environmental and economic impacts of projected climatic change can be identified.

Figure A15.2 Research framework



Research Framework

Note:

A: Agriculture
F: Forestry
W: Wildlife
D: Defence
P-T: Parks-Tourism
E-M: Energy-Mines
S: Settlements
T: Transportation

A15.2.2.2 Data Base and Spatial Unit

Information is required on the quantity, quality, and distribution of the land resource base. A long time series of data on resource systems is very important to this study. Various impact results of the first- and second-order impact analyses of the MBIS will be used as inputs for the integrated impact assessment. Remote sensing processing technology will be adopted to extract, enhance, and classify satellite images and to input the processed information into a geographic information system (GIS). The GIS will also incorporate other existing data sets. The GIS will perform efficient storage, retrieval, and manipulation of spatial data, and will meet the following objectives:

a. to be suitable for climatic impact assessment at various geographical scales;

b. to utilize data collected and compiled from various studies of single sectors, as well as other sources;

c. to be flexible and efficient, with ease of operator use.

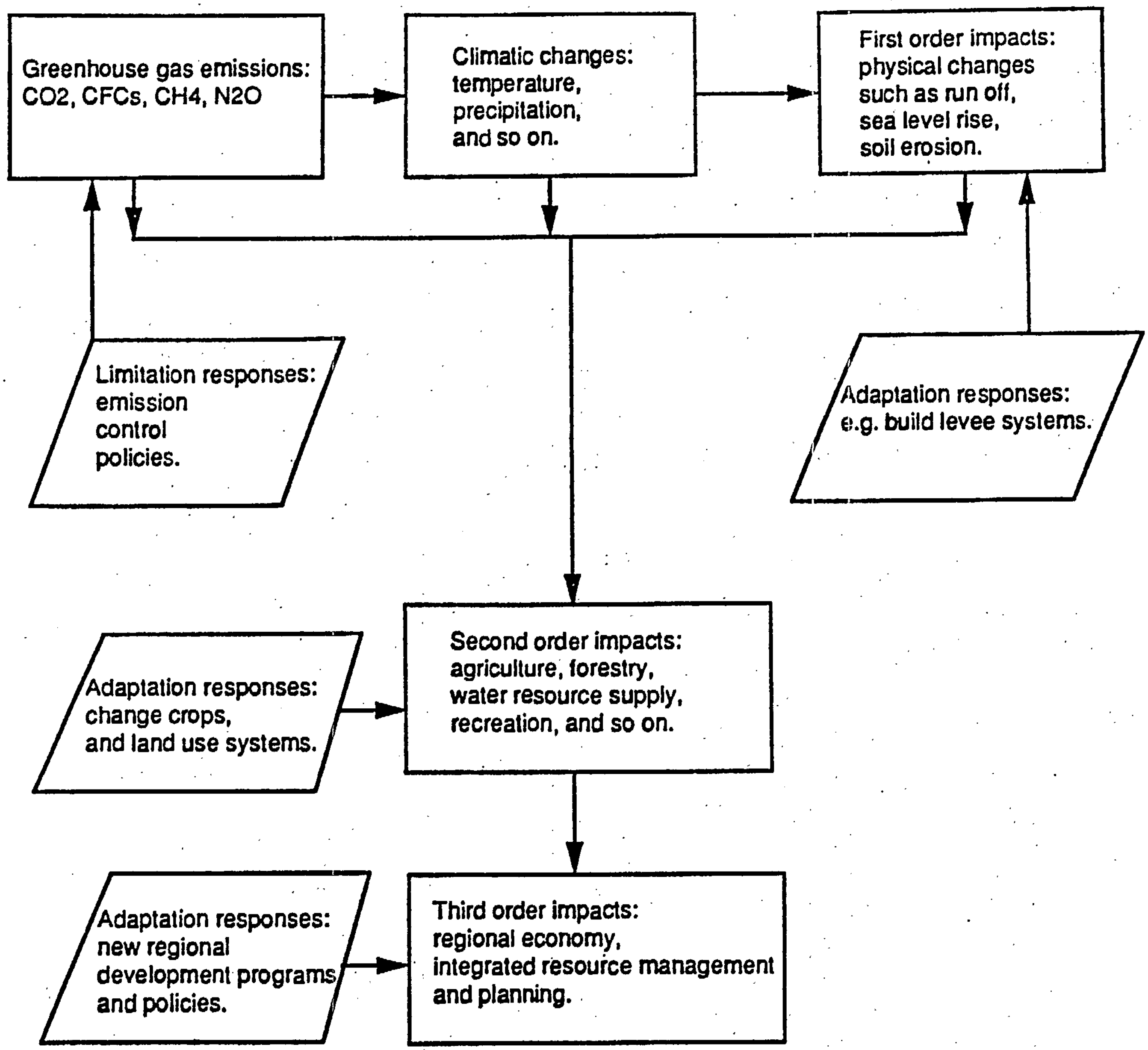
The Mackenzie Basin has a range of subregions varying in terms of resource availability, suitability, and productivity. One important step of the study is to choose a suitable spatial framework which is the basic unit for analysis. Spatial units should be relatively homogeneous with respect to the biophysical, social, and economic conditions. However, the spatial scales adopted for climatic impact study are usually larger than scales traditionally used by ecologists and environmental scientists.

A15.2.2.3 Scenario Design

One of the distinctive features of the research framework is the emphasis placed on design of meaningful scenarios representing different climatic change perspectives, future social and economic conditions, and response options or policies. These scenarios will be translated into the model's structure to examine their economic-environmental implications. In this study, three types of scenarios will be developed and investigated: climatic change, socio-economic changes such as population and economic growth, and response options. Regional climate and socio-economic change scenarios are discussed in Chapters A13 and A14.

Figure A15.3 shows the possible types of public responses available to deal with global warming. Basically, these responses can be grouped in two categories: adaptation and limitation. Adaptation seeks to lower the negative consequences of global warming. Anticipatory adaptation involves actions taken in advance of projected warming. Examples include development of new plant strains suitable under the changed climate, and land use planning to keep new construction away from areas that may be inundated by sea-level rise. Limitation is aimed at reducing net emissions of greenhouse gases to contain future climatic warming below certain levels. Various policy options can be taken either by reducing sources of greenhouse gases (e.g. reducing the burning of fossil fuels or the use of CFCs) or by increasing the sinks of these gases (e.g. protecting the wetlands and reforestation). Scenario analysis can deal with alternative response policies to. An integration workshop was held to discuss major policy issues related to global warming, and to produce a detailed framework that tightly integrates the various components of the MBIS. Horizontal and vertical integration matrices were presented at the integration meeting for scientists from various disciplines and representatives of different interest groups to produce descriptions of all the information which needs to be exchanged among projects. Key policy issues and linkages of the major components of the MBIS were defined in the workshop. More detailed information about the integration sub-committee and the integration workshop is presented in Chapter 2.

Figure A15.3 Climatic change and public responses (adapted from Warrick et al., 1988).



A15.2.3 Study Area, Land Use Activities, and Resource Sectors

The integrated assessment covers the whole basin, but due to time and resource constraints, the study will focus on five critical zones: (1) Mackenzie Delta-Tuktoyaktuk; (2) Mackenzie River-Fort Good Hope-Norman Wells-Fort Simpson-Hay River; (3) Liard River; (4) Peace River; and (5) Northeast Alberta-Fort McMurray-Peace-Athabasca Delta (Figure A15.4). These were chosen by the MBIS Working Committee.

Figure A15.4 Mackenzie Basin critical regions

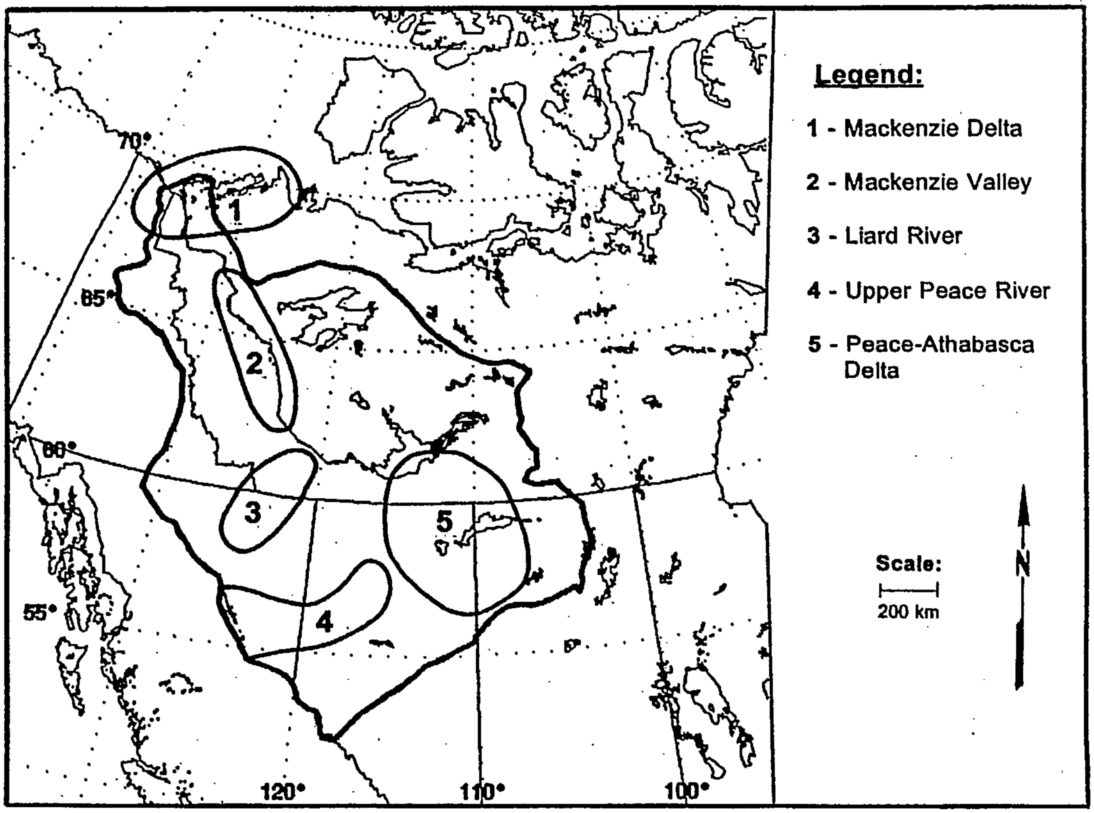


Table A15.2 Land bases and land use activities

Land Bases				
Improved	Woodland	Wetland	River & Lake	Other
		(land use activities in various resource sectors)		
Agriculture	Forestry	Wetland	Fishery & Transportation	Other Sectors
Wheat Oat Barley Canola Hay Summer-Fallow	Spruce Pine Deciduous Park Habitat	Status Quo Enhancement Park	Fishing River Transportation Other	Mining Defense Other

Resource sectors whose activities are sensitive to climate and whose decisions have outcomes stretching over long time periods are selected for the MBIS study. The information will be sorted into land bases and activities (Table A15.2). Land use activities considered for the agricultural sector may include wheat, barley, oats, canola, hay, and summer-fallow. These crops and forage may be grown in land units suitable for agricultural production. The activities in the forest sector may include timber production, ungulate habitat, and recreation use. In the wetland sector, different management alternatives are defined on the basis of wetland management intensity. Other activities in mineral, transportation, and defence sectors may also be included in the model.

A15.2.4 Setting Goals, Targets, Priorities, and Thresholds

One important procedure of the ILAF is to set goals, targets for goals, priorities, and thresholds. It is assumed in this study that a set of goals are ranked in order of importance on an ordinal scale, such as 'most important' or first priority, 'next most important' or second priority, and so on. This is also named lexicographic ordering of goals, which reflects decision making in the real world (Ignizio, 1982). In addition, a target level or achievement level is assigned to each goal. Priority rank and target level represent the decision maker's preference and aspiration respectively for a set of goals.

In model solving, GP operates by minimizing the deviation from the target levels of various goals (Romero and Rehman 1987).

Moreover, minimal values or thresholds for different goals or criteria can be established to ensure that critical, sensitive factors are achieved before a response option can be considered as 'acceptable'.

These goals, targets, and priorities are being developed throughout the course of the study. The goals are based on the MBIS ongoing consultations with the study's ultimate recipients (i.e. aboriginal and other residents of the region, private sector, governments responsible for natural resource management, and other policy makers).

Much of the work required to identify general concerns and goals has been done through several Working Committee Workshops. An example of the effort expended in the goal investigations was the integration workshop which was held at the end of February, 1992. This workshop, with the assembled scientific expertise, community representatives, and policy planners, sought to identify various policy issues which can be used to identify regional development goals, so as to facilitate the measurement of these goals. The identification of assessment goals, criteria, and endpoints is necessary to ensure that the outputs of this study represent truly the concerns of various 'stake holders'.

The workshop provided a forum for senior decision makers in the Basin to discuss major regional policy issues related to global warming. These policy concerns were used as a guideline for a goal interview which was conducted in order to improve the reliability of the information derived from the literature review and to obtain opinion from local representatives. The interviews were conducted with approximately 50 people, including study participants, planners, and native residents in the region, who were representatives of various interest groups.

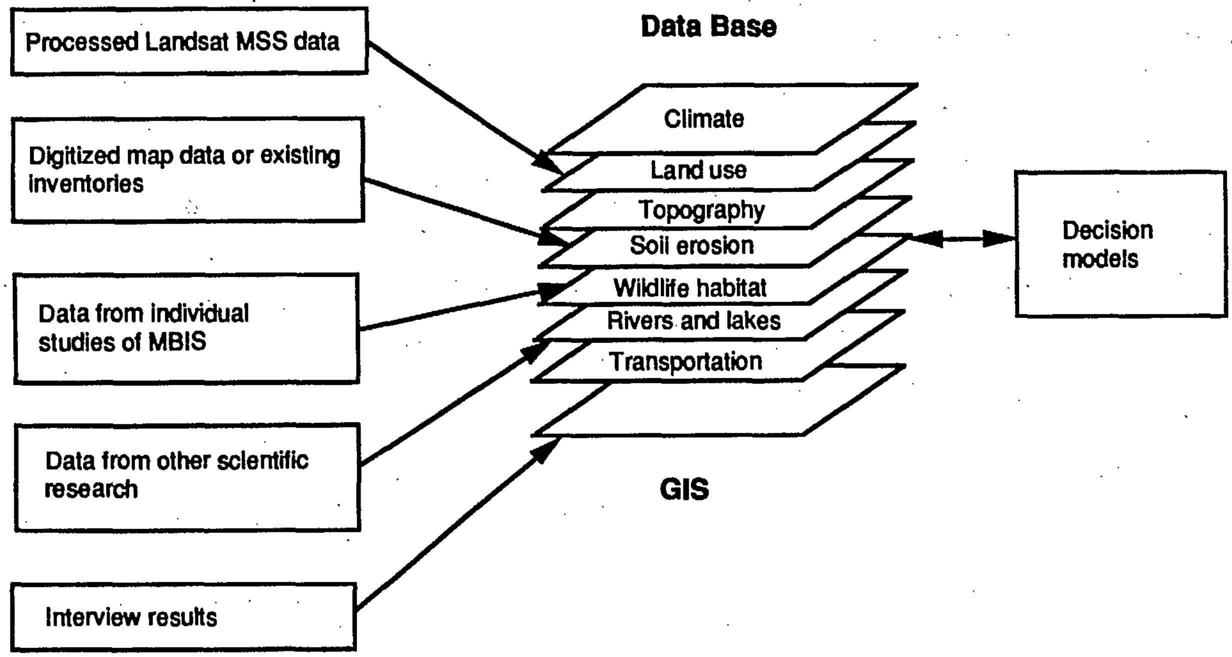
A multi-criteria decision making (MCDM) technique, the analytic hierarchy process (AHP) developed by Saaty (1980), was used to facilitate the survey. In conducting the AHP with the aid of a number of structured questions and goal matrices, individuals were asked to rank a set of goals in order of relative importance and to relate each goal to an acceptable target level so that each goal could be expressed in the form of an achievement level. The survey and AHP analysis provided information on policy concerns, goal priorities, and goal targets of regional resource development.

A questionnaire was distributed and explained during each interview. From the 50 interviews, 25 responses to the questionnaire were received from the upper Peace River region (Alberta and B.C.), Edmonton, Norman Wells, Inuvik and Tuktoyaktuk. We are working to expand the sample size, and expect to conduct additional interviews at other locations during 1993.

A15.2.5 Data Base for the ILAF Study

It is apparent that large data sets containing geographically or spatially referenced data are required to parameterize and validate models for climatic change impact assessment. The collection of enormous volumes of detailed, diverse data which incorporate various data sets from different government departments, interest groups, and scientific research, is a prerequisite for the integrated land assessment of the MBIS. Information about natural resources, land and water uses, and response alternatives in the Mackenzie Basin may be available from a wide range of sources. However, comprehensive data bases with a wide array of categories are uncommon. Data required for the integrated impact assessment comes from several sources including: existing data; results of individual impact studies of the MBIS; calculation results of simulation models; interviews and workshops; and remote sensing imagery.

Figure A15.5 Structure of the computer based analytical system



All the data from different sources will then be incorporated into a SPANS geographic information system (GIS) for this study. Figure A15.5 shows the information flow in the integrated study. Digitized soil maps, elevation maps, and other resource maps will be imported into the SPANS. Other existing data derived from literature and reports will be transferred into the GIS.

Digitized soil maps, elevation maps, and other resource maps will be imported into the SPANS GIS. Other existing data derived from literature and reports will also be transferred into the GIS. Many studies have indicated that a global warming could have significant impacts on farms, forests, rivers, lakes, fish, wildlife, and many other aspects of our society. One critical source of information for the integrated impact study is the impact results of various individual research projects on impacts of climatic change upon physical, biological, and economic components of MBIS. The impact results will be used to calculate the integrated impacts of climatic change and to evaluate alternative response options or policies to global warming.

Some impacts of climatic change on certain aspects of the resource systems are not available from other individual projects of the MBIS. In these cases, impacts will be calculated in the integrated study by using some existing simulation models such as the Universal Soil Loss Equation (USLE) and sediment transport model. Workshops and interviews will provide additional information on goals, targets values, priorities, and possible response options.

Due to the huge geographical coverage of the Mackenzie Basin (about 18% of the land area of Canada), it is impossible to map the resource base and to detect up-to-date land use changes in reasonable detailed scales (e.g. 1:500,000 to 1:1,000,000). French (1986) and IGBP-DIS (1991) recommended that satellite imagery be investigated to provide information on surface variation, soil conditions, marine phytoplankton and sea ice distributions in global change studies. Data on resources, particularly land cover and use, change very rapidly under modern economic development. In order to capture change, and to obtain timely updated and comprehensive information about our resource base, remotely sensed imagery provides a useful source of data. The main applications of remote sensing in the Mackenzie Basin study will be to detect broad land cover and use, areas of forests, wetlands, open water, roads, and other land uses. NOAA Advanced Very High Resolution Radiometer (AVHRR) and Landsat's Multi Spectral Scanner and/or Thematic Mapper (MSS and/or TM) data will be used to map this region to provide baseline conditions and to monitor changes.

In this study, computer software technologies for satellite image processing will be adopted to extract, enhance, and classify digital images, and to input the processed information into a GIS system. Data from the AVHRR of the NOAA series of satellites will be used as the source to generate information on general land cover, land use change, and vegetation index. The AVHRR can provide near daily data acquisition for any given target. Associated with this are a 1.1-km ground resolution at nadir looking direction, five spectral channels ranging from visible, near infrared to thermal infrared, a $\pm$ 56° scanning range, and an approximately 2700-km swath width. The coverage, frequency, and spectral channels of AVHRRs are very suitable for the study of the whole Mackenzie Basin. However, the relatively low spatial resolution limits the capabilities of AVHRRs in capturing relatively fine details on the ground which are required for studies on the critical areas of the MBIS. For this reason, in several critical subregions of the Mackenzie Basin, the Landsat MSS and/or TM data, which have spatial resolutions of 80x80m and 30x30m respectively, will be used to generate finer land cover and use classes, and to identify land use change.

Considering the current land use dimensions in the Mackenzie Basin, and the purpose of this study, land resources in the study area will be classified into five groups: (1) farmland which is land availability for agriculture; (2) woodland denoting the area available for timber production, ungulate habitat, and other forest uses; (3) wetland which is land available for waterfowl habitat; (4) surface water (river and lake); and (5) built-up area. Maps of land use, land capability class, vegetation cover, wetland distribution, water and land transportation networks, and soil erosion and sediment representing current biophysical conditions of the region, will be generated for the study. Computer software technologies for image processing will be used to generate various maps.

A prototype study in the Peace River Subregion of British Columbia has been undertaken to test the capability and the suitability of the remote sensing technology and the GIS for data base establishment. The case study includes three steps: (i) collection of existing data for the case study from existing sources; (ii) processing remotely sensed data to generate land use classes; and (iii) using the processed remote sensing data and the existing data as input for the GIS to create a data base of the case study.

In the prototype case study, the Maximum Likelihood Decision Rule (MLDR), a supervised classifier, was used for image processing to generate land use classifications. Training sites were chosen for each land use class by cursor on the video display with reference to the 1985-86 Air Photo Maps and the Land Use Maps generated by the B.C. Standing Committee on Agriculture. The trained computer classifier learns the data characteristics (spectral signatures) of training areas of different land use classes and then uses these spectral signatures as criteria to delineate the remaining areas of the image. The output of the computer image process is a map of land use classification for the study region. The classified MSS data were then incorporated into the GIS system for this study.

The next phase of data base establishment will include the following steps: (i) all the AVHRR, MSS, and TM data will be processed, enhanced, and classified; (ii) the processed data will be input into the GIS to establish a data base representing base-line conditions; and (iii) other biophysical and socio-economic data for the Mackenzie Basin will be acquired from existing documents.

NOAA AVHRR data from 1981 up will be examined. A multi-temporal dataset covering the study area for summer, fall, and winter seasons of each year will be established. Aerial photographs of the critical areas will be collected for reference. Current Landsat MSS and TM data will be collected for the Peace River Region and the Mackenzie Delta for more detailed land-cover and land-use mapping. Existing physiographical and socio-economic maps will be collected for reference purpose. Field trips to the critical regions will be taken to obtain ground information for generating vegetation indices and checking land-use classification.

The scan angle effect will be corrected. A linear radiative transfer model will be used to eliminate atmospheric effects on the AVHRR data which will be geometrically transformed to a specific map projection of the base map in the SPANS GIS.

A classification procedure will be developed to make use of spectral, temporal, and textural information from the AVHRR data. The near-infrared and red spectral channels of AVHRR data of each individual data will be used to calculate the normalized difference vegetation index which can be used to measure vegetation vigour and abundance. Advanced classification algorithms will be developed to handle satellite, topographic, other map data, and non-spatial information such as crop calender data. All results will be transformed into the format of SPANS GIS.

A15.2.6 Scenario Development for Assessment

Scenario specification for this study represents a systematic process to explore the possible future conditions under global warming. Scenario outputs are not predictions of the future, and should not be used as such. In this study, three types of scenarios are specified: climate change, socio-economic, and adaptation options to global warming.

MBIS specified that all researchers involved in this study are to use the same climate scenarios. Three scenarios chosen for the MBIS are hybrid between GCM outputs and historic weather data. A fourth is derived from proxy and instrumental data. Development of climatic change scenarios for the MBIS study is discussed in Chapter 4 and A13.

The population and economic growth scenarios are being developed by Dr. Lonergan's group at University of Victoria and are presented in Chapter A14.

The number of adaptation option scenarios required for this study depends on how many adaptation alternatives or options need to be investigated. Attempts are being made to identify and categorize the possible response options or policies to climatic change which could be entertained by different interest groups. Workshops will be arranged to bring people from various interest groups to discuss possible options from their perspectives. Surveys will also provide information on response of different interest groups to global climatic change.

A15.2.7 The Analytical System for Integrated Impact Study and Policy Analysis

The analytical methods employed for impact study and policy analysis is part of a computer based spatial decision support system (SDSS). The SDSS will improve the efficiency and effectiveness of the integrated assessment through the use of advanced analytical tools. The analytical system is based on goal programming (GP) and multi-criteria decision making (MCDM) techniques. The basic structure of the GP model developed for this study includes goals and constraints. The mathematical formulas of the model are grouped into the following types: resource and other restrictions, supply-demand balances, and goal constraints and objective functions which represent the resource development goals. A simple formation of the GP model is expressed in Table A15.3.

Resource use activities are represented in the GP model by decision variables (Table A15.3). Data required for coefficients of various activities include prices of products, costs of production, average yields, areas of different types of land, soil erosion rate, sediment transport rate, and others. Decision variables and data requirements listed on Table A15.2 are not exclusive. The model is flexible enough to incorporate other variables for assessment.

The GP model is used mainly for impact assessment. The procedure of the assessment is to translate climatic change and/or response policies into specific analytical questions that can be addressed by the model. Climatic change or response policies will influence resource production, resource availability and suitability for each sector, demands for resource products, greenhouse gas emission and soil erosion rates, and other resource use factors. In the analysis process, different scenarios are represented in the structure of the GP model by modifying parameters in the coefficient matrix, the right-hand-side (RHS) vector, and the objective function.

In order to assess the impacts of different adaptation responses on regional development, a base scenario reflecting 'business as usual' conditions of the resource base is usually created for comparison. Alternative scenarios can then be created to reflect conditions coupled with a specific public response to climatic change. The adaptation impacts are the difference between status quo scenario and the adaptation scenario. After a solution for the base scenario is obtained, the procedure followed is to alter the model in a way that reflects new conditions under global warming scenarios, and then to solve the model again. By proceeding in this manner through a series of scenarios, it is possible to evaluate whether the changes that will occur are in keeping with the projected goals or objectives. Sometimes it is preferable to make only one change at one time, and then obtain a solution before making further changes. This permits identification of the impacts of each individual climate change scenario. Sometimes several changes are needed to reflect a new scenario.

Several algorithmic techniques can be adopted to solve GP models. The algorithm employed in this study is the Interactive Mathematical Programming System (IMPS) which was written specifically for nonspecialists in operations research. The codes for this algorithm were written in FORTRAN and are available at Simon Fraser University by request. A detailed explanation of this algorithm and some examples of application of the algorithm can be found in a user manual (Love, 1986).

The assessment with the GP model runs will show the impacts of possible climate change or response options on goal achievement levels. How to relate this kind of results to decision making requires some judgment and interpretation. It may create difficulties for decision makers. To deal with this concern in the integrated study, in addition to the integrated impact assessment through the application of a GP model, a multi-criteria decision making (MCDM) technology might be adopted as an evaluation instrument by which possible response options could be compared and assessed in an orderly and systematic manner. Given a set of response options to climatic change and their implications for goal achievement, the MCDM model identifies the desired options among the alternatives. Results from the GP model runs are imported into the MCDM model for further analysis.

There are many techniques for decision analysis with multiple criteria, which can possibly be used for the study. For example, the analytic hierarchy process (AHP), developed by Saaty (1980), was designed to assist decision makers in solving complex problems involving multiple criteria. The process requires the decision maker to provide judgments about the relative importance of each of the criteria and then to specify a preference for each decision alternative relative to each criterion. The output of the AHP is a prioritized ranking indicating the overall preference for each of the decision alternatives. A software package named Fuzzy Choice (FC) can provide a user-friendly procedure for implementing the AHP on a PC. One important concern in applying this approach to MCDM is that it depends to a large extent on subjective judgment.

The MBIS is still at its early stage of development. Results of other research projects and other important data are still not available at this moment to test the conceptual ILAF system.

Table A15.3 The GP model of the ILAF system.

Objective Function	Min.	$Z = [P1(d^-, d^+), P2(d^-, d^+),...,Pk(d^-, d^+)]$							
	Agri. X1	Forest X2	Wetland X3	Mineral X4	water X5	Total X	d+	d-	RHS
Land constraints	1								LE A1
Land constraints		1							LE A2
Land constraints			1						LE A3
Land constraints				1					LE A4
Land constraints					1				LE A5
Land constraints	1	1	1	1	1	-1	-1	1	LE 0
Ag. production	Y1						-1	1	E b_1
Forest production		F2					-1	1	E b_2
Ungulate habitat		Vuf	Vuw				-1	1	E b_3
Waterfowl habitat			Vww				-1	1	E b_4
Forest cover		1					-1	1	E b_5
GHG Emission	G1	G2	G3	G4			-1	1	E b_6
Soil erosion	E1	E2	E3	E4			-1	1	E b_7
Sediment in water	D1	D2	D3	D4	-Ds				E 0
Sediment constraint					Ds				LE b_8
Economic return	R1	R2	R3	R4	R5		-1	1	E b_9
Water balance	W1	W2	W3	W4	-W		-1	1	E 0
River transport					T		-1	1	E b_{10}
Fishery					N		-1	1	E b_{11}

Note: LE: less than; E: equal.

A15.2.8 Questions to be Answered

It will be important to the Mackenzie Basin that we assess the economic-environmental impacts of public policies and programs associated with global warming. This study seeks to provide answers to some important questions in relation to climatic impact assessment and public response to climatic change. In particular, some broad questions examined will be the followings:

1. What are the implications of climatic change for achieving regional resource development objectives? Should governments within the Mackenzie Basin alter their current resource use policies or plans regarding water resources, resource extraction, forests, fish and other wildlife in anticipation of global warming?
2. Does climatic change increase land use conflicts among different economic and social sectors? If potential conflicts are identified, how serious might they be and how could compromises be reached?
3. What are the possible trade-offs for alternative public responses to climatic change? Should parks and forests be managed to anticipate change or to preserve existing conditions? What are the implications for fire control, recreation and tourism, and wildlife management?
4. What are the implications of global warming for community management of resources under land claims agreements?

A15.2.9 Summary

Much remains to be done to improve the structure of the analytical system and to test the accuracy of the ILAF system. Nevertheless the ILAF presented here provides an introduction to a possible approach for global change study. Application of the ILAF system in the Mackenzie Basin will indicate the possible regional economic, social, and environmental impacts of the global climatic change. The analytical system is also founded on the premise that the overall value of any cause of action to adapt possible climatic change can be judged by considering the performance of the option against a broad set of goals or criteria. Thus, we evaluate response options before they are implemented and the implications observed. A desirable option would be one which achieve certain goals. There is considerable flexibility in the treatment of the components within the research framework. The inventory of response options or policies, for example, is able to be modified or expanded as new ideas are developed. The criteria or goals used for assessing the impacts of climatic change and response options can be applied in a number of different ways depending on the underlying objectives, policies, and values which the study seeks to address. The essential focus is to proceed through the analytical process in a systematic way that identifies and explains the reasons for arriving at the findings that are developed.

In addition, the research framework can serve as a forum for interaction and communication among decision makers from different government agencies, and among policy makers, the public, and analysts. Inclusion of public opinion will help to avoid the use of unrealistic assumptions, and will provide an educational value in informing the public and policy makers of the implications of alternative courses of action when viewed within the context of the 'stake holders'.

There are numerous uncertainties associated with climatic change and its impacts. Substantial gaps in current knowledge about the socio-economic systems and the physical science of global warming. Studies of environmental, socio-economic impacts of climatic change in the distant future are inherently less reliable than forecasts of weather and policy effects in the short term. However, our response to global warming depends in part on the degree of risk aversion attached to poorly understood, low-probability events with extremely adverse outcomes. Lack of scientific certainty should not be used as a justification for avoiding reasoned decisions about responses to possible greenhouse effects. The global warming study represents a right research direction to protect our life support system and to safeguard its sustainability for the sake of both industrialized and less developed countries (LDCs), and of both present and future generations.

Because of the great uncertainties involved in climatic change, it will be difficult to be sure that we are employing the correct response: the climate may change more or less than anticipated. For example, in the case of precipitation, we do not even know the direction of change. An extensive sensitivity analysis may be required to indicate how sensitive the model output is to changes in parameter values, scales, or assumptions. More efforts should be allocated to check and refine the values or scenarios that have significant effects on the model.

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