*Climate Change Research: Evaluation and Policy Implications*
*S. Zwerver, R.S.A.R. van Rompaey, M.T.J. Kok and M.M. Berk, (Eds.)*



# The potential effects of climate change in a riverine hydrological system in northwestern Canada

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**Abstract**

Assessments of climate change risks, and system vulnerabilities, may benefit from a focus on a watershed. A riverine hydrological system is an integrator of natural and human systems, and so constitutes an appropriate setting for determining the regional effects of climate change scenarios. The Mackenzie Basin Impact Study (MBIS) is presented as a case study that illustrates the challenges and opportunities presented by integrated regional assessment of climate change scenarios in a large watershed in northwestern Canada.

## 1. Climate Change Impact Assessment: The Integration Challenge

The Framework Convention on Climate Change (FCCC) is now a part of international law, committing more than 80 nations to action. Its ultimate objective is to stabilize global concentrations of carbon dioxide and other 'greenhouse gases' at a level that does not represent 'dangerous anthropogenic interference' to the atmosphere. At issue, however, is the definition of the term 'dangerous.'

This is an important challenge for climate impact assessment at the regional scale. Global scale atmospheric anomalies, such as El Niño-Southern Oscillation (ENSO), are known to produce region-specific impacts (e.g. Glantz et al., 1987). The same thing is likely to happen with an enhanced greenhouse effect. What might these impacts be and what might (or should?) be the nature of the adaptive responses?

Regional impact assessment is a complex multidisciplinary research challenge. To make matters even more difficult, we are considering an assessment not of an observed climatic event (such as the 1993 Mississippi River flood) but of a theoretical warming of the earth's climate by increased concentrations of greenhouse gases. There are many uncertainties associated with the data and methods used to construct scenarios of a future warmer world, and some have argued for the use of analogues (Glantz, 1988; Kearney, 1994) as an alternative to scenarios based on climate model simulations, population projections, and other forecasting tools. There is little doubt, however, that if climate warming occurs, the earth and its people will feel its effects through a variety of "pathways" and "filters," and the impact assessment needs to account for these.

**1.1 What is integration?**

In order to capture the complex linkages between climate and regions, a research framework is needed which effectively combines information about individual sectors so that the result is more than the sum of the parts. The Intergovernmental Panel on Climate Change (IPCC) defines integrated assessment as "the most comprehensive treatment of the interactions of climate and society" (Carter et al., 1992). It addresses the "net" effect of climate-related stress, so that the indirect linkages between atmosphere, land and water resources, resource management and other policy matters, can be considered in a way that can be understood by decision makers. This would prevent the implementation of strategies or policies which assist one group or sector at the expense or detriment of others. Working at the regional scale is important because at larger scales, impacts may offset each other, and the final result may hide critical details (e.g. Rosenzweig and Parry, 1993).

There are two main approaches to integrated assessment: a) models, including integrated system models such as IMAGE (Alcamo, 1994), and a new model being developed by Battelle/Pacific Northwest Laboratories in the United States (Frederick and Rosenberg, 1994), and b) assessments of policy instruments (e.g. development plans, conservation plans (e.g. Inuvik, 1993)), or regulatory bodies (e.g. river authorities (e.g. Arnell et al., 1994)). There are a wide range of options available within these two sets. Rather than relying on only one approach, a regional study could make use of several integrating techniques if they provide unique and complementary assessments. This could be called the "family of integrators" approach.

With the growing interest in global-scale assessment models, and their potential application in policy gaming exercises, there remains a need for detailed information on smaller scales, which could provide the foundation for global models to produce regional simulations that are plausible to stakeholders. Integrated regional assessments could provide this information. At the same time, however, there is a requirement to convince policy makers that these decision support tools are useful for assessing response options. Policy makers do not represent a global constituency, so there is a need to address issues at their regional/national scales of interest.

It is suggested that an integrated assessment should not rely exclusively on integrated system models, since most of these do not necessarily involve the stakeholder, nor make direct use of the stakeholder's perception of the climate change issue. This perception is not based solely on whether a climate change has been noticed, but on whether any observed or simulated changes in the landscape or economic production can be linked to observations or simulations (scenarios) of climate change. Stakeholders can be an important source of "ground truth," and that is the frame of reference they would use when considering responses to future scenarios of climate change (e.g. Aharonian, 1994; Bielawski, 1994).

Henderson-Sellers (1993) warns that integrated impact assessments might still be circumvented in the rush towards responding to the climate change threat, and that uncertainties make such assessments premature. If full integration is impossible to achieve due to insufficient information, what about partial integration, in which there are some aspects that remain outside of the assessment, and assumptions have to be made about their level of influence. For example, the study of the Corn Belt in the United States (Crosson and Rosenberg, 1993) considered an area bounded by four states (Missouri-Iowa-Nebraska-Kansas or MINK). Water resources issues were still addressed even though upstream sub-basins were located outside the MINK region. Despite some obvious problens, can partial integration provide useful input to the debate on policy responses to climate change? How could this more limited framework be designed so that climate-society issues could still be addressed, while recognizing the limitations that prevent consideration of all factors?

### 1.2 Purpose

In order to attract the breadth of expertise and interests needed for an integrated assessment with stakeholder collaboration, some common ground must be laid out. Many impact assessments have focused on individual sectors (e.g. agriculture, wildlife, water resources), and while these can provide important technical information on direct 'first-order' impacts (IPCC 1990; Tegart and Sheldon, 1993), a wide range of external factors are often assumed to remain unchanged (Carter et al., 1992). Regional and national assessments have been produced elsewhere (e.g. Henderson and Colls, 1993; Hulme et al., 1992; Liverman, 1992; New Zealand Climate Change Programme, 1990; Ninh et al., 1991; Nishioka et al., 1993; Smith and Tirpak, 1990), but these have generally consisted of parallel sectoral studies. Crosson and Rosenberg (1993) and Parry et al. (1992) have attempted integrated assessments based on regions defined by sectoral dominance (e.g. agriculture) and/or political borders.

The purpose here is to suggest that riverine hydrologic systems may provide an appropriate setting for producing an integrated regional assessment of climate change scenarios. What follows is a description of a watershed-based case study from northwest Canada, which is still in progress. The regional/watershed focus has been used to attract scientific expertise and diverse stakeholders with local knowledge. The common ground for all of them is an interest in the future of this place, with water serving as an important link.

## 2. Watersheds as Integrators of Natural and Human Systems

The choice of study area can influence many aspects of an impact assessment, including the identification of issues and the collection of data. There are various administrative and ecological settings that might be considered (Carter et al. 1992), but the focus here is exclusively on watersheds as integrators. Land cover and land use affects hydrology and water quality, so water users (e.g. hydroelectric utilities, fisheries, navigation, domestic users, wildlife, agriculture, recreation) are necessarily linked with forces that modify the landscape (e.g. agriculture, forestry, hydroelectric utilities, industrialization, fire, pests).

Governments have used watersheds as the basis for the creation of customized management structures (e.g. basin commissions, water boards). These attempt to reconcile the goals of competing interests while providing direction for regulation, water allocations and other matters. For the purpose of climate impact assessment, this is an important source of information on regional issues and their stakeholders. Although economic data are rarely collected on a watershed basis, it should be possible to at least partially address this requirement through the use of census data or other local/regional sources of information. Watershed-based assessments have been tried for the North American Great Lakes (Smith and Tirpak, 1990; Mortsch et al., 1993) and a series of international basin studies including the Nile, Indus and Zambezi (Strzepek and Smith, forthcoming). Arnell et al. (1994) provide a case that focusses on a water management authority in the United Kingdom.

It is expected that climate warming would lead to an acceleration of the water cycle, with increased throughputs along the pathways linking atmosphere, ocean, landscape, freshwater bodies, and society (Falkenmark, 1991). Climate warming may impose its most significant effects on water sensitive sectors, through changes in a) the frequency and severity of extreme events (floods, drought, etc.), b) timing of seasonal and annual events (e.g. spring runoff peak, autumn low flow, ice formation and break up, etc.), c) thresholds and ranges (e.g. maximum summer water temperatures), and d) land cover (e.g. erosion, fire, etc).

Riverine hydrological systems will exhibit basin-specific adjustments to global climatic changes. Most warming scenarios tend to show increases in precipitation, but this does not necessarily mean wetter land surfaces or more soil moisture. Gleick (1993) concludes that if the future climate will not look like the past, there will be a great increase in the overall uncertainty associated with water management and supply.

Understanding impacts is a necessary prerequisite for determining the kind of measures that could promote both limitation of greenhouse gas emissions and adaptation to environmental stresses. Assessing adaptation options requires a greater understanding of how individuals, companies and governments operate when faced with environmental stresses (Smit, 1993).

## 3. Case Study: Mackenzie Basin, Canada

The Mackenzie Basin Impact Study (MBIS) is part of the Government of Canada's Green Plan, and has passed the halfway point in its six-year mandate to assess the potential regional implications of global climatic change (Cohen, 1993, 1994). The program includes studies on water resources, permafrost, vegetation, wildlife, economic activities, resource-based and subsistence-based communities, and applications of remote sensing and geographic information systems (GIS). Attention is also given to the challenges of producing an integrated assessment, and to incorporating traditional ecological knowledge into the MBIS.

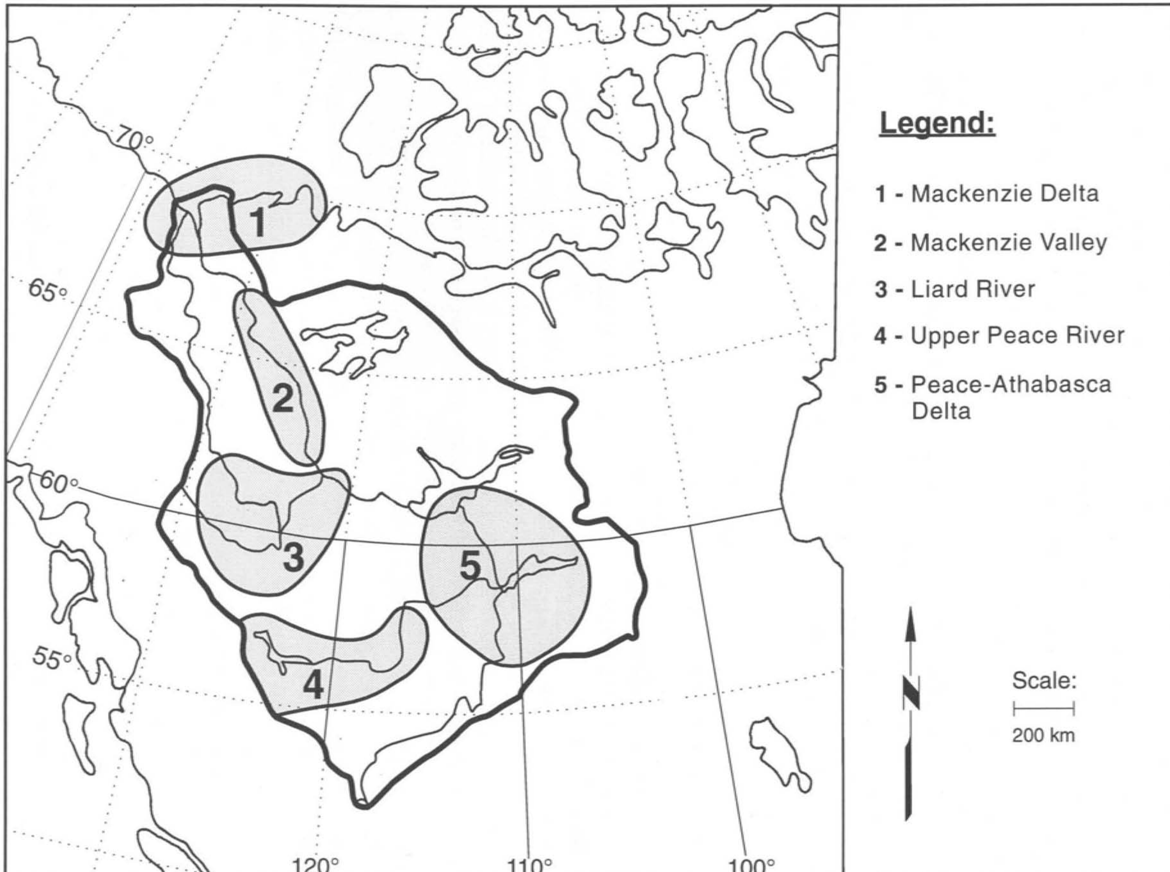
### 3.1 Setting

This region was chosen because it is a major high latitude watershed, 1.7 million $km^2$ in area, with many climate-sensitive landscapes and transition zones: tree lines (Arctic, montane, aspen parkland), discontinuous permafrost, wetlands and deltas, the edge of multiyear sea ice, and the northern limits of commercial forestry and agriculture. Freshwater and terrestrial migratory wildlife might be sensitive to climate-induced changes in the landscape.

The study area is defined by the watershed boundary of the Mackenzie River and its tributaries, plus the southern Beaufort Sea and coastal zone north and east of the Mackenzie Delta. The large size precludes detailed study of all areas, though there are some activities that are conducted on the Basin scale. For the MBIS to achieve its objective, however, the range of impact-related policy questions are limited to the following: a) interjurisdictional water management, b) sustainability of native (aboriginal) lifestyles, c) economic development opportunities, d) maintenance of infrastructure, and e) sustainability of ecosystems.

Additional focus has been provided by defining critical regions within the study area (Figure 1). Each of these represent potential flash points due to the intersection of potential biophysical changes with human activities. For example, the Upper Peace River region includes a major hydroelectric facility (Bennett Dam), agriculture, expanding forestry operations and communities with a history of flooding. The operation of the dam has led to concerns about the viability of the freshwater wetlands and delta, and consequently, the

# Mackenzie Basin Impact Study: Critical Regions



wildlife and subsistence-based communities in the Peace-Athabasca Delta region, located downstream. How would a scenario of climate warming affect dam operations, water levels at the Delta, fisheries, migrating waterfowl, agriculture and forestry operations? Would resource-based and native communities experience the same impacts, or would climate change be felt in different ways depending on lifestyle (wage economy, subsistence/non-wage economy)?

### 3.2 Objective

If climate warming occurs, governments and their constituents will need advice on how to adapt to the new climate. Since decision making occurs in an environment where different stakeholders compete for resources, any response options will have to account for tradeoffs between these various interests. Land and water use patterns today represent the result of historic and current compromises between these various interests, combined with knowledge gained from research and personal experience. At the scale of most current GCM-based impact assessments (e.g. grid sizes larger than 2° latitude x 2° longitude), land in a grid cell is not necessarily assigned to a single optimal use today, so it is unlikely that this would be different in the future. The assessment, therefore, should not restrict itself to changes in physical capability to support a particular activity (e.g. crop production).

The objective of MBIS is to provide an integrated regional assessment of scenarios of climate warming for regional stakeholders and the scientific community. As a high latitude watershed, the Mackenzie Basin has been seen as an area that might benefit in certain ways by a warmer climate. These include a) longer growing season for agriculture, b) greater productivity for forestry, c) longer ice-free season for navigation, d) reduced energy demand for space heating, e) longer summer tourist season, and f) reduced cold weather stress on infrastructure. Taken individually, economic impacts could be quantified, and these might show substantial benefits for the region. Other factors need to be considered, however, and some of these may constrain the potential benefits. This list includes: a) current use of land for subsistence hunting and trapping, b) current system of land transportation, much of which is based on a stable ice and snow cover for winter roads, c) current ranges and habitats of wildlife, which underpin conservation plans and native land claims (currently being negotiated between aboriginal people and governments in Canada), and d) scientific uncertainty which hampers anticipatory responses to projected beneficial conditions.

Potential negative impacts of climate warming must also be considered, because they may offset possible benefits. Examples are: a) increased erosion due to permafrost thaw, b) increased frequency and severity of forest fires, c) extension of mid-latitude pests and diseases into high latitudes, and d) reduction of habitat suitable for cold climate species of vegetation and wildlife.

### 3.3 Study Framework

MBIS is attempting to produce an integrated regional assessment of global warming scenarios, as a way of identifying the indirect linkages between climate and regional policy concerns, such as land and water management. Several exercises are being tried, including 1) resource accounting with input-output modelling, 2) land assessment (including goal programming and multiobjective program modelling), 3) review of water resources policy instruments and their sensitivity to hydrologic changes, and 4) study of settlement patterns and their sensitivity to landscape changes. Each of these utilize the outputs of various individual studies in order to address some of the human dimensions of climatic change (Cohen, 1993, 1994).

All of these approaches are being tried because there is no consensus on which method is best for producing an integrated study. System models (1 and 2 above) provide a closed integrated model or set of linked models that describe particular components of the system. Analyses based on planning/management instruments (3 and 4 above) consist of a mixture of models and expert judgement. These instruments (e.g. plans, policies, regulations, indices) represent the integration of scientific information and stakeholders' preferences, and their performance under climate change scenarios would provide an important measure of impact.

There is a difference between the level of control exerted by the researcher in these approaches. While the idea of "megamodels" (Frederick and Rosenberg, 1994) is growing in popularity in Europe and North America, the family of integrators concept presented here serves to provide an opportunity for other forms of input to contribute to the assessment, particularly those which are difficult to quantify. Policy analysis has both quantitative and qualitative aspects, and may be preferred by stakeholders who are leery of 'black box' models.

There are several opportunities to facilitate linkage between individual study components. Within MBIS, integrated system models, economic models, and other similar tools, are being used to address complex issues related to land use and economic growth (e.g. Lonergan, 1994; Yin and Cohen, 1994; Huang et al., 1994). These mathematical or statistical techniques require a wide range of inputs, including census data, outputs of other models, and/or indices obtained from remote sensing, thereby serving as integrators of information obtained from other disciplines.

### 3.4 Preliminary Results

One theme that has clearly emerged in the MBIS is that climate is a complex agent of change. Although scientific and political discussions have tended to focus on atmospheric change, the land and its people will likely experience climate warming through changes in streamflow, water levels, ice and snow cover, permafrost, plant growth, wildlife patterns, fire, pests and diseases. Some changes may occur gradually while others may come in the form of large steps or new extremes.

The linkage between changes in air temperature and regional socio-economic concerns is largely through these landscape 'filters.' Biophysical changes are what people will notice before they pay attention to climate statistics. Has the winter road season changed? Is anything new with the caribou migration? Are current fire management strategies still working satisfactorily? What is the status of permafrost along the Mackenzie Valley and the Beaufort coastal zone?

Some preliminary indications of landscape and socioeconomic impacts for the scenarios being assessed by MBIS are shown in Tables 1 and 2, respectively. Many MBIS activities are not yet at the stage where scenario results can be reported, but some information is available.

Table 1
MBIS Preliminary Summary of Landscape Impacts of Climate Warming Scenarios

| PARAMETER | DETAILED IMPACTS |
|---|---|
| **Permafrost** thaw occurs, but rate of change varies with site | •thaw would occur primarily in discontinuous zone<br>•seasonal active layer would increase<br>•rate of thaw in wetland areas would lag behind other sites<br>•slopes and Beaufort Sea coastal zone may experience accelerated erosion |
| **Water Supply** changes slightly, with earlier spring peak | •annual Basin runoff changes -7% to -3% in GCM-based scenarios, +7% in composite analogue scenarios<br>•increased precipitation offset by increased evapotranspiration in many subbasins<br>•spring snowmelt peak begins up to 1 month earlier<br>•longer snowmelt season, lower peak in some subbasins (including Williston, upstream of Bennett Dam) |
| **Peace River Ice Cover** reduced in duration and extent | •ice cover reduced by up to 4 weeks<br>•upstream progression of ice reduced by up to 200 km<br>•runoff reduction (or reduction of discharge from Bennett Dam) would offset effects of temperature increase on ice cover |
| **Soil Capability for Agriculture** increases | •increase in availability of marginal and suitable land for spring seeded small grains and forages due to longer growing season and frost free period<br>•decrease in soil moisture supply |
| **Pine Weevil Hazard** increases | •increase in temperature-based pine weevil hazard index<br>•low elevation sites particularly vulnerable<br>•non-temperature factors not yet included |
| **Fire Weather Index** increases | •median index for four GCM-based scenarios corresponds to change of -15% to +81% in burned area |

Summarized from Cohen (1993, 1994).

Runoff for the Basin was obtained using a square grid model (Soulis et al., 1994), and for the Williston subbasin with the UBC Watershed Model (Chin and Assaf, 1994). Although increased runoff was anticipated (e.g. see Miller and Russell, 1992), this does not appear to be the case for the GCM-based scenarios (Canadian Climate Centre or CCC, Geophysical Fluid Dynamics Lab or GFDL (R30 version)) for the Basin as a whole. Only the composite analogue scenario shows an increase. Newton (1994) has therefore concluded that scenario spring flood risks for vulnerable communities may not be that different from current climatic conditions. What is not clear as yet is the implication of hydrologic and landscape changes on water management agreements currently being negotiated by various governments (Felton, 1994). Peace River ice cover, for example, will be affected by both temperature changes and changes in outflow from the Bennett Dam at Williston subbasin (Andres, 1994). This may not be the final word on runoff impacts, since the Global Energy and Water Cycle Experiment (GEWEX) is pursuing a research programme in the Mackenzie (Lawford, 1994).

It would appear that the other main threats to the Mackenzie landscape are a) accelerated erosion caused by permafrost thaw, especially in sloping terrain and the Beaufort Sea coastal zone (Aylsworth and Egginton, 1994; Solomon, 1994), b) increased fire hazard (Kadonaga, 1994), and c) invasion of new pests and diseases from warmer regions (Sieben et al., 1994). These landscape impacts could lead to changes in plant succession (Wein et al., 1994), thereby affecting wildlife habitat and subsistence activities of native communities. Additional information on ecosystem impacts should become available for the MBIS Final Report in 1997.

First-order and second-order impacts eventually lead to others which are considerably more difficult to address. Will land claims or water resources agreements be affected? Could there

Table 2
MBIS Preliminary Summary of Socio-Economic Impacts of Climate Warming Scenarios

| SECTOR/LOCATION | DETAILED IMPACTS |
|---|---|
| **Tourism/Nahanni National Park** would experience mixed impacts | •little impact from projected minor changes in streamflow<br>•extended season for water-based recreation would provide economic benefits to communities near the Park<br>•increased Fire Weather Index (fire frequency and severity) could affect runoff, landscape character, visitor safety |
| **Community Vision of Impacts** depends on vision of lifestyle | •response to flood hazard varies by community, according to the interplay of individual, community and government responses<br>•significance of landscape impacts depends on whether community maintains subsistence lifestyle, or switches to wage economy |

Summarized from Cohen (1994).

be new conflicts over land use, especially if agriculture expands northward to take advantage of improved soil capability to support crop production (Brklacich and Curran, 1994)? What might be the effects on parks and other protected areas (Pollard and Benton, 1994)? Could climate change affect the economics of oil and gas production in the Beaufort Sea (Anderson et al., 1994)?

Expressing socio-economic impacts in monetary terms is going to be difficult, but it should be possible to do so for agriculture, forestry, energy, and some aspects of tourism. In the case of Nahanni Park located in the Liard subbasin (see Figure 1), water-based recreation is expected to benefit from the longer summer, but this could be offset by the threat of increased fire (Staple and Wall, 1994). There is no assessment, yet, on the potential costs of increased fire or fire protection. Community impacts could be quantified, but the effects of climate warming scenarios may vary depending on whether a traditional aboriginal lifestyle of hunting and trapping is maintained, or a shift to greater reliance on the wage economy occurs. Aharonian's (1994) case study of Aklavik, in the Mackenzie Delta region (see Figure 1), shows that residents can provide detailed visions of both "futures." In their view, community vulnerability to climate warming scenarios will change if their lifestyles changes. This may parallel circumstances that could be experienced in some developing countries during the next several decades.

The integration component is currently focussed on data collection. One activity is on the development of a resource accounting framework, including a Mackenzie Basin input-output model. This will be used to determine impacts of changes in energy and forestry on the region's employment and economic productivity (Lonergan, 1994). A second modelling exercise is the integrated land assessment framework or ILAF. Its purpose is to compare changes in land capability with stakeholders' goals in order to identify possible land use conflicts in a climate warming scenario (Yin and Cohen, 1993, 1994). Potential expansion of commercial agriculture and forestry could create a conflict with existing subsistence activities, so there is a need to determine whether this is possible within the scenarios. Additional activities in multiobjective programming (Huang et al., 1994), and a study of the non-wage economy in a native community, will complement ongoing MBIS socioeconomic studies in agriculture, forestry, energy, tourism and community development (Cohen, 1994).

Impacts and responses will not be felt by individual sectors in an isolated manner. A unit of land (at a scale comparable to GCM output) is not likely to end up becoming exclusively devoted to one kind of land cover or use. This set of research activities will hopefully enable MBIS to address some important cross-cutting issues at a scale comparable to regional stakeholders' interests.

## 4. Conclusions

A riverine hydrologic system is presented as an appropriate setting for integrated regional assessment of climatic warming scenarios. The Mackenzie Basin Impact Study (MBIS) illustrates the application of the "family of integrators" approach, consisting of several integrated system models and analyses of policy instruments.

We have considered the difficulties in producing a fully integrated assessment of climate warming scenarios, and acknowledge that in the case of the MBIS, several aspects are not covered (e.g. marine wildlife in the Beaufort Sea, native communities in Alberta, future economic linkages with the rest of Canada and other countries). MBIS includes population and economic growth scenarios (Lonergan and Difrancesco, 1993), but technological and institutional change scenarios have not been constructed. Although it is unlikely that MBIS can achieve full integration, we hope that partial integration can provide relevant information on sectoral and cross-cutting regional impacts.

MBIS is an exercise in interdisciplinary research with stakeholder collaboration. Maintaining linkages between researchers and stakeholders has been a challenge. It may be difficult at this stage to appreciate the long term value of the MBIS experience, but it is clear that collaboration with stakeholders is vital for there to be any hope of producing an assessment that could be useful and relevant to the region of interest. In fact, partially or fully integrated assessments may be impossible without stakeholder involvement during all phases of research. For example, stakeholders participating in MBIS planning meetings contributed to the selection of economic growth scenarios, and the identification of communities and individuals willing to be interviewed as part of surveys conducted by MBIS investigators.

During the remainder of the MBIS program, investigators will be completing biophysical and socio-economic impact studies, transferring information to the "integrators" (i.e. systems modellers, policy analysts, etc.), and completing integration exercises. There will be a workshop on water management, and a larger gathering in 1996 similar to the event that facilitated the production of MBIS Interim Report #2 (Cohen, 1994). MBIS investigators are expected to exchange information with each other before and after their components are completed. There are also plans for more discussions on the MBIS within the region, before and after publication of the final report in 1997.

## 5. ACKNOWLEDGEMENTS

My thanks to Krystyna Czaja for producing Figure 1. Any opinions expressed in this chapter are my own, and not necessarily those of Environment Canada.

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