ROSENBERG INTERNATIONAL FORUM: THE MACKENZIE RIVER BASIN

JUNE 2013

REPORT OF THE ROSENBERG INTERNATIONAL FORUM'S WORKSHOP ON TRANSBOUNDARY RELATIONS IN THE MACKENZIE RIVER BASIN

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GORDON FOUNDATION

The Rosenberg International Forum on Water Policy
On Behalf of The Walter and Duncan Gordon Foundation

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MACKENZIE RIVER BASIN
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EXECUTIVE SUMMARY

The Mackenzie River is the largest north-flowing river in North America. It is the longest river in Canada and it drains a watershed that occupies nearly 20 per cent of the country. The river is big and complex. It is also jurisdictionally intricate with tributary rivers running through three provinces – British Columbia, Alberta and Saskatchewan – two territories – Yukon and the Northwest Territories – and areas which fall under the jurisdiction of numerous independent indigenous governments. Large tributary rivers, the Liard, Peace and Athabasca drain much of north central Alberta and parts of the Rocky Mountains in northern British Columbia. The Peace and Athabasca Rivers flow to Lake Athabasca, which is drained by the Slave River, the primary feeder to Great Slave Lake. The Mackenzie River itself flows from Great Slave Lake to the Arctic and lies wholly within the Northwest Territories.

The Mackenzie River Basin is among the most intact large-scale ecosystems in North America. It provides significant breeding habitat for migratory birds and aquatic habitat. Sixty-three per cent of the Basin is covered by boreal forest, with another 20 per cent covered by wetlands. While the Basin is relatively undisturbed ecologically, it is at risk both from a warming climate and development pressures from the exploitation of hydrocarbons, non-renewable minerals and hydroelectric potential. These large forces of change threaten the ecological integrity of the Basin, its capacity to provide important environmental services, and its role as homeland to Aboriginal Peoples who rely on the land and its resources to provide food, clothing, water and other necessities of life.

The Mackenzie River Basin is a unique global resource. It provides benefits not only to residents, but to populations across Canada, throughout the Western Hemisphere, and to some extent, the world over. The Basin contains globally important natural resources. The Mackenzie Estuary harbours extraordinary biodiversity and its biological productivity is enormous when compared to other ecosystems in the region.

The Mackenzie Delta and other boreal areas absorb carbon dioxide. There is a clear link between the freshwater flows of the Mackenzie and Arctic Ocean circulation. These are thought to contribute in important ways to the stabilization of the regional and global climate. In this respect, the Mackenzie River Basin must be viewed as part of the global commons. The challenge of protecting the Basin and conserving its resources and environmental services is further complicated by its status as a commons, and by the need to recognize stakeholders who are not residents. The problems of the commons cannot be successfully addressed unless the population of the Basin and the constituent governments forthrightly assume the responsibilities of its stewardship.

The Mackenzie River has not been studied as extensively as other major rivers of the world. The scarceness of major studies conducted in the 1970s means that the working knowledge of the Mackenzie is relatively minute. Efforts to protect and preserve the Mackenzie, and develop its resources in a balanced way, will require both the full use of all existing science and the need for additional study. The primary need is for a perpetual, robust and well-funded comprehensive monitoring program. Responsibility for the conduct of this program should be vested in the Government of Canada. There are other questions about hydrological, chemical and biological aquatic regimes in the Basin that deserve high priority on the research agenda. Similarly, there are important questions in the domains of the social science that should be accorded high priority on the research agenda.

The Basin's governance is complicated by jurisdictional fragmentation. The need to address this problem arose in the 1990s with the development of the *Mackenzie River Basin Transboundary Waters Master Agreement* of 1997. The Master Agreement required multi-party collaboration and co-operation in managing the land and water resources of the Basin. There has been little effective follow-through on this Master Agreement. This report includes a careful consideration of the obstacles to governance and offers recommendations for an appropriate governance structure for the Basin.

One major recommendation is that the Mackenzie River Basin Board (MRBB), originally created by the Master Agreement, be reinvigorated as an independent body charged with managing and protecting the Basin. Additional personnel, including representatives from indigenous communities, will be required to sharply increase funding support and a capacity for creating policy based on the best available science. Bilateral agreements among the governments represented in the Basin may be helpful in some instances, but they must be consistent with the provisions of the overarching Master Agreement.

The MRBB must devise governance and management schemes that are comprehensive and holistic. Piecemeal and/or fragmented approaches are unlikely to be successful. Management regimes must also be adaptive because there is much scientific uncertainty about many of the Basin's natural features. Thus, programs that allow learning from experience and adjust management regimes to account for such learning, will be essential. Scientific uncertainty can be addressed more directly by supporting the aforementioned monitoring program and by application of the "precautionary principle." This principle holds that the absence of full scientific certainty is not a valid reason for delaying or postponing measures that would avoid serious or irreversible environmental damage.

The MRBB should be supported by an independent International Science Advisory Committee. The role of this Committee should be to ensure that the best possible science is used, and to develop and prioritize research agendas to create new scientific information needed to guide the MRBB in other appropriate ways. Indigenous peoples should be represented on the Committee. Additionally, educational programs should be established to educate the region's residents, as well as the larger world, about the Mackenzie River Basin. Such a program should also offer training to indigenous peoples to allow them to have major roles in programs that manage and protect the Basin.

It is important to recognize that traditional knowledge should be fully utilized as part of the scientific base upon which policies and plans for the Basin will be based. Traditional knowledge forms a continuum with Western scientific knowledge and the two are complementary and not mutually exclusive. A number of cultures throughout the world have applied traditional knowledge to the management of environmental changes of precisely the sort that are anticipated here. The traditional knowledge of the Basin's indigenous residents should be sought out and utilized to the fullest extent possible. Funding to support participation of indigenous peoples and the use of traditional knowledge should be made available in generous amounts.

Enhancing knowledge and communication within the Basin will be critical, as will the development of scientific capacity. The activities of the Board should be fully transparent and broadly communicated. Input should be sought from all classes of stakeholder and there should be full sharing of scientific information that explicitly includes a thorough examination of research outcomes that some interests may not like.

There are also value questions and judgments which must be addressed in the making of policies and plans for the Basin. While science alone cannot fully inform such judgments, that is not an excuse for ignoring the need to make the judgments forthrightly and transparently. Examples of the questions that should be addressed are: 1) How should the values and philosophies of traditional cultures be respected in the fashioning of balanced management policies? 2) What rates of economic growth are appropriate for the Basin and its distinctive regions? 3) How should extractive industries and hydroelectric developments be regulated?

The report includes a strong recommendation that extractive industries be required to post a significant performance bond before site development and operations commence. This ensures that clean-up costs and mitigation following closure of the site are fully paid by the industry itself. Failure to require a significant performance bond or some similar incentive almost surely means that the legacy of despoiled environments, toxic wastes and other waste will continue unabated, and that taxpayers will be left to bear costs that are properly those of the mining industry.

INTRODUCTION

The Rosenberg International Forum on Water Policy was created in 1996 with an endowment gift to the University of California in honour of Richard Rosenberg upon the occasion of his retirement as Chairman of the Bank of America. The theme of the Forum is: *Reducing Conflict in the Management of Water Resources*. The Forum meets biennially at different locations around the globe. Past Forums have been held in San Francisco, U.S.; Barcelona, Spain; Canberra, Australia; Ankara, Turkey; Banff, Canada; Zaragoza, Spain; and Buenos Aires, Argentina. Attendance at the Forum is by invitation only and is restricted to 50 water scholars and senior water managers from around the world.

In 2006, the Advisory Committee of the Rosenberg International Forum launched a second activity subsumed under the general title of Regional Workshops. These workshops use small, international, expert panels to assist governments and other institutions in addressing regional water issues. The first of these Workshops, in 2007, reviewed Alberta's provincial water strategy, *Water for Life*, and the "Groundwater Action Plan" for the province. The second, in 2008, brought together water management experts and water policy scholars from Iran and the United States with the aim of identifying commonalities in the challenges of assuring water supply for cities and agriculture in arid and semi-arid regions that exist in both countries. A third Regional Rosenberg Workshop was held in Yellowknife in Canada's Northwest Territories in June of 2009, with the purpose of identifying barriers to the implementation of *Northern Voices, Northern Waters: Towards A Water Resources Management Strategy for the Northwest Territories* and to recommend examples from elsewhere from which the government could benefit as it sets out to integrate the strategy into larger governance structures.

This document is the report of the fourth Regional Workshop held in Vancouver, British Columbia in September 2012. The Vancouver forum was convened at the request of the Walter and Duncan Gordon Foundation and hosted by Simon Fraser University. The Foundation is committed to addressing various issues of water policy reform and improvement of water governance, particularly in the Canadian North. The purpose of this Regional Rosenberg Workshop was to provide the latest scientific information needed to arrive at a transboundary arrangement that would assure the sustainability of the system, while at the same time ensuring that desired social and economic benefits accrue for each of the jurisdictions that share the Basin.

THE STRUCTURE & OBJECTIVES OF THE FORUM

In July 1997, the governments with jurisdiction to manage water and the environment in the Basin signed the *Mackenzie River Basin Transboundary Waters Master Agreement*. The agreement commits all six governments to work together to manage the water resources of the entire Basin. The governments with jurisdictional interests in the Basin are the western provinces – British Columbia, Alberta and Saskatchewan – as well as the territories of Yukon and the Northwest Territories, and the Government of Canada.

As identified in the Master Agreement, relevant parties in Western Canada have recognized the need for multi-party transboundary co-operation in the governance of land and water use (and management) in the larger Mackenzie River Basin. However, 15 years have passed, and no progress has been made with respect to the development of multi-party co-operation in the Basin. Meanwhile, population and economic growth have continued throughout the Basin. Without planning and co-ordination, such growth, in addition to threatening the stability and sustainability of the Basin and its resources, could undermine the purpose of the agreement and render the benefits of co-operation unachievable. It was the purpose of this Regional Rosenberg Workshop to examine the obstacles to the crafting of a multi-party agreement on the management of the Mackenzie, and to set forth recommendations as to what kind of governance structures might be put into place that allow all parties to meet their social, economic and environmental goals, while at the same time recognizing their individual and collective obligations as stewards of a globally significant resource.

As the Rosenberg Forum has already undertaken independent analyses of the water strategies of both the Government of Alberta in 2007 and the Government of the Northwest Territories in 2009, it has been invited by Canada's Walter and Duncan Gordon Foundation and Simon Fraser University in British Columbia to convene a panel of experts to identify and summarize the pertinent scientific principles and findings that should be acknowledged in the processes leading ultimately to an agreement concerning the Mackenzie. The panel was also asked to identify pertinent legal principles that may apply.

STATEMENT OF TASK

The specific assignment to the panel was to deliberate and prepare a report that responded to the following questions.

1 What is the state of scientific knowledge of the Mackenzie River Basin? What are the important scientific findings that should be acknowledged in the negotiations leading to a multi-party agreement? What are the major scientific questions that need to be addressed to ensure that the waters and lands of the Basin are managed in a way that protects their integrity? To what extent does scientific uncertainty need to be addressed and specifically acknowledged in any transboundary agreement? What does science tell us about the continental and global significance of the Basin?

2 To what extent does traditional knowledge supplement or reinforce typical Western science or social science? To what extent does traditional knowledge need to be acknowledged or incorporated in any agreement? Are there examples of transboundary agreements that rely upon traditional knowledge?

3 Given the prevailing levels of uncertainty, what should be the role of adaptive management in scoping and implementing any transboundary agreement? What are the positive and negative lessons that have been learned from experience with adaptive management? Are there examples of transboundary agreements that rely on adaptive management?

4 Is it possible to revamp existing co-operative governance structures for the Mackenzie River Basin so as to build upon rather than infringe upon the jurisdictions of the federal, provincial, territorial and indigenous governments? Are there examples where this has been successfully accomplished in a federal system? Are there examples of where it has been attempted but failed to work effectively?

5 Could an existing layer of government or a regional governmental entity be given regulatory authority related to the purely basin-level aspects of such overarching issues as climate change, cumulative environmental impacts, as well as transboundary indigenous treaties and governance agreements? Note that to the extent that these issues are addressed at all, they tend to be handled at the provincial/territorial and /or federal level.

THE REGIONAL WORKSHOP PANEL

The Rosenberg International Forum on Water Policy convened a Regional Workshop of international experts with appropriately diverse disciplinary backgrounds and experience. The names, institutional affiliations and areas of expertise of the panel members and others formally involved in the forum are listed below.

WORKSHOP MEMBERS

Professor Henry Vaux, Jr., Chair
Department of Agricultural and Natural Resource Economics
University of California, Berkeley
(Natural Resource Economics)

Professor Gordon Christie
University of British Columbia
(Law)

Professor Helen Ingram
University of California, Irvine
(Political Science)

Professor Stephen Mumme
Colorado State University
(Political Science)

Professor Pamela D. Palmater
Centre for Indigenous Governance
Ryerson University (Law)

Professor John Pomeroy
University of Saskatchewan
(Hydrology and Climate Science)

Professor Mary Power
University of California, Berkeley (Biology)

Professor David Schindler
University of Alberta
(Biology, Water Chemistry)

Professor Patricia Wouters
University of Dundee (Scotland)
(International Law)

Principle Reviewer
Professor Stephen McCaffrey
University of the Pacific
(Law)

SUPPORT STAFF

Robert Sandford
UN Water for Life Decade, Canada
Rapporteur & Writer

Deborah Harford
Simon Fraser University
Administrative Officer

PANEL MEETING AND PROCESS

The panel met for three days in Vancouver, British Columbia on Sept. 5 to 7, 2012. The first day, a "Day of Discovery," was focused on the gathering of general and specific information about the Mackenzie River Basin and its associated land resources. The panel heard presentations by representatives of the Canadian federal government, by the premier of the Northwest Territories and from representatives of the government of the Northwest Territories. It also heard from several academics whose expertise is focused on the Basin. The intent was to supplement the collective knowledge of the panel about present and future conditions in the Mackenzie River Basin.

The second and third days were devoted in their entirety to panel deliberations that were held "in camera." During these two days the panel outlined its report, deliberated its contents, and identified its ultimate conclusions and findings. Thereafter, the report emerged through a series of drafts that were the focus of comments and interactions on the part of panel members leading to the final draft which was completed in early 2013.

The panel acknowledges and thanks those who participated in and contributed to the "Day of Discovery," and others who provided detail and helped to clarify points along the way. The panel wishes especially to thank Professor Stephen McCaffrey of the McGeorge School of Law, University of the Pacific, for his careful and insightful review of an advanced draft of the report. Professor McCaffrey was designated at the outset as a peer reviewer for the report. His review resulted in significant improvements in the report, though he bears no responsibility for the final product.

PRINCIPLE FINDINGS & CONCLUSIONS

1 The ecologic, hydrologic and climatologic regimes of the Mackenzie River Basin are at risk from planetary warming. The area is ecologically fragile and could become more so.

2 The Mackenzie River Basin is a globally important resource. Its biological, hydrological and climatological properties affect the welfare of people throughout the Western Hemisphere and, to some extent, globally.

3 The Mackenzie River Basin is less studied than many of the other large basins of the world. The ambient environment of the Mackenzie is changing relatively rapidly. These two factors mean that management of the lands and waters of the Basin will have to occur in the face of significant uncertainties.

4 The Basin is fragmented jurisdictionally, making holistic management of its resources nearly impossible. Overarching authority for the management of the Basin should be vested in a strengthened Mackenzie River Basin Board (MRBB), authorized by the *Mackenzie River Basin Transboundary Waters Master Agreement* of 1997. A reinvigorated MRBB will need significantly more financial support and will benefit from the advice and counsel of an independent International Science Advisory Committee.

5 The reinvigorated MRBB should manage the Basin adaptively and holistically. This will require a perpetual, robust and adequately funded monitoring program that should be the responsibility of the Canadian federal government.

6 Adaptive management and the precautionary principle need to be employed assiduously in managing scientific uncertainty in the Mackenzie River Basin.

7 Extractive industries should be required to post a substantial performance bond which would be used to cover the costs of site clean-up should the enterprise fail financially or otherwise fail to fully remediate damage and destruction at the site in question. The performance bond should be secured prior to site development and the commencement of operations.

8 There are a number of value issues that must be addressed forthrightly and transparently. They involve the interplay of two distinctly different cultures within the Basin – issues related to rates and types of appropriate economic growth, and the oversight and regulation of extractive industries and hydroelectric development.

SETTING THE STAGE: THE MACKENZIE SYSTEM

➤ *See Figure 1.* The Geographic Area Encompassed by the Mackenzie River Basin.

PHYSICAL GEOGRAPHY & HYDROLOGY

The Mackenzie River is the largest north-flowing river in North America. It is the longest river in Canada, stretching for 4,241 kilometres. It drains the largest watershed in Canada, a watershed that occupies nearly one-fifth of the country. In addition, the measure of unimpaired discharge of the Mackenzie at its mouth places it among the two largest rivers in Canada. By any measure, the Mackenzie River is a big river. It is also a complex and unique river both in terms of water and associated land resources. Moreover, the Basin is jurisdictionally complex with tributary rivers running through three Provinces – British Columbia, Alberta and Saskatchewan – as well as the territories of Yukon and the Northwest Territories (Culp, Prowse and Luiker 2005).

As shown in Figure 2, the Mackenzie River has many tributaries, with the largest being the Liard, the Peace and the Athabasca. The latter two rivers drain much of the boreal region of north-central Alberta and parts of the Rocky Mountains in northern British Columbia before coming together at the Peace-Athabasca Delta near Lake Athabasca, which also receives runoff from northwestern Saskatchewan. The waters of Lake Athabasca then flow northward by way of its outlet, the Slave River.

The Slave River contributes about 77 per cent of the inflow to Great Slave Lake. The Mackenzie River itself rises out of the western end of Great Slave Lake and flows generally west-northwest for about 300 kilometres, passing the communities of Fort Providence and Fort Simpson, where the river turns north. Other upstream inflows include the Taltson, Lockhart and Hay Rivers. While the Taltson and Lockhart Rivers have their origins in the Northwest Territories, the Hay River is fed by tributaries that originate in Alberta and British Columbia.

The Mackenzie's largest tributary is the Liard River which joins at Fort Simpson. Thereafter the main stem begins a northward flow toward the Arctic and is joined by the North Nahanni River. The Great Bear River, draining Great Bear Lake, joins at Tulita. After crossing the Arctic Circle in a northwesterly direction, the river receives the waters of the Arctic Red and Peel rivers. Tributaries that join from the west have their origins in the mountains of eastern Yukon.

The Mackenzie River Basin is conveniently divided into two geographical regions based on subsurface geology. The eastern part of the Basin is characterized by vast regions of lake-studded boreal forest underlain by the Precambrian rock of the Canadian Shield. Some of the largest lakes in North America are found in this part of the Basin. By both volume and surface area, Great Bear Lake, with a surface area of 31,153 sq. km and a volume of 2,236 cu. km is the largest in the Basin and third largest on the continent. Great Slave Lake is slightly smaller, with a surface area of 28,568 sq. km containing 2,088 cu. km of water. At its maximum, Great Slave Lake is considerably deeper than Great Bear Lake, even though the latter has a deeper mean depth. Though still large by continental standards, Lake Athabasca is the third largest in the Basin with an area of 7,800 sq. km. Six other lakes in the Basin cover more than 1,000 sq. km. Not all of these lakes are natural. The Williston Lake reservoir, for example, became the second-largest artificial lake in North America after it was created behind the W.A.C. Bennett Dam on the Peace River in British Columbia.

The western part of the Basin contrasts with the east rather sharply because it is underlain by sedimentary rock. This rock forms the Rocky Mountains as well as the Franklin and Mackenzie ranges. In the western area of the Mackenzie River Basin, the erosion of the softer geological substrate creates sediments that are borne away by the Mackenzie River and its western tributaries. These sediments contribute in important ways to the nutrient regime of the Mackenzie River estuary (Lesack 2012). About 60 per cent of the unimpaired average flow of the Mackenzie at its mouth comes from the western half of the Basin, with the Peace and the Liard contributing 23 per cent and 27 per cent of the total flow, respectively. By contrast, eastern portion of the Basin provides only 25 per cent of the Mackenzie's discharge. This is explained by the fact that the eastern Basin is dominated marshland and large lakes and lacks snow-capturing mountainous highlands.

The difference between the two portions of the watershed is accentuated during the spring freshet. While mountain snow and glacial melt contribute to raising water levels in the Mackenzie's western tributaries, the large lakes in the eastern portion of the Basin slow springtime discharges. Break-up of ice jams caused by sudden increases in temperature can further exacerbate flood peaks. Thus, for example, an interesting phenomenon seen in the Peace-Athabasca Delta is the "mechanical breakup" when melt waters physically lift the ice without melting it, sweeping it downstream where it hangs up in narrow bends, causing water to spill over into the Delta because it cannot flow down the stream. The resulting floods are the largest observed in the Peace-Athabasca Delta (Prowse et al. 2006).

From sources to mouth, the Mackenzie falls only 156 metres. For much of its distance the Mackenzie River is a broad, slow-moving waterway with numerous sandbars and side channels. The river ranges from two to five kilometres wide and eight to nine metres deep in most parts, and is thus easily navigable when it is not frozen. There are, however, a number of places where the river narrows to less than half a kilometre and flows turbulently, such as the Sans Sault Rapids where Mountain River joins

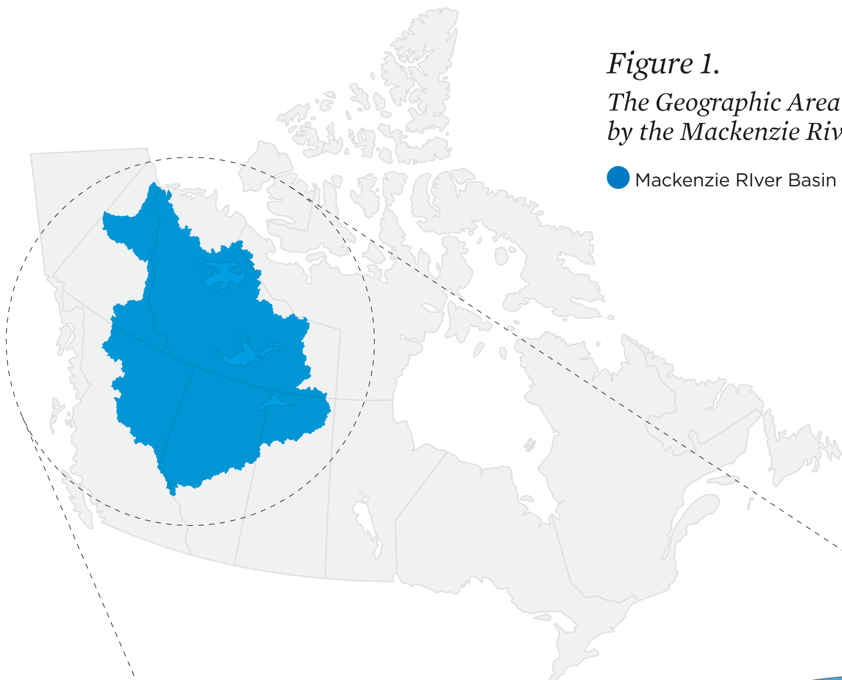


Figure 1.
The Geographic Area Encompassed by the Mackenzie River Basin

Mackenzie RIver Basin

Figure 2.
The Mackenzie River and its sub-basins

LEGEND:

SUB-BASINS: PEEL, MACKENZIE MAIN STEM AND GREAT BEAR LAKE, GREAT SLAVE, ATHABASCA, PEACE, LIARD the Mackenzie and at "The Ramparts," near Fort Good Hope where the entire flow of the river is channeled spectacularly through a 40-metre deep canyon.

At its terminus, the Mackenzie empties into the Beaufort Sea, which is part of the Arctic Ocean. The Mackenzie Delta is a spectacular natural feature that plays an important role determining adjacent hydrologic and oceanographic regimes. At its mouth, the river discharges on average around 313 cu. km of water each year, accounting for roughly 11 per cent of the total river flow into the Arctic Ocean. The mixing of these huge volumes of warmer freshwater with the cold seawater in its estuary is thought to have a significant effect on the local climate in this region of the Beaufort Sea which in turn appears to influence the circulation of waters in the Arctic Ocean.

ECOZONES: Boreal Cordillera, Boreal Plains, Boreal Shield, Montane Cordillera, Southern Arctic, Taiga Cordillera, Taiga Plains, Taiga Shield

Figure 3.

Ecozones of the Mackenzie River Basin

CREDIT: ©Map from the Mackenzie River Basin Board website. Reproduced with the permission of the Mackenzie River Basin Board

THE ECOLOGICAL CHARACTERISTICS AND ROLE OF THE MACKENZIE RIVER BASIN

The ecological zones of the Mackenzie River Basin are shown in Figure 3. The Basin is considered among the most intact large-scale ecosystems in North America. Some 63 per cent of the Basin – 1,137,000 sq. km – is covered by forest, of mostly boreal character. Wetlands comprise some 18 per cent of the Basin – about 324,900 sq. km. It has been estimated that more than 93 per cent of the wooded areas in the Basin are virgin forest.

While it has been estimated that there are as many as 53 fish species in the Basin, none are endemic. Most of the aquatic species in the Mackenzie River are descendants of species that have their origins in the Mississippi River and its tributaries. This anomaly is believed to have been caused by the fact that the two river systems were linked by meltwater lakes and channels during the last major glaciation (Pielou 1992; Rempel and Smith 1998).

The main fish species in the Mackenzie River proper are the northern pike and the lake whitefish, the latter being highly-prized as a food source and a celebrated dish in restaurants from Fort Chipewyan to Inuvik. The most significant fish species spawn in the autumn when low stream flows can be a concern. In the upper reaches of the Basin the river's shores are lined with dwarf birch and willows, which thrive in the region's abundant peat bogs. As the river flows north, its banks are densely forested right to the coast. Due to its cold climate, the northern part of the Mackenzie system is not as ecologically diverse as the headwaters region to the south. Permafrost underlies about three-quarters of the Basin proper, reaching down to 100 metres depth in the area of the Mackenzie Delta. In comparison, the southern half of the Basin is characterized by temperate and alpine forests as well as fertile floodplain and riparian habitats. Large rapids on the Slave River prevent upstream migration of fishes with the result that the southern part of the Basin is home to fewer fish species. While some mountain regions such as those in Jasper National Park receive as much precipitation as 400 millimetres a year, precipitation is meager to moderate elsewhere in the Basin. Precipitation in Inuvik, for example, amounts on average to only 265 millimetres annually (The Weather Network 2013; World Meteorological Organization 2013).

Some 215 bird species have been catalogued in the Mackenzie Delta. These include high-profile endangered species such as the whooping crane, peregrine falcon and bald eagle. In spring and summer, vast numbers of migratory birds occupy the two major deltas in the Mackenzie River Basin – the Mackenzie Delta and the inland Peace – Athabasca Delta. Located at the convergence of four major North American migratory routes, or flyways, the Peace-Athabasca Delta is consider to be one of the most important avian resting and breeding places in North America. As recently as the mid-20th century, more than 400,000 birds passed through during the spring and up to a million in autumn.

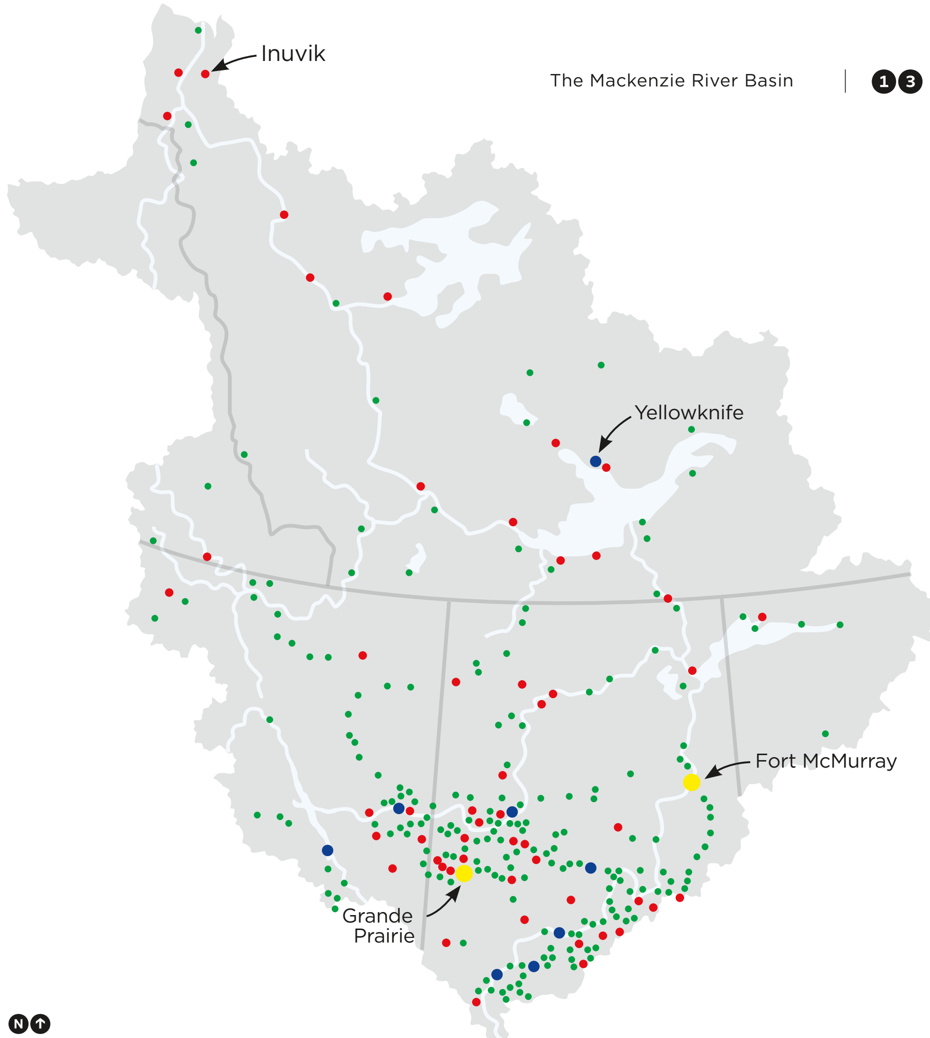
While most of the Mackenzie River Basin is ecologically undisturbed, the construction of the W.A.C. Bennett Dam on the Peace River has clearly reduced seasonal variations in water levels in both the Peace and Slave River deltas, resulting in ecological damage. Damage to the former delta, as well as a reduction in natural habitat in other parts of the migratory bird range throughout the continent, are seen to contribute to the steady reduction of migratory bird populations in the area, a decline that has been observed since the 1960s.

CULTURAL GEOGRAPHY

Approximately 400,000 people reside in the Mackenzie River Basin – representing just over one per cent of Canada's population. Ninety percent of these people live in the Peace and Athabasca River drainage areas, mainly in Alberta. In the past decade, the pace of oil sands development in northern Alberta has increased substantially and Fort McMurray has become the largest community in the Basin (Mackenzie River Basin Board 2012). Boomtowns composed almost solely of people that have arrived within a short period of time from elsewhere, such as Fort McMurray and Grand Prairie, have their own dynamics that are often at odds with long-established local sensibilities related to place. The boomtowns, however, are largely in the southern part of the Basin.

The distribution of the population in the Mackenzie River Basin is shown in Figure 4. As the figure shows, population tends to be concentrated in the southern part of the Basin. The cold northern permafrost regions beyond the Arctic Circle are very sparsely populated, but are the traditional territory of many of Canada's indigenous peoples. This sparse population is concentrated along the banks of the Mackenzie, its tributaries and lakes. As a result, much of the Mackenzie River Basin remains wilderness and – historically, at least – human activities have had little influence on water quality and quantity in the Basin's major rivers. The exception is found in the southern part of the Basin where there are several large boomtowns associated with exploitation of hydrocarbons and non-renewable resources. The population data in the table does not show the extent to which the populations of these places have grown. For example, the population of Fort McMurray was almost 73,000 in 2011, and is expected to increase by more than 80 per cent by 2041 (Alberta Treasury Board and Finance 2012). The exploding population in these southern-Basin centers contrasts sharply with the population of the Northwest Territories.

The Northwest Territories, in which the



Population Distribution: 1996

0-499, 500-4999, 5000-24999, 25000-50000

Figure 4.
Population distribution in the Mackenzie River Basin.

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Mackenzie proper rises, covers an area of 1,346,106 sq. km, approximately 13 per cent of Canada's land mass. As of the 2011 census, it had a population of 41,462, showing little change from the 2006 census. The population density of the Northwest Territories is approximately 0.03 persons per square kilometre. By comparison, Canada (including the Northwest Territories) has a corresponding population density of 3.5 persons per square kilometre, or more than a hundred times that of the Northwest Territories.

Approximately one half of the people residing in the Northwest Territories are of aboriginal descent. Indigenous cultures have lived in the area for thousands of years. They have been supported by the land and its resources, which provide food, clothing, water and other necessities of life. Over generations these people have developed a detailed knowledge of the land, animal behavior, seasonal and climatic changes and ecological relationships. Today, indigenous peoples maintain strong bonds to their traditions while adapting to modern technology and lifestyles. The indigenous peoples of the Northwest Territories have legally recognized rights negotiated through land claims agreements that are uncommon elsewhere in the Western Hemisphere (Sandford 2012).

Travel in the northern part of the Mackenzie River Basin can be challenging and expensive. Canada's northernmost major railhead is located at the town of Hay River, on the south shore of Great Slave Lake. Goods shipped to Hay River by train and by truck and not meant for local consumption are loaded onto barges owned by the Inuit-owned Northern Transportation Company. During the ice-free season, barge traffic on the

The Ice Road between Inuvik and Tuktoyaktuk on the Mackenzie Delta.
Photograph courtesy of R.W.Sandford, UN Water for Life Decade, Canada

river supplies numerous scattered and isolated communities and mining operations along its course. Goods are shipped as far north as the town of Tuktoyaktuk on the eastern end of the Mackenzie Delta. From there they are further distributed among communities along Canada's Arctic coast and the numerous islands north of it. During the winter, the frozen channels of the Mackenzie River are crisscrossed with ice roads which often serve the same purpose of supplying northern communities as barges do in the summer.

It has been observed that ice roads have to be built later and close earlier in the year because of climatic warming. Ice spray technology is being used more widely to create thick load-bearing ice on frozen rivers and lakes and ground-penetrating radar is used to ensure that ice thickness is adequate to bear the weight of vehicles and to locate weak spots in the ice. There is concern that ice roads will not be a reliable alternative to expensive air freight options in the future if warming continues.

SETTING THE STAGE: RESOURCE DEVELOPMENT ACROSS THE BASIN

The greatest economic activity in the Basin is resource extraction. This includes wood products and pulp and paper in the Peace River headwaters, oil and gas in central and northern Alberta and northwestern British Columbia, uranium in Saskatchewan, precious metals and diamonds in the Northwest Territories, and tungsten in Yukon. The Northwest Territories and Yukon experienced the highest growth in the mining and oil and gas extraction sectors from 2002 to 2008. The threats to environmental integrity posed by the potential exploitation of each of the resources vary with the scale of their operations.

There is a long history of abandoned and orphaned mines in the Mackenzie River Basin. The most emblematic of these is the Giant Mine. Located just a few kilometres from Yellowknife, the Giant Mine opened in 1947. Its name derives from the fact that it remains the largest gold mine ever explored in Canada's history. At full operation, it employed 700 to 800 people and for decades was the mainstay of the Yellowknife economy. Mining gold actually entails the extraction and processing of arsenopyrite. The processing or milling separates the gold from the rock, creating a significant volume of mine tailings containing high concentrations of arsenic trioxide. Arsenic trioxide is one of the more poisonous substances on Earth and is water-soluble, posing significant potential for contamination of both surface and ground waters.

The gold milling at the Giant Mine involved "roasting" to melt the gold out of the ore. In the early years of the mine, the arsenic trioxide from the milling simply went up the smokestack and was rinsed off the surrounding rock by rain and snowmelt. Soon, however, every living thing around the mine began to die. Scrubbers were then put on the roasters to remove the arsenic trioxide, which was bagged and stored in old tailings and workings. But soon there was so much of the deadly poison that special below-ground storage chambers had to be built. The storage chambers were called stopes. These stopes were protected by five to 100 metres of surrounding permafrost. Some 270,000 tonnes of arsenic trioxide were disposed of in this way.

The engineering thinking behind this solution is highly relevant in the context of contemporary debate over the future management of the Mackenzie River Basin. It was believed that the permafrost would protect the stopes, encasing and freezing the arsenic dust in ice. Not taken into account, however, was the amount of heat entering the storage stopes by way of the mine workings, which eroded the permafrost from below. Another consideration not taken into account was that the arsenic trioxide dust was still warm from the roasting when it was bagged and stored, which caused permafrost melt to radiate outward from the stopes. The melting was further exacerbated by a decision made in the hard economic times of the early 1980s to permit open-pit, instead of underground mining, of the ores. While the decision to allow surface mining made it cheaper to access the gold-bearing ores, temporarily saving the economy of Yellowknife, the open-pit system began to erode the remaining permafrost from above.

The milling of ore ceased in 1999 and in 2004 the company that owned the Giant Mine declared itself bankrupt. The principals of the company went successfully on to other ventures, including the redevelopment of Pine Point on the south shore of Great Slave Lake. But the permafrost did not stop melting. What exists now at Giant Mine is an enormous tonnage of arsenic trioxide that is water soluble and therefore potentially highly mobile. The only thing presently standing in the way of that mobility is the fact that the dust and its surroundings are a few degrees below the freezing point of water. The Government of the Northwest Territories and the Government of Canada are now faced with having to artificially refrigerate the water-soluble arsenic trioxide stored in the stopes to prevent it from being mobilized by groundwater. The land surface around the abandoned mine and even the tailings can be remediated, but the stopes and the surrounding permafrost will require constant

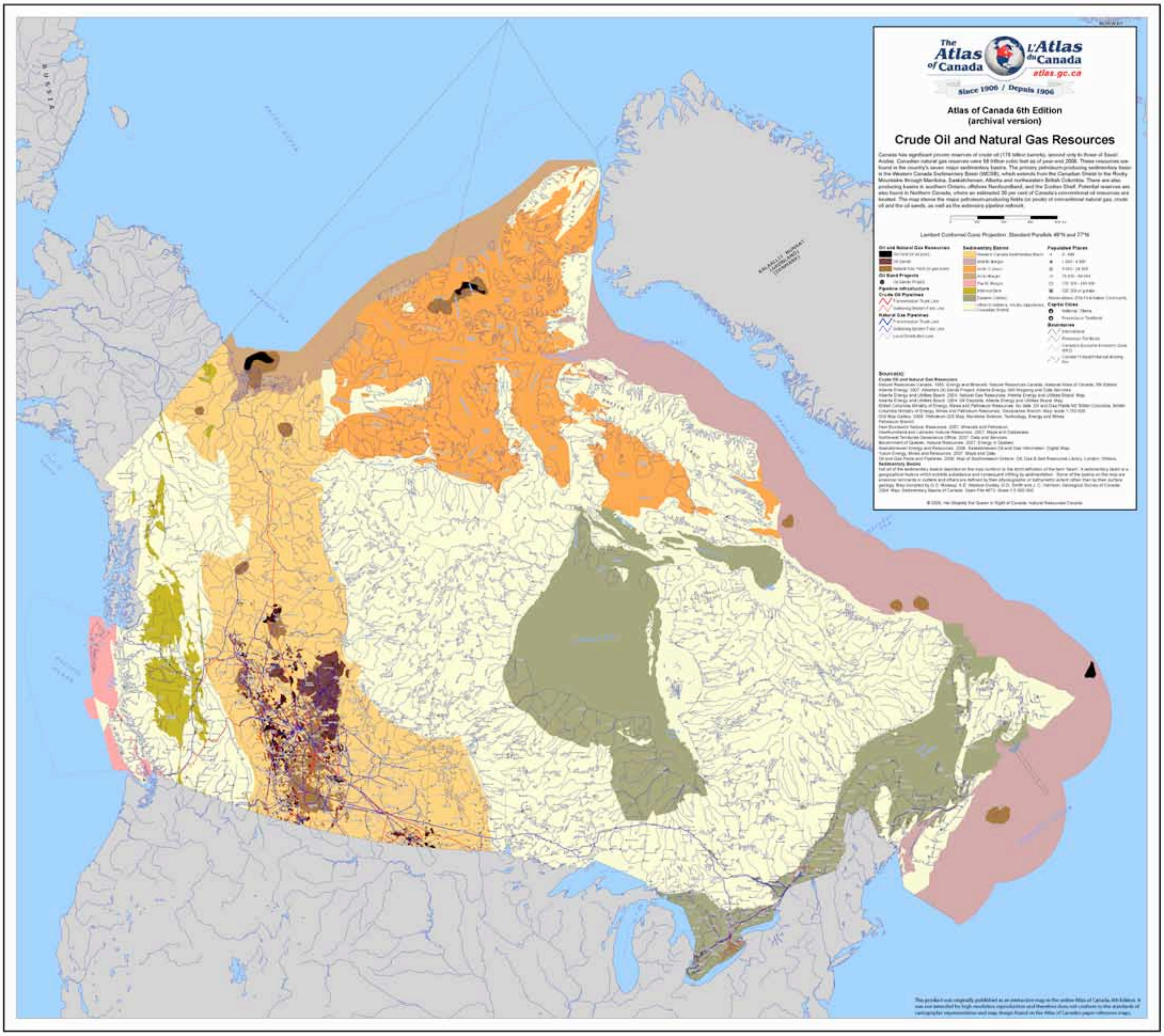

Figure 6.
Oil and gas development in the Mackenzie River Basin region.
CREDIT: Map provided by the Atlas of Canada.

artificial refrigeration and monitoring at huge public cost, possibly forever (Sandford 2009). New regulations associated with the implementation of the Northwest Territories' *Northern Voices, Northern Waters* water stewardship strategy should prevent similar circumstances from occurring again, at least within the Northwest Territories. Development upstream of the Northwest Territories, however, remains a threat (Government of the Northwest Territories and Ministry of Indian and Northern Affairs 2010).

As illustrated in Figure 6, oil and gas extraction in the Mackenzie River Basin is extensive. As a result of new technologies, subsurface mining of shale gas is becoming a major resource development focus. This activity requires the fracturing of subsurface sedimentary rock formations to release the methane trapped therein. There is considerable concern in some areas of the Basin regarding the long-term effect of "fracking," as it is called, on groundwater flows.

The largest resource developments on the Athabasca River system are Alberta's oil sands operations. The website for the Government of Alberta (2013) identifies the oil sands as the third-largest proven crude oil reserve in the world, next to Saudi Arabia and Venezuela. The website indicates that "through responsible development, advancement of technology and significant investment, the Government of Alberta, in conjunction with industry, seeks to enhance Alberta's role as a world-leading energy supplier. New projects are being added every year, and production is expected to increase from 1.31 million barrels per day in 2008 to 3 million barrels per day

Figure 7.
The W.A.C. Bennett Dam on the upper reaches of the Peace River in British Columbia

CREDIT: ©Dave Aharonian. Image provided courtesy of BC Hydro

in 2018, keeping pace with demand and providing a sound economic basis for the future."

Exploitation of the resource potential of the oil sands in the lower Athabasca Basin in Alberta, however, poses a recognized threat to aquatic ecosystem health and stability in the headwaters of the Mackenzie River. Production has exploded in the oil sands over the last decade as improved technology and higher oil prices have established the existence of a proven reserve of approximately 167 billion barrels of oil. In 2011, there were over 90 active oil sands projects in Alberta. The effective monitoring of threats posed by such large-scale resource development is impeded by controversy.

Much of the oil sands development to date has occurred north of Fort McMurray, where bitumen deposits can be mined at the surface using open-pit mining practices. Over 600 sq. km are currently under development. Some 170 sq. km of tailings ponds are part of the development (Mackenzie River Basin Board 2012). Outside of the area where the surface is not mineable, bitumen is removed from deeply buried oil sands deposits using *in situ* methods.

The *in situ* method of extracting bitumen from deeper oil sands formations distinguishes itself from surface mining in that it does not require the creation of an open pit mine with its attendant removal of the boreal forest, topsoil and overburden above the bitumen deposit and the creation of an open pit mine. Steam-assisted gravity drainage (SAGD) is the prevalent form of *in situ* extraction. SAGD recovery involves the horizontal drilling of a pair of wells, one at the top and one at the bottom of the bitumen deposit. In a manner that more resembles conventional oil and natural gas production, steam and solvents are pumped into the upper part of the bitumen reservoir. This warms and thins the bitumen, which then drains through gravity to the lower well where the bitumen-water mixture is captured and pumped to the surface. In ideal circumstances solvents are also captured in this way.

Mining and *in situ* oil sands development have impacts on air, water, land and people. Surface mining of oil sands have led to modification of natural drainage patterns in many tributary watersheds to the Athabasca River. This, in conjunction with airborne emissions, has been shown to affect water quality. *In situ* extraction facilities will dominate future oil sands development. The ever-present potential for structural failure of the tailing ponds will pose risks, both large and growing, of environmental catastrophe. *In situ* extraction will likely result in similar or greater levels of habitat destruction. The impacts of *in situ* extraction include road, seismic line, well pad and pipeline development, all of which affect aquatic and terrestrial habitats through construction-related effects created by stream crossings, changes in the water table that could lead to land subsidence or drying of wetlands, and the indirect effects of increased access to fish and wildlife resources these rights-of-way may provide. In the case of large mammals, noise is also a significant factor (Dyer et al. 2001).

HYDRO-POWER DEVELOPMENT IN THE BASIN

A hydro-power study has been conducted for every river in the Basin. The hydro-power potential of the Mackenzie system has been deemed to be equal to that of all the rest of Canada combined. Although the entire main stem of the Mackenzie River is undammed, many of its tributaries and headwaters have already been developed for hydroelectricity production, flood control and irrigation agriculture. The W.A.C. Bennett Dam (Figure 7) and Peace Canyon Dam on the upper Peace River were completed in 1968 and 1980, respectively, for power generation purposes. The two dams, both owned by BC Hydro, have a combined capacity of more than 3,400 megawatts (MW). The reservoir of W.A.C. Bennett – Williston Lake – is the largest body of fresh water in British Columbia and the ninth largest man-made lake in the world, with a volume of 70.3 cu. km. While Williston's flood control operations have reduced flooding in the Peace River Valley, it has had significant impacts on wildlife and riparian communities lower in the Basin, particularly in the Peace-Athabasca Delta and the delta of the Slave River. Impacts associated with the decrease in annual flow fluctuations in the Peace system have had measureable impacts as far downstream as the main stem of the Mackenzie.

Agriculture in the Mackenzie River Basin is mainly concentrated in its southernmost portion, namely the valleys of the Peace and Athabasca Rivers. It is widely held that the Peace region possesses some of the best northern farmland in Canada. It is likely that warming temperatures resulting from climate change will mean longer growing seasons which will make the Peace River Valley even more attractive for agriculture. Much of the rest of the Basin, especially in its eastern portion will never become desirable for farming, regardless of warming, as it is underlain by the Canadian Shield, hard bedrock which does not produce soils suitable for agriculture.

Upstream reaches of the highly productive Peace River Valley, however, are threatened with flooding by the proposed Site C Dam, pictured in Figure 8. The dam and its associated power plant would generate enough electricity to power about 460,000 households. Site C has been the centre of a protracted and ongoing environmental battle since the 1970s, and a decision has not yet been reached as to whether or not to build the dam. At the very least, construction of this dam will create a barrier to the passage of migratory fish such as whitefish and goldeye.

Site C is not the only hydro-power project proposed for the Mackenzie River Basin.

A proposed US$1 billion run-of-the-river hydroelectricity station just inside the Alberta border on the Slave River would generate at least 1,350 MW of power, most of which would be used in further expansion of oil sands activities in the Fort McMurray area. Changes in federal legislation in 2012 removed the Slave River from federal jurisdiction under the Navigable Waters Act. One utility group, ATCO, has recently announced plans to build two 800 MW dams on the Athabasca River. Some tentative proposals have gone as far as to also include dams on the main stem of the Mackenzie itself (Mackenzie River Basin Board 2012). Should these proposals come to fruition, their implications for the environment of the downstream Mackenzie Basin, as well as its tributaries, could be significant.

These proposed hydropower developments, in combination with rapidly expanding mining operations throughout the region, further threaten the integrity of the Mackenzie as a coherent eco-hydrological system. In order to protect the larger system for the benefit of all who share its water – and to fulfill local obligations to the management of a globally significant resource – decisions made regarding these developments cannot be made unilaterally by the jurisdiction in which such developments have been proposed. The crucial importance of the Mackenzie system demands that decisions related to Site C on the Peace River, dam development on the Slave River, and dam proposals for the main stem of the Mackenzie River, be viewed and considered within the context of their impact on the larger Mackenzie system, and the larger system's profound effects on the climate of the region, the continent, the hemisphere and the planet, via impacts on global oceanic circulation.

Figure 8.
The proposed Site C Dam on the Peace River in British Columbia

CREDIT: Image provided courtesy of BC Hydro

THE MACKENZIE SYSTEM: THE EFFECTS OF COLD ON HYDRO-CLIMATIC CONDITIONS

Only 2.5 per cent of the Earth's water endowment occurs in the form of freshwater and only a tiny fraction of that is available in liquid form for consumptive, instream and environmental uses (Carpenter et al. 1992). Shiklomanov (1997) estimated that, of the tiny portion of the Earth's freshwater, approximately 24 per cent, is groundwater at depths from which economical extraction is infeasible. Additionally, nearly 74 per cent of the freshwater supply is found in the world's glaciers and perpetual snow. Although the latter quantities of water are not readily exploitable for everyday uses, they play a very important role climatologically. The portion of the planet's freshwater assets that are frozen in the form of ice and snow is called the cryosphere. The vast expanses of ice, snow and terrain underlain by permafrost in the Mackenzie River Basin exert globally significant influences on Earth's climate. Thus, for example, the cryosphere can moderate atmospheric temperatures by as much as 5°C, for example (Fitzharris 1996).

The amount of snow and ice-covered land area located in the Northern Hemisphere is significant. Currently, snow cover in the Northern Hemisphere ranges from about 46 million sq. km in January to about 3.8 million sq. km in August. Almost all of the 9.9 million sq. km-area of Canada, including all of the Mackenzie River Basin, can be covered by snow in January. The portion of the cryosphere within the Basin influences the global climate system in a number of important ways, some of which are unique. Cryospheric influences contribute to the health of life, land, water, and the weather-climate interface that defines the climate of not just North America, but of the entire Western Hemisphere (Rouse et al. 2003; Szeto et al. 2007). The more important of these influences are enumerated below and help to explain why the Basin is a resource that contributes benefits to populations well outside its borders.

INTACT ECOSYSTEMS SLOW AND MODERATE CLIMATE EFFECTS

It is well known that various kinds of ecosystems generate, capture, purify and release water at different rates. Forests modulate the hydrological cycle by absorbing heavy rains, enhancing the seepage of water into the ground, which is held firmly in place by tree roots, and reducing surface run-off. In combination, these effects moderate the release and availability of water throughout the year.

If this role is reduced below certain thresholds, affected systems can no longer act as buffers to disturbance. We now know that supplying water to nature is crucial in preventing ecosystems from changing in undesirable ways. Desertification is but one example. The careful capture of as much water as possible in upstream areas by rainwater harvesting, and through natural processes, has been proven to assist in maintaining resilience that prevents or moderates the possible effects of both flooding and drought, while at the same time generating greater flow volume downstream (Safriel 2011).

Research conducted at the University of Saskatchewan and Environment Canada shows that intact boreal forests are natural water managers that will protect the stability of surface water resources and local climate under substantial global climate variability (Pomeroy and Granger 1997; Granger and Pomeroy 1997). Removal of the boreal forest by harvesting was found to increase the incidence of both spring flooding and summer drought and surface heating. The clear cuts were hydroclimatically fragile while the intact forest demonstrated resilience. As one of the largest relatively intact forest ecosystems in the Western Hemisphere, the Mackenzie River Basin's current stability contributes to global natural system resilience that moderates climate and freshwater cycling variability, not just regionally, but continentally and globally (Broecker 2000).

THE MACKENZIE SYSTEM HAS A REFRIGERATING EFFECT ON THE NORTHERN HEMISPHERE

The cryosphere affects the global climate system through its direct influence on air temperature. In general, a quarter of the globe is covered by snow at any given time. Ice and snow cover have enormous potential powers of reflection. Snow and ice can reflect as much as 95 per cent of sunlight that falls on it back into the atmosphere. This high degree of reflectivity, or albedo, as it is called, is an important climate feedback mechanism. Snow cover affects climate in regions remote from the snow cover itself because it increases the amount of radiation lost near the Earth's surface. Arguably, these effects are global. Snow cover, atmospheric circulation and temperature are interrelated to each other and interact with one another for form feedback mechanisms (Groisman and Davies 2001). Temperature is a major determinant of the form and speed through which water moves through the global hydrological cycle. Water and temperature are major determinants of climate and climate exerts a major influence on ecosystems – and ecosystems define us. There is not a person on Earth who is not affected by what ice does (Pollack 2009). Long-term spatial and temporal change in snow cover in the Mackenzie system will propagate well beyond that basin to alter snow and ice cover and other controls of climate regionally and globally (Groisman and Davies 2001; Sandford 2012).

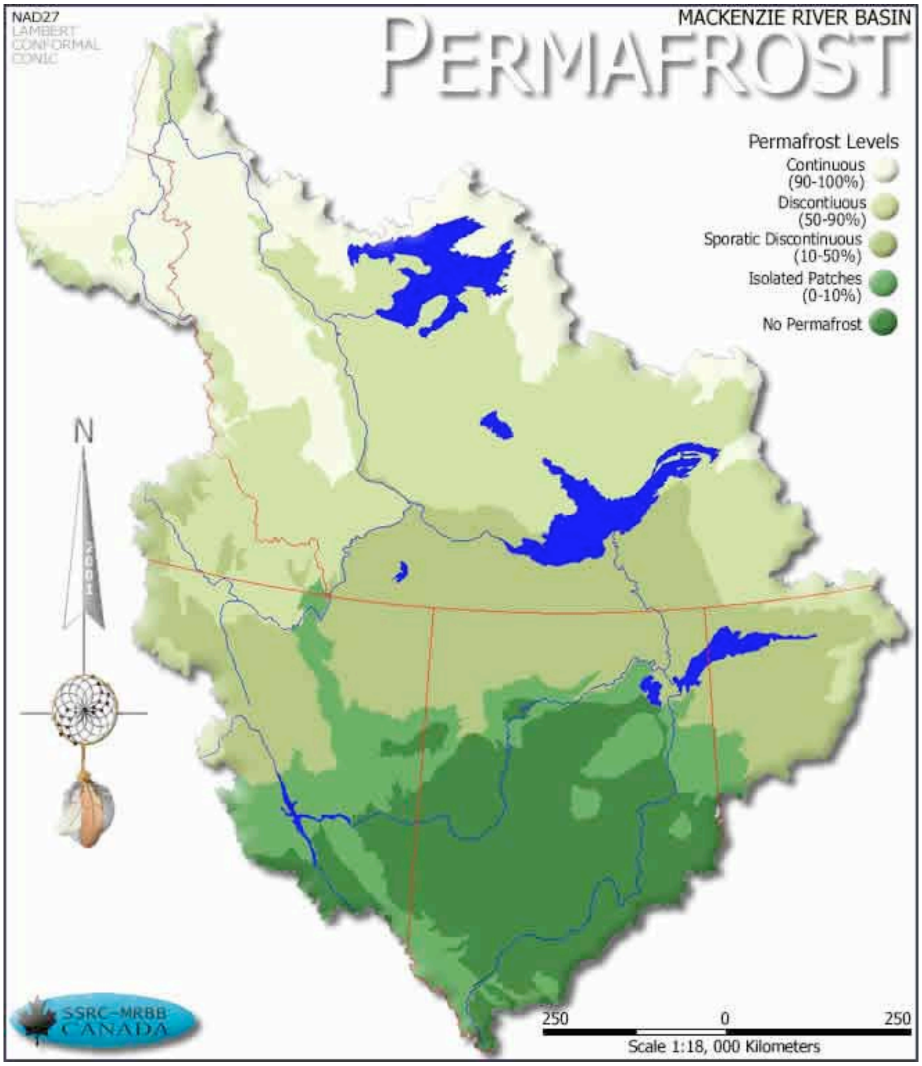

Figure 9.
The distribution of permafrost in the Mackenzie River Basin.

CREDIT: ©Map from the Mackenzie River Basin Board website. Used with the permission of the Mackenzie River Basin Board.

Recent research conducted by Wadhams (2012) indicates that the loss of Arctic ice may be compounding the heat trapping impacts of greenhouse gas emissions. The polar ice cap acts as a giant parasol, reflecting sunlight back into the atmosphere through the albedo effect. White ice and snow reflect far more of the sun's energy than the open water that is replacing it as the ice melts. Instead of being reflected away from the Earth, this energy is absorbed, and contributes to warming. The extent of sea ice is currently at its lowest in recent history, causing greater and greater absorption of warmth (Wadhams 2012).

It is also important to note that a countervailing force in the Mackenzie arises from the fact that it serves as a "heat pump" carrying warm water northward. The importance of this effect is easily seen by the position of the tree line, which extends right to the mouth of the river in the Mackenzie Delta, but ends as far south as Great Bear Lake in parts of the Basin away from the main stem of the river. The effect is most pronounced in spring, when warm waters from the southern parts of the Basin are carried north, causing a mechanical breakup of ice on the river long before melting occurs in downstream parts of the Basin. A similar effect is seen in late autumn, as the river does not freeze until the surrounding landscape is much colder. Overall, the mean annual temperature in the immediate Mackenzie Valley can be 4-5^{o}C warmer than outlying parts of the Basin at the same latitude (Mackay 1963).

Modeling studies may also be instructive. Brown and Mote (2009) examined the sensitivity of snowpack models by comparing satellite measurements of snowpack with simulations from multiple models. The analysis of trends in the satellite data on snow cover duration showed that during the period 1966-2007 the largest declines in snow cover were concentrated in zones where seasonal air temperatures were in the range of −5^{o} to 5^{o}C. The analysis also suggested that the interaction between snow accumulation rates and the duration of the snow season is linked non-linearly to increasing temperature and precipitation (Brown and Mote 2009). A later analysis of the Northern Hemisphere spring terrestrial snow cover extent based on National Oceanic and Atmospheric Administration data for the April to June period reveals significant reductions in snow cover extent in May and June. Successive records for the lowest June snow cover extent have been set each year for Eurasia since 2008 and in three of the past five years for North America. The rate of loss of June snow cover extent between 1979 and 2011 is estimated at 17.8 per cent per decade which is greater than the loss of September sea ice extent (10.6 per cent per decade) over the same period (Derksen and Brown 2012).

The presence of polar ice has an even greater refrigerating effect than snow (Holland and Bitz 2003). Researchers are discovering that ice is the central element in the planet's thermostat. It appears that the entire globe is somehow affected by the moderating influence of ice on global mean temperatures (Conkling et al. 2011). Arctic ice acts as a mirror, reflecting as much as 95 per cent of the sun's energy but without it, 90 per cent of that energy will instead be absorbed. This is a concern because the Arctic ice pack has thinned by 40 per cent in the last half-century and is still receding. Less Arctic ice in summer means more ocean water is exposed, which in turn means more solar radiation will be absorbed, resulting in ice forming later and later in the fall. The newly formed sea ice will be thinner when it melts the following spring. Spring breakup will come earlier, resulting in a longer warming season for ocean water. This warming eventually mixes into the deeper ocean, which leads to sea-level rise through thermal expansion.

Since temperature variations between the equator and the poles help shape ocean currents and jet streams alike, melting at the poles threatens disruption of global weather patterns.

If the Arctic sea ice disappears it will be for the first time in 55 million years and thus will be the largest change in the earth's surface ever experienced by human beings. Knowledge of the Earth's climate system is still comparatively limited, so it is difficult to predict what the ultimate impacts might be. The Mackenzie system is globally important, in part, because it influences the changes in the extent and duration of sea ice in proximity to its mouth. These changes are now occurring faster than anywhere else in the Northern Hemisphere (Comiso 2002).

THE PERSISTENCE OF PERMAFROST

Cold regions like the Mackenzie River Basin also moderate Earth's climate system by storing or capping enormous volumes of carbon under permafrost, preventing its escape to the atmosphere. Deep permafrost can take 100,000 years to form. Permafrost covers 20 per cent of the Earth's surface and is in some places two kilometres deep. But in some regions, such as the Mackenzie River Basin, where average annual temperature is only slightly below freezing, the permafrost is much thinner. Loss of this permafrost will release massive quantities of methane into the atmosphere. Figure 9 shows the distribution of permafrost across the Basin.

Tarnocai et al. (2009) found that permafrost contained even more carbon than the peatlands that overlie it. The carbon inventory that these authors observed in boreal permafrost suggests that the boreal forest may be a larger carbon sink than previously realized, and that the consequences of melting permafrost may be releases that are at least double the estimates of carbon losses from peatlands alone. Schindler and Lee (2010) used the estimates of Tarnocai et al. to conclude that boreal carbon stores may be as much as four times those of tropical forests.

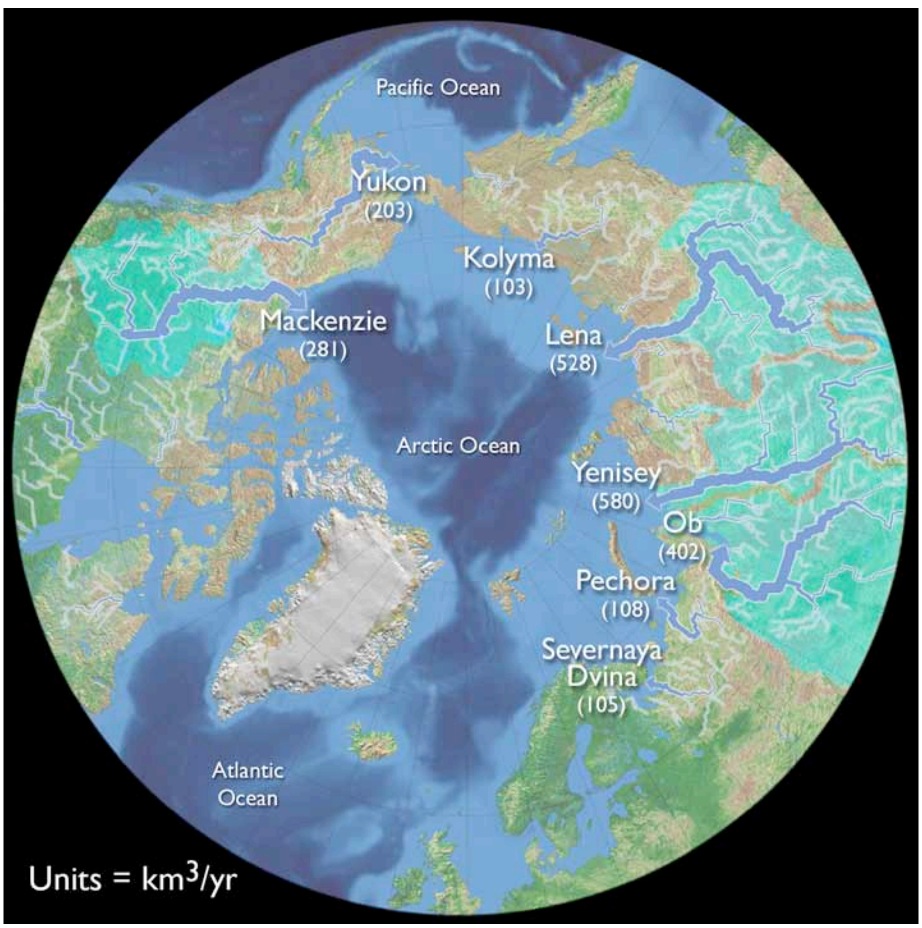

Figure 10
Relative flow contributions to the Arctic Ocean (discharge in cubic kilometres per year).
CREDIT: ©2004, ACIA / Map ©Clifford Grabhorn

Very little is known about the role that permafrost plays in the larger geomorphological context of the Mackenzie River Basin. The work of Quinton et al. (2009) shows that much of the permafrost at the southern boundary of its extent in the Basin has a mean annual temperature of −0.1 to −0.2°C. In these locales this means that small temperature changes can have large impacts on the physical landscapes' associated biota. The thawing of permafrost in what are called "peat plateaus" has led to significant land subsidence. The impact of such subsidence on roads, bridges and airport runways, and potentially on pipelines, is a major threat to existing infrastructure. In parts of the Arctic, buildings are beginning to tilt and sink into ground that is no longer solid because the permafrost is melting (Sandford 2012).

The fact that permafrost is diminishing in the North is not just a problem for existing and proposed transport facilities in the Mackenzie Valley. It is an example of a self-reinforcing "positive feedback" process in which a small disturbance can trigger a chain reaction leading to a large magnitude perturbation. That is, *A produces more of B, which in turn produces more of A*. Warming in the Mackenzie Valley is causing more permafrost to melt, which releases greenhouse gases and lowers albedo, causing more warming. These self-reinforcing chains of reactions are also accelerating in the region of the Beaufort Sea. Not only is the hydrology of the entire Arctic changing, but positive feedbacks that increase the generation of greenhouse gases appear to be already accelerating warming.

In the Arctic, the crystalline structure of ice is similar to a semi-spherical cage (National Research Council 2004). The form of ice is found at relatively shallow depths within the underlying sedimentary deposits. This type of ice is widespread on the continental shelves and, on rare occasions, continental deep lakes such as in Siberia's Lake Baikal. Such ice is of special interest because of its capacity to trap methane within the molecular cage (Sandford 2012).

Drilling into the shelf sediments has yielded samples of this gas-bearing ice from a great many sites throughout the circumpolar region. When ignited, samples put on quite a show – chunks of ice aflame defy all intuition. Methane, of course, is an important source of energy in the industrialized world, but it is also a significant greenhouse gas when released into the atmosphere. The release of methane from its subsurface ice cage is therefore a worry in the context of runaway climate change

Figure 11. “Strudel hole” in offshore iceflow here is strong, causing a drain-hole whirlpool.
Photograph courtesy of Dr. Lance Lesack, Simon Fraser University

and further sea level rise (Sandford 2012).

Methane release from the Arctic seabed in 2011 significantly exceeded what had been observed over the preceding 20 years (Semiletov et al. 2012). Though it does not reside as long in the atmosphere, methane is up to 21 times more potent a greenhouse gas than CO_2. One potential consequence of global warming in the Arctic and yet another positive feedback effect could be the release of the hundreds of millions of tonnes of methane presently frozen in permafrost or held in place on sea floors by the cold temperature of Arctic seawater. Such release would increase the capacity of the atmosphere to trap more heat and further acceleration of global warming would be the result.

THE MACKENZIE RIVER HAS A DEMONSTRABLE EFFECT ON SEA ICE FORMATION AND A PROBABLE EFFECT ON THE DYNAMICS OF GLOBAL CIRCULATION OF DEEP OCEAN CURRENTS

Nearly two-thirds of the water flowing into the Arctic Ocean comes from four rivers as shown in Figure 10. The Mackenzie is the fourth largest of these, but is the only large northward flowing river in the Western Hemisphere (although some would consider the Yukon a large north-flowing river). The remainder of the northward flow of approximately 40 per cent comes from smaller rivers in other parts of the circumpolar world.

While it appears to contribute only a modest amount of water to the Arctic, some researchers think it is more than proportionately important in terms of its influence on Arctic Ocean currents (Spence 2012). Of all the Arctic rivers, the Mackenzie carries the most sediment, especially in flood. The reason for this is that the great Russian rivers flow through interior plains, while the Mackenzie has its origins in upland mountains. The Mackenzie also brings a great deal of heat into the Beaufort Sea.

In spring, the turbid water of the estuary flows out over the land-fast ice to create what researchers call “Lake Mackenzie.” Stimulated by 24 hour-a-day sunlight, bacteria and algae proliferate massively in the freshwater on top of the ice. As the spring melt progresses, this water and the life within, drains through “strudel holes” into the ocean (Figure 11). The “Lake Mackenzie” river water is prevented from flowing into the Arctic Ocean, however, by the Stamuki Ridge, a pressure ridge that has formed at the interface between the land-fast ice and the sea ice. What results is an 18-metre nutrient-rich lens of freshwater floating on the top of the Arctic Ocean (Lesack 2012).

When cold Arctic air freezes sea water in winter, the salt in that sea water is released into the waters below making that water heavier than that which is above it. This denser, saltier water sinks to become part of what is known at the Arctic Halocline. Because of the extent of its freshwater inflows and their influence on wave height and ice formation, the estuary of the Mackenzie is one of the few places in the world where the creation of sea ice allows ocean water to sink enough to maintain deep-water circulation. While knowledge of how freshwater flows in sea ice formations is far from complete, diminished flows could affect deep water ocean current circulation (Broecker 2005).

CONCLUSIONS

The Mackenzie River Basin has unique hydrologic, ecologic and climatological features and processes. Planetary warming threatens the stability of these processes and the integrity of the Basin ecosystems. Simultaneously, exploitation of the Basin’s considerable non-renewable resources and hydroelectric generating potential has become more attractive economically as demands for these resources and energy grow. The threats posed by global warming mean that the resiliency and capacity of the Basin for self-repair are in jeopardy. One major consequence is that development activities are likely to be even more harmful than they would be in the absence of planetary warming. The existence of warming and its potentially profound impacts on the natural systems of the Mackenzie River Basin emphasizes the fact that future development must be undertaken in a balanced and sensitive way if the capacity of the Basin to provide environmental services, unique habitat and a stable homeland for indigenous peoples, is to be protected and preserved.

EXISTING SCIENCE & SCIENTIFIC EVIDENCE: WORRISOME SIGNALS AND TRENDS

LANDMARK EARLIER RESEARCH

The Mackenzie River appears to be less well studied than most other major rivers of the world. There is, nevertheless, an important body of research focused on the Mackenzie River Basin. Some of this research, large in volume, may be important but is now inaccessible. For this reason, the working body of knowledge about the Mackenzie appears relatively small. Nevertheless, significant research has been conducted there. Among the major research projects are the Mackenzie Basin Impact Study conducted under Environment Canada's Project Lead Stewart J. Cohen. Interim Mackenzie Basin Impact Study Reports were submitted in March of 1993 and November of 1994. The final report, *Mackenzie Basin Impact Study (MBIS) Final Report* was published in 1997. The four major findings of that report were consistent with later research findings presented to the Rosenberg Panel:

1 Most of the regional effects of climate warming scenarios will be adverse. They include lower minimum water levels in the region's waterways and increased erosion from thawing permafrost, as well as a rise in the number of forest fires and landslides and a reduction in the yields of forests. These effects will probably offset any potential benefits from a longer growing season. Some of these changes have been observed during the recent 35-year warming trend.

2 Most participating stakeholders believe the region could adapt if the changes occur slowly. However, rapid warming will make adaptation considerably more difficult. If vegetation and wildlife patterns are modified by climate change, then indigenous peoples' subsistence lifestyles are at risk. The effect of long-term climate change on communities, however, will also be determined by other factors, including lifestyle choices made by the region's inhabitants. Although socio-economic patterns and determinants are not well understood, it is possible that subsistence lifestyles will not be feasible in the future.

3 Increased local and regional control of land and water resources will help to reduce the area's vulnerability and help local residents adapt to climate change. That, however, may not be enough to respond effectively to global warming. Similarly, reducing regional emissions will not be enough to prevent the climate from changing. If the governments that signed the convention on climate change fail to slow the change in climate, then regional stakeholders may need to intervene at national and international levels to warn others about the consequences to the Mackenzie River Basin.

4 The effect of a change of climate on the Mackenzie River Basin is more than the sum of changes to the trees, water and permafrost. Governments, communities, industries and people will respond to the combined effects of climate change on water and land resources. These responses will be tempered and shaded by the choices of government officials, community residents and industry leaders in response to other issues such as the demands of the global economy, traditional lifestyles and political realities. Computer models are one way to bring together or integrate many parts of the whole, but these models are limited in their abilities to describe how regions and people relate to climate change and other stresses. The experience of the Mackenzie Basin Impact Study suggests that an integrated assessment requires a partnership of stakeholders and scientists, in which visions are shared and respected, and information is freely exchanged.

Canada also participated in the Global Energy and Water Cycle Experiment (GEWEX), which examined cold regions atmospheric and hydrological processes with a special focus on the Mackenzie Basin. The Mackenzie GEWEX study came to be known as MAGS. The GEWEX-MAGS study remains relevant and timely in that it was the first comprehensive study aimed at understanding and modeling the high-latitude energy and water cycles that play roles in the climate system. The research strengthened the scientific bases for assessing changes to Canada's water resources that arise from climate variability and anthropogenic climate change. Much of the research conducted since the GEWEX-MAGS study confirms the trends and concerns it identified, particularly those related to warming effects on wildfires, snow, permafrost, lakes, river ice and stream flow. There is strong scientific evidence that subtle hydro-climatic changes are triggering accelerating effects on the Mackenzie system, and that these same effects are beginning to manifest themselves further south (Szeto 2002; Szeto et al. 2008). Thus, for example, Canada's southern boreal forests are expected to be increasingly sensitive to change in the 21st century because hydrology so dramatically affects vegetation (Bergengren et al. 2011). Changes in the timing and volumes of stream flow resulting from a possible shift in the climate regime are expected to impact forest ecosystem resilience to other stressors (Peng et al. 2011; Anderegg et al. 2012). In both the prairie region and in Canada's northern boreal forests, adaptation is tied to hydrologic processes and human activities.

These major studies establish that small changes in temperature in the Mackenzie River Basin are likely to have big consequences over time which will introduce a great deal of uncertainty into the management of the system. A number of troubling positive feedbacks from increasing mean temperature are already occurring throughout the Basin. While there is little clarity about the extent to which these feedbacks will accelerate over time or exactly how they will change the future ecology, hydrology and climate of the Mackenzie, even small changes clearly matter.

ACCELERATED WARMING

Summer weather in the Mackenzie River Basin comes from the Pacific Ocean in the west, and occasionally from the south. When southern air masses collide with Pacific masses in summer, it can result in large storms. In winter, the weather comes mostly from the west, cools, and then moves southward to freeze the Central Great Plains. Most of the precipitation in the Basin falls in the mountains.

It is has been observed that temperatures are sometimes unexpectedly high in the central Mackenzie River Basin in summer. Winter temperatures are also rising dramatically. Warm air has begun to come north earlier in the spring and often persists longer into the autumn. The northern regions of the Basin are warming faster than anywhere else in Canada.

While atmospheric modeling is being advanced, it is still inadequate as a tool for determining how much temperature might rise given a variety of climate change scenarios. The mean temperature rise in the Mackenzie River Basin is already beyond the 2°C mean annual warming that was agreed upon in Copenhagen as being undesirable for humanity to exceed. The most noticeable effects of this warming relate to changes in the extent and timing of spring runoff; changes in spring and fall precipitation; changes in the amount of precipitation that falls as rain as opposed to snow; changes in evaporation; changes in freeze-thaw patterns; and changes in the extent and depth of lake, river and sea ice. In addition, plants are leafing out and flowering earlier and some avian migrations are occurring earlier.

The hydrology of the Northwest Territories is already changing and all signs indicate these changes will accelerate over time. This means that the Northwest Territories water strategy could become irrelevant in the face of hydro-climatic changes that are completely outside human ability to cope. This could happen in other parts of Canada as well. These changes in the Mackenzie are a major part of the ongoing global Arctic ice collapse.

SEA ICE LOSS

In 1980, the eight million sq. km of Arctic ice in summer made up some two per cent of the Earth's surface, but by 2007, the area of this ice had roughly halved (Wadhams 2012). The same research indicates that since 1979, an area of sea ice twice the size of Quebec has been lost, likely creating feedback that further accelerates ice losses. Thinner ice in one year leads to easier and quicker melt in the next. When white, highly reflective ice is melted, the darker opened water absorbs more solar energy, diminishing new ice accumulation.

The World Meteorological Organization (2012) reported that ice cover in the Arctic between March and September of 2012 had been reduced by an area of 11.83 million sq. km (Figure 12). This means that the area of Arctic sea ice that melted in the summer of 2012 is two million sq. km larger than the entire landmass of Canada. The implications of such rapid melt are manifold. The loss of Arctic sea ice and the reduction of the extent and duration of snow cover in the Northern Hemisphere are reducing the gradient in temperature between Arctic air masses and those of more temperate regions to the south that could affect weather patterns throughout the Western Hemisphere and around the world.

It has been demonstrated (Wadhams 2012) that the increased absorption of the sun's rays taking place as a result of the loss of Arctic sea ice is having a warming effect equivalent to adding about 20 years of additional CO_2 through human emissions. If these estimates are correct they imply that over recent decades the melting of the Arctic ice cap put as much heat into the Earth's hydro-climatic system as all the human-generated CO_2 during that time. If the ice continues to decline at the current rate, its loss could play an even bigger role in changing plants' climate and water cycle than greenhouse gases.

PERMAFROST LOSS

Approximately half of Canada's landmass is underlain by permafrost. The thawing of some of this permafrost over extensive areas of the Canadian North is one of the most important and dramatic manifestations of warming in Canada. Documented examples include land-cover transformations occurring at the southern margin of the permafrost as ground thaw results in forests collapsing into wetlands and the widely documented rapid colonization by shrub species across the pan-Arctic. This ongoing permafrost thaw feeds back synergistically with its effects on vegetation, snow cover, soil moisture, and subsurface permeability. These changes are transforming the ecology, surface energy balance and hydrological cycle of northern regions. Widespread thaw of permafrost will alter the pattern, timing and rates of heat, gas and mass exchanges both vertically and laterally at local and regional scales. This change will have widespread impacts on the atmosphere, vegetation communities, and the Arctic Ocean through changes in the quantity and timing of runoff (Quinton 2011; Woo 1992).

RUNAWAY METHANE EMISSIONS

Huge volumes of methane are trapped within the permafrost. Methane released from thawing permafrost migrates up through the sediments and bubbles into the ocean water above. We can anticipate some changes in the Mackenzie from research done in Siberia. Shakhova et al. (2010) estimate that the Siberian Shelf alone harbours some 1,400 billion tonnes of methane in gas hydrates, about twice as much carbon as is contained in all the trees, grasses and flowers on the planet. If just one per cent of this escaped into the atmosphere within a few decades, it would cause abrupt climate change (Mascarelli 2009; Shakhova et al. 2010).

Recent scientific observations of dramatic and unprecedented volumes of methane bubbling to the surface in the Russian Arctic have been cited as a cause for concern. Semiletov's (2012) findings that the methane emissions from the Russian Arctic were about eight million tonnes a year, some two to 10 times more than previously predicted. In 2011, Semiletov and his colleagues conducted an extensive survey of some 16,000 sq. km of sea off the East Siberian coast. They used seismic and acoustic instruments to monitor the "fountains" or plumes of methane bubbles rising to the sea surface from beneath the seabed. In a very small area, the research team counted more than 100 fountains, or torch-like structures, bubbling through the water column and injecting methane directly into the atmosphere from the seabed.

Methane fields on a scale not reported

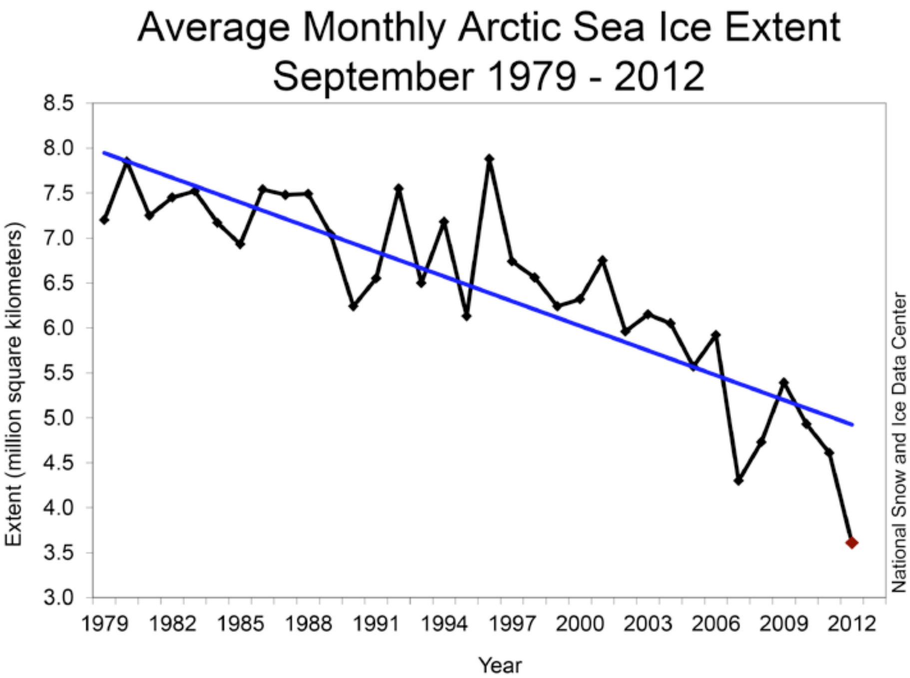

Figure 12.

Monthly September ice extent for 1979 to 2012 shows a decline of 13% per decade.

CREDIT: National Snow and Ice Data Center.

before were discovered by Semiletov (2012) and his colleagues. Among the discoveries were methane plumes a kilometre, or more, wide, which emitted highly concentrated quantities of methane directly to the atmosphere. This was also the first discovery of seeping structures deep on the ocean floor, more than 1,000 metres in diameter. More than a hundred such structures were found in a small area, but there are likely thousands of them over a wider area.

The deeper sediments of the Beaufort Sea also contain deep layers of methane hydrate – an ice-like mixture of water and natural gas. As the seafloor warms as a result of rising air and water temperatures, these hydrates decompose, releasing additional methane gas from the sediment into the waters of the Beaufort Sea.

In the fall of 2010, a collaborative research cruise was conducted to the Beaufort Sea on the Canadian Coast Guard ice breaker *Sir Wilfred Laurier* to investigate sites where methane venting, possibly associated with decomposing gas hydrate and/or permafrost, was established as a possibility. During this expedition a small submersible was used to document the nature of these seafloor gas vents and the existence of methane bubbles on several occasions (Paull et al. 2012). Based on observations, as well as the contents of sediment cores collected by the Geological Survey of Canada, the researchers concluded that the shelf edge in the Beaufort region is an area of "widespread diffuse venting" and that "methane permeates the shelf edge sediments in this region."

While researchers have begun to understand where the gas in the Beaufort Sea is coming from, many other questions remain unanswered. Research has demonstrated that undersea landslides are common along the continental slope of the Beaufort Sea, but circumstances under which they happen are not yet clear. Decomposing methane hydrates have been shown to trigger major landslides in other deep-sea areas of magnitudes that could potentially destabilize oil platforms or pipelines on the seafloor, and have the potential to generate tsunamis. Adequate research has yet to be conducted, however, on how the water temperature, flow rates and circulation of freshwater inflows of the Mackenzie River might influence the release of methane from the floor of the Beaufort Sea. Recent research results suggest that 85 per cent of the methane suspended in northern permafrost and on Arctic seafloors would be released by a warming of only 3°C (Mosher 2009; Mosher et al. 2012).

The threat posed by uncontrolled release of methane hydrates adds additional uncertainty to the management of the Mackenzie system. In order to deal with uncertainty, much more needs to be understood related to cause, effects and timing of all phenomena related to changes in the hydrological cycle and energy balance of northern regions brought about by warming temperatures.

NITROGEN FIXATION IN THE BEAUFORT SEA

Recent research (Blais et al. 2012) has indicated that global gaseous nitrogen fixation rates may be underestimated. This research indicates that critical data are lacking from many regions, such as the world's cold oceans, which do not possess conspicuous diazotrophic cyanobacteria – known nitrogen-fixing species whose fixation rates have been used to estimate global nitrogen fixation rates. This research, which estimated nitrogen fixation rates at diverse sites in the Canadian Arctic, including the mouth of the Mackenzie River, the offshore Beaufort Sea, Lancaster Sound and Baffin Bay, revealed that the Mackenzie River is the source of biological nitrogen fixation. Genetic analysis suggested this was from freshwater cyanobacteria in the order Nostocales that contributes new nitrogen to the nitrogen-depleted surface waters of the Beaufort Sea. This nitrogen contribution is a vital foundation of the food web that emanates from the estuary of the Mackenzie through the entire Arctic Ocean (Blais et al. 2012).

This first record of nitrogen fixation at high latitudes yields a greatly refined understanding of the global nitrogen budget. Virtually nothing, however, is presently known about how changes in upstream activities in the Mackenzie system will alter the nitrogen budget of the Mackenzie Delta or the food web that is created as its inflows mix with the waters of the Beaufort Sea.

THE EFFECT OF WARMING ARCTIC TEMPERATURES ON CANADA'S WESTERN MOUNTAINS

Rising Arctic temperatures are already affecting the hydrological cycle in other parts of Canada. Canadian regions that are already undergoing unprecedented change include permafrost areas of northern Canada and the Western Cordillera, as it is known. In Canada's western mountains declining spring snow cover and glacier cover are exhibiting dramatic responses to climate warming. Glacier coverage has declined by approximately 25 per cent in the last quarter century and the spring snow covered period has decreased by approximately one month in the Canadian Rockies (Bolch et al. 2010).

Glacial recession in this region is occurring in tandem with a shift from snow to rain on the eastern slopes and a decrease in streamflow in both glaciated and non-glaciated streams in the headwaters of both the Peace and Athabasca Rivers (Demuth and Pietroniro 2003; Marshall et al. 2011; Stahl and Moore 2006). In the northern half of the Western Cordillera that feeds the Mackenzie River, however, stream flow is increasing and peak flows occur much earlier for reasons that are not fully understood (Jacques and Sauchyn 2009). Ecosystem responses to these changes are difficult to specify in this region because of natural topographic and geological variability, and the cumulative effects of pine beetle infestations on forests already heavily harvested.

Instrumental and proxy records demonstrate that both the western boreal forest and the Canadian prairies have experienced large swings in climate over the past several centuries, with the greatest extremes of wetness and dryness over the course of the past 140 years occurring since 2000 (Stewart et al. 2011). These swings in climate in combination with agricultural activity have resulted in extensive soil depletion, the decline of aspen forests and the widespread disappearance of wetlands and streams. Groundwater levels have dropped dramatically, particularly during droughts such as the one that occurred between 1999 and 2004 (Stewart et al. 2011).

Overall, the greatest increases in temperature have occurred during winter and spring, with the biggest increases being in minimum, as opposed to maximum temperatures (Zhang et al. 2010). Temperature increases as expressed by the number of warm days where the maximum temperature has been in the ninetieth percentile or higher, and the number of summer days above 25°C, have increased over most of the Mackenzie River Basin in the last half-century (Vincent and Mekis 2006).

A measured general increase in precipitation has occurred across Canada since the 1950s. Nevertheless, there is still considerable regional variability in rainfall (Insurance Bureau of Canada 2012). The general increase in precipitation has been characterized by an increase in the number of multi-day rain events as opposed to local convection storms; and more precipitation falling as rain compared to snow (Zhang et al. 2010; Shook and Pomeroy 2012). Snow cover duration and the extent of spring snow cover in the Northern Hemisphere, including the Mackenzie Basin, have also declined (Brown and Mote 2009; Schindler and Donahue 2006). Terrestrial ecosystems are already responding to the changes. Forests are being converted to wetlands in areas where permafrost is thawing; and shrub height and coverage are already increasing in areas characterized as tundra.

Over the last 30 to 50 years, mean stream flow has decreased in many parts of Canada. There has been a particularly significant reduction in the south, where spring freshet is occurring earlier (Zhang et al. 2010). However, earlier and sometimes higher stream flows are occurring in the North, which is also experiencing generally increased winter baseflows. Despite visibly obvious and instrumentally measureable changes, evaluation of hydroclimatic trends and their potential future impacts on ecosystems and people has been inconsistent. Apart from a very specific evaluation of the Prairie Drought of 1999-2004 (Stewart et al. 2011) there has been little synthesis of observable change in Earth system properties in the Mackenzie River Basin or in the biogeographical regions that adjoin it to the south. Little is known about compounding ecological effects.

COMPOUNDING CONTINENTAL ECOLOGICAL EFFECTS

The cold interior region of Western Canada east of the Continental Divide, from the United States border extending northward over the Prairie Provinces to the Northwest Territories and on to the Arctic Ocean, has one of the world's most extreme and variable climates and is experiencing rapid environmental change (Spence et al. 2005). Changing hydrological conditions will affect the entire region, impacting the climate of the entire continent. Climate warming and changes in precipitation patterns have resulted in altered patterns of snowfall and snowmelt; greater temporal variability of precipitation; conversion of snowfall to rainfall (Groisman and Davies 2001); loss of glaciated area (Marshall 2012); and thawing of permafrost (Arctic Council 2005). The wide-ranging effects of hydrological change on terrestrial ecosystems in the Mackenzie and in adjacent ecosystems include changing Arctic and alpine tree lines, extreme variability in prairie wetland extent and variability in the storage of subsurface water in soil and groundwater. They also include "browning" of the boreal forest and prairie aspen woodlands due to changing hydrological regimes (Goetz et al. 2005; Bunn et al. 2006); forest conversion to wetlands in areas of permafrost loss; increased tundra shrub height and coverage, with associated impacts on snow accumulation; and melt and ground thaw regimes throughout the entire region (Sandford 2012).

These atmospheric, cryospheric and ecological changes have in turn produced changes to water storage and cycling with lower, earlier and more variable streamflow issuing from the Western Cordillera, early and more variable Prairie streamflow, greater variability in agricultural and soil moisture (Sauchyn and Kulshreshtha 2007), substantially earlier and sometimes higher streamflows with greater winter baseflows in the North (Zhang et al. 2001) and indications of changes in extreme precipitation events and resulting flood and drought (Bonsal et al. 2004). Though these changes are already significant, and in some cases border on catastrophic, climate simulations suggest increased warming will lead to temperatures not seen during the Holocene (the last 10,000 years) (Sauchyn 2004). In addition, extremes of high precipitation and drought over the region will likely exceed those experienced since records began in the 1800s (Sauchyn and Kulshreshtha 2007). This rapid rate of change raises concern that current Earth system models, developed on historical data and an assumption of climate stationarity, may not adequately predict the future (Furgol and Prowse 2008; Rosenberg 2010; Trenberth 2010).

LOSS OF HYDROLOGICAL STATIONARITY

Climate change – past and projected – sheds great doubt on the viability of what hydrologists call "stationarity." Stationarity is the notion that natural climate and hydrologic phenomena fluctuate within a fixed envelope of certainty. When this assumption holds, the effects of weather and climate on urban areas and agriculture can be predicted and managed with a relatively high degree of certainty. Unfortunately, it is now generally accepted that the evidence does not support assumptions of climatic stationarity (Milly et al. 2008). A report issued by the National Research Council (2011) confirms the likely serious consequences associated with the newfound understanding that assumptions of hydrological stationarity are not valid. The findings of the National Research Council (2011) include consensus on the fact that anthropogenic land cover changes such as deforestation, wetland destruction, urban expansion, dams, irrigation projects and other water diversions have significant impact on the duration and intensity of floods and drought. They also have a significant impact on downstream hydrology in all of the world's river basins. The report concludes that "continuing to use the assumption of stationarity in designing water management systems is, in fact, no longer practical or even defensible." Loss of hydrologic stationarity means that the Mackenzie and other river basins must be managed under a great deal more uncertainty than in the past.

OTHER WORRISOME THREATS

In addition to these threats posed by planetary warming, there are a host of other threats to the region that are rooted in the specter of unrestrained development, lack of attention to environmental protection and a lack of will to acknowledge and recognize the lifestyles of the Basin's indigenous peoples. Many of these threats are already present as the following discussion of the risks posed by exploitation of the oil sands indicates. These kinds of risks are likely to grow rapidly if the scale of development is allowed to expand without limit. Other kinds of unbridled development are likely to result in a new panoply of risks that will have to be dealt with as they arise. Three of these worrisome risks, including exploitation of the oil sands, development of hydroelectric power and the extensive construction of roads are discussed below.

The panel was of the opinion that the largest single threat to the Mackenzie River Basin would be a large breach in the tailings ponds at one of the sites where surface mining bitumen is conducted. Some argue that such a breach is unlikely but the failure of flood control dikes and embankments that contain wastewaters of various sorts are almost everyday news. The panel was told that if such a breach occurred in the winter and tailings liquid were to get into the Athabasca River under the ice, it would be virtually impossible to remediate or clean-up. A 1982 episode was cited in which a relatively modest spill at an oil sands site ended up in Lake Athabasca, causing the fishery to be closed for two years. A large spill, such as would occur in a major breach of a tailwater pond dike, could threaten the biological integrity of the lower Athabasca River, the Peace-Athabasca Delta, Lake Athabasca, the Slave River and Delta, Great Slave Lake, the Mackenzie River and Delta, and perhaps also the Beaufort Sea. It would have an unprecedented effect on human society in the Northwest Territories.

Even relatively small hydrocarbon exploitation operations can create environmental disasters. Small-scale oil development at Norman Wells on the Mackenzie River entails the construction of artificial islands in the river to support drilling platforms. A spill of virtually any magnitude would have nowhere to go except the river. Again, ice would create a particular problem for any containment in the winter months. In the Norman Wells case, the picture is complicated further because the drilling platforms are just upstream from the Fee Yee (also known as the Ramparts), where the river is pinched between high cliffs to form impressive rapids that would mix any spill. Just downstream from Fee Yee is a large migratory wildfowl breeding area.

The potential for hydroelectric power development within the Northwest Territories and elsewhere in the Mackenzie Basin is enormous. There is likely to be intense pressures for large hydropower developments in the future. It should be recognized, however, that *any* dam blocks the passage of migratory fish. Many of the species valued by indigenous peoples are migratory, including lake and mountain whitefish, cisco and char. Reservoir formation also causes increased methylation of mercury, leading mercury concentrations in the remaining fish to rise to levels where eating them more than once or twice a month creates a substantial risk of mercury poisoning (Rosenberg et al. 1997). Global emissions of mercury have already increased atmospheric concentrations by two or threefold (Fitzgerald and Lomborg 2003), adding to the mercury problem in northern areas (Arctic Council 1997). All of this suggests that development of additional hydroelectric power is unlikely to be consistent with the lifestyles of indigenous peoples.

Finally, the panel heard that the construction of roads and railroads into remote areas may bring unwanted influences to indigenous communities. Among them are drugs, alcohol and crime. Currently, a road connecting the Dempster and Mackenzie highways is under discussion. A railroad connecting Valdez, Alaska with the oil sands is also under consideration. The lesson here is that mining, production of hydrocarbons and development of hydroelectric generating facilities almost always entail construction of roads and/or railroads. These developments are highly controversial among the populations of northern communities, with the potential negative effects being of central concern.

CONCLUSIONS

The evidence, both formal and casual, indicates that there are a number of worrisome signals and trends in the Mackenzie River Basin. Many of these are symptoms and potential symptoms of planetary warming. Others, however, are associated with past and prospective development of non-renewable resources, hydroelectric power and hydrocarbons. It is likely that the climatological threats will have to be managed adaptively. The developmental threats need to be managed to protect the livelihood of indigenous and northern peoples and the capacity of the Basin to provide environmental services of all types. This undoubtedly means that future resource development schemes must be managed in a balanced way that accounts for a broad range of values including those of indigenous peoples. As discussed in the next chapter, it is also true that the stakeholders in the Basin include people who do not reside there and people who reside far from there.

CANADA'S COLD AMAZON: THE MACKENZIE SYSTEM AS A UNIQUE GLOBAL RESOURCE

The Rosenberg Panel examined evidence from Western science and traditional and local knowledge and substantiated five reasons why the Mackenzie system is a resource of global importance that benefits people far removed from the physical location of the Basin.

THE MACKENZIE RIVER BASIN POSSESSES GLOBALLY IMPORTANT NATURAL RESOURCES

The prediction that the fabled Northwest Passage would soon become ice-free as a result of global warming was first put forward by climate scientist Jim Hansen in 1981 (Hansen et al. 1981). Since that time, studies have made it clear that the melting of Arctic sea ice will not only create an ocean transportation route between Europe and Asia that was 7,000 kilometres shorter, but that the opening of that route will also enhance the economics of exploiting energy resources and the mineral wealth of northern regions, not just in Canada, but throughout the circumpolar world. These resources are valued in the trillions of dollars. The Mackenzie River Basin represents an area of 1.8 million sq. km – one-fifth the area of Canada – in which these resources remain highly concentrated, yet largely undeveloped. The extent and quality of the region's renewable and non-renewable resources will be of global significance as the world population continues to grow. The exploitation of these resources will also be vital to the economy, security and sovereignty of Canada as well as to the well-being of other nations. As both environmental and non-renewable resources become more precious, its careful management will become more and more important not just to Canada, but to the world (Byers 2009; Coates et al. 2008).

THE PEOPLE OF THE MACKENZIE HAVE UNIQUE CULTURES, RELATIONSHIP TO PLACE & ESTABLISHED CONSTITUTIONAL RIGHTS

Aboriginal cultures are known to have inhabited the Mackenzie River Basin for thousands of years, relying on the land and its resources to provide food, clothing, water and all the necessities of life, leading to a detailed knowledge of the land, animal behavior, seasonal and climatic changes and ecological relationships (Berkes 1999). Indigenous peoples in the Northwest Territories today maintain strong ties to their traditional way of life and cultural traditions, even as they adopt and embrace modern technology and lifestyles. The indigenous peoples of the Northwest Territories have legally recognized constitutional rights negotiated through land claims agreements that are uncommon elsewhere (Miltenberger forthcoming). These rights are unique in the Western Hemisphere in that the Canadian constitution enshrines the rights of indigenous peoples to land and traditional livelihood to which most other indigenous peoples have lost or are no longer entitled (Miltenberger forthcoming). The indigenous peoples of the Mackenzie River Basin are among the last on Earth to live as they choose in such an expansive landscape. This is a landmark in its own right, which in many ways can be attributed to long and hard-won adaptation to the region's cold climate and long, dark winters as well as low population densities that make for a less intensive use of resources.

The implementation of land claims and self-government agreements have not only given aboriginal groups greater political control, and the resources to use Western-style scientific research findings, they have also resulted in the evolution of co-management bodies that are more open to the routine use of traditional knowledge (Miltenberger 2010). In the Mackenzie River Basin, there is a wealth of locally acquired knowledge among people who, irrespective of culture or ethnicity, live in close contact with the land through agriculture, fishing or other land-based activities; and who have accumulated multi-generational lifetimes of observations and experience with particular environments.

What distinguishes traditional knowledge is the accumulation of knowledge over many generations, leading to a broad and deep understanding of environmental conditions and patterns over time in a particular area that allow people to adapt to changing environments as long as they are in the range experienced by past generations. Traditional knowledge encompasses a body of functioning community stories that remain both coherent and relevant through constant and iterative re-telling within a society over time. In this respect, traditional knowledge is similar to a living literary canon upon which a society constructs an ideological image of itself that can be fairly stable in the midst of long-term change (Bringhurst 2007). The problem, however, is that the most profound changes that have begun to affect indigenous and local ways of living in the North are not incremental. It is now recognized that the rate and extent to which the northern landscapes are changing under the influence of a warming climate may make even the most enduring traditional knowledge about those landscapes difficult to sustain and embrace. If they continue to accelerate, the rate and extent of change may well undermine part of the foundation of the meaning and relevance of the traditional knowledge that currently exists. It may even undermine the *possibility* of traditional knowledge itself, at least as it is known presently (Diamond 2012; Sandford 2012).

The Mackenzie River Basin is important globally because the water governance example provided by the Northwest Territories clearly demonstrates that proven ways of managing** watershed sustainably are both available and threatened (Government of the Northwest Territories and Ministry of Indian and Northern Affairs 2010). Thus, for example, the Northwest Territories may harbor enduring ways of living on the land and relating the value of water to accustomed patterns of life. The Mackenzie River Basin may be one of the last places in the entire Western Hemisphere where a comprehensive water strategy could lead to natural river flows, good water quality and aquatic ecosystem health, as well as a biodiversity-based planetary life-support function that permits the perpetuation of ancient and highly-adapted human cultures in the midst of rapidly changing global hydro-climatic realities.

THE MACKENZIE ESTUARY IS ONE OF THE LARGEST IN THE WORLD AND A PLANETARY BIOLOGICAL HOTSPOT

The Mackenzie Delta covers an area equivalent to that of Lake Ontario. Researchers have also compared the Mackenzie Delta to the Serengeti in Africa in part because they are roughly the same area, but principally because both places have high biodiversity and biological productivity compared to other ecosystems in their regions. There are some 45,000 biologically productive lakes in the area of its estuary formed in thermokarst depressions underlain by permafrost in the region. Many of these lakes refill each year, others less frequently. The entire system is driven by spring melt freshets. These outflows contribute huge amounts of nutrients to the Mackenzie system. During the spring melt, warm water pools form on the surface of the ice jams on the river. Bacterial and algae flourish in these pools in the 24 hour-a-day spring sunlight, and a significant food web develops around these primary food sources. The Mackenzie Delta is so productive that, like other boreal areas, it absorbs CO_2 out of the atmosphere, making it a global carbon sink. The concern is that under warming conditions, it is possible the Delta will no longer have the capacity to absorb CO_2 in this way, which could flip the region from a carbon sink into a carbon source (Kurz et al. 2008).

THERE IS A CLEAR LINK BETWEEN THE FRESHWATER CONTRIBUTIONS OF THE MACKENZIE, ARCTIC OCEAN CIRCULATION AND REGIONAL AND GLOBAL CLIMATE

Recent research outcomes suggest that freshwater runoff from continents drives clockwise coastal currents around both North America and Eurasia. Though much remains unknown, it has been observed that the main flow of the Arctic Ocean is from west to east. The inflow begins with relatively fresh water from the Pacific entering the Arctic through the Bering Strait (Figure 14). This inflow is cold in winter and warm in summer. When the bitter winter winds that blow off the coast of Alaska freeze this water and send the resulting ice out to sea, the salt expelled from the ice dissolves in the water that is left behind. This heavier, salt-laden water eventually sinks and spills over the continental shelf into what is called the Canadian Basin of the Beaufort Sea. When this water comes into contact with an Atlantic current composed of warmer, much saltier water moving counter-clockwise around the Arctic from Fram Strait in-between Greenland and Spitzbergen, the lighter, colder water from the west naturally settles on top. As a result, the warm current trapped below loses its heat to the overlaying layer of colder water. None of this warm water reaches the ice at the surface. Without the cold blanket of water, not nearly so much ice will form in the Arctic. But there is more: in the Beaufort Sea, strong winds push the inflow of relatively fresh Pacific water – which is made fresher by the inflow of the great Mackenzie River – into a huge rotating current called a gyre which circulates in a clockwise direction over a two million sq. km area (Struzik 2009).

The Beaufort Gyre is where Arctic freshwater is concentrated. When these winds weaken, as they appear to do every decade or so, large volumes of water leak out of the circulating gyre and pass through channels between the islands of the Arctic Archipelago before spilling into two main channels leading into the North Atlantic (Struzik 2009).

Some researchers have compared the circulation of surface water in the Arctic Ocean to an air conditioner that keeps the northern hemisphere cool (Pollack 2009). Any disruption in the system that drives the air conditioner, these researchers argue, not only has the potential to lead to a change in the temperature, salinity, chemistry and ultimately the composition of marine ecosystems in the Arctic Ocean, but could also affect climate on a global scale. The temperature differential between the poles and the equator is the genesis of cold fronts that bring snow and rain to more southerly climes. If polar ice shrinks in area, winters will not go away but will become warmer, making drought and extreme weather events more common at more southerly latitudes (Conkling 2011).

Figure 14.
Ocean Deep Water Circulation

CREDIT: Image courtesy of Dr. Greg Holloway, Institute of Ocean Sciences – Fisheries and Oceans Canada.

THE MACKENZIE RIVER BASIN IS A LYNCH-PIN HOLDING THE ICE-WATER-WEATHER-CLIMATE NEXUS OF THE CONTINENT TOGETHER

As documented earlier, warming in the Mackenzie River Basin and throughout the Arctic has already begun to produce ecological change. Loss of the insulating effect of snow and changes in the duration and extent of snow cover will affect ecological processes in ways that will create biological winners and losers as change cascades through trophic levels. As already noted, increased ecosystem respiration rates in the Mackenzie could alter the ecosystem's annual net carbon exchange from a sink to a source, resulting in a net release of CO_2 into the atmosphere, creating additional greenhouse concerns for the region and North America as a whole.

It is not reasonable to expect that the western provinces, territories and federal government of Canada will address global change by themselves. Rather, inter-governmental collaboration and co-operation between Canadian levels of government are necessary to ensure that management of the land, air, and water resources of the Basin minimizes, to the extent practicable, the adverse impacts of both economic development and climate change. To manage the system for greater total resilience the broader eco-hydro-climatic regime has to be considered. This suggests that nothing less than a basin-wide approach to its management

** The panel does not use the word "manage" prescriptively to imply human control. Rather, it recognizes that management is defined by the objectives to be pursued. Thus, for example, in the U.S. wilderness, lands are managed so as to protect and preserve their essential wildness.

is needed for sustainability and resilience.

Despite its importance, the Mackenzie River Basin is under threat from unrestrained development and externally driven climate change. Integrated water and land management based on science will be essential if the adverse effects of global change are to be minimized. Integrated, science-based management is going to require additional scientific knowledge and the co-operation of the various governmental entities: national, provincial and local.

CONCLUSIONS

There are many who hold stakes in the Mackenzie River Basin. The resident population, especially indigenous peoples, are obvious stakeholders. The importance of the Mackenzie system in influencing broad climatic regimes, the behaviour of ocean currents and in providing habitat for migratory birds and waterfowl, means that stakeholders include residents of the Western Hemisphere and, to some extent, the globe itself. Indeed, this fact means that the Basin is a part of the global commons and it presents all of the vexing problems associated with management of the global commons. These problems are made even more difficult by virtue of the fact that the Mackenzie has been less intensively studied than many other rivers of the world. In looking to the problems of managing the Basin in the future, it seems clear that additional science needs to be done and made available in ways that will facilitate the fashioning of policies for governing and managing the Basin.

NEW KNOWLEDGE NEEDED

The previous chapter outlined the extent to which the Mackenzie River Basin is under threat from global change. Some of that threat is magnified by scientific uncertainty. Some of that uncertainty can be addressed by extensive and routine monitoring. There will, however, always be some residual uncertainty that will have to be managed.

New knowledge and understandings are needed if the Mackenzie system is to be managed sustainably for local and regional benefit, as well for responsible stewardship of a part of the global commons. The most pressing questions related to the management and future of the Mackenzie system concern the nature and direction of positive feedback processes, especially as they relate to hydrology. In order to manage the Basin effectively, we need to know which feedback processes are critical and how they will charge and possibly intensify in the future.

Basic questions about the hydrological, chemical and biological aquatic regimes within the Basin remain unanswered for lack of adequate monitoring. Monitoring and tracer studies are critically needed to understand temporal-spatial scales and the impacts of both historic and current resource extraction developments. Major questions also remain unanswered regarding how to predict and manage the cumulative impacts of land-use changes and climate warming. A more complete understanding of watershed processes and functions must be developed iteratively. More effective systems for collaborating and communicating science to build, maintain and effectively use monitoring networks are also critically needed. The influence of the freshwater inputs of the Mackenzie system on Arctic currents is yet another area of critically necessary research. Further research, data-gathering and the development of collaborative arrangements to facilitate the exchange of data and science are needed in the following areas:

NEW KNOWLEDGE REQUIRED IN THE AQUATIC SCIENCES

• Monitoring and the routine gathering of knowledge should be accorded the highest priority;
• Monitoring and mapping of patterns of water and air quality related to the fate and transport of contaminants;
• Studies of the chemistry, physics and biology of the three Northern Great Lakes, Lake Athabasca, Great Slave Lake and Great Bear Lake;
• More complete determination of the flow regime and definition of the function of linkages between elements in the Mackenzie system;
• Exploratory research to further define vulnerable locations and aspects of the landscapes;
• Definition of key spawning and rearing habitats for fish and other organisms on which they depend, in both the main stem Mackenzie and its tributaries;
• Analysis of the effects of feedbacks on the vulnerability of landscapes to ecological and hydrological change.

Given that it will likely be impossible to explore all of these research needs simultaneously, it will also be important to establish mechanisms related to how to prioritize the quest for this additional knowledge.

NEW KNOWLEDGE REQUIRED IN THE SOCIAL SCIENCES

• Further clarification of human health threats related to water quality in the Basin;
• The relationship of people to local environments in subsistence interaction with landscapes;
• The impacts of combined development, landscape change and cumulative effects on Mackenzie River Basin communities;
• Examination of social elements of the boomtown phenomenon and their consequences for the landscape and its indigenous residents;
• The impacts of combined development and cumulative landscape change on local and regional governance capacity;
• Evaluation of the most appropriate and effective ways to advance collaborative planning processes with respect to the future of the Mackenzie system;
• Exploration of impediments to balancing short-term economic benefits with the long-term environmental and social costs of development decisions and evaluation of the potential of different institutional arrangements for redressing imbalances.

Evaluation of the most appropriate and effective way to advance legal and legislative structures in a manner that can preserve Canadian societal values in the face of rapid landscape change.

MANAGING THE MACKENZIE

The specter of global climate change and its resulting adverse effects on the Mackenzie River Basin poses clear threats to the biological, hydrologic and climatic integrity of the river and its associated land resources. Residents of the Basin, the region and the Canadian state cannot fully address and resolve the emerging problems of global change in isolation. They can only do their part in collaboration with other nations and peoples. However, at present, business as usual, even without additional change, threatens the integrity of the Basin and its capacity to supply resources and environmental services. There is a clear need for the Basin to be managed in an effective and integrated fashion if the environmental services and other resources that it includes and provides are to be sustained and protected. This does not mean that further development of hydroelectricity, mineral deposits and petroleum-based resources should be declared "off limits." Rather, all of the Basin's resources need to be actively managed in a balanced way with particular emphasis on the protection of the environmental services that benefit the residents of the Western Hemisphere and, to some extent, the globe. This will require that all Canadians, not just the residents of the Basin, assume full responsibility for the stewardship of the Basin's resources. Indeed, the panel believes that the governments involved need to be proactive in announcing their willingness to assume and discharge the responsibilities of being the stewards of the Mackenzie River Basin. This includes abiding by international and transboundary obligations already agreed to in treaties and agreements that apply to the Mackenzie.

The management of the waters and land resources of the Mackenzie River Basin is complicated by the fragmentation of the overlying political, legal and administrative jurisdictions. Three western provinces, including British Columbia, Alberta and Saskatchewan, as well as the territories of Yukon and the Northwest Territories, all lie partly within the basin of the Mackenzie and its tributaries. In addition, the Government of Canada and numerous indigenous groups who enjoy independent sovereignty have varying responsibilities for the management of part of or – in the case of the federal government – all of the Basin. It has long been recognized that fragmentation of jurisdictions makes the integrated management of river basins difficult (National Research Council 1999). Indeed, this was recognized by the various jurisdictions in the Basin more than a decade ago. The result was the *Mackenzie River Basin Transboundary Waters Master Agreement* (1997) that required multi-party collaboration and co-operation in managing land and water use within the Basin. To date, there has been little effective follow-through on that agreement which sets the framework for enhancing co-operation across the Basin.

INTEGRATED BASIN MANAGEMENT AND THE MACKENZIE RIVER BASIN BOARD

Following the example of the National Research Council findings in *New Strategies for America's Watersheds* (1999) the Rosenberg panel concluded that effective planning and execution of schemes to manage the water and land resources of the Mackenzie River Basin require development and implementation of strategies of integrated river basin management. Such integrated management must entail representation and meaningful involvement from the various political jurisdictions and stakeholders in the Basin and the nation. Involvement should include specifically appropriate representation of indigenous peoples through all phases of planning and management. In addition, planning and management should be supported by the vigorous pursuit and use of all relevant scientific knowledge. Moreover, planning and management should address in innovative and proactive ways, the considerable scientific uncertainties about the key hydrologic, geologic and atmospheric attributes of the Basin, and manage those uncertainties in innovative and proactive ways. The panel concludes further that the Mackenzie River Basin Board (MRBB), as originally constituted by the *Mackenzie River Basin Transboundary Waters Master Agreement* of 1997, when appropriately strengthened and with full and complete implementation in the spirit intended, provides a workable and concrete way forward for achieving integrated management on a continuing basis. While in the abstract it is possible to conceive of a better institutional design of a basin governance framework, political realities suggest that adoption of an alternative model would be difficult. Moreover, better designs do not necessarily lead to better implementation. Consequently, building on what already exists offers the best opportunity for improved management.

The need for an effective Basin-wide governing body is justified by the presence of numerous problems and issues that will require collaborative arrangements, including rules and regulations that can only arise from an overarching approach that is inclusive and holistic. Examples of the sorts of problems that require such an approach, and are simultaneously unlikely to be solved if left to local or provincial interests, include:

- The threat to water and air quality posed by the likely failure of retention ponds at the oil sands in Alberta and elsewhere, as well as mining activities throughout the Basin. Responsibility for the management and protection of water quality needs to be regional in nature, while responsibility for monitoring water (as well as other environmental parameters) should reside with the federal government. Future agreements and contracts with developers should acknowledge, demand and enforce responsibility to leave the environment unimpaired and unpolluted during the conduct of their enterprises, and after. One mechanism for implementing the existence of such responsibilities would be a requirement that developers put up a performance bond that would be forfeited in the event of failure to exercise the responsibilities outlined above.
- Further development of hydroelectric power that results in alterations of the flow regimes of the Mackenzie River and its tributaries. Such development must be carefully weighed in terms of both additional energy production and the

protection of significant environmental values.
• The interests, knowledge and voice of indigenous populations must be included, acknowledged and respected in ongoing management operations. This result is required by Canadian national law and is, to some extent, consistent with the need to protect larger global values.

While the panel is reluctant to stipulate specific design modifications for the MRBB that should rightfully emerge from discussions of the parties, several measures should be seriously considered in deliberations leading to the strengthening of the Board.

First, the panel agrees that the mandate of the MRBB should be strengthened in conjunction with the spirit and purpose of the Master Agreement and its overall responsibilities for integrated river basin management. Specifically, the MRBB should have final authority (subject to pertinent national laws) for decisions with regard to major land and water use practices, as well as proposals for the further development of minerals and power that could interfere with the continued production of important environmental services. The vesting of such authority in the MRBB should explicitly require the obligation to consult provincial, indigenous and other local government, as well as interested stakeholders. In the absence of a board with such authority, management is likely to remain fragmented among relatively independent and potentially conflicting interests, which would likely undermine efforts to accomplish basin-wide integrated management.

Second, to be effective, a strengthened MRBB will require ongoing financial support to undergird its planning and management authorities. The panel was told that current support for the MRBB totals approximately $280,000 annually. The panel regards this figure as totally inadequate. While it is difficult for the panel to make a specific recommendation as to the magnitude of financial support, figures in excess of 10 times the current amount seem like the minimum that would be required.

Third, the MRBB needs to be a party to, and have oversight regarding, all bilateral agreements focused on the management of the Mackenzie River Basin in accordance with the provisions of the 1997 Master Agreement. Such an arrangement would ensure that any bilateral water management agreements align with the substantive principles agreed to by all parties under the Master Agreement. It would also meet the demands of ecosystem integrity and ensure that the stewardship responsibilities for the management and protection of the Basin are fulfilled. As a general proposition, the panel concluded that bilateral agreements must comply with the provisions of the Master Agreement and must be consistent with the goals of integrated basin-wide management. While it is true that there may be circumstances where bilateral agreements would be helpful in managing tributary basins, the development of multiple bilateral agreements would severely constrain, if not undercut altogether, the capacity of an overarching board to engage in whole-basin management. The panel observed that *ad hoc* reliance on bilateral agreements could result in incoherent management across the Basin with a lack of attention to legal, economic, environmental, social and cultural interests across the Basin. A final consideration relates to the use of science and the development of science to underpin integrated basin management strategies. Science developed by parties to serve their own specific interests, rather than comprehensive science, will lead to strategies that are less effective than they could be. At worst, piecemeal use of science will lead to management regimes that are totally ineffective.

The importance of science and science-based management is in no way diminished by the fact that existing scientific knowledge of the Mackenzie River Basin is less comprehensive than would be desirable. Thus, the mission of a strengthened MRBB must include systematic ways of strengthening the scientific bases of management and effective management of scientific uncertainty coupled with an enhanced capacity of the Board.

STRENGTHENING THE SCIENTIFIC BASE

The panel agreed that development and application of the best possible science to inform Mackenzie River Basin planning and management processes would be significantly facilitated by the establishment of an internationally respected International Science Advisory Committee. This Committee should have the authority to inform the MRBB's deliberations and decisions regarding the use of available science and in the development of an agenda of scientific research to further strengthen the scientific base. The activities of the Committee should fall into three broad areas:

First, the Committee should ensure that available science is used to the fullest extent possible. This means that scientific knowledge that is both available and pertinent needs to be identified. Also, there must be methods developed so that access to such knowledge is readily available. Beyond identifying the pertinent science and ensuring that the MRBB and those with responsibilities for planning and management in the Mackenzie River Basin have access to it, the Committee needs to ensure insofar as possible that such science is used by the MRBB in developing plans and executing management strategies. All too frequently, available science is neglected in modern public decision-making. This occurs because of ignorance or lack of access to the science. It also occurs because in some instances scientific findings are "inconvenient" and are ignored simply to avoid bother and controversy. This fact underscores the importance of creating an International Science Advisory Committee that is both independent of the MRBB and possesses the resources and authority to provide effective scientific guidance to it.

Second, the panel believes that the International Science Advisory Committee should be charged with developing a prioritized research agenda to strengthen the scientific knowledge about the Mackenzie River Basin. In addition, a budget of appropriate size should be made available to the MRBB to support such research. The panel envisions that the research to be conducted would be of the highest priority. The research support should be made available to highly qualified scientists in the usual competitive fashion. The International Science Advisory Committee should oversee the progress of such research and ensure that the results are incorporated into the planning and management activities of the MRBB to the extent possible.

Third, the panel urges that a permanently funded educational program be created as a core activity of a strengthened MRBB. The purpose of this activity should be to inform residents of the Basin as well as broader national and international publics about the characteristics the Mackenzie River Basin, the management issues confronting those charged with managing the Basin and the implications of management decision on the broad availability of the Basin's resources and services across Canada and throughout the Western Hemisphere and the globe. To be effective, such a program must have a very strong outreach component. The issue of whether the program should be housed in a separate institute or college, or sited in an existing educational institution(s), is one that should be determined by the MRBB on the advice of the International Science Advisory Committee in appropriate consultation with local, indigenous, provincial and territorial governments.

It is important that the education program entail capacity building from within. Outside experts typically have generic experience and are sometimes a poor fit with local needs and cultures. For example, much of the actual monitoring activity within the Basin should be done by locals who have been well trained in the conduct of appropriate procedures and protocols. The development of local capacity presents a unique opportunity to educate a population of scientists who are comfortable with both traditional knowledge and Western science. At present, there are few such persons. The panel acknowledges that Western science and traditional knowledge are a continuum, not separate entities. One is often able to supply answers where the other cannot. And, it is important to recognize that traditional knowledge entails more than just passing down stories. It is the generation-to-generation passing on of experiential knowledge and skills that is too often forgotten.

The panel acknowledges that much of the important existing scientific information about the Mackenzie River Basin is lacking. There was testimony to the effect that less is known about the Mackenzie than many other major rivers of the world. Nevertheless, the lack of scientific information is not a justification for proceeding without carefully crafted planning and management schemes. Indeed, one of the most important gauges of the success of a strengthened MRBB will be its ability to manage uncertainty.

ADDRESSING UNCERTAINTY

Uncertainty arises because existing scientific information is inadequate and because the environment is constantly changing. The potential for global change in the Mackenzie River Basin is very large and this means that management efforts will inevitably have to be conducted in a context of uncertainty. The panel concluded that successful management of uncertainty in the Mackenzie would require:

1 a carefully designed and managed basin-wide monitoring system;

2 employment of the principles of adaptive management whereby management protocols and strategies could be periodically adjusted based upon real-time experience with them; and

3 application of the precautionary principle – "do no harm" – in instances where failure to act with precaution might result in significant or irreversible impacts.

The panel concluded that a perpetual, robust and adequately funded monitoring program was a necessary condition if basin-wide, holistic management of the Mackenzie River Basin is to succeed. Stated differently, the obligation to monitor comprehensively and perpetually (including systematic monitoring of compliance with the Master Agreement and its subsidiary bilateral agreements) is at the heart of any stewardship program for the management of the Basin. Success in protecting and enhancing the resource and environmental values of the Basin will be very hard to achieve, if not impossible, without an effective, ongoing monitoring program. Monitoring should not be limited to water quality but should focus on measures of ecological health and integrity as well. In the panel's view, the federal government should assume responsibility for long-term basin-wide monitoring. This will ensure that monitoring protocols are appropriate and identical across jurisdictional boundaries within the Basin. It should also ensure monitoring data are archived centrally and are easily accessible to all interested parties. Adequate long-term monitoring lies at the heart of any effective integrated Basin management plan. The panel noted, therefore, that it would be difficult to overestimate its importance.

The panel also concluded that the management regimes for the Mackenzie River Basin should be adaptive. Adaptive management quite simply entails "learning by doing" (Pahl-Wostl 2007). Adaptive management is particularly appropriate for systems known to be subject to unpredictable change. Adaptive management is a systematic approach to learning wherein management strategies are designed to be periodically reviewed and updated as more information becomes available. It follows then that successful adaptive management programs require monitoring and the design of monitoring systems in ways that will inform the learning process. Pahl-Wostl (2008) points out that adaptive management systems are open and participatory, require different kinds of information (gleaned from monitoring), and entail interactive learning cycles embedded in the management approach.

Adaptive management appears to be particularly well-suited to the circumstances of the Mackenzie River Basin. There are several reasons for this:

- The state of the scientific knowledge of the Basin is incomplete and the environmental circumstances of the Basin are changing in their nature and in directions and rates that cannot be predicted with any confidence.
- Adaptive management requires open sharing of knowledge and decision making is participatory. This will be particularly necessary to ensure success in a basin where resource and environmental values may conflict and where there are multiple jurisdictions.
- Adaptive management and monitoring go hand-in-hand. Both are an equally necessary part of integrated management of the Basin, where uncertainty is large and will likely remain so.

The panel urges that upgrading of authorities for the MRBB carry a mandate for the development of adaptive management strategies for the unified management of the Basin.

The panel also discussed the application of the precautionary principle as a means of managing uncertainty in the Mackenzie River Basin. The precautionary principle has many interpretations but can be generally stated as holding that the lack of complete scientific uncertainty is a valid reason for postponing measures that might lead to environmental degradation (Foster et al. 2000). A widely-accepted definition of the precautionary principle is contained in Principle 15 of the 1992 Rio Declaration on Environment and Development. It reads as follows:

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (United Nations 1992: 1).

The panel notes that all of the elements of this statement are met in the Mackenzie River Basin. There are threats of serious or irreversible damage to the climate system and other environmental elements of the Basin. There is scientific uncertainty due to the inadequacy of existing scientific information and a constantly changing environment. As the principle holds, this uncertainty should not result in the failure to take reasonable preventive measures to protect the environment of the Basin. The panel concluded that the need to apply the precautionary principle in the making of policy and in the creation and execution of management plans is compelling in the Mackenzie River Basin and should be fundamental to any approach for managing scientific uncertainty in the Basin.

THE ROLE OF INDIGENOUS PEOPLES AND TRADITIONAL KNOWLEDGE

The panel wishes to reiterate the importance of including indigenous peoples in the integrated basin planning and management activities in the Mackenzie River Basin. The panel heard testimony to the effect that indigenous groups had been prevented from full participation in MRBB activities in the past because of a lack of funding to support indigenous participation. In the panel's view, the permanent funding support that is required to strengthen the MRBB must include support for appropriate representation of indigenous peoples. This is needed if adaptive management regimes are to be fully effective, transparent and participatory. The panel concluded that it seems clear that the aboriginal and treaty rights of peoples of the North protected under section 35 of the Constitution Act, 1982, can only be adequately respected when indigenous peoples have opportunities to participate in decision-making over matters that will clearly impact their aboriginal and treaty rights.

Similarly, for reasons set forth earlier in this report, traditional knowledge should be fully employed as part of the scientific base upon which policies and plans will be based. It is notable that traditional ecological knowledge has been documented as an important contributor to adaptive management in a wide range of indigenous cultures (Berkes et al. 2000). A number of these cultures have applied traditional knowledge to the management of environmental changes of precisely the sort that are anticipated in parts of the Mackenzie River Basin.

GOVERNING THE MACKENZIE: THE LEGAL AND INSTITUTIONAL REGIME

The Mackenzie River Basin is governed through a complex system of interconnected legal and administrative jurisdictions, duties and responsibilities.

> "Under the Canadian Constitution, control over water management is divided between the federal government and the provinces and territories. The federal government has control over water on federal land, in the territories, national parks and on Indian reserves. It also has jurisdiction over inland and ocean fisheries, inter-provincial/territorial waterways and commercial navigation. However, since both surface and groundwater move across human-made boundaries and borders, interagency collaboration is critical" (Holroyd and Simieritsch 2009: 27).

In addition to this complex matrix of federal, provincial/territorial and indigenous jurisdictions over the Mackenzie, Canada is party to a significant body of international treaties that have direct bearing on how the Basin is managed, especially with respect to environmental issues. This nested system of governances poses significant challenges for the development of management systems that are coherent, co-ordinated and unified.

The *Mackenzie River Basin Transboundary Waters Master Agreement* provides the overarching management framework for the Basin that must be viewed in terms of the inter-jurisdictional realities within which it operates. The Master Agreement sets forth a clear purpose:

> "The purpose of this Agreement is to establish common principles for the cooperative management of the Aquatic Ecosystem of the Mackenzie River Basin, to establish an administrative mechanism to facilitate application of these principles and to make provision for Bilateral Water Management Agreements" (Mackenzie River Basin Transboundary Waters Master Agreement 1997: 2).

The Master Agreement also sets forth several key principles that provide the substantive framework for management, including provisions that cover the five integral elements of a transboundary water legal regime: i) scope, ii) substantive rules, iii) procedural rules, iv) institutional mechanisms, and iv) dispute settlement (Global Water Partnership 2013). While the Master Agreement provides for bilateral agreements to be concluded between the various provinces and territories, these should be seen as supplemental to the Master Agreement. To date, only one bilateral agreement, between Yukon and the Northwest Territories, has been entered into, although a series of others are scheduled to be finalized in 2013. Importantly, "The Master Agreement and bilateral agreements do not supersede the authority over water mandated to the provinces, territories and federal government" (Holroyd and Simieritsch 2009: 38). However, the panel concluded that the Master Agreement is the preferred instrument for co-ordinating and integrating basin-wide management.

While bilateral agreements may be useful at the sub-basin level, the primary framework for management across the Mackenzie River Basin is the Master Agreement. Reliance on bilateral agreements as the focal points for management of the Basin would be inconsistent with the purpose articulated in the Master Agreement. The bilateral agreements tend to provide limited scope for management, especially when they are founded solely upon flow percentages and fail to account for the larger picture. The presence of an inclusive regional body has proved to be more effective than reliance on a series of bilateral agreements. The panel considers that the MRBB should be supported fully to realize its mandate under the Master Agreement. This would require enlarging the membership, the provision of additional resources and the support of an International Science Advisory Committee. From a science, policy and legal perspective, such a governance regime, operating in an overarching capacity with a basin-wide perspective and a mandate for the stewardship of the entire system, is the preferred way forward and provides the best available opportunity for addressing the issues identified in this report. The bilateral agreements provided for in the Master Agreement must be designed in ways that support this approach.

The scope of the management regime, as reflected in the Master Agreement, must take into account the range of scales relevant to managing this particular basin. It would be difficult or impossible for such scales to be addressed adequately via a series of bilateral agreements. Thus, for example, a reduction in the flows of the largest river flowing into the Canadian Arctic Ocean – the Mackenzie – could affect coastal currents in ways scientists have determined could further destabilize global climate, disrupt marine ecosystems with potential adverse impacts on fisheries, and bring on droughts that could devastate the Canadian prairies. These realities preclude transboundary agreements among the provinces or territories that affect the mean annual flows of the Mackenzie systems as could be caused by upstream abstractions. International practice demonstrates that proportional flow agreements are frequently ineffective and often fail to provide for future uncertainties such as the adverse impacts of natural events and change in global climate patterns. The Colorado River in the southwestern U.S. is a preeminent example (see, for example: National Research Council 2007; Milly et al. 2008; Hundley 2009).

The panel observed that reliance on bilateral agreements as the central governance architecture for the Basin simply could not work effectively. The complex nested legal regimes that apply to the Basin require considerable co-ordination, especially within the context of the entire Basin. Bilateral arrangements concluded under the aegis of the Master Agreement and an appropriately mandated MRBB would better suit this situation. The reasons are numerous. The bilateral agreements must be consistent with the spirit and purpose of the Master Agreement, must follow international best practice, and must provide the most logical approach to co-ordinating and implementing a broad range of scientific, policy and legal challenges related to this basin, especially within a fragmented governance regime (Muys et al. 2007; Global Water Partnership and International Network of Basin Organizations 2012; Global Water Partnership 2013).

The panel recommends that complete implementation of the Master Agreement as the overarching and governing legal regime for the Mackenzie River Basin with an enhanced role for the MRBB as the central body responsible for ensuring the co-operative management of the Basin. The bilateral agreements, provided for in the Master Agreement, shall be concluded within the context of, and in accordance with the principles of that umbrella agreement, as has been the case with the *Yukon-Northwest Territories Transboundary Water Management Agreement*. Consistent with the Master Agreement, bilateral agreements should facilitate and enhance the implementation of the fundamental principles of the Master Agreement. As the *Bilateral Water Management Agreements Guidance Document* provides:

> "The objectives of the bilateral agreements are: to effect cooperative watershed management among the jurisdictions which share the water resources of the Mackenzie River Basin: to sustain the ecological integrity of the aquatic ecosystems of the Mackenzie River Basin, and, to facilitate equitable and sustainable use of shared water resources by establishing criteria and desired outcomes that address water consumption, flows, quality, ground water management and aquatic ecosystem health commitments" (Mackenzie River Basin Board 2009: 6).

It also provides that "the bilateral agreements will commit jurisdictions to work co-operatively to achieve results in the terms set out in the agreement." The Guidance Document clarifies the role of the MRBB, which is "...to ensure consistency and coherence among the agreements and to ensure that collectively the agreements will result in fulfillment of the terms and principles of the Master Agreement." The key principles to be embodied in the bilateral agreements, must align "in spirit and purpose" with the Master Agreement (2009: 6).

The legal regime governing the Basin includes international obligations agreed to by Canada under several important Multilateral Environmental Agreements, which support the key objectives for the Mackenzie as set forth in the Master Agreement. For example, Canada's report on the Convention on Biodiversity states that:

> "Canada is one of the largest countries on the planet and is the steward of almost 20% of the world's wilderness, 20% of its freshwater, 24% of its wetlands and 10% of its forests. Canada boasts a wide variety of ecosystems including arctic ecosystems that cover one quarter of the country's landmass and great species diversity with over 70,000 described species" (United Nations 2012: 1).

Canada's commitment to the Convention on Biodiversity is carried out through a series of initiatives supported by specific legislation and includes participation by indigenous peoples. This undertaking by Canada provides considerable guidance for managing the resources of the Mackenzie River Basin especially with regard to its ecosystem resources. Such activities could support the efforts of the MRBB (United Nations 1992). Canada's participation in RAMSAR is another example of its international commitments and signifies the global importance of the Mackenzie River Basin aquatically and biologically. There are no fewer than five RAMSAR sites within the Mackenzie River Basin, and Canada's commitments to these sites, which includes regular reporting, potentially provides support for and is consistent with the key principles under the Master Agreement (Holroyd and Simiertsch 2009).

TRANSBOUNDARY ISSUES

Transboundary water issues in the Mackenzie River Basin have at least one special dimension, one that must be considered in virtually all policymaking, regulatory and managerial activities. Most transboundary water issues are fundamentally issues of allocation – who gets how much? When? And, occasionally, of what quality? In the Mackenzie case, the boundary between the Northwest Territories and the rest of the Basin demarks a fundamental difference in cultures with people of mostly European ancestry in the south and indigenous peoples who have occupied the land for a thousand years in the North. The values and philosophies of these two cultures differ. The southern culture is driven to a large extent by a philosophy of economic growth while the northern culture is committed to a society which emphasizes "traditional values" centered on a hunter-gatherer, non-wage, subsistence lifestyle. The panel notes that many of the issues surrounding the management of water and associated land resources in the Mackenzie River Basin cannot be only based on science or on economics. This is especially true of issue resolutions that end up defining the terms of co-existence between the two cultures. Such issues must be resolved by resorting to value judgments and value questions, matters about which scientists have no special expertise to address.

The panel was mindful of the fact that its collective scientific expertise did not carry with it special qualifications to address value-laden issues. Indeed, the panel acknowledged that such questions lie within the purview of political leaders and others who have been elected and appointed precisely to resolve value-laden issues. The panel was nevertheless concerned that too often important value questions are not addressed systematically or transparently, and in some instances, not addressed at all. Rather than offer "answers" to some of these questions or issues, the panel chose to delineate some of the more important issues for the purpose of underscoring the need for policymakers to address them in an open and forthright way.

The panel recognized that unfettered economic development is inconsistent with the protection and preservation of traditional ways of life in the Northwest Territories. It urges that this be recognized by the MRBB and other policymaking bodies as a fundamental principle that must underlie the making of balanced decisions about the rate and extent of economic growth in the Basin.

How should the values and philosophies of traditional cultures be respected in the fashioning of balanced management policies to guide the planning for and management of the resources of the Mackenzie River Basin?
The panel is of the opinion that the people of the Northwest Territories are still in a position to chart their own path, one that has not been traditionally taken by populations committed entirely to a philosophy of economic growth.

What rates of economic growth are appropriate for the Basin and its distinctive regions?
To accomplish this, the Northwest Territories probably needs to develop slowly and with limits to economic growth that are arrived at with due consideration to the ecological and cultural impacts of such growth.

How should extractive industries and hydroelectric developments be regulated?
The panel is mindful of what commonly happens to states, provinces and regions whose primary economic activity is centered on extractive industries. In general, the economic wealth of such places is withdrawn and residents are left with the residue of the extractive industry, which is frequently toxic waste. This has happened in the Mackenzie River Basin as evidenced by the Giant Gold Mine. The panel makes two recommendations below on actions that can be taken to counter the propensity for extractive industries to impoverish the region in which they operate, both spiritually and economically.

The issues identified above ought to be resolved by the people of the Northwest Territories and their elected representatives. The panel concluded that there are at least two methods available for limiting the growth and overall role of extractive industries in the Northwest Territories. The first would be to establish very tight restrictions on outside investors – foreign investors as well as investors from outside the Territories. This has been done for some time with great effectiveness in the Scandinavian countries. This simply minimizes the extent to which extractive industries dominate the economy.

To the extent that extractive industries will be permitted to operate in Mackenzie River Basin, the panel urges that the problems of clean-up that are typically associated with such industries be addressed forthrightly. Specifically, the panel recommends that consideration be given to adopting some method of ensuring that extractive industries clean-up and remediate the sites that they occupy when operations are no longer possible. One means of accomplishing this would be through a requirement that such industries put up a performance bond of sufficient magnitude to pay for site clean-up if the firm should fail to clean the site as operations wind down. (In this latter event, the performance bond would be fully refundable). All of the Americas are littered with the sites of extractive industries that decamped, leaving waste – toxic and otherwise – as well as destroyed landscapes for the taxpayer to remediate. For Canada, the Auditor General recently noted that there were 22,000 contaminated sites with a collective liability of $8 billion. The Auditor noted also that, to date, $800 million has been spent to remediate the Giant Mine site in Yellowknife, and expenses are expected to continue for centuries (Office of the Auditor General of Canada 2012). There is no reason to expect that this practice will not continue in the absence of a performance bond requirement or some similar mechanism that ensures that extractive industry has ample incentive to clean and remediate sites that are to be abandoned, or provide the funding for such activities. The panel notes that the size of such performance bonds should be very substantial but believes that the resolution of issues about the size of such performance bonds be determined by actuaries in accordance with the established principles of actuarial science.

CONCLUSIONS

1. THE NATURAL REGIMES OF THE MACKENZIE RIVER BASIN ARE AT RISK FROM PLANETARY WARMING

The ecologic, hydrologic and climatic regimes of the Mackenzie River Basin are at risk from planetary warming. Changes in these regimes have already been observed and there is evidence of accelerating change in some domains. The basin is ecologically fragile and could become more so. There are concerns about the loss of environmental stability and resiliency. Development pressures of all sorts are likely to intensify within the Basin and, unless managed properly, these pressures will intensify the risks posed by warming.

2. THE MACKENZIE RIVER BASIN IS A GLOBALLY IMPORTANT RESOURCE

The panel's observations validate the conclusion of the Rosenberg Forum's December, 2009 report that the water resources of the Mackenzie River Basin and the Northwest Territories are of global importance. While the lands and waters of the Basin do, in fact, form the cultural and economic foundation of the peoples who live in the region, they also perform eco-hydrological functions that bring benefit not just to the rest of Canada and the Western Hemisphere but, to some extent, to the globe as a whole. The Basin should be considered part of the global commons, and the management challenges it poses are complicated by the large and diffuse population that benefits from the environmental services that it provides. It is clear that the resources in question cannot be managed in an effective way unless the Basin's residents and the Government of Canada assume stewardship for the beneficial management of the Basin's resources.

3. THERE IS A NEED FOR BASIN RESIDENTS AND CANADIAN NATIONALS TO ASSUME STEWARDSHIP RESPONSIBILITIES FOR THIS GLOBALLY IMPORTANT RESOURCE

The fragmentation of the political jurisdictions found in the Mackenzie River Basin suggests that effective management can only occur through collective action. The residents of the Basin and, to some extent, all citizens of Canada, must assume stewardship responsibilities for the Basin. The commitment to assume stewardship responsibilities should be forthrightly acknowledged and assumed. It is virtually a necessary precursor to the effective management of the Basin. Without it, the Basin is likely to suffer the fate of many commons.

4. THE FUTURE OF THE MACKENZIE RIVER BASIN IS CHARACTERIZED BY MUCH UNCERTAINTY

The Mackenzie River system has been studied less than rivers in other regions in warmer climes. In addition, the Mackenzie River Basin is undergoing relatively rapid change. These two factors combine to create high levels of uncertainty that must be addressed in any effort to manage the basin in a holistic, integrated way. More science will be needed.

5.UNCERTAINTIES WILL REQUIRE THAT THE BASIN BE MANAGED HOLISTICALLY AND ADAPTIVELY

Efforts to manage the Basin in spatially piecemeal fashion are likely to fail because of neglect of significant trans-regional interrelationships. The fragmentation of the underlying political jurisdictions provides considerable temptation to manage sub-regionally. This must be resisted. The Basin must be managed as a whole by some overarching institution which has the resources and the funds to manage it holistically. Given the lack of scientific knowledge, the Basin must also be managed adaptively in which progressive management schemes are deployed experimentally and successive schemes embody the knowledge learned from experience with earlier schemes. Holistic and adaptive management schemes are necessary pre-requisites for successful management of the water and land resources of the Basin.

6. THE PRECAUTIONARY PRINCIPLE SHOULD BE APPLIED TO PROPOSALS FOR DEVELOPMENTS AND ACTIONS THAT COULD ADVERSELY IMPACT THE BROAD HYDRO-CLIMATIC CONDITIONS OF THE REGION

The precautionary principle holds that the lack of complete scientific information is not a valid reason for postponing measures that would protect the environment. Principle 15 of the Rio Declaration articulates the precautionary principle and it is clear that all of the elements identified in that principle are present in the Mackenzie River Basin. Application of the precautionary principle is all the more important given the relatively high levels of uncertainty that characterize the various natural processes that are ongoing within the Basin.

7. A PERPETUAL, ROBUST AND WELL-FUNDED MONITORING PROGRAM MUST BE AT THE HEART OF ANY EFFORT TO MANAGE THE BASIN HOLISTICALLY AND ADAPTIVELY

The relative lack of scientific information; the absence of an ongoing robust monitoring program; and the need to understand how the various elements of the Basin are behaving and changing makes the need for a strong, well-designed and ongoing monitoring program an absolutely essential precondition for effective management of the Mackenzie River Basin. Without such a monitoring program, it will be impossible to manage the Mackenzie in any informed way. The monitoring program should be located within the purview of the Canadian federal government, which should have the responsibility for the ongoing conduct of the monitoring program.

8. THE LEGAL INSTITUTIONAL ARRANGEMENTS FOR THE MANAGEMENT OF THE BASIN NEED TO BE REINVIGORATED AND STRONGLY SUPPORTED

The Mackenzie River Basin is jurisdictionally fragmented among three provinces, two territories, the Canadian federal government and numerous independent indigenous governments. A central overarching institution is required if the Basin is to be managed holistically, and if the interests of all of the Basin's beneficiaries are to be accounted for. The panel urges that the Mackenzie River Basin Board, created by the *Mackenzie River Basin Transboundary Waters Master Agreement* of 1997, be reinvigorated and clearly assigned with the necessary planning and management functions for the complete implementation of the Master Agreement. Reinvigoration of the MRBB will require additional personnel, additional financial resources and perhaps additional authorities. The specifics of the Board's reinvigoration should be worked out by the various stakeholders in the Basin.

9. BILATERAL AGREEMENTS BETWEEN VARIOUS ENTITIES MAY BE HELPFUL, BUT IN ALL INSTANCES THEY SHOULD BE CONSISTENT WITH AND SUBSERVIENT TO *THE MACKENZIE RIVER BASIN TRANSBOUNDARY WATERS MASTER AGREEMENT*

The panel is clear in its conclusion that the Mackenzie River Basin could not be managed effectively and/or optimally via a series of bilateral agreements. It recognizes and underscores emphatically the need for a strong MRBB with overarching responsibilities for planning and management of the Basin's resources. The panel acknowledges that there may be instances where bilateral agreements are helpful, but such agreements must be consistent with and subservient to the Master Agreement.

10. THE MRBB WILL BE STRENGTHENED BY THE APPOINTMENT OF AN INDEPENDENT, INTERNATIONAL SCIENCE ADVISORY COMMITTEE

The International Science Advisory Committee should have multiple roles, including ensuring that the MRBB has access to the most up-to-date science. It should be developing and prioritizing a research agenda to generate needed new scientific information, and it should be ensuring that policies and plans are based upon the best available science. Indigenous peoples should be represented on the International Science Advisory Committee.

11. THERE IS AN IMPORTANT ROLE FOR LOCAL AND TRADITIONAL KNOWLEDGE

Local and traditional knowledge must have a place in the decision-making process through which the Mackenzie River Basin is to be managed. The panel notes that traditional knowledge and Western science are not mutually exclusive, but rather form a continuum in which answers to different questions may come from across the continuum. The panel is also mindful of the fact that many of the findings from traditional knowledge have been replicated dozens of times over many centuries. The panel also urges that indigenous peoples be represented at each stage of planning, management and policymaking processes. Resources should be made available to support such representation on a continuing basis.

12. ENHANCING KNOWLEDGE AND COMMUNICATION IS CRITICAL

The panel also urges that the riparian neighbours who share the Mackenzie River strengthen local, regional, national and international knowledge dissemination and exchange. The development of common knowledge about the Basin among the intended audience will be crucial to the ultimate sustainability of the Basin. The full sharing of scientific information must include a thorough examination of research outcomes that some interests may not like. Open access standards must be developed and respected. Information of all sorts must be transparently available to all who have interests in the Basin.

13. DEVELOPING SCIENTIFIC CAPACITY WITHIN THE BASIN IS IMPORTANT

It will be important for the Mackenzie River Basin to build internal scientific capacity. There is a need for scientists who have equal levels of comfort with Western science and traditional knowledge. There is also a need for Basin residents to engage in science of both types themselves. It is not an unreasonable goal to agree that within a generation, local people will be participating extensively in the conduct of the monitoring program and other scientific elements associated with the management of the Basin.

14. EXTRACTIVE INDUSTRIES SHOULD BE REQUIRED TO POST A PERFORMANCE BOND AS A WAY OF ENSURING THAT THEY REMAIN FULLY RESPONSIBLE FOR SITE CLEAN-UP AND REMEDIATION

The Mackenzie River Basin contains a number of large-scale sites containing enormous amounts of mining and other extractive waste, much of it toxic. All too frequently, the industries involved in extraction of non-renewable resources leave the residues of their activities behind, either because the enterprise fails financially or because there is no obligation or incentive to clean and remediate. In the absence of a performance bond, or some similar incentive, there is no reason to believe that such practices will not continue and the taxpayers will be left to pay the sometimes enormous clean-up bills from private extractive activities.

15. EFFECTIVE POLICY-MAKING IN THE BASIN REQUIRES THE FORTHRIGHT MAKING AND EXPLICATION OF CERTAIN VALUE JUDGMENTS

The panel acknowledged that certain value judgments have to be made in establishing effective planning and management activities for the Basin. It also acknowledges that its singular and collective scientific expertise does not allow it to provide scientific answers to these questions. Rather, the panel wishes to emphasize the need to address and make value judgments, which may often be difficult in the development of policy. The panel cautions that the failure to make such judgments explicitly, and/or the failure to communicate them forthrightly, will jeopardize any effort to manage the Basin. It urges the Basin's policy makers to address these issues and be very clear about the conclusions they arrive at.

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