

Rivers at Risk:

The Status of Environmental Flows in Canada

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Acronyms

BC	British Columbia
CBM	Coalbed methane
CEMA	Cumulative Effects Management Association
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CRI	Canadian Rivers Institute
DFO	Fisheries and Oceans Canada
EBF	Ecosystem base flow
IBA	Important Bird Area
IFN	Instream flow needs
IJC	International Joint Commission
IPP	Independent Power Producer
GRCA	Grand River Conservation Authority
LWR	Low Water Response
MOE	Ministry of Environment (Ontario)
MNR	Ministry of Natural Resources (Ontario)
MRBB	Mackenzie River Basin Board
MW	Megawatt
NB	New Brunswick
NGO	Non-governmental organization
NWT	Northwest Territories
P2FC	Phase 2 Framework Committee
PTTW	Permit to Take Water
QC	Quebec
RAP	Remedial Action Plan
SSRB	South Saskatchewan River Basin
UNESCO	United Nations Environmental, Scientific and Cultural Organization
US	United States
WCO	Water Conservation Objectives

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INTRODUCTION

Across the Prairies, river flows are declining in an already changing climate, while more water is licensed for irrigation than even exists in the rivers at one time, leaving wetlands high and dry when they need water the most.

In the boreal wilderness, the largest river flowing into Lake Superior, the world's biggest freshwater lake, is the site of an ongoing struggle over how to share water so that there will be enough in the river for brook trout to spawn and survive.

In the Maritimes, Atlantic salmon have stopped returning to large rivers that have been blocked and had their flows permanently changed by massive hydroelectric dams.

While it is increasingly common to hear of conflict over freshwater in arid nations, it may come as a surprise to many that all across Canada — where we often fall under the misconception that water resources are plentiful and limitless — battles are raging over freshwater. And more often than not, when there are multiple, competing uses of water (and, more often than not, there *are* multiple competing uses of water), it is the environment — the birds, fish, insects, wetlands, trees, and ecosystems that need water just as much as we do — that ends up last in line.

Freshwater systems are home to 40% of all fish species in less than 0.01% of the world's total surface water, and when freshwater amphibians, reptiles and mammals are added to the fish totals, together they account for as much as one third of global vertebrate biodiversity. It is increasingly evident, regionally and globally, that this amazing freshwater biodiversity is severely endangered — much more so than in terrestrial or marine environments. Even at a conservative estimate, freshwater invertebrates declined globally by 55% between 1970 and 2000,¹ and the Freshwater Living Planet Index shows that populations of species in inland waters decreased on average by 35% from 1975 to 2005 (Figure 1).²

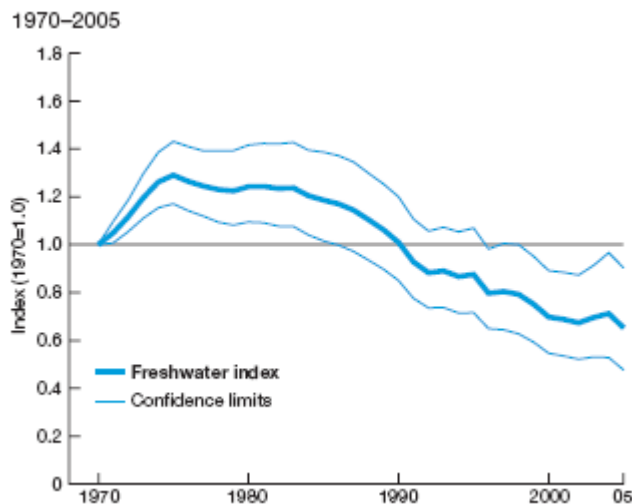


Figure 1: Freshwater Living Planet Index
(from WWF's *Living Planet Report 2008*)

impacts for the people and ecosystems that depend on them.

At the same time, people need to use rivers, lakes and wetlands — for drinking water, irrigation for food and fibre production, industry, power generation, fishing, recreation and cultural activities. If we are careful, rivers can do all these things for us while maintaining their essential ecosystem functions. Unfortunately, however, we haven't always been careful, and growing pressure on freshwater has resulted in serious consequences for our rivers. As seen in the examples above, the result of excessive water withdrawals, dams for hydroelectricity, and now the rapidly changing climate is dramatic changes to how our rivers flow and function, which in turn is causing significant

Hence, it is clear that securing water for people and nature — *environmental flows* — is among the most profound sustainability challenges that we face in the 21st century.³

What are Environmental Flows?

As defined in the widely-endorsed Brisbane Declaration, environmental flows describe the **quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems.**⁴

Each river exhibits its own natural hydrologic signature, which is an expression of the local climate interacting with the geology, soils and vegetation cover in each river's watershed. Over long periods of time, the plants and animals living in or adjacent to rivers have become adapted to the natural patterns of variation in river flow. In order to maintain freshwater biodiversity and the many ecosystem goods and services that freshwater ecosystems provide, it is necessary to maintain some semblance of natural flow patterns, along with other key conditions and processes such as water quality and sediment transport. Flow is the main driver of biodiversity in rivers, and a key determinant of river health — it creates aquatic habitats, carries food and nutrients from upstream, covers the floodplain with water during high flows, and flushes sediment and poor quality water through the system.⁵

It has become widely recognized that the “flow regime” — the pattern of flow variability in a river — is central to sustaining the ecological function and structure of river ecosystems, and that in order to protect these ecosystems, a flow regime must be provided that will account for a wide range of natural variability.⁶ Commonly known as the “natural flow paradigm”, this has become the fundamental concept guiding river restoration and management, and the emerging field of environmental flow science and management.^{7,8}

According to scientists, the critical components of the flow regime that influence river ecosystems and biodiversity are:

- i) Magnitude: the amount of water moving in a river reach (e.g., floods or low flows);
- ii) Frequency: the number of flow events of a given magnitude per time interval;
- iii) Duration: the length of time associated with a particular event;
- iv) Timing: the occurrence of events and their predictability; and
- v) Rate of change: how rapidly flow changes in magnitude.

It is easy to see how many of our actions that impact freshwater and rivers, such as the operation of dams, water withdrawals and land use practices, could cause changes to these components of flow. If these changes are too drastic, they will negatively impact aquatic ecosystems and biodiversity. It is therefore necessary to manage our rivers to prevent damaging changes to their natural flow regimes — protecting *environmental flows*.

Water and Environmental Flows in Canada

In Canada, jurisdiction over freshwater is complex, and is constitutionally divided between the federal and provincial governments. While the provinces exercise primary jurisdiction over water management, the federal government holds important authority over water in relation to fisheries and fish habitat, shared waters (both national and international boundary waters), navigable waters, and water on First Nations land and in the northern territories.⁹ With a multitude of federal and provincial agencies and departments sharing and dividing responsibility, water management in Canada has been described as “fragmented” and “bewilderingly complex”,⁹ and a great deal of tension exists between federal and provincial regulatory frameworks and shared responsibilities over water.

Each province and territory in Canada has its own system of water management, including mechanisms for aquatic ecosystem protection and water allocation, or the rules and procedures through which access to water is determined.¹⁰ A recent assessment of water security across each of Canada's provinces and territories found that, as of 2007, eight jurisdictions in Canada had some form of provision for environmental flows, including aquatic reserves (a special status assigned to certain bodies of water), instream flow needs (water set aside for maintaining ecological functions and processes in water bodies), and limits on water extraction.¹⁰ The approaches taken differ widely across jurisdictions; a few selected examples are described in Box 1.

PROVINCE	SELECTED ENVIRONMENTAL FLOW PROVISIONS
Alberta	Has provisions for holding back up to 10% of license/permit transfers for instream flow needs in highly allocated systems.
New Brunswick	Requires maintenance of a designated water flow rate for ecological purposes within the terms and conditions of water-taking permits and licenses.
Ontario	Approvals for water taking permits must consider protection of natural ecosystem functions, including the impact of water taking on natural flow variability, minimum streamflow, and habitat.
British Columbia	New dams are prohibited on some "sensitive" rivers, and Water Use Plans have been developed for most hydro facilities to balance the water needs of fish and wildlife, recreation, and power generation.

Box 1: Examples of Provisions for Environmental Flows in Canada

While aquatic ecosystem protection is addressed to some extent in most jurisdictions, maintaining environmental flows is, at best, a secondary consideration in Canadian water management.⁹ Generally, the current approach is oriented to regulating consumptive use of water rather than ensuring that environmental flow needs are met.⁹ While some limited provincial programs have been initiated for selected rivers and streams, federal practice and interjurisdictional frameworks, such as the Prairie Provinces Water Board (PPWB), the Mackenzie River Basin Board (MRBB), and the International Joint Commission (IJC), lack the authority to address environmental flows in transboundary systems.¹¹ Overall, the limited environmental protection that does exist is generally piecemeal rather than comprehensive, and not required by law, instead relying heavily on the discretionary power of decision makers.

Monitoring and enforcement of ecosystem protection and environmental flow provisions in Canada is also limited.^{9,10,11} The federal *Fisheries Act*, for instance, prohibits activities that cause harmful alteration, disruption or destruction of fish or fish habitat, but the federal government has appeared reluctant to fulfill its responsibilities to protect fisheries and has been criticized for its failure to safeguard fish habitat, and for its unwritten policy of grandfathering historical water uses.¹¹

Aquatic ecosystems throughout Canada are impacted by climate change, excessive water withdrawals, diversions and dams, among other pressures. In the face of these challenges, Canada's current approach is inadequate for protecting and restoring environmental flows in our rivers.

Addressing the Environmental Flows Challenge

Managing for environmental flows requires striking a balance between the human benefits that require the use and extraction of water in rivers, and the benefits that we derive from maintaining healthy river ecosystems; environmental flows necessarily implies trade-offs. Rivers can do many things for people, but they can't do all these things, all the time, for everybody. For communities that are not content to see their natural resources over-exploited but want to get the best out of the ecosystem goods and services provided by rivers, protecting and restoring environmental flows is becoming an integral part of sustainable water management.¹

Public support for the protection and restoration of environmental flows is strong and growing around the world. In the 2007 Brisbane Declaration, leading scientists, economists, engineers, resource managers and policy makers from more than 50 countries formally recognized that environmental flows are essential for freshwater ecosystem health and human well-being.⁴ A number of jurisdictions, most notably South Africa and Australia, have explicitly legislated for the protection and provision of environmental flows on a national scale, and elsewhere, such as in the European Union's *Water Framework Directive*, environmental flows are implicitly mandated. In addition to WWF, international agencies such as the United Nations,¹² the World Conservation Union (IUCN),¹³ and The Nature Conservancy¹⁴ have recognized and been actively working towards protection of environmental flows within integrated conservation policy and planning.

In Canada, despite increasing pressure on freshwater resources and threats to ecosystems and species, progress on dealing with the issue of environmental flows has lagged behind that of other industrialized nations. Though there are isolated cases where measures have been put in place to protect or restore environmental flows, these actions have generally been piecemeal, and are not guided by clear policy or strategies at provincial or federal scales.

We are fortunate in Canada to be stewards of some of the planet's last remaining large free-flowing rivers, and many others that are still in good ecological condition — a rarity in much of the world today. We also have the institutional capacity and resources to look after these rivers, which many countries similarly lack. Hence, it is essential that we not forego the opportunity to protect our rivers *before* they become highly threatened, and the ecosystem goods and services they provide lost forever.

Despite a seeming abundance of freshwater, Canada's rivers are at risk. Though not an easy task, it is possible to balance the needs of people and the environment for water — this is an issue that cannot go unaddressed. Consequently, there is a dire need to raise awareness of the importance of environmental flows in Canada's rivers, and to move towards protecting and restoring environmental flows as part of conserving the rich freshwater heritage and ecosystem values that our rivers provide, to Canadians and the rest of the world.

Purpose of this Report

The purpose of this report is to assess the status of environmental flows in ten rivers across Canada, and, on the basis of this assessment, to recommend actions aimed at furthering the recognition, protection and restoration of environmental flows in Canada.

It is important to note that this study represents a preliminary assessment centered on one aspect of freshwater health in Canada: environmental flows. It is not our intent to imply that other aspects of freshwater health are any less significant, and have chosen to scope this assessment in terms of

environmental flows because it is a key piece of the freshwater health “puzzle”— and one which has largely been ignored in the broader dialogue on Canadian freshwater issues to date.

This assessment is science-based but subjective. Largely qualitative in nature, the data used to undertake this assessment was derived primarily from secondary sources, including peer-reviewed, academic and grey literature, all of which have been supported by the perspectives and opinions of local river experts.

The following pages contain a review of the major threats to environmental flows in Canada, a description of the methods used to carry out this assessment, the results of this assessment presented in a summary for each river, and finally conclusions and recommendations for action on environmental flows in a Canadian context.

THREATS TO ENVIRONMENTAL FLOWS IN CANADA

It is well known that many human activities are placing the world's rivers at risk; pollution impacts water quality and biodiversity, exotic species alter ecosystem dynamics, and overharvesting threatens fish populations — these threats are well documented and widely publicized. Less attention is generally given, however, to what are increasingly recognized as the most widespread and significant threats to rivers and freshwater worldwide: the alteration and modification of environmental flows by dams, diversions, withdrawals, infrastructure, and the pervasive threat of climate change.^{15,16,17,20,28}

Fragmentation and Flow Regulation

Fragmentation and regulation by dams and other infrastructure represents one of the most significant threats to environmental flows in the world's rivers.^{18,19,20} In 2000, there were 849 large dams in Canada,²¹ 70% of which were built solely for hydroelectric generation, and thousands more small dams less than 10 m high.²² While the era of dam building in Canada was once thought to be over, growing demand for low-carbon energy supply (e.g., hydropower) is now driving new construction. New proposals and projects of various sizes – from small-scale projects to large-scale developments – are emerging across Canada.

Dams and other infrastructure such as weirs and dykes affect freshwater ecosystems by altering flows and severing or changing connections between different parts of the river, disconnecting rivers from floodplains and wetlands, and often storing large quantities of water that would naturally flow freely downstream.²³ Natural flow fluctuations, such as seasonal floods and droughts, are important for maintaining biodiversity in river systems,²⁴ but after regulation by dams, floods typically decrease or disappear altogether, and the natural timing of flows — to which many species are adapted — is often dramatically altered, upstream and down.^{19,25} Alteration of the quantity and timing of flows can have devastating impacts on aquatic environments,^{25,26} and recent research has also concluded that dammed waterways will be more vulnerable to the impacts of climate change than rivers left undammed.²⁷

The impact of dams can be characterized by the number and size of existing and proposed dams and reservoirs on a particular river,^{18,20,23} but many researchers have also attempted to quantify 'fragmentation' as an indicator of the degree to which rivers have been modified by dams.^{21,28,29} The index developed by Nilsson et al. (2005),³⁰ which classifies rivers as *strongly affected*, *moderately affected*, or *unaffected* by fragmentation and regulation based on the number and concentration of dams and proportion of flow regulation in a river (the proportion of annual flow that can be stored in dams), has been widely cited (e.g., by the UN World Water Assessment Programme and the World Resources Institute).

Water Withdrawals and Diversions

The total amount of water withdrawn from freshwater systems globally has risen 35-fold in the past 300 years,³¹ and has increased by 20% per decade since 1960.¹⁷ In many of the world's rivers and water bodies, such as the oft-cited Colorado River in North America and the Aral Sea in Asia, water withdrawal has become so intense that no water is left instream for much of the year, or flows are reduced to a fraction of what they once were.^{19,28} In Canada, water is withdrawn for a multitude of needs, including irrigation and agriculture, drinking water, manufacturing and industry, and thermal power generation.¹⁸ Most surface water that is withdrawn is returned to its source after it is used, however some water uses are more *consumptive* than others. Consumptive use removes water from a river system and makes it unavailable for further use downstream. Irrigation is by far the largest consumptive use of water; according to Environment Canada, 94% of water withdrawn for agriculture in

2005 was consumed, or not returned to its source.³² Consumptive water uses pose a greater threat to environmental flows than uses that return water directly back into the same water body or watershed.

The withdrawal of large amounts of freshwater can have devastating consequences for rivers, often not leaving enough water in the system to sustain vital ecosystem processes and species. Removing large quantities of water from rivers flowing to the ocean can cause adverse impacts on marine ecosystems by reducing sediment and nutrient inputs, and has been shown to impact fish populations.³³ Groundwater directly affects surface waters by sustaining base flow, moderating water level fluctuations and maintaining specific temperature regimes, thus groundwater withdrawal can also have significant impacts on environmental flows.³⁴ Diversions, especially when water is artificially moved between watersheds, can significantly change the quantity and timing of flows, sometimes to the point where entire rivers cease to exist. Viewed globally, Canada diverts more water from one watershed to another than any other country. *When* water is withdrawn or diverted, however, is as important as *how much*.¹¹ Taking water during low flows and droughts typically has a greater impact on river health than does taking water during other periods.

Coarse-scale methods for quantifying and assessing the scale and impact of withdrawals and diversions consider the total volume (m³), or percent of river flow that is allocated, withdrawn, or diverted. Projected increases in demand can give an indication of future threats, and distinguishing between consumptive and non-consumptive uses can provide information about the magnitude of the threat posed by water withdrawals.²⁰

Climate Change

It is well accepted that climate change will result in — and indeed is already causing — significant impacts to water quality and quantity in Canada.^{15,35,36} The hydrological cycle is greatly influenced by temperature and precipitation, and small changes in these parameters can result in relatively large changes in the magnitude and timing of streamflow and runoff and the intensity of floods and droughts, all important components of environmental flows.³⁵ These impacts are already being experienced in Canada's rivers; annual minimum and mean daily flows appear to be increasing significantly in northern British Columbia, the Yukon and southern Ontario, while flows are decreasing in southern British Columbia and the Prairies.³⁶ Studies show that maximum flows are generally decreasing across most of Canada, and that spring freshets are occurring earlier than in the past.³⁶ These impacts are expected to persist and intensify into the foreseeable future, especially in regions where environmental flows are already under threat from other stressors.³⁵ In addition to causing direct changes to aquatic ecosystems, climate change is likely to intensify competition for increasingly scarce water resources, making it even more difficult to secure water for ecosystem needs.

Freshwater impacts can be described in terms of three different but inter-related components: water quality, water quantity or volume, and water timing (sometimes called water seasonality or flow regime).³⁷ Knowledge of past trends and future projections of climate change in relation to these components can help us to understand how climate change will impact freshwater systems and environmental flows. However, there are limitations to using existing data to predict future trends. In a recent review of worldwide changes in river flows, scientists concluded that the traditional assumption of “stationarity” — which assumes that river flow data from the past can be used to predict the availability of water in the future — is almost certainly wrong in this new era of climate change³⁸.

Land Use

The quantity and timing of streamflow and runoff are influenced by precipitation as well as surface and sub-surface water flow and storage, and evaporation from soil, vegetation and water bodies.³⁹ Land use practices that impact these components of the hydrological cycle, such as agriculture, forestry, mining, urbanization, roads and linear development, such as hydro transmission lines or pipelines, can thus impact the flow regime of rivers and streams in a watershed, and affect environmental flows.¹⁸ It is well known, for instance, that the removal of forest cover can cause changes in streamflow quantity and regime (often increased flooding), faster runoff causing increased erosion, and changes to local groundwater dynamics.³⁹ In an urbanized watershed, much of the land surface may become impervious,⁴⁰ which can lead to reductions in infiltration, increased rates of runoff and altered hydrographs. While the impacts of these activities differ depending on the specific characteristics of each watershed, they can nevertheless have a significant impact on environmental flows.

Cumulative Effects

Taken individually, any of the threats outlined above can have serious impacts on environmental flows in a river. Watersheds are complex systems, however, and rarely does a single threat occur in isolation. For instance, while a single small water taking may not remove enough water to negatively impact aquatic ecosystems, hundreds of small water takings in the same watershed could combine to significantly reduce the flow in a river. Similarly, the impacts of dams may be more serious when considered cumulatively with the impacts of climate change, as shown in a recent study which found that the area in need of management to mitigate climate change impacts is much greater for basins with dams than for those with free-flowing rivers.²⁷ It is therefore essential to consider the cumulative effects of stresses on rivers, and to recognize how threats to environmental flows interact with one another and possibly result in magnified impacts.^{15,18}

METHODS

This assessment of the status of environmental flows in Canada was undertaken in four steps:

- Selection of rivers
- Literature review and development of an assessment framework and status classification system
- Data collection and compilation of evidence of status of environmental flows for each river
- Assignment of overall status and forecast for environmental flows for each river

River Selection

The ten rivers highlighted in this report were chosen based on a number of criteria. Importantly, we did not simply choose the longest or largest rivers in Canada, or attempt to define which are the ‘most’ significant. Instead, we set out to profile rivers that represent a range of geographical regions and ecosystems, including examples from within each of Canada’s major drainage basins (Pacific, Arctic, Hudson Bay, and Atlantic). We wanted to draw attention to the diversity of threats to environmental flows in Canada’s rivers, so we selected rivers affected by a range of issues, highlighting those where effort has been put forth to mitigate these issues as well as where problems remain unaddressed. We also chose rivers representing a range of conditions, from pristine and free-flowing to highly modified and managed. Finally, rivers were chosen based on issues that are nationally significant — many are transboundary or boundary rivers (international and interprovincial/territorial), some represent regions of significance for Canada’s primary industries such as fishing, mining, or forestry, and some represent areas of high national conservation value. In one way or another, these rivers *matter* to Canadians.

Status Assessment and Data Collection Framework

In order to understand the existing and anticipated threats to environmental flows on a broad scale, we first undertook an extensive literature review. This involved reviewing research papers, reports, government and NGO publications, peer-reviewed journal articles, and web literature on environmental flows theory and practices from around the world. A brief overview of the major threats to environmental flows in Canada, as well as how these can be measured and/or quantified, can be found in Section 3 of this report. Based on this review, a framework was developed to guide data collection — basically, “what to look for” with respect to the status of environmental flows in each river. An outline of this assessment and data collection framework is included in Appendix 2.

Data Collection and Analysis

Guided by the assessment framework, data was collected for each river under investigation. Data collection involved both document review and key informant interviews. Document review included analysis of federal and provincial government publications, technical studies on instream flow needs and/or environmental flows for the rivers in question, peer-reviewed journal articles, water budget reports, river management plans, dam operating guidelines, regional climate modeling reports, NGO publications and web material.

Key informant interviews were carried out with individuals involved in various aspects of river management, water use, or advocacy for each river, including staff from numerous NGOs, provincial governments, conservation authorities, industry and water users, and the research and academic community. Interviews were conducted with 22 individuals in total, with 19 interviews carried out over the phone, two via email and one in-person. All interviews took place between December 2008 and April 2009, and ranged in length from 20 minutes to over 2 hours. Following a common protocol that was

tailored according to the perspective of the individual and relevant issues for each river, interviewees were asked open-ended questions relating to what they perceived to be the most significant threats to environmental flows in the river in question, what impacts are occurring as a result of these threats, as well as whether there are any management or advocacy initiatives going on to mitigate these issues and who the key players are advocating for each river. The generic interview protocol can be found in Appendix 3. Information gained through key informant interviews was used to confirm and contrast that gained from document review, and to understand key issues in greater detail.

Once collected, data were compiled according to the framework components, and summarized in a brief write-up for each river that focused on presenting relevant background information as well as an overview of the major threats to environmental flows, the impacts of these threats, and any management and advocacy actions taking place.

Status and Forecast of Environmental Flows

Based on an extensive literature review, indicators of the status of environmental flows were identified and used to develop a system to allow for classification of the status of environmental flows in each river into one of four categories: Natural, Good, Fair, or Poor (Figure 2, below).

Indicators		NATURAL	GOOD	FAIR	POOR
Drivers	River fragmentation and flow regulation	Unaffected by fragmentation and flow regulation	Main stem unaffected by fragmentation and flow regulation	Moderately affected by fragmentation and flow regulation (main stem and tributaries)	Strongly affected by fragmentation and alteration (main stem and tributaries)
	Water withdrawals and diversions	No or very few minor withdrawals; no evidence that demand will increase in the future	Few, infrequent minor withdrawals or evidence that demand may increase in the future	Some withdrawals or evidence that growing demand will cause future threats	High level of withdrawals or diversions; evidence that demand will increase
	Observed and/or predicted impacts of climate change on flow regime	As climate change is expected to impact hydrology across Canada, there is no natural classification for the impacts of climate change	Observed and/or predicted impacts of climate change are minor or not expected to change flow regime	Observed and/or predicted impacts of climate change could result in moderate changes to flow regime	Observed and/or predicted impacts of climate change expected to result in significant changes to flow regime, changes already observed
Impacts	Quantity of water, high and low flow events, impacts on connectivity	Quantity of flows not altered from natural; no losses of connectivity or impacts observed	Quantity of flows slightly altered from natural, no or minor losses of connectivity	Quantity of flows somewhat altered from natural, resulting in moderate losses of connectivity	Quantity of flows significantly altered from natural; major changes to high/low flows, connectivity
	Timing of flows, flow patterns, seasonality	Timing of flows not altered from natural; no changes in seasonal flow patterns	Timing of flows slightly altered from natural; minor or infrequent changes in flow patterns	Timing of flows somewhat altered from natural; moderate changes in flow patterns	Timing of flows significantly altered from natural; frequent changes in seasonal flow patterns
	Species/ ecosystem condition in relation to flow regime	Evidence that species/ecosystems dependent on natural flow regime are healthy; no negative impacts from changes to flows	Evidence that species/ecosystems dependent on natural flow regime are healthy; few negative impacts from changes to flows	Evidence that species/ecosystems dependent on natural flow regime are somewhat impacted by changes but not in imminent danger	Evidence that species/ecosystems dependent on natural flow regime are severely threatened by changes to flow regime
	Water quality in relation to flow regime	No flow-related water quality problems	Minor, localized water quality problems; in part related to changes in flows	Evidence that changes in flows are moderately impacting or could impact water quality	Evidence that changes in flows are negatively impacting water quality

Figure 2 Status of Environmental Flows Classification System

It is important to note that this classification system is focused only on one specific aspect of river health — environmental flows, and does not rigorously consider additional components of river health such as water quality or riparian health. Consequently, it is appropriate for use in assessing the status of environmental flows in a river, but is *not* meant to serve as a comprehensive river health assessment tool.

While this study is focused specifically on environmental flows, the approach used to classify the “status” of rivers is broadly consistent with international best practices in the field of river health assessment. The classification system used in this study draws heavily on similar approaches that have been developed and implemented for assessing the status of river health in leading jurisdictions worldwide, including South Africa’s River Health Programme,⁴¹ Australia’s National Framework for the Assessment of River and Wetland Health,⁴² and the European Union’s Water Framework Directive.⁴³ A quick overview of these assessment protocols can be found in Box 1, with more detailed information on the South African River Health Programme in Appendix 4.

In this study, the data collected for each indicator was used to classify each river into one of four categories — Natural, Good, Fair or Poor. For example, for the indicator “River Fragmentation and Flow Regulation”, the Nilsson Index was used to determine status, if available for the river in question (the Nilsson Index, which classifies how strongly a river is affected by fragmentation and flow regulation, is described in Section 3). If the Nilsson Index was unavailable, the researchers applied the same concept/approach as Nilsson (by considering whether there were dams on the mainstem and tributaries, and how many of each) to arrive at a determination of the degree of fragmentation and flow regulation. The opinions of expert interviewees also helped to discern appropriate classifications. For other indicators in the classification system, relevant literature and the perspectives of key interviewees were used to determine the most appropriate classification.

South Africa: River Health Programme⁴¹

- 4-level River Health Classification System

Natural	Good	Fair	Poor
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Australia: National Framework for the Assessment of River and Wetland Health⁴²

- Each river given an index score between 0 and 1 for each criteria, and then classified into one of 4 categories

Largely Unmodified	Moderately Modified	Substantially Modified	Severely Modified
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European Union: Water Framework Directive⁴³

- Sets a 5-class scale for the status of each water body

High	Good	Moderate	Poor	Bad
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Box 2: International River Health Classifications

Once each indicator was classified, these were aggregated to determine the overall status of environmental flows for each river. Overall status was determined based on which indicator categories were most prevalent for each river. For instance, if most indicators fell into the Poor category, then the overall status of environmental flows in the river was assigned a Poor classification, and if the indicators fell under a combination of categories, such as Poor, Fair and Good, then the river was generally classified in the mid-range category, in this case, Fair.

This was carried out for each river, recognizing that data was often not available for all indicators for each river, that ecological importance may arguably differ among the indicators and thus they are not necessarily equally weighted, and that assigning classifications for each indicator was not always straightforward. In order to confirm that aggregation and classification were carried out consistently across all ten rivers, the researcher undertook an additional numerical weighting and classification exercise, the details of which are outlined in Appendix 5 of this report.

Forecast (improving, declining, or steady) was determined using the best judgment of the research and interviewed experts, based on the likely trajectory of the status of environmental flows in each river. This was based on future projections of key threats (e.g., future plans for dams or increasing surface water demand) as well as the management actions taken to date aimed at protecting and restoring environmental flows in each river. For example, where environmental flow issues have been identified and a river management plan implemented to restore environmental flows, the forecast would be considered “improving”. Where current management actions are considered inadequate for protecting environmental flows, or future threats are expected to worsen environmental flow conditions, the forecast would be considered “declining”. Where conditions appear to be relatively stable, with no clear indication that conditions will decline or improve markedly, the forecast was considered “steady”.

While this study represents a science-based assessment, there are obvious limitations to the approach taken. Due to limitations and inconsistencies in the available data for each river, status classifications are based largely on qualitative information and relied heavily on the best judgment/opinion of experts in the field as well as the researchers. We acknowledge that this type of assessment is, by nature, subjective; however this does not make the study or its results any less relevant. Despite these limitations, the methods and results of this study have been peer-reviewed and we are confident that they depict, as accurately as possible, the status and forecast of environmental flows in the ten rivers assessed.

STATUS OF ENVIRONMENTAL FLOWS - RIVER ASSESSMENTS

Athabasca River

One of North America's largest remaining free-flowing rivers and the longest river in Alberta, the Athabasca flows northeastward from its source in the Columbia Icefields of the Rockies across the prairies into the Peace-Athabasca Delta in northern Alberta. Along the way, this majestic river provides water and important habitat for fish and migratory waterfowl, but the lower portion of the Athabasca also flows directly through one of the largest known oil reserves in the world — the Alberta Oil Sands.⁴⁴ Current technology requires between 2.03 and 4.09 barrels of water for each barrel of oil produced, and most of this water is withdrawn from the Athabasca River.^{45,46,47,48} Water withdrawals for the expanding and water-consumptive oil sands industry pose a significant threat to environmental flows in the Athabasca River.^{49,50} The rapid pace of industrial development and corresponding growth in water demand from the Athabasca River, especially when considered cumulatively with climate change, necessitate immediate action to protect its vulnerable aquatic ecosystems by limiting withdrawals to within sustainable levels.

<i>at a glance...</i>	Athabasca River
Length:	1,538 km
Average Discharge:	784 m ³ /s
Drainage Area:	155,000 km ²
Major Drainage Basin:	Arctic Ocean
Jurisdiction:	Alberta
Major Issues:	withdrawals, climate change

Status: GOOD

Forecast: DECLINING



For most of its length, flow in the Athabasca River is relatively undisturbed due to the fact that there are no dams or reservoirs and very little development upstream of the oil sands.⁴⁹ Its significance is recognized nationally and internationally, with its pristine upper reaches in Jasper National Park designated as a Canadian Heritage River. Here the river is fast-flowing and silt-laden, plunging through narrow gorges and rapids and braiding through alluvial plains, making it a popular destination for whitewater canoe and kayak enthusiasts.⁵¹ As the terrain flattens, the Athabasca winds its way more slowly across Alberta to its lower reaches in the northeastern corner of the Province. Where it empties into the western end of Lake Athabasca, the delta of the Athabasca River joins those of the Peace and Birch rivers to form the Peace-Athabasca Delta — a 6000 km² wetland complex that forms one of the world's largest freshwater deltas and its largest boreal delta.⁴⁹

The Peace-Athabasca Delta is internationally recognized as a Ramsar wetland site and part of Wood Buffalo National Park, a UNESCO world heritage site.⁵² It is one of the most important waterfowl nesting and staging areas in North America, crossed by all four major North American flyways; up to 400,000 birds are known to use the Delta in the spring, and more than one million in the autumn.⁴⁹ As with all delta ecosystems, the ecological integrity of the Peace-Athabasca Delta is highly sensitive to water level

Important Ecological Features

- Peace-Athabasca Delta is a World Heritage Site, world's largest boreal delta; crossed by all 4 major N. Am. flyways⁵²
- Lower Athabasca supports 31 fish species, over half the fish

and flows; its hundreds of shallow perched lakes and side channels rely on a range of high and low flow conditions in order to maintain their productivity.^{53,54,55,56}

Upstream of the Delta, portions of the river itself are also sensitive to flow levels. The lower Athabasca River supports 31 species of fish — over half the total number of fish species found in Alberta.^{57,50} These species are adapted to the natural flow regime in the Athabasca River, which is naturally highly variable from year to year as well as seasonally.⁵⁸ For

example, fish that spawn in the spring need high flows at that time, while fall spawning fish typically do best with low flows then. Field studies and local traditional knowledge have shown that fish in the lower

Athabasca River are especially vulnerable during the winter months, when flows are naturally very low and the river is ice-covered and thus habitat is significantly reduced and may also be susceptible to low dissolved oxygen.^{49,50,59} Therefore, it is very important to ensure, in addition to maintaining natural flow variability, that enough water is left instream in the winter months to sustain the aquatic environment. Canadians are concerned about the impact of oil sands development on our water resources. A recent poll found that concern about impacts on freshwater was cited as the single most important oil sands environmental issue by Canadian citizens.⁶⁰ Aboriginal groups, locally and throughout the greater Mackenzie Basin (of which the Athabasca River is part) are directly affected by the health of the Athabasca River and its ecosystems. Traditionally and presently, they rely on the waters of the Athabasca for cultural, spiritual, and recreational purposes, as well as for commercial and subsistence fisheries.^{69,61} The nearby Athabasca Chipewyan and Mikisew Cree First Nations, along with many other stakeholders, have spoken out about the need for strong protection of environmental flows and water quality in the Athabasca River.⁶⁶

Threats to Environmental Flows

Oil Sands Water Withdrawals

The oil sands mines along the lower Athabasca River, north of Fort McMurray, are by far the principal water users in the Athabasca River basin, accounting for 76% of licensed water use in 2005, with another 8% allocated for other petroleum purposes.⁴⁹ The Athabasca River is the main source of water for these operations, which use large quantities of water to extract oil from bitumen. In 2007 alone, oil sands operations withdrew more than 128 million m³ of water from all sources,⁶² which represents only a portion of their maximum allocations — current projects are licensed to divert over 441 million m³ of freshwater from the Athabasca each year,⁶² and this is expected to increase to more than 500 million m³ per year if proposed projects are also approved.^{63,64} Although oil sands projects generally use less than their maximum allocation, at full development they will be entitled to withdraw more water than is used by the entire City of Toronto in one year.⁵⁰ But while cities return most of the water they withdraw back into its source after it has been treated, only 3.3% of the water used in oil sands processing is returned after use, and the rest ends up in toxic tailings ponds.^{50,66,65}

Status of Environmental Flows: GOOD

- Oil sands water consumption projected to increase over 200% by 2015⁶⁶
- Oil sands withdrawals represent 1-2% of mean annual flow,⁶⁹ but a much greater proportion of flow during winter, placing ecosystems at risk⁷⁰
- Climate warming in Athabasca region 3x global average⁷²
- One study found Athabasca summer flows declined almost 30% between 1978 and 2005⁴⁹

Development in the oil sands is rapidly expanding; only two oil sands mining projects were operational prior to 2002, and now there are four, with three more approved.⁶⁴ Oil production from these operations is expected to more than double by 2015 to 3 million barrels per day⁶⁶ (although the actual pace of development may be tempered somewhat as a result of the recent drop in oil prices⁶⁷).⁵⁸ Along with this expansion will come increased water demand and use, in response to which

the Government of Alberta has acknowledged that, over the long term, the Athabasca River may not be able to meet the needs of all planned mining operations and maintain adequate environmental flows.⁶⁸

The Canadian Association of Petroleum Producers reports that the oil sands currently use less than one percent of the Athabasca's flows, and that future projects could increase that number to 2%.⁶⁹ However while withdrawals may represent only 1 to 2% of mean annual flow, in a river like the Athabasca with highly variable flows, mean annual flow tells only part of the story. For instance, spring and summer peak flows are commonly ten times greater than winter low flows and flows as low as 75 m³/s have been observed. During these low flow periods, when it is known that ecosystems in the Athabasca River

are most vulnerable to impacts from withdrawals,⁷⁰ water requirements of current and proposed projects, which are projected to reach 16 m³/s,⁷¹ represent a much larger proportion of the Athabasca River's flow. When the winter "potential sustainability threshold" of the Athabasca is reached (a low flow that is exceeded 95% of the time where the ecosystem is expected to experience significant changes),⁷⁰ maximum water withdrawals are set at 15 m³/s and decrease each week in the winter to a low of 8.2 m³/s. Oil sands mining operators are always permitted to withdraw this amount regardless of the severity of a low flow event,⁷⁰ which gives precedence to water withdrawals over ecosystem protection. Future water withdrawals during these low flow conditions could cause the status of environmental flows in the Athabasca River to easily slip from Good to Fair or even Poor.

Similarly, in an assessment of the compatibility between oil sands projects and ecosystem water needs, a 2006 WWF-Canada report found that, even at the lower end of projections of oil sands water withdrawals, there would have been 10 times during the past 25 years when the minimum flows in the Athabasca River would have been low enough to cause short term impacts on ecosystems.⁷² The report concludes that, because estimates of water requirements for current and planned projects exceed Alberta's recommended target for aquatic ecosystem protection in the Athabasca River in low flow periods, the projected rate of water use by the oil sands industry is unsustainable.⁷² It is clear that, if left unchecked, current and future water withdrawals from an expanding oil sands industry could represent a very real threat to environmental flows in the Athabasca River.

Climate Change

The Athabasca River basin is already experiencing climate change, with an observed increase in air temperatures of 1.5 – 1.8°C from 1961 to 2000 — three times higher than the global average of 0.6°C.⁷² Over the past century, river flows have declined throughout the prairies,⁷³ and the Athabasca appears to be no exception. According to Schindler *et al.* (2007),⁴⁹ summer flows in the Athabasca River at Fort McMurray declined by 19.8% between 1958 and 2003, and by almost 30% in the time since 1970. While other studies have found less dramatic trends in declining flows over different time periods and seasons,^{74,75} decreasing streamflow is consistent with observed trends in declining winter and spring precipitation and increased evapotranspiration driven by warmer temperatures.⁴⁹ Also, the glacier feeding the Athabasca River has shrunk by 25% over the last century,⁷⁶ and while this may have contributed increased meltwater in recent years, it will soon (if has not already) result in reduced meltwater into the Athabasca system, further reducing flows. Climate change prediction is fraught with uncertainty, and Alberta's natural climatic variability may also be contributing to recent warmer, drier conditions,⁷² however nonetheless it appears to be generally accepted that flow in the Athabasca has declined in recent years, a trend that is expected to continue into the future.

Central and northern Canada, including the Athabasca region, is expected to experience much greater climate warming than the global average — temperatures are predicted to rise by as much as 3.5 to 4°C in this region by 2050.⁷⁷ Efforts to model the combined effects of predicted temperature and precipitation changes on flows in the Athabasca River have been undertaken as part of the Mackenzie GEWEX Study,⁷⁸ and these studies suggest that further declines in annual runoff of up to 30% may occur, with minimum flows in the river declining a further 7 to 10%.⁷⁷

Ironically, oil sands operations are among the largest sources of greenhouse gas emissions in Canada (by 2015 they are projected to emit more greenhouse gases than the country of Denmark⁷²), and as such are contributing significantly to the climate warming that is predicted to reduce flows in the Athabasca River — exacerbating the problem of water insecurity not only for ecosystems but for industry itself. With annual and winter low flows decreasing in recent years, a trend expected to persist into the future,

the potential exists for oil sands water withdrawals to threaten environmental flows in the Athabasca River to a much greater degree than has occurred to date. If they decline as predicted, flows in the Athabasca River will be insufficient to satisfy both the needs of rapidly expanding oil sands production and sustain the natural environment.

Management and Advocacy Initiatives

Environmental flows, or “instream flow needs” (IFNs) as they are known in Alberta, have been given explicit consideration in only a few of the Province’s rivers, one of which is the Athabasca.⁷⁹ Initially, the Cumulative Effects Management Association (CEMA), a multi-stakeholder group created to manage the cumulative impacts of oil sands development, was tasked with developing IFNs for the lower Athabasca.⁶¹ However, when CEMA failed to reach consensus by 2005, Alberta Environment and DFO (on the recommendation of two joint federal-provincial panel hearings for two separate oil sands mines held in 2003) released a two-phase framework in March 2007.⁷⁰ Phase 1 of the Water Management Framework (currently in place) was designed to manage environmental flows on an interim basis until development of Phase 2, which is ongoing. Essentially, the Phase 1 Framework specifies different management strategies for ranges of river flow — in the “green” zone, where (according to the Framework) there is sufficient water to meet industry and ecosystem needs, industry can withdraw up to 15% of flow; in the yellow zone, allowable withdrawals are reduced; and in the red zone, where withdrawals could threaten ecosystems, industry is allowed a smaller percentage of flow.⁷⁰

The Phase 1 Framework has been criticized for a number of shortcomings, including not being sufficiently precautionary, not being enforceable, not providing incentive for industry to reduce water use, and for failing to consider the impacts of climate change.^{49,50,80} For instance, it does not establish an “ecosystem base flow” (EBF) which would require industry to stop withdrawing water during low flow periods, when fish and fish habitat may be impacted.⁶⁴ Also, as discussed, under the Phase 1 Framework oil sands mining operators are always permitted to withdraw at least 5.2% of historical median flows regardless of the severity of a low flow event. WWF-Canada has recommended that Alberta consider withholding approval of future oil sands projects until it can ensure that environmental flows will be provided to protect ecosystems in the lower Athabasca in the face of a changing climate.⁷²

Coordinated by CEMA, the Phase 2 Framework Committee (P2FC), a multi-stakeholder group consisting of representatives of the federal and provincial governments, industry, NGOs, and First Nations and Metis groups, has been tasked with recommending a long-term management framework for the lower Athabasca by the end of 2009, for implementation in 2011. Using information from field studies and modeling, and striving for consensus, the P2FC is considering environmental, social and economic values in order to build on Phase I and develop a water management framework that will protect environmental flows. Specific environmental criteria being used include connectivity in the Peace-Athabasca Delta, channel maintenance, walleye recruitment, Lake Whitefish spawning, fish habitat, and winter dissolved oxygen. Social values include traditional land use, boating, and recreational use of the river. Industry is assessing their water needs, which the committee will use to evaluate what combination of mitigation and water withdrawal will meet future needs while protecting aquatic ecosystems and social values.^{67,70} Additionally, research will be directed towards defining an EBF, a level of low flow where industry water withdrawals would effectively stop.⁷⁰

What’s being done about it?

- Current framework is not sufficient — not enforceable, does not consider climate change^{49,50,80}
- Recommendations for long-term framework in development (2011 implementation)⁷⁰
- Many stakeholders (including WWF-Canada) advocating for protection of environmental flows from increasing oil sands withdrawals. See www.oilsandswatch.org

WWF-Canada has been an active participant in the P2FC, with the interests that a long-term framework must incorporate the effects of climate change on flows, provide protection during low flows (an EBF) as well as peak flows, establish industry water conservation objectives, and be legally enforceable. While efforts to date represent positive and constructive steps towards sustainable water management, these further elements are essential to protect environmental flows and truly balance economic, social and environmental objectives for the Athabasca River.


Figure 3. Summary of Environmental Flow Classification for the Athabasca River

Indicators	Status of Indicators
River fragmentation and flow regulation	Unaffected by fragmentation and flow regulation
Water withdrawals and diversions	Some withdrawals, evidence that growing demand will increase withdrawals and cause future threats
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change expected to result in significant changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows somewhat altered from natural, resulting in moderate losses of connectivity
Timing of flows, flow patterns, seasonality	Timing of flows not significantly altered from natural; slight changes in seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species/ecosystems dependent on natural flow regime are healthy; few negative impacts from changes to flow s
Water quality in relation to flow regime	There are significant water quality issues in the Athabasca River, but these are not caused by alterations to environmental flows

Status of Environmental Flows/Forecast: GOOD/DECLINING

Fraser River

The Fraser River, named after Simon Fraser, the first non-Aboriginal explorer to reach its mouth, is truly a great Canadian river in every sense, sustaining rich natural and cultural values throughout its basin. The fourth largest North American river with no mainstem dams, the Fraser is the largest river in British Columbia, and its massive and diverse watershed covers more than a quarter of the province from the Rockies to the Pacific Ocean, representing 11 of BC's 14 biogeoclimatic zones.⁸¹ A Canadian Heritage

at a glance...		Fraser River
Length:	1,375 km	
Average Discharge:	3,972 m ³ /s	
Drainage Area:	234,000 km ²	
Major Drainage Basin:	Pacific Ocean	
Jurisdiction:	British Columbia	
Major Issues:	Tributary dams, water withdrawal, climate change	
Status: GOOD		Forecast: STEADY

River, the Fraser is one of the world's greatest salmon rivers, producing more salmon than any other river on earth.⁸² Its vast natural resources have sustained diverse Aboriginal cultures in the Fraser Basin for at least 10,000 years.⁸¹ Today, the Basin is home to two-thirds of British Columbians (2.7 million people) and contributes 80% of the province's economic output.⁸³ Although considered one of the less-impacted major rivers in North America,⁸¹ the Fraser tied for second on the Outdoor Recreation Council of BC's 2008 "Most Endangered Rivers" list, and has been in the top five

for 15 of the past 16 years,⁸⁴ and approximately one of every ten vertebrate species in the Basin is "red-listed" - extirpated, threatened or endangered.⁹⁸ While progress has been made on many fronts, there are persistent concerns about the Basin's long term health, and continued commitment is needed to address the many issues facing the Fraser River.

High in the Rockies, the Fraser River begins in Mount Robson Provincial Park, near where the Athabasca and North Saskatchewan Rivers also arise. The upper river flows northwest through a deep, narrow valley until just east of Prince George it turns sharply to flow south between the Coast Mountains to the west and the Cariboo Mountains to the east. It is in this mid-section that the Fraser is joined by the West Road, Quesnel, Chilcotin and Bridge Rivers, and further downstream it meets the Thompson River, one of North America's largest rocky-bottom rivers.⁸¹ After tumbling through the Fraser Canyon, it turns west and flows through the heavily populated lower Fraser Valley, through the city of Vancouver and surrounds, to the Fraser Delta where it finally empties into the Strait of Georgia in the Pacific Ocean.

The waters of the Fraser system provide spawning and rearing habitat for millions of salmon from all five Pacific species, and support 30 other fish species and 87 more in its estuary.⁸² Many of these species are commercially important; fishing in the Fraser Basin is worth more than \$300 million per year.⁸⁵ Highly sensitive to water levels, temperatures and pollution, salmon in the Fraser River have shown marked declines in recent years.⁸⁶ For example, sockeye returns in 2007 and 2009 were the lowest observed in 30 years.^{87,88} The white sturgeon, North America's largest freshwater fish, is listed as endangered under COSEWIC,^{89,90} and has been a species of concern throughout the Fraser River since the early 1900s when commercial fishing reduced its numbers to dangerously low levels.⁹⁰ White sturgeon continue to face significant obstacles, including habitat degradation in the Fraser and flow regulation and dams on some of its tributaries.^{90,91}

Important Ecological Features

- World's most productive salmon system; tens of millions of salmon return to Fraser to spawn each year.⁸²
- Endangered Upper Fraser River white sturgeon⁸⁹
- Fraser River Delta, one of BC's most productive waterfowl habitats and migratory staging areas^{83,92}

The Fraser Basin also provides important terrestrial habitat, most notably the Fraser Delta which is one of BC's most productive waterfowl breeding and overwintering areas, and is a crucial staging area for migratory birds along the Pacific Flyway.⁸³ It supports the highest densities of wintering birds in Canada,⁹² and portions of it have been designated Ramsar sites and Important Bird Areas, but its integrity is threatened by human impacts such as expansion of agriculture and urban areas as well as river dredging, dyking, and channelization, which interrupt natural flow and sedimentation patterns in the Delta.⁹³

While the mainstem of the Fraser River remains free-flowing and only moderately affected by fragmentation and flow regulation, a host of emerging issues are creating cause for concern. Declining sockeye salmon returns, increasingly low streamflow, fragmentation and regulation of tributaries, and competition for water from agriculture and urban growth all point to the future challenges that must be addressed in order to sustain the rich natural and cultural values that flow from the mighty Fraser River.

Threats to Environmental Flows

Flow Regulation and Modification

While there are no dams on the main stem of the Fraser River, some of its major tributaries have been dammed and thus the system is considered to be moderately affected by fragmentation and flow regulation.³⁰ Specifically, the Nechako, Bridge and Stave Rivers have been dammed, primarily for generation of hydroelectricity, and on waterways throughout the Basin there are many smaller dams that generate hydroelectricity or serve various other purposes such as water storage for irrigation.⁹⁴

Dams on Fraser tributaries have significantly impacted hydrology and ecosystem dynamics in these sub-watersheds. The Nechako River, which drains the northwest corner of the Fraser Basin and contributes 8.3% of the Fraser's flow, was dammed in 1952 by Alcan Aluminum, raising upstream water levels 50 m and permanently diverting 60 to 70% of the river's flow for power generation.^{81,95} As a result of the Kemano Diversion, summer flows in the Nechako downstream of Kenney Dam have decreased by as much as 60%, flow velocity has decreased, and 85% of Type 1 side channels have been lost.^{95,96} The timing of these habitat changes coincided with significant recruitment failure in endangered white sturgeon populations,⁹¹ and water temperature changes have ignited concerns about thermal stress to migrating sockeye salmon in the Nechako system.⁸¹

Status of Environmental Flows: GOOD

- Mainstem free-flowing, but some major tributaries have been dammed³⁰
- Summer flows in Nechako River down 60% below dam, impacting endangered white sturgeon and salmon^{91,95}
- Groundwater taking not regulated in BC, impacting environmental flows in the interior¹⁰⁰
- Climate change already altering Fraser River hydrology, causing warmer water and reduced flows, threatening already-stressed salmon^{100,107,108}

Along the Lower Fraser, delta and floodplain dynamics have been altered by extensive dyking and drainage, built in response to major flooding in the late 1800s.⁸¹ Stabilization of river channels and land on the Fraser Delta facilitated agricultural and urban development on low-lying floodplains, and still protects 65,000 ha of land along both sides of the river from the town of Agassiz to the river's mouth.⁹⁷ While providing important flood control, this infrastructure has nevertheless altered floodplain ecosystems, reducing the extent of wetlands and habitat in the Lower Fraser River.^{40,98}

Changes in land cover, due to logging and urbanization, have also modified hydrology and river flow in the Fraser Basin. For instance, assuming that 11% of the basin is urbanized, of which 30% is estimated to

be impervious, it has been estimated that approximately $3.79 \times 10^8 \text{ m}^3$ of water per year no longer infiltrates the soil to recharge aquifers in this region — enough to supply the needs of 1.9 million people.⁴⁰ Instead, this water quickly runs off impervious surfaces, changing the discharge profiles of rivers and streams in the Basin and increasing erosion.⁴⁰

Water Withdrawal

In the drier interior of the Fraser Basin, excessive withdrawals of both surface and groundwater, especially during increasingly common periods of low flow, have resulted in local water shortages, reduced streamflow and stressed aquatic habitats and species.^{84,98} Despite far reaching concerns about the maintenance of environmental flows in the interior, requests for new water withdrawals in this area are still being considered by the province,⁸⁴ and despite evidence that groundwater is being depleted and its extraction is impacting environmental flows and aquatic ecosystems,^{99,102} BC remains the sole province in Canada that does not require a government license for groundwater extraction.¹⁰⁰

In the Nicola watershed, for instance, in the interior of the Fraser Basin, extensive withdrawals of surface and groundwater — mainly for irrigation — have had major effects on stream flows and fish habitat.¹⁰¹ In rivers such as the Nicola where flows are reduced, either naturally or due to water withdrawal, the remaining water is more quickly heated by solar radiation and water temperature becomes a problem, often exceeding the optimal levels for salmonids and routinely reaching lethal levels (above 25°C).¹⁰² This problem is exacerbated where groundwater takings reduce cooling groundwater flows, and by extensive removal of riparian vegetation that results in a loss of shade.¹⁰²

Climate Change

Excessive water extraction is even more problematic in the Fraser Basin when superimposed with the increasingly evident impacts of climate change. Average air and water temperatures have warmed over the past 50 to 100 years, and Fraser River freshets are occurring earlier than in the past 85 years.⁸⁷ Record low streamflow and water levels have been recorded in the interior, such as in the Thompson and Nicola basins, which have been attributed to lower snowpack, earlier snowmelt, and warm and dry weather, conditions that are expected to persist with continuing climate change.¹⁰⁰

Scenarios predict that average temperatures in BC will increase over the next century and precipitation patterns will vary across the province. By the 2050s annual average temperature is expected to warm by 1.7°C and annual precipitation will increase by 6%, within a range of 3 to 11%,¹⁰³ with generally wetter winters, drier summers and increasing extreme precipitation events.¹⁰⁴ Due to BC's diverse climate and hydrology, even within the Fraser Basin, these impacts will be experienced differently in different places.¹⁰⁵ For example, temperatures are expected to rise more in northern BC than in the south.¹⁰³

In the Fraser River, shifts in streamflow are projected to occur as the climate changes. Warmer temperatures could cause the river to peak earlier, and this peak may be reduced because of decreased snowpacks and storage.¹⁰⁶ Changes in flow could increase the frequency of floods and water shortages, and higher water temperatures are likely to impact fish.^{104,106} The impact of climate change on salmon is one of the issues of greatest concern in the Fraser Basin;¹⁰⁷ temperature increases and reduced flows are threats to salmon, and in the Fraser River there has been some indication that warmer water has delayed sockeye migration.^{107,108} Scientists predict that if streamflows continue to decline, Fraser salmon may have difficulty accessing and navigating migration routes and could be seriously threatened.¹⁰⁸

An indirect albeit significant impact on flows in the Fraser Basin is expected to occur as a result of the recent climate change driven mountain pine beetle infestation in the BC interior, which has devastated

forests across the province, affecting 60% of the Fraser Watershed.¹⁰⁹ Lost forest cover from infestation and secondary logging will result in major impacts on rivers and streams — forests of beetle-killed trees have higher snowpacks, higher water tables, faster snow melt, higher spring floods, and more flash flooding and erosion.¹⁰⁹ These changes will significantly alter watershed hydrology and ecology, further threatening already stressed salmon runs and other species that rely on environmental flows.

Management and Advocacy Initiatives

A main objective of the federal *Wild Salmon Policy* is to maintain marine, freshwater and terrestrial habitat and ecosystem integrity,¹¹⁰ which could provide a vehicle through which to protect environmental flows in the Fraser Basin. The BC *Fish Protection Act* also includes a number of provisions for protecting environmental flows in the province, such as prohibiting new dams on “sensitive” rivers (some of which are in the Fraser Basin), and enhancing the ability of managers to consider fish habitat needs in water licensing; however some innovative provisions such as “streamflow protection licences” for environmental flows were considered but never brought into force.¹⁰⁰ Provincial agencies, in collaboration with the Department of Fisheries and Oceans, have developed guideline documents for evaluating instream flow needs of fish as they relate to hydroelectric proposals,¹¹¹ and through its *Living Water Smart* initiative, part of modernizing water management in the province, the BC government aims to review existing water legislation to include provisions for environmental flows,¹¹² though little action has been taken on this issue to date.¹¹³

What’s being done about it?

- BC has tools to protect environmental flows, but action so far has been weak — groundwater still unregulated^{112,113}
- BC Hydro Water Use Planning undertaken on several Fraser tributaries — positive outcomes in most rivers¹¹⁵
- Innovative initiatives, such as Nicola Water Use Management Plan, consider environmental flow needs of rivers¹⁰²
- Many groups advocating for protection of environmental flows in Fraser Basin. See:
 - Fraser Salmon and Watersheds Program (www.fswp.ca)
 - Watershed Watch Salmon Society (www.watershed-watch.org)

In 1998, under the *Water Act*, the BC government requested that BC Hydro undertake a Water Use Planning process to review operating conditions at their generating facilities, with the overall goal of balancing competing uses of water including fish and wildlife, recreation, and power generation needs.^{114,115} This process has resulted in Water Use Plans for most of BC Hydro’s facilities,

including several Fraser River tributaries such as the Bridge and Alouette Rivers.¹⁰⁰ Developed in consultation with government, First Nations, local citizens and interest groups, these Water Use Plans have resulted in improved knowledge of the environmental flow requirements for fish in BC, and outcomes to date have generally been positive, although not without some level of compromise on fish conservation objectives and a lack of full consensus at some facilities.¹¹⁵

Other innovations in water management are occurring within the Fraser River Basin on a smaller scale. In the Nicola Watershed, for example, a successful community-led process has led to the ongoing development of the Nicola Water Use Management Plan, which specifies how water will be managed to balance the needs of people and ecosystems in the watershed.¹⁰²

The only organization of its kind in Canada today, the Fraser Basin Council is a unique partnership of public and private interests, involving but at an arms-length from governments, made up of broad representation from all sectors of society that emphasizes an integrated approach to realizing social, economic and environmental goals.^{85,116} As part of its work toward sustainability, the Fraser Basin Council is a founding partner, along with the Pacific Salmon Foundation, Living Rivers Trust Fund, and the Fraser Basin Initiative of Fisheries and Oceans Canada, in the Fraser Salmon and Watersheds Program, which functions by enabling groups to recognize activities that threaten their local watersheds

and works with individuals, organizations and institutions on projects to improve community engagement, governance, habitat and fisheries in the Fraser Basin.¹¹⁷

Watershed Watch Salmon Society and the David Suzuki Foundation are two of the numerous groups active in science-based advocacy towards protection of environmental flows and improving water management in the Fraser Basin, with a particular focus on how these relate to conservation of sensitive pacific salmon habitat.

Figure 4. Summary of Environmental Flow Classification for the Fraser River

Indicators	Status of Indicators
River fragmentation and flow regulation	Main stem unaffected by fragmentation and flow regulation
Water withdrawals and diversions	Few, infrequent withdrawals overall; but significant in parts of the basin, evidence that demand may increase in the future
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change could result in moderate changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows slightly altered from natural, no or minor losses of connectivity
Timing of flows, flow patterns, seasonality	Timing of flows not significantly altered from natural; slight changes in seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species/ecosystems dependent on natural flow regime are somewhat impacted by changes but not in imminent danger
Water quality in relation to flow regime	No evidence that water quality problems (if present) are related to changes in flows

Status of Environmental Flows/Forecast: GOOD/STEADY

Grand River

Flowing through rich agricultural land and expanding cities in the largest inland watershed in southern Ontario,¹¹⁸ the Grand River has undergone a great deal of change in its history. Prior to European settlement, which occurred around the mid-1700s, the Grand River watershed was largely covered with forests and wetlands. Since then, however, the land has been progressively cleared and most its wetlands drained to make room for farms, industry and settlements; by the 1950s only remnants of the region's forests remained.^{119,120} These land use changes caused significant changes to the watershed's hydrology and flow regime, which, along with subsequent river modification and use for waste disposal, led to a rapid decline in the health of the watershed¹²¹ — to the point where, in the 1940s, the Grand

at a glance...	Grand River
Length:	300 km
Average Discharge:	80 m ³ /s
Drainage Area:	6,800 km ²
Major Drainage Basin:	Atlantic Ocean (Great Lakes)
Jurisdiction:	Ontario
Major Issues:	Dams, water withdrawals, urban growth, climate change

Status: FAIR

Forecast: STEADY



was described as a sewer.¹²² Since then, considerable effort has been put toward restoring the river and its watershed by the Grand River Conservation Authority (GRCA) and others, and the Grand is now touted as one of the healthiest rivers in North America in a heavily populated area.¹²³ However despite improvements in water quality and watershed condition, the legacy of years of river modification along with pressure from population growth and increasing demand for water continue to impact environmental flows in the Grand River watershed.

Near its source at the highest point in Ontario in the Dundalk Highlands, the Grand River receives water from the Luther Marsh wetlands. It winds south as it widens and deepens, flowing steeply as it tumbles over a 15 m waterfall and through a limestone gorge at the town of Elora. Passing through the cities of Waterloo, Kitchener and Cambridge, it picks up two of its major tributaries, the Conestogo and Speed Rivers, and joins with the Nith River north of Brantford. Broadening further, it continues southwest through the territory of the Six Nations of the Grand River (which has the largest population of any First Nations in Canada¹²⁴), toward Lake Erie where it flows into the Great Lakes at Port Maitland.

The Grand River watershed offers cold, warm, and mixed water habitats, supporting a range of species. There are 82 species of fish in the watershed, which is about 50% of all fish species in Canada.¹¹⁸ Additionally, six of 29 COSEWIC-listed (as Vulnerable, Threatened or Endangered) fish occur in the Grand: black and river redhorse suckers, reidside dace, silver shiner, greenside darter, and eastern sand darter.¹²⁵

The Grand River and its watershed provide drinking water, from surface and ground sources, for almost a million people, and assimilates waste from 28 water treatment plants.^{118,126} The river also provides important recreational opportunities including canoeing, hiking, and fishing; fly fishing alone contributes more than \$1 million to the local economy each year.¹¹⁸ In recognition of its exceptional natural and cultural values, the Grand River was designated a Canadian Heritage River in 1994,¹²⁷ and is the one of only two Canadian rivers to be awarded the prestigious International Thies Riverprize for outstanding achievement in river management.¹²⁸

Important Ecological Features

- 82 fish species (50% of species in Canada), in cold, warm and mixed water habitat (brook trout, brown trout, steelhead, walleye, bass...)¹¹⁸
- 6 COSEWIC-listed fish, including black redhorse sucker and reidside dace¹²⁵
- Grand River Forest contains Carolinian forest species rare to Canada¹¹⁸

The Grand is a complex system, where hundreds of years of development continue to influence river flows and ecosystems, and where water quantity and quality are inextricably linked. Protecting the integrity of the Grand River in the face of current and future threats will require building on past successes and considering environmental flows as an essential component of watershed management.

Threats to Environmental Flows

Flow Regulation and Modification

Flow in most of the Grand River watershed, especially its main stem, is highly regulated.¹²⁹ This is mainly for flood control and low flow augmentation — the system’s many dams and reservoirs are operated to reduce the extremes of spring floods and top up summer low flows. Such extremes were not always the case on the Grand River, however. When European settlers cleared most of the land in the watershed in the 1700s and 1800s, they effectively removed the ability of the watershed to retain water, moderate high flows, and sustain flows in the river year round. The consequences of these hydrological changes were catastrophic spring flooding, followed by severe summer drought, which reached a critical point by the early 1900s.¹²⁰ In response, the Grand River Conservation Commission (predecessor of the GRCA) was formed and in 1939 began building the Shand Dam upstream of Fergus, the first multi-purpose dam of its kind in Canada, built to stabilize flows by replacing the natural holding capacity of the watershed.^{120,123} There are now numerous dams in the watershed, 32 of which are owned and operated by the GRCA and over 100 more that are privately or municipally owned.¹³⁰

Although river regulation on the Grand is a somewhat different story than in most places — it has provided beneficial and much needed flow stabilization and flood control, and greatly improved river health — it has also resulted in a highly modified river and flow regime. Indeed, the Grand River and its watershed have been so heavily modified that a return to the historical natural flow regime is not practical and will never occur.¹²⁰ Dams in the watershed have fragmented the river, modified flows and flood hydrographs, and altered water temperatures, sometimes negatively impacting fish habitat.¹³¹ Additionally, dams have dampened high flows that would naturally flush nutrients, sediment and organic materials downstream.¹³² Dams elsewhere in the watershed also limit the amount of water that can be released from the Shand Dam, which may impact habitat quality for the downstream brown trout fishery which requires specific water flows, quality and temperature.¹³³ It is recognized that naturalization of river flow regimes, within the limits of GRCA’s operating constraints, may improve the ecological integrity and health of the river.¹³²

Status of Environmental Flows: FAIR

- Hundreds of dams in the watershed; flow is highly regulated¹²⁹
- Water withdrawals — demand highest when supply is lowest; total permitted withdrawals exceed supply in parts of watershed^{129,136}
- Population expected to grow 57% between 2001 and 2031 to 1.2 million¹⁴⁰
- Temperature to increase 2.6 to 5.6°C over next century, causing hydrological changes¹⁴¹

Water Withdrawal and Use

Annual water use in the lower Grand watershed is classified by the Ministry of Natural Resources as “medium” (all other watersheds in the province are considered “low”, with the exception of one to the southwest that is “high”).¹³⁴ Municipalities are the main water users in the watershed, making up 36.9% of water use in 2005.¹³⁵ Approximately 70% of municipal supply comes from groundwater, with the remaining 30% withdrawn from surface water sources (91% of which is from the Grand River), although surface water is becoming more significant.¹³⁵ Other noteworthy water uses include aggregate extraction and agricultural irrigation, which jumps from being the 8th (annually) to the 2nd largest user of water during the summer months.¹³⁵

Water withdrawals peak in the summer, when, in the Grand River watershed, water supply is lowest. As such, the upper Grand is classified as a “medium” water use watershed during summer low flow conditions, and the lower Grand as “high”, one of only three high use watersheds in the province.¹³⁶ Summer water takings are of particular concern with respect to aquatic ecosystems, as they coincide with natural low flows caused by less precipitation, higher temperatures and increased evapotranspiration in the watershed.¹²⁹ At peak demand, as much as 20% of the water is withdrawn from the middle section of the Grand River.¹³⁷ In the Whitemans Creek sub-watershed, where irrigation water use is very high, surface water demand can be as much as 76% of supply during peak irrigation periods.¹³⁸ All permitted surface and groundwater takings total 3.6 m³/s, which exceeds the summer mean flow of 1.7 m³/s and approaches the mean annual flow of 4.3 m³/s.¹²⁹ If all of these were withdrawn at the same time, there would be no water left for the aquatic environment.¹²⁹ Groundwater withdrawals are known to affect streamflow in portions of the watershed. Again, Whitemans Creek is situated on a sandy plain, and groundwater from the shallow aquifer discharges to local creeks, contributing significantly to baseflow — groundwater takings in this vicinity are known to reduce surface water levels and streamflow.¹²⁹ Summer low flows can have significant water quality implications, especially downstream of any of the 29 sewage treatment plants that discharge into the Grand watershed,¹³² which exemplifies how threats to environmental flows can affect water quality.

Urban Growth

Population growth has been identified by the GRCA as one of the key challenges facing the Grand River watershed.^{135,139} A study done by the Ontario government to support its *Places to Grow* planning policies predicted that the population of urban areas in the Grand River watershed will grow by 57% between 2001 and 2031.¹⁴⁰ The Grand River watershed is currently home to 925,000 people, and this is expected to grow to 1.2 million in the next 20 years.¹¹⁸ While a recent water budget study found that current demand is less than supply in most of the watershed, demand is very high in some areas and increases in demand could reduce water availability for people as well as the natural environment.¹³⁸ The provincial government acknowledges that there are both water and wastewater limitations associated with ground and surface water in the Grand River watershed,¹⁴⁰ and as the watershed continues to experience growth there will be increased demands on the basin’s limited water resources.

Climate Change

Climate change is one of the most significant challenges facing the Grand River watershed.¹³⁹ Precipitation in the watershed has followed an upward trend, increasing over the past century.¹⁴² By 2090, temperatures in the Grand River watershed are predicted to be 2.6 to 5.6°C warmer annually, and precipitation (both rainfall and snowfall) is expected to increase 11 to 18%.¹⁴¹ It is not known with certainty what impacts these changes will have on the hydrology of the Grand River watershed.^{141,142} Warmer temperatures could mean more frequent and intense periods of drought, as well as an earlier spring melt. More snow could also mean larger spring floods for the watershed, but warmer winters could also mean that snow accumulation could decline, thus lowering the overall storage of the watershed and reducing streamflow.¹⁴¹ By reducing flows, climate change could also impact water quality in the Grand River. One study estimated that a 10% reduction in peak discharge of the spring flood due to climate change will decrease the flushing action required to remove accumulated sediment and sludge from the river, thus negatively affecting water quality.¹⁴³

In addition to reducing streamflow and water availability, climate change will also likely increase water demand and use in the Grand River watershed, further exacerbating the threat to water security and the natural environment.¹⁴⁴ Many water uses in the watershed are sensitive to climatic variation; the longer the watershed goes without rain, for instance, the more water is used to water lawns and irrigate crops.

Thus climate change, especially when considered in combination with other threats such as water withdrawals and a growing population, represents a multi-faceted threat to environmental flows in the Grand River watershed.

Management and Advocacy Initiatives

The Ontario Ministry of the Environment (MOE) regulates water takings through the Permit to Take Water (PTTW) process. Under the *Ontario Water Resources Act*, the *Water Taking and Transfer Regulation* specifies that, when considering a PTTW application, protecting the natural functions of the ecosystem must be considered, including the impact of the water taking on natural variability of water flow or levels, minimum streamflow, and habitat that depends on water flow or levels.¹⁴⁵ Currently, Category 3 PTTW applications (those that may pose a greater risk to existing users or the natural environment) must be accompanied by a surface water study evaluating the potential impacts of the water taking, including impacts on environmental flows.¹⁴⁶ In 2002, the MOE initiated research aimed at determining methods for characterizing environmental flow requirements in the context of PTTWs for a number of watersheds, including the Grand.¹⁴⁷ In order to protect flows and existing water users, no new PTTW applications will be accepted in “high use” watersheds during low flow periods,¹⁴⁸ therefore no new PTTWs will be issued in the lower Grand that plan to take water during the summer.

What’s being done about it?

- Ontario’s PTTW process considers environmental flows; no new PTTWs in high use watersheds (which includes the lower Grand during low flows)^{145,148}
- GRCA responsible for watershed management, reservoir and dam operation¹¹⁸ (www.grandriver.ca)
- GRCA looking for ways to incorporate environmental flows into river operation, limited by lack of funding¹⁵²
- Trout Unlimited Canada is active in river restoration and fisheries management¹⁵³ (www.tucanada.org)

Measures have also been implemented to protect river flows in the case of drought. In response to recent low precipitation and water levels in the Province, the *Ontario Low Water Response* was developed in 2000, specifying three low water conditions, each of which requires a different response from water users.¹⁴⁹ At Level 3, for example, when flows are less than 30% of normal summer low flow in the Grand River watershed and

there may be harm to water users and/or the natural environment, a local Low Water Response (LWR) Team can impose mandatory restrictions on PTTW holders.¹⁵⁰ Research on environmental flow requirements in the Grand River watershed has shown, however, that current LWR levels in some areas may not be adequate for preventing harm to aquatic habitat.¹²⁹ In addition to the LWR, several municipalities in the watershed have passed water conservation bylaws which include restrictions on lawn watering and other outdoor water use (e.g., the City of Guelph’s Outside Water Use Program¹⁵¹).

The GRCA is responsible for operating the major flow regulating structures in the watershed to reduce flood damage, improve water quality and ensure water supply. Summer low flows are augmented from reservoir storage to meet minimum flow targets throughout the watershed, which also improves aquatic habitat and maintains connectivity during low flows. Minimum flow targets are driven in large part by the need to provide suitable drinking water quality for downstream communities such as Brantford, a city of 90,000 that takes its water from the Grand. The GRCA acknowledges that flow regulation requires a balancing act, for instance that dam operation for flood control may impact opportunities to manage flows for fisheries.¹³¹ They are currently looking at ways to incorporate environmental flow considerations into river management, such as providing high flows to restore natural channel form and geometry in order to improve the assimilative capacity and natural functioning of altered reaches, although often a lack of sufficient funding limits what can be done.¹⁵²

As part of fisheries management in the Grand River watershed, the GRCA, along with MNR and other partners, has identified management strategies that include removing and retrofitting dams and

reservoirs in order to improve fish habitat and restore free-flowing water in the watershed.¹³¹ Trout Unlimited Canada has been an active partner in watershed and fisheries management on the Grand River, as well as in undertaking on-the-ground restoration work such as removing dams that alter environmental flows and threaten fish habitat (e.g., the Five Oaks Dam on Whitemans Creek).¹⁵³

Figure 5. Summary of Environmental Flow Classification for the Grand River

Indicators	Status of Indicators
River fragmentation and flow regulation	Strongly affected by fragmentation and alteration (main stem and tributaries)
Water withdrawals and diversions	Some withdrawals, evidence that growing demand will cause future threats
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change could result in moderate changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows somewhat altered from natural, resulting in moderate losses of connectivity
Timing of flows, flow patterns, seasonality	Timing of flows significantly altered from natural; frequent changes in natural seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species and/or ecosystems dependent on natural flow regime are somewhat impacted by changes but not in imminent danger
Water quality in relation to flow regime	Evidence that changes in flows are impacting or could impact water quality

Status of Environmental Flows/Forecast: FAIR/STEADY

Mackenzie River

Named *Deh Cho*, or “big river”, by the Dene people who call its neighbouring lands home, the Mackenzie River is truly one of Canada’s — and the world’s — great river systems. Flowing swiftly northward from Great Slave Lake for almost 1,800 km, through vast expanses of pristine wilderness, globally important forests and tundra, it is Canada’s longest river.^{154,155} Where it finally empties into the Arctic Ocean, it deposits an enormous amount of silt and sediment forming the intricate channels, lakes and sandbars of the magnificent Mackenzie Delta, which, covering an area of 13,500 km², is Canada’s largest delta and second largest wetland.¹⁵⁴ The Canadian Boreal Initiative has estimated that the ecosystem services provided by lakes and rivers in the Mackenzie Basin are worth \$153 billion per year to Canadians — the greatest value of any land cover type in the Basin.¹⁵⁶

at a glance...	Mackenzie River
Length:	1,738 km
Average Discharge:	9,020 m ³ /s
Drainage Area:	1,800,000 km ²
Major Drainage Basin:	Arctic Ocean
Jurisdictions:	River: NWT Basin: NWT, Yukon, BC, Alberta, Saskatchewan
Major Issues:	energy development, climate change

Status: NATURAL

Forecast: STEADY



Though teeming with wildlife, the Mackenzie River Basin is sparsely populated. The region along the Mackenzie River from Great Slave Lake to the Mackenzie Delta is home to approximately 7,800 people in 13 communities, 70% of whom are Aboriginal.¹⁵⁴ Despite this small population, demand for the region’s rich mineral, energy, and forestry resources is increasing. The Mackenzie River itself is not directly threatened by fragmentation or water withdrawals, yet upstream development and climate change will undoubtedly cause watershed-scale impacts, and immediate action is essential to ensure a future for the

Mackenzie River Basin that includes protection of its globally significant freshwater resources.

The Mackenzie River Basin, the tenth largest watershed on earth, drains 20% of Canada’s landmass — an area twice the size of Ontario.^{157,158} Flow in the Mackenzie Basin begins in the Peace and Athabasca^a Rivers, which originate in British Columbia and Alberta, respectively. The Athabasca River then flows into Lake Athabasca, which straddles the Alberta-Saskatchewan border, and converges with the Peace River to form the Peace-Athabasca Delta in northern Alberta (one of the world’s largest freshwater deltas). From there, the Slave River runs north into Great Slave Lake, out of which the mainstem Mackenzie River, joined on its way by the Liard, Great Bear and Peel Rivers, flows north to the Beaufort Sea. This large and complex watershed spans provincial, territorial, federal and First Nations jurisdictions, which adds a challenging element to ensuring protection of the species and ecosystems that depend on Mackenzie River and its watershed for life.

The Mackenzie Delta, one of the most productive ecosystems in northern Canada, is entirely dependent on flows in the Mackenzie River. There are almost 50,000 lakes in the delta, which are constantly changing in shape and size due to sedimentation and changes in river flows.¹⁵⁹ These lakes greatly influence the surrounding environment — they affect permafrost, provide habitat for fish and wildlife, and store water and sediments.¹⁵⁴ The high productivity of this ecosystem is primarily due to frequent spring flooding of the delta, which carries sediment and nutrients to the lakes and tops up water levels in

Important Ecological Features

- Mackenzie Delta — Canada’s largest Delta, 50,000 lakes¹⁵⁹
- Home to muskrat, beaver, lynx, moose, musk-ox, caribou, beluga whales¹⁶¹
- 7 Important Bird Areas (IBAs), breeding and staging areas for millions of migratory birds¹⁶¹

^a While it is impossible to assess threats to environmental flows in the Mackenzie River without considering potential downstream impacts from the Athabasca, one of its major tributaries, a detailed discussion of threats in the Athabasca River is not included here, but can be found on page 13 of this report where the Athabasca River is featured individually.

“perched lakes”, enclosed lakes which are only replenished by periodic high river flows.¹⁶⁰ This complex delta ecosystem supports a diverse array of wildlife (including muskrat, beaver, moose, mink, lynx and beluga whales off the coast), fish (such as whitefish, inconnu and arctic char) and numerous species of birds. In fact, there are seven internationally recognized Important Bird Areas (IBAs) occurring along or near the Mackenzie River, including the Mackenzie Delta, which serve as breeding or staging areas for millions of geese, tundra swans and other migratory birds.¹⁶¹ Beyond its delta, the Mackenzie, which provides 11% of streamflow into the Arctic Ocean, also plays a significant role in regulating ocean circulation, nutrient transport and Arctic climate systems.^{75,162} Due to its complexity, relatively small environmental changes could significantly alter the hydrology and ecosystem dynamics of the Mackenzie Delta, resulting in dramatic ecological consequences.¹⁶⁰

Though it remains one of the last truly wild river basins on earth, providing important homeland for people and for wildlife, the future of the pristine Mackenzie Basin is somewhat uncertain. Current and proposed future development of the rich energy resources of the basin, including hydroelectric, oil and gas, as well as the effects of global climate change pose potential threats to environmental flows in the Mackenzie River.

Threats to Environmental Flows

Current and Future Energy Development

Currently, the Mackenzie River remains largely natural and free-flowing; its mainstem it is not modified or fragmented by any dams. However, a major hydroelectric development on the Peace River, a key tributary, has implications for environmental flows throughout the Mackenzie system,⁷⁵ and as a result the Mackenzie is considered moderately affected by fragmentation and flow regulation.³⁰

The W.A.C. Bennett Dam, constructed in 1967, is located on the Peace River in northern British Columbia. Water storage and releases from the Bennett Dam can influence water levels on Great Slave Lake, and evidence suggests that flow regulation in the Peace River sub-basin, which contributes 23% of flow in the Mackenzie system in an average year, has reduced seasonal flow variations in the Mackenzie system.⁷⁵ During the filling of the Williston Reservoir behind the Bennett Dam, reductions in Peace River discharge exacerbated the short-term effects of climatic and hydrologic drought in western Canada, though the impacts of ongoing flow regulation on the hydroecology of the Peace-Athabasca Delta are not known with certainty; some research has found that lower peak water levels have decreased wetland habitat in the Delta,¹⁶⁰ while more recent work has concluded that changes are driven by local and regional climatic variability, ongoing warming and drying, as opposed to flow regulation.⁵⁵ Flow in the Slave River, downstream of the Peace-Athabasca Delta, declined by 35% between 1950 and 2005, which has been attributed to the effects of the Bennett Dam along with climate change.¹⁶³

Status of Environmental Flows: NATURAL

- Mackenzie is free-flowing, but increasing pressure to exploit its 10,450 MW of hydroelectric potential^{30,164,165}
- Upstream threats: Bennett Dam on Peace River, proposed dam on Slave River, oil sands on Athabasca River^{75,163,166}
- Mackenzie Delta has experienced greatest climatic warming in Canada (1.7°C)¹⁷¹
- Traditional knowledge reveals concern about low water levels on Mackenzie River¹⁵³

While no specific hydro projects are proposed for the Mackenzie River in the near future, pressure is mounting to develop the river's 10,450 MW¹⁶⁴ of untapped hydro potential. The Government of the Northwest Territories' recent Energy Plan clearly aims to expand hydro development in the territory, and points to hydroelectricity as the most feasible source of energy for NWT residents as well as a potential export to Southern markets.¹⁶⁵ The Energy Plan identifies three potential sites for hydro generation on the Bear River (126 MW), which flows into the Mackenzie from Great Bear Lake.¹⁶⁴

Development of this project, however, is dependent on the Mackenzie Valley Gas Project proceeding, which will create new industrial energy demands and thus add to pressure to develop hydroelectricity in the Mackenzie Basin. For instance, the Slave River Hydro Development is currently being proposed along the Slave River near the Alberta-NWT border, about which community consultation is ongoing.^{166,167}

Water demand for oil and gas development is another significant issue with implications for flows in the Mackenzie Basin. Water withdrawals from the Mackenzie River itself are currently only a negligible fraction of total flow;¹⁵⁶ licensed communities used 874,425 m³ in 2000, and one oil processing facility withdraws 2.8 million m³ per year.¹⁵⁴ Accordingly, the Mackenzie River Basin Board reports that the Mackenzie River can accommodate additional local water withdrawals.¹⁵⁴ The greatest demand for water, however, is not locally on the Mackenzie River but upstream on the Athabasca River, where rapidly expanding oil sands projects are currently licensed to extract 445 million m³ of freshwater per year.⁶² Current development and planned expansion of the massively water-consumptive oil sands industry may impact the quantity and quality of water flowing north into the NWT and throughout the Mackenzie system, representing a significant transboundary threat to water in the Basin.¹⁶³ These threats are discussed more specifically on page 13 of this report, which focuses on the Athabasca River.

Climate Change

The Northern Rivers Ecosystem Initiative concluded that global warming is the greatest threat to the northern environment,¹⁶⁸ and impacts from upstream water withdrawals and regulation will certainly be compounded by the effects of climate change in the Mackenzie River Basin. According to the Intergovernmental Panel on Climate Change, the Arctic is expected to experience some of the earliest and most profound climate-induced changes,¹⁶⁹ and northern river basins such as the Mackenzie are particularly sensitive to these changes.¹⁷⁰ Recent evidence shows that the Mackenzie River Basin is getting warmer, and that the Mackenzie Delta region has experienced some of the greatest increases in air temperatures in Canada during the last century (an increase of 1.7°C).^{171,172}

The effects of climate change on streamflow in the Mackenzie River are not known with certainty. Predictions suggest that warmer temperatures could be accompanied by lower streamflow in the Mackenzie River.¹⁵⁴ Climate warming may cause higher precipitation in the Mackenzie Basin, but also higher evaporation; water levels and flows in the Basin are expected to be lower, spring breakup is expected to be earlier, and early spring flows are expected to be higher.¹⁷³ Under a 2°C global warming scenario, which could be reached between 2026 and 2060, the downstream impacts of the Athabasca oil sands are expected to be magnified, which could compromise the productivity of the Peace-Athabasca Delta and impact the quantity of water available for ecosystem support in the Mackenzie River system.⁷²

Recent studies have found no consistent trend in annual average flow rates in the Mackenzie River over the past 30 years, but Aboriginal residents of the Mackenzie Delta have raised concerns about low water levels.^{154,75} Research has also revealed that the spring freshet, a significant influence on the hydrological regime of the Mackenzie River, is beginning earlier in the year, as predicted, due to warmer winter and spring temperatures, which could contribute to decreased runoff later in the year.¹⁷¹ It is known that even slight changes in runoff patterns and flood frequencies could have devastating impacts on the delicate hydrological regime of the Mackenzie Delta ecosystem.¹⁶⁰

Overall, it appears that further study and more precise monitoring are needed to confirm the impact of climate change on water and aquatic resources in the Basin.^{171,174} It is known, however, that the Arctic is warming faster than anywhere else on earth, and, inevitably, this will cause changes to the hydrology of Arctic rivers,¹⁷⁵ including the Mackenzie. Though the full implications of these changes are not yet understood, climate change represents a very real threat to environmental flows in the Mackenzie River.

Management and Advocacy Initiatives

The government of the NWT acknowledges the importance of protecting water quantity and flow in the Mackenzie River Basin. To this end, the territorial and federal governments are developing a Water Resources Management Strategy to ensure the health of the territory's water into the future. This strategy, framed in the *Northern Voices, Northern Waters* discussion paper, could include "Ecosystem Sustenance Objectives", explicitly setting out the need to ensure adequate quantities and quality of water levels and flows to provide the conditions necessary to ensure ecosystem health¹⁷⁶ — essentially, environmental flows. However, the fact that the NWT does not hold jurisdiction over water management (which is a federal responsibility in the territories) means that implementation of any such strategy will not be straightforward. Effectively, meaningful action towards protection of water resources in the Mackenzie Basin will require leadership on the part of the Federal government — which for the most part has been lacking thus far.

What's being done about it?

- NWT Discussion Paper on a Water Strategy identifies need for environmental flows¹⁷⁶
- Lack of federal leadership constraining transboundary water negotiations¹⁶³
- Numerous groups advocating for protection of the Mackenzie River Basin. See:
 - NWT Water Strategy (www.enr.gov.nt.ca)
 - Mackenzie River Basin Board (www.mrbba.ca)
 - WWF-Canada's Mackenzie River Basin Conservation Program (www.wwf.ca/conservation/mackenzie)

Water governance challenges in the Mackenzie system are further complicated by the fact that it is located in a transboundary basin. Recognition of the need for effective water resources management across jurisdictional boundaries has given rise to the Mackenzie River Basin Board,¹⁷⁷ a forum for informing basin management and promoting the ecological health of the Basin, and the *Mackenzie River Basin Transboundary Master Agreement*.¹⁷⁸

Signed by the Governments of Canada, BC, Alberta, Saskatchewan, the Yukon and the NWT, the Master Agreement came into effect in 1997 and commits its signatories to a set of principles, first of which is to manage water resources "in a manner consistent with the maintenance of the ecological integrity of the aquatic ecosystem" (Part C, 1).¹⁷⁹ It also makes provisions for jurisdictions to negotiate bilateral water management agreements to address transboundary issues,¹⁷⁷ although only one such agreement, between the NWT and the Yukon, has been implemented.¹⁶³ Negotiations between the NWT and Alberta, which began in 1982 and were revived in 2007, are scheduled to conclude in 2010, which — if effectively completed — could result in quality and quantity objectives for the water flowing into the Northwest Territories from Alberta, though any agreement will not be legally binding and rely solely on the honour of its signatories.¹⁶³ The Pembina Institute, recognizing that the current framework limits the potential for successful resolution of transboundary water conflicts, recommends that any agreement be based on clear water quality and quantity objectives (including environmental flows) and be enforceable.¹⁶³

Mounting threats to water resources in the Mackenzie River Basin are mobilizing numerous stakeholders to advocate for protection of its pristine and globally significant ecological resources. Aboriginal and non-Aboriginal residents of the Basin have repeatedly spoken out about the urgent need to protect their rivers at a number of forums, including the Keepers of the Water Conferences.¹⁸⁰

Further, a number of partners, including government, First Nations, industry and NGOs such as WWF-Canada and the Canadian Parks and Wilderness Society, have been working since 1999 towards a Protected Areas Strategy for the NWT.¹⁸¹ Identifying lands with natural and cultural significance to be protected from industrial development, the PAS has successfully set aside large areas of the Mackenzie River Basin for interim and permanent protection. In addition to raising awareness of the critical need to protect the land and water of the Mackenzie Basin, protection of land through the Protected Areas Strategy will serve to safeguard against future development that could threaten environmental flows in the Basin.

Figure 6. Summary of Environmental Flow Classification for the Mackenzie River

Indicators	Status of Indicators
River fragmentation and flow regulation	Main stem unaffected by fragmentation and flow regulation
Water withdrawals and diversions	No or very few minor withdrawals; no evidence that demand will significantly increase in the future
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change could result in moderate changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows not altered from natural; no losses of connectivity or impacts observed
Timing of flows, flow patterns, seasonality	Timing of flows slightly altered from natural; minor changes in seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species/ecosystems dependent on natural flow regime are healthy; no negative impacts from changes to flow s
Water quality in relation to flow regime	No flow-related water quality problems

Status of Environmental Flows/Forecast: NATURAL/STEADY

Nipigon River

Flowing through the rugged Boreal landscape of northwestern Ontario, the Nipigon River drains the remote and sparsely populated Lake Nipigon Basin from the edge of the Arctic watershed to the cold, clear waters of Lake Superior. Truly the headwater of the Great Lakes, the Nipigon Basin is home to some of Ontario's most spectacular wilderness, where towering cliff faces overlook vast forests and powerful rivers that for generations were home only to the Ojibway people and then the fur traders.¹⁸² The watershed boasts world-renowned fisheries and provides critical habitat for threatened woodland caribou as well as the American white pelican and bald eagle, both endangered in Ontario.^{183,184} The Nipigon River and Basin are internationally significant and play an integral role in the Great Lakes ecosystem,¹⁸³ but diverting and harnessing this wild river for hydroelectricity has highly modified environmental flows with devastating consequences for aquatic ecosystems.

at a glance...	Nipigon River
Length:	51 km
Average Discharge:	330 m ³ /s
Drainage Area:	24,650 km ²
Major Drainage Basin:	Atlantic Ocean (Great Lakes)
Jurisdiction:	Ontario
Major Issues:	Dams and diversions, climate change

Status: FAIR

Forecast: IMPROVING



The largest tributary flowing into Lake Superior, the Nipigon River begins at the south end of Lake Nipigon, which at 4,848 km² is the 8th largest lake in Canada and the largest entirely within Ontario. Roughly 1,500 rivers and streams flow into Lake Nipigon,¹⁸⁵ including water from the Ogoki Diversion. Constructed in 1943 by the US Army Corps of Engineers to divert water from the Arctic watershed into the Great Lakes to provide additional hydroelectricity at Niagara Falls, the Ogoki Diversion more than doubled the area of the Nipigon Basin.¹⁸⁶ The Nipigon River, which at one time tumbled over 16 km of whitewater rapids and 7 waterfalls through its gorge following a fault in the Precambrian shield, drains the basin south to Lake Superior.^{187,188} The original character of the river has been forever changed by hydroelectric dams on the river, and its large volume of water now flows through a series of lake and turbulent stretches to its mouth near the most northerly point of Lake Superior at the town of Nipigon.¹⁸⁶

Important Ecological Features

- Largest remaining 'coaster' brook trout population; world class brook trout and lake trout fisheries^{187,189}
- 46 fish species, including COSEWIC-listed shortjaw cisco and deepwater sculpin¹⁸⁷
- Critical habitat for woodland caribou and American white pelican (Threatened), and bald eagle (Special Concern)^{183,184}

The Nipigon Basin is home to 46 fish species, most famous of which are its brook trout.¹⁸⁷ Prominent anglers have come from around the world to fish the Nipigon River since the mid-1800s, and the world record brook trout (14.5 lbs (6.58 kg), a record that still stands) was caught in the Nipigon River in 1915.¹⁸⁷ The lower river, below the first dam, is home to most fish species found in Lake Superior, including important habitat for the largest remaining population of "coaster" brook trout, a unique ecotype of brook trout endemic to Lake Superior.^{187,189} Historically found in virtually all Lake Superior tributaries, their population declined dramatically throughout the 20th century and today are found only in a handful of streams,

including the Nipigon River. This decline has been attributed to habitat loss and alteration from hydro dams and flow fluctuations, and protecting the Nipigon River brook trout is a high priority for both water and fisheries management in the region.^{190,191}

As recognized precociously in 1889 by an American outdoors writer, “Unless it is cherished, the glory of the Nipigon [sic] may fade, and the story of its marvelous attractions may become a tradition of the past.”¹⁹² While the Nipigon River will never be fully restored to its former glory, great strides have been made in recent years toward restoring and protecting environmental flows in the river, and its ecosystems appear to be recovering as a result. As shown by the story of the Nipigon River, it is never too late to begin to cherish our rivers and to work together to protect them.

Threats to Environmental Flows

Dams and Diversions

The Nipigon River has been extensively modified by dams and diversions for hydroelectric generation, which has been the single most disruptive activity to occur in the Nipigon Basin.¹⁸⁶ There are three hydroelectric facilities on the Nipigon River, which produce 275 MW of power. The first, Cameron Falls Dam, was built in the mid-section of the river in 1920, followed in 1925 by the Virgin Falls Dam at the outflow of Lake Nipigon, which created the largest storage reservoir in existence at the time.¹⁸⁶ Alexander Dam was built in 1930 just downstream of Cameron Falls Dam, flooding 2.4 km of white water between the two, and in 1950 Pine Portage Dam was built at the top end of the river, flooding over the Virgin Falls Dam and the remaining white water, rapids and waterfalls.¹⁸⁶ Upon completion of the Pine Portage Dam at the last available development site on the river, the Hydro-Electric Power Commission of Ontario proudly noted that, “Once again the swift waters of the Nipigon are being tamed to provide electric power...” and that “240 feet of the 250 feet [drop] from Lake Nipigon to Lake Superior will be developed”.¹⁹³ Indeed, today only 3 m of the river’s original 95 m vertical drop remains unharnessed by dams;^{186,194} the rugged and once free-flowing Nipigon River has been irreversibly tamed.

One of the most significant changes to environmental flows in the Nipigon River watershed occurred as a result of the Ogoki Diversion, constructed in 1943. The Ogoki River north of Lake Nipigon was dammed and a channel dredged through the height of land, forcing water that normally flowed north to the Albany River and James Bay south through the Little Jackfish River into Lake Nipigon, and then through the Nipigon River into the Great Lakes. The diversion has had dramatic effects on the Little Jackfish River, where average flows increased from approximately 4 m³/s to 120 m³/s, which has turned this stream into a wide, excavated channel, causing significant erosion and sediment deposition.¹⁸⁵ As a result of the Ogoki Diversion and the dams on the river, the water level in Lake Nipigon is now 0.62 m higher than it would be under natural conditions, and average flows in the Nipigon River have increased 50%, from 227 m³/s to 340 m³/s.^{195,196} The Nipigon River channel is still physically adjusting to this increase, which continues to cause significant bank erosion, slumping and large landslides along the length of the river.¹⁹⁰

Status of Environmental Flows: FAIR

- Flows entirely regulated by 3 hydroelectric dams; ¹⁸⁶Ogoki Diversion increased flow in Nipigon River by 50%^{195,196}
- Prior to management plan, rapidly fluctuating water levels often stranded fish and eggs¹⁸⁷
- Northern Ontario experiencing climate change more acutely than rest of province; 1 to 1.5°C warming occurred in past 100 years²⁰⁰
- Reduced groundwater flows and increased water temperatures predicted to threaten sensitive brook trout and walleye populations^{200,202}

Intense flow regulation has changed the hydrology of the Nipigon River. Prior to dam construction, natural flows were much less variable and had only one peak flow period during spring runoff; current regulated river flows show a great deal of variation and peak multiple times per year.¹⁹⁶ Until 1990, the dams on the river were operated by Ontario Hydro using a “peaking” regime: holding back large quantities of water when power demand is low (resulting in low flows below the dams), and then releasing large quantities of water to generate power when demand is high. From the 1960s to the

late 1980s, the river level changed by as much as three metres every day.¹⁸⁷ Though a water management plan has since been put in place to minimize the impacts of water level fluctuations, flows continue to differ significantly from those that would occur naturally, impacting aquatic ecosystems.

It was believed that these dramatic water level fluctuations were to blame for destroying brook trout spawning habitat and contributing to the species' decline, but this was not proven until April of 1990, when Ontario Ministry of Natural Resources (MNR) staff observed exposed spawning beds and dead, stranded brook trout fry.^{187,190} Subsequent field studies revealed that fluctuating water levels exposed up to 90% of identified brook trout redds to drying out and freezing during spawning and incubation periods.¹⁸⁷ Water level fluctuations were also found to significantly alter groundwater discharge characteristics in the Nipigon River, which are critical for brook trout spawning.¹⁹⁷ Brook trout only spawn where there is groundwater upwelling from the river bottom, thus it was concluded that changes to groundwater due to rapid river level fluctuations could severely impact the reproductive success of brook trout in the Nipigon River.¹⁹⁷ Other studies have shown water level fluctuations in the Nipigon River to also have massive impacts on benthic organisms.¹⁹⁸ Despite the implementation of a water management plan, river draw-down, though not as devastating as in the past, continues to impact the productivity of the Nipigon River by stranding fish and drying out aquatic invertebrates.¹⁸⁴

Unfortunately, the threat posed by dams and diversions to flows in the Nipigon Basin is not a thing of the past. Because Ontario had made a commitment to phase out coal-fired power, it is likely that there will be increased interest in hydro development in northern Ontario in the near future. For instance, Ontario Power Generation is currently proposing a hydroelectric facility (85 MW) on the Little Jackfish River, the tributary that connects the Ogoki Diversion to Lake Nipigon, where a similar development was proposed and then abandoned in the late 1980s due to economic reasons.^{186,199} The Ontario government recognizes that proposals for hydroelectric development on tributaries of the Lake Nipigon Basin could have significant impacts on fish and fish habitat in the basin,¹⁸⁴ and there are concerns that development on the Little Jackfish River specifically could block walleye migration and negatively impact habitat with basin-wide significance.¹⁹⁰

Climate Change

Climate change poses a significant threat to water resources and river flows in the Nipigon Basin. Over the past 100 years northwestern Ontario has warmed more than the rest of the province, with temperatures increasing 1 to 1.5°C.²⁰⁰ Climate change models suggest that northwestern Ontario will experience some of the most acute climate change impacts in Ontario. By 2090, it is predicted that the region will see a 4 to 6°C increase in growing season temperature, with April to July temperatures increasing as much as 6.5°C.²⁰⁰ Precipitation is generally expected to decrease, with a 0 to 5% reduction by 2040 and a 0 to 20% reduction by 2090, depending on the month (the greatest moisture reductions are expected to occur between June and August).²⁰⁰ Finally, an increase in the variability of temperature and precipitation regimes and in the frequency of extreme weather events is expected for this region.²⁰⁰

For the Nipigon River, these predicted warmer temperatures are expected to cause earlier snowmelt and runoff events. Combined with the predicted reduction in precipitation, this could result in a corresponding decrease in summer runoff and reduced overall water volumes in the watershed. There will be an increased risk to brook trout specifically, from reduced groundwater flows and stream volumes, increased groundwater temperatures and warmer water temperatures.²⁰⁰ From a management perspective, these changes will mean that river flow objectives based on historical climate data will need to be revised based on the most recent data, and managed adaptively and flexibly according to changing climatic conditions.

Walleye populations have also dramatically declined in the Nipigon River and Nipigon Bay since the mid-1900s, and continue to struggle to this day.^{188,201} Walleye is a cool-water fish species that needs water in the 18 to 22°C range to thrive.²⁰² Climate impact modeling predicts that warmer surface water temperatures in northwestern Ontario will reduce the amount of available habitat for walleye, making lakes and rivers such as those in the Nipigon Basin less suitable for walleye production and further placing these sensitive populations at risk.

Management and Advocacy Initiatives

A 2002 amendment to Ontario's *Lakes and Rivers Improvement Act* requires the preparation of Water Management Plans for all dams and water control structures in the province, to ensure that they balance environmental, social and economic concerns.²⁰³ This is to be achieved by considering the environmental flow requirements of Ontario's regulated rivers and developing flow and water level options that best satisfy the multiple values placed on the resource.^{204,205} Well before this legislative requirement, however, efforts to address the impacts of water level fluctuations on the Nipigon River set an early precedent for management of environmental flows in the province.^{187,190}

In 1990, upon observing firsthand the negative impacts of water level fluctuations on brook trout, local MNR staff approached Ontario Hydro about modifying dam operation. The decision to act was hastened by a major landslide that occurred in the Nipigon River in April 1990 due to bank destabilization caused by water level fluctuations. This event, which resulted in a boil water advisory for the town of Nipigon, damaged phone lines and pipelines and caused slumping along the CN railway, brought public attention to the impacts of the river's highly altered flow regime. As a result, an interim flow agreement was established in September 1990, representatives of the provincial and federal governments, Ontario Hydro, and citizens formed the Nipigon River Management Committee,^{187,196} and a local campaign was launched to raise awareness of the link between hydro operations and flow fluctuations, touting the slogan "Turn off a light, save a Nipigon brook trout".¹⁹⁰

What's being done about it?

- Nipigon River Water Management Plan established in 1994 has significantly improved ecosystem health^{190,191},
- Lake Superior National Marine Conservation Area protects brook trout habitat.²⁰⁹ See www.pc.gc.ca/amnc-nmca/on/super/index_e.asp
- Trout Unlimited, with Ontario Government and others, purchased land to protect spawning habitat.²¹¹ See www.tucanada.org/NP_GapensPool.shtml

In 1994, directed by the *Remedial Action Plan (RAP) for Nipigon Bay*, the interim agreement was expanded into a Watershed Management Plan for the Nipigon River. A study was undertaken to establish, with public involvement, a management option that would reduce the impacts of hydroelectric dams on the Lake Nipigon/Nipigon River watershed, particularly the Nipigon River fishery.²⁰⁶ This was accomplished using optimization models that identified and evaluated a number of options and weighted the multiple river uses according to public values; the flow needs of fish were given first priority in plan development.²⁰⁷ This plan was converted to a Water Management Plan under the *Lakes and Rivers Improvement Act* in 2005, and remains in place today.

Though the threat posed by flow regulation in the Nipigon River has not been eliminated, there has been enormous improvement in the ecological condition of the river since establishment of the water management plan.^{190,191} For instance, since dam peaking operations were ended, brook trout and pike populations on the river have rebounded.¹⁹⁰ The process also increased transparency in river management, and inspired greater public involvement in and awareness of the river and local environment. Monitoring is ongoing, and MNR is currently considering updating flow models to better reflect climatic change and incorporate the needs of additional ecosystem components.¹⁹⁰

Activities continue under the Nipigon Bay RAP, and the Lake Nipigon Basin has been identified as a Signature Site under *Ontario's Living Legacy* initiative, affording it special recognition.^{183,208} The Lake Superior National Marine Conservation Area, established in 2007 following ten years of work by local residents, First Nations, MNR and Parks Canada, supported from the beginning by WWF-Canada, was extended to protect Gapen's Pool on the Nipigon River, one of only three known spawning sites for coaster brook trout.^{209,210} Recognizing the critical link between land use and hydrology, in 2007 Trout Unlimited Canada, with assistance from the Ontario government and private donors, purchased the land adjacent to Gapen's Pool to protect it from development and ensure source protection of the groundwater discharge that is vital for brook trout reproductive success in the Nipigon River.^{211,212}

Figure 7. Summary of Environmental Flow Classification for the Nipigon River

Indicators	Status of Indicators
River fragmentation and flow regulation	Strongly affected by fragmentation and flow regulation
Water withdrawals and diversions	No or very few minor withdrawals; no evidence that demand will increase in the future
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change could result in changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows significantly altered from natural; major changes to high and low flows and connectivity
Timing of flows, flow patterns, seasonality	Timing of flows somewhat altered from natural; changes in seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species and/or ecosystems dependent on natural flow regime are somewhat impacted by changes but not in imminent danger
Water quality in relation to flow regime	Minor, localized water quality problems; in part related to changes in flows

Status of Environmental Flows/Forecast: FAIR/IMPROVING

Ottawa River

The Ottawa is the second largest river in eastern Canada and the largest tributary of the St. Lawrence, and boasts of a rich and colourful history. It provided a route for the early voyages of First Nations peoples and European explorers, guided fur traders and settlers, carried log drives, and has been so integral to Canada's formation that our capital — the city of Ottawa — was built on its shores. For 580 km the river forms the natural boundary between Quebec (containing 65% of its watershed) and Ontario (the remaining 35%).²¹³ The Ottawa River also provides drinking water for over a million people, offers many recreational opportunities, and generates a significant amount of hydroelectricity. In order to facilitate navigation and electricity production, hundreds of dams, large and small, have been built in the watershed, forever erasing its many chutes, rapids and waterfalls and creating what is now one of the most highly regulated and fragmented river systems in Canada.^{213,214} Environmental flows are altered throughout the watershed, and there are no guidelines for dam operators to protect ecosystem interests.²¹³

at a glance...	Ottawa River
Length:	1,271 km
Average Discharge:	1,950 m ³ /s
Drainage Area:	146,300 km ²
Major Drainage Basin:	Atlantic Ocean
Jurisdictions:	Quebec & Ontario
Major Issues:	Dams, water quality, wetland and floodplain development, climate change

Status: FAIR

Forecast: DECLINING



Beginning in the sparsely-inhabited wilderness of western Quebec at Lake Capitchigama, the Ottawa River makes its way westward through a chain of lakes to the long, narrow waters of Lake Temiskaming on the Quebec-Ontario border. From here it flows southeasterly, through a more developed landscape that includes agriculture, mining and logging, past the towns of Mattawa, ON and Deux Rivières, QC. As it flows past Pembroke and Arnprior to Ottawa, the river's rocky banks transition to slopes that supports

farms and cottages as it makes its way through a series of wide lake-like stretches broken by the odd set of rapids that have escaped harnessing by the river's many dams. Overlooked by the Parliament Buildings in downtown Ottawa, the river continues flowing eastward to its confluence with the St. Lawrence River above the Island of Montreal.

The Ottawa River supports an amazing range of ecological diversity. Its shorelines provide habitat for the nationally significant wood turtle and the endangered musk turtle, which depend on natural shoreline conditions.²¹³ Unique wetland and floodplain habitats support more than 300 bird species, about half of which are migratory, making the Ottawa one of North America's most important flyways.²¹⁵ Globally rare "shore alvar" vegetation can also be found along the Ottawa River, and a group of shifting alluvial sand islands supports hackberry-ostrich fern swamp, a rare flood-tolerant vegetation community that, in Canada, is only found here and perhaps in the St. Lawrence River.

Important Ecological Features

- 85 fish species, including COSEWIC special concern river herring and lake sturgeon²¹⁵
- Home to endangered musk turtle and nationally significant wood turtle²¹³
- Supports globally rare "shore alvar" vegetation/habitat²¹³
- Alluvial islands with rare hackberry-ostrich fern swamp²¹⁷

People and ecosystems alike depend on flows in the Ottawa River. For instance, the rafting and kayaking industry requires good water quality and natural river flows, while swamps and wetlands, and the species that live there, depend on natural water levels for survival. Though it has been highly modified, the Ottawa River continues to support amazing ecological diversity, and in order to protect and enhance life within the basin it is essential that consideration be given to improving the management of water quantity and quality across provincial boundaries within the watershed as a whole.

Threats to Environmental Flows

Flow Regulation and Modification

One of the most highly regulated rivers in Canada,²¹⁶ the Ottawa River is classified as *strongly fragmented* due to the high number of dams located in its basin.²¹⁷ There are over 50 major dams and hydroelectric generating stations scattered throughout its watershed, with over 300 impoundments and smaller water control structures on its tributaries.^{216,217} The first locks and dams were built on the Ottawa River in the 1800s to facilitate navigation, augment low flows and provide flood control, and soon after, beginning in the 1880s, reservoirs were built to harness the river's power for hydroelectricity.²¹⁸ The combined capacity of the hydroelectric generating stations in the watershed is now over 4000 MW, capable of producing more than \$1 million worth of energy daily.²¹³ These dams, most often constructed at the natural rapids and waterfalls separating the lake-like stretches of the river, drowned most of these sections of the river. Chats Falls and Rapids, for example, described by early travelers as the river's most beautiful waterfalls, originally dropped 15.2 m through 15 distinct waterfalls across a 3.2 km wide section of the Ottawa River near Arnprior.²¹⁴ In 1929, construction of the Chats Generating Station immediately upstream of the falls permanently changed this section of the river, flooding over all of the rapids and falls.²¹⁴ Similar changes have occurred throughout the watershed. In fact, along the entire length of the Ottawa River only one set of large rapids, the Deschênes Rapids, remains intact and not impacted by dams or regulation.²¹³

Despite its high level of regulation, the Ottawa River continues to experience significant seasonal flooding.²¹⁵ The lower Ottawa River experiences peak flows in early spring, from its unregulated southern tributaries, and a second higher peak flow period a bit later in the season from snowmelt in the upper basin.²¹³ However the magnitude of these high flows has been dampened by flow regulation on the river. Dams and reservoirs along the river store a significant portion of spring runoff, substantially reducing the magnitude of the second spring peak flow period.²¹³ Overall, river regulation caused the ratio of maximum to minimum flows to decrease from about 10:1 in 1870 to only 5:1 by 1930.²¹⁹

These changes in river flows have affected the diversity and distribution of fish and wildlife in the Ottawa River.²¹⁴ For example, the Ottawa-Gatineau alluvial islands (Kettle Island, the Duck Islands and Petrie Islands) support unique habitats and many rare plant species that are adapted to cycles of extensive spring flooding and drying and continual erosion and deposition.²²⁰ At one time, these habitat types would have been common along much of this stretch of the river between Ottawa and Montreal, but flooding and water level controls from hydroelectric projects and development have altered much of the floodplain and as a result these vegetation communities are now found only in a few locations.²²⁰ The tiny remaining examples of these special habitats are not immune to impacts either, as it is known that all sites of hackberry-ostrich fern swamp located on the Ottawa-Gatineau alluvial islands have been negatively impacted by upstream flooding caused by the Carillon Dam 150 km downstream.²¹³

Status of Environmental Flows: FAIR

- One of Canada's most regulated rivers; over 50 major dams and over 300 smaller structures on tributaries²¹³
- Ratio of maximum to minimum flows decreased from 10:1 in 1870 to only 5:1 by 1930²¹⁹
- Nationally rare riverweed, which requires fast water, survives in only one location²¹³
- Climate expected to warm by 4 to 5°C by 2100, causing earlier spring melt and changing peak flow patterns^{213,224}

Similarly, riverweed, a nationally rare aquatic plant, was once commonly found throughout the Ottawa River in its many fast water habitats. However alterations to river flows caused by dams and reservoirs have made most of the river inhospitable to this rare and ecologically significant species.

Consequently, the only remaining substantial population of riverweed is located at the Deschênes rapids, which are the last intact large rapids on the Ottawa River still in a natural condition.^{213,221}

Once considered a common fish in the Ottawa River system, lake sturgeon populations have declined dramatically over the past century due to anthropogenic stresses and heavy exploitation; it is estimated that the current Great Lakes population is less than 1% of historical levels.^{213,222} On the Ottawa River, this decline has been largely attributed to impacts from hydroelectric dams and flow regulation, as well as from high fishing pressure, but even though commercial sturgeon harvest has been regulated on the Ottawa River for some time now, few populations have been able to recover.²¹³ Recent research on lake sturgeon in the Ottawa River found that the fish are more abundant in natural reaches of the Ottawa River compared with impounded reaches, and of the three reaches in which no lake sturgeon were found, two are frequently exposed to winter drawdown from hydroelectric facilities on the river.²²² It is believed that hydroelectric dams negatively affect lake sturgeon on the Ottawa River by blocking their migration routes, altering natural water flows and altering their spawning habitat, which scientific evidence suggests is indeed the case.²²²

Climate Change

The observed impacts of climate change in the Ottawa River watershed are generally reflective of those being felt across Canada. In the past 60 years, mean annual temperatures in the National Capital Region have warmed 0.7°C, with minimum temperatures increasing by 1°C over that time,²²³ and climate models predict a further increase of 4 to 5°C in mean temperature by 2100.²¹³ Winter temperatures have been especially affected, with mean winter temperature being 1.5°C warmer today than it was 60 years ago. The effects of this winter warming have been especially noticeable and much publicized in the National Capital Region as above-normal temperatures in recent years have often delayed the opening of the skating rink on the Rideau Canal and shortened the length of the skating season.²²³

In addition to impacting recreational activities in the Ottawa River watershed, warmer winter temperatures can have significant impacts on hydrology and aquatic ecosystems through changes in snowmelt and runoff patterns as well as changes in the magnitude and timing of peak flows, to which many organisms in the watershed are adapted. For instance, for many rivers in and near the Ottawa River watershed and the Great Lakes-St. Lawrence Basin, spring snowmelt and ice break-up are now occurring earlier in the year and winter flows are increasing, which is causing spring freshet flows to decrease in magnitude.^{213,224}

Precipitation has also been increasing over the long term in the Ottawa River watershed, with an average increase in precipitation of 13% since 1939.²²³ Global climate models predict a further 5 to 17% increase in annual precipitation in the Ottawa region by 2075.²²⁵ Despite these increases in precipitation, studies predict that higher temperatures and rates of evapotranspiration will result in a reduction in flow (of between 1 and 8%) in the Ottawa River.²²⁶

Given that the Ottawa River is the site of many hydroelectric generating stations, reductions in flow and water levels due to climate change could cause less power to be generated, which could result in changes to the way in which dams in the watershed are operated. This could further impact aquatic species and ecosystems by altering natural flow patterns to an even greater degree than occurs today.

Management and Advocacy Initiatives

As aptly summarized by Meredith Brown, the Ottawa Riverkeeper, “the Ottawa River runs through a jurisdictional quagmire”.²²⁷ As an interprovincial river, there remains much confusion about who is responsible for managing the ecological health of the Ottawa River, including environmental flows. The only agency that considers the watershed in its entirety is the Ottawa River Regulation Planning Board, which was established in 1983 to ensure integrated management of dams and reservoirs in the watershed, and to minimize flooding while maintaining the interests of river users, primarily hydroelectricity.²²⁸ The Board has no control over how the environment is considered in dam operations, as each operator is responsible for developing their own operating criteria within the constraints set out by their respective governments,²²⁹ and provincial regulations differ greatly on each side of the river.²¹³ A study investigating the impacts of climate change on transboundary water management concluded that, given the state of management in the basin, if climate change were to reduce water levels in the Ottawa River in the future, there is little that the Ottawa River Regulation Planning Board nor provincial or federal governments could do to place limitations on hydroelectricity generators in order to protect downstream users from water shortages, including the natural environment.²³⁰

There are currently Water Management Plans for the Madawaska and Bonnechere tributaries in Ontario, developed by Ontario Power Generation and OMNR, which spell out how dams will be operated to balance environmental and hydro water requirements, and these have resulted in some improvements to fish habitat and flow management on those rivers.²³¹ While some dams on the mainstem Ottawa River must maintain water levels for recreation or adhere to minimum flows, there are no existing guidelines for dam operators to protect ecosystem interests on the mainstem.^{213,232}

What’s being done about it?

- No basin-wide strategy for water management nor guidelines to protect environmental flows²²⁷
- Numerous sub-watershed agencies; Conservation Authorities (ON) and Watershed Committees (QC)²¹³
- Ontario portion of the river nominated for designation as a Canadian Heritage River.²³³ (<http://ottawariver.org/>)
- Ottawa Riverkeeper: a strong advocate for river health in the watershed.²³⁶ See <http://ottawariverkeeper.ca>

Nevertheless, there are many organizations working towards a healthier river. Many agencies are active in managing tributary sub-watersheds, such as Conservation Authorities in Ontario and Watershed Committees in Quebec. Also, following years of work, the Ottawa is expected to be granted designation as a Canadian Heritage River in 2009,²³³ which it is hoped will facilitate dialogue around developing an integrated management strategy for the river as a whole.^{213,218} Some First Nations groups are actively campaigning to “free the Chaudière Falls” by un-damming the portion of the Ottawa River between Ottawa and Gatineau, which is currently regulated by a large hydroelectric dam.²³⁴ Traditionally used as a sacred meeting place, the site holds great archaeological and historical value, and this ongoing campaign aims to restore the falls and renew the natural values of the Ottawa River at this location.²³⁵

The Ottawa Riverkeeper has been especially active in calling for coordinated action to protect the Ottawa River.²³⁶ Part of the international Waterkeeper Alliance, the Ottawa Riverkeeper aims to protect and promote the ecological health of the Ottawa River and its tributaries through advocating for responsible decision-making, public education and participation, and ensuring regulatory compliance. In addition to bringing attention to threats to environmental flows in its first River Report on Ecology and Impacts,²¹³ the Riverkeeper has recommended a number of steps for mitigating the threat of dams on

the river, including modifying current dam operations in the watershed to better mimic the river's natural flow regime and variability and ensuring that no dams are built on the Dumoine River, the Ottawa's last remaining free-flowing tributary and the last undammed river in southern Quebec.²¹³ The Canadian Parks and Wilderness Society (CPAWS) is also active in advocating for protection of the wild Dumoine River by pressing for the establishment of a core protected area in its watershed.²³⁷

Figure 8. Summary of Environmental Flow Classification for the Ottawa River

Indicators	Status of Indicators
River fragmentation and flow regulation	Strongly affected by fragmentation and flow regulation
Water withdrawals and diversions	No or very few, infrequent, minor withdrawals; no evidence that demand will increase in the future
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change could result in moderate changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows significantly altered from natural; major changes to high and low flows and connectivity
Timing of flows, flow patterns, seasonality	Timing of flows somewhat altered from natural; slight or infrequent changes in seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species and/or ecosystems dependent on natural flow regime are somewhat impacted by changes but not in imminent danger
Water quality in relation to flow regime	Evidence that changes in flows are moderately impacting or may impact water quality

Status of Environmental Flows/Forecast: FAIR/DECLINING


Saint John River

The Saint John River, so named in 1604 by Samuel de Champlain as he reached its mouth on the feast of John the Baptist, was first known as the *Wolastoq*, or “beautiful river” by the Maliseet people whose livelihoods were intimately tied to the river for thousands of years before European contact.^{238,239} The longest river in Atlantic Canada, the Saint John is a transboundary river: it flows from Maine (USA) into New Brunswick, with part of its watershed in Quebec, before emptying into the Bay of Fundy where the world’s highest tides form the famous “Reversing Falls” at its mouth. The river has been at the centre of a colourful history that includes First Nations, European, Acadian, and Loyalist heritage. Given its storied past, it should not be a surprise that the St. John River has been highly modified, and is known to be one of the more ‘disrupted’ rivers in Canada.²⁴⁰ While the basin has an adequate supply of water,²⁴⁰ there are numerous stressors that affect the river and its tributaries, including land uses such as agriculture and forestry, effluent discharge from pulp and paper mills and sewage treatment plants, and, most relevant to environmental flows, severe fragmentation by multiple hydroelectric dams.²⁴¹

at a glance...	Saint John River
Length:	673 km
Average Discharge:	1,110 m ³ /s
Drainage Area:	55,000 km ²
Major Drainage Basin:	Atlantic Ocean
Jurisdictions:	New Brunswick, Maine (USA)
Major Issues:	Dams, climate change

Status: POOR

Forecast: DECLINING



The headwaters of the Saint John River are located in the sparsely populated and relatively pristine forests of northern Maine, in the US. From here the river flows northeast to form part of the Canada-US border and at Edmunston, NB turns southeast for the remainder of its journey to the Atlantic. It flows along the border to Grand Falls where the river plunges 23 m into a deep gorge, forming a natural barrier to upstream movement of fish. From here the river continues within New Brunswick, highly regulated by hydroelectric dams along the way, through the cities of Fredericton and Oromocto towards its estuary where it slows and widens, fringed with wetlands and filled with waterfowl and wildlife. Finally, it empties into the Bay of Fundy with dramatic flair at the Reversing Falls in the city of Saint John.

The Saint John River watershed supports a range of plant and animal species. Furbish’s lousewort, an endangered plant once thought to be extinct, is found nowhere else in the world but on the banks of a small stretch of the upper, unregulated portion of the Saint John River.²⁴² It grows only where the riverbank has been disturbed by flooding or ice-scouring, and scientists believe that it survives here because, as the longest free-flowing stretch of river in this region, the natural fluctuations in river flow create the very specific conditions necessary for its survival.²⁴² Alterations to environmental flows in this portion of the river would undoubtedly threaten this sensitive endangered species.²⁴²

Important Ecological Features

- Third largest producer of COSEWIC-listed Atlantic salmon in NB²³⁸
- Furbish’s lousewort: endangered plant only found in the St. John River valley²⁴²
- Grand Lake Meadows: home to small population of COSEWIC-listed yellow rail and significant black tern colony^{239,243}

Located along the floodplain of the lower Saint John River, Grand Lake Meadows is Atlantic Canada’s largest wetland, and portions have been designated as a Protected Area, a National Wildlife Area, and an Important Bird Area.²³⁹ Its shallow marshes and grassy floodplains are naturally inundated by floodwaters each year, and rely on these flows to maintain a productive ecosystem that is used by thousands of waterfowl during migration. It also supports a small breeding population of the nationally vulnerable yellow rail and the largest breeding colony of black terns in the northeast.^{243,244}

The Saint John River is the third largest producer of Atlantic salmon in New Brunswick.²³⁸ Wild Atlantic salmon abundances in North America are currently at their lowest levels ever, and in early 2009 COSEWIC listed all populations of wild Atlantic salmon as “high priority candidates”²⁴⁵. In rivers draining to the Bay of Fundy, including the Saint John, salmon are negatively impacted by hydroelectric developments, reservoirs and altered flow regimes.^{246,247} Salmon in the Saint John River above Mactaquac Dam, the first dam encountered by migrating salmon on their way upstream, have shown one of the greatest declines, with numbers well below conservation requirements (the minimum number of adult salmon needed to maintain a viable, self-sustaining population).²⁴⁶ Though historic salmon runs may have been in the range of 100,000 fish, only 2,734 salmon, or 2.7% of this, returned to the Maqtaquac Dam in 2002, and the future of this population looks bleak.²⁴⁷

A highly complex system under pressure from extensive flow regulation and fragmentation, land uses, and climate change, the Saint John typifies the state of many rivers in which environmental flows are highly threatened. Yet it is not too late to address these threats, and through world-class efforts to study the cumulative effects of these multiple stressors and improvement of actions to reduce their impacts, the St. John stands to serve as a model for rivers facing similar stress around the world.

Threats to Environmental Flows

Fragmentation and Flow Regulation by Dams

The Saint John River is classified as strongly affected by fragmentation and flow regulation;³⁰ there are 11 dams in the watershed and three on the mainstem, with valley-wide impoundments in the river.^{238,240} The Grand Falls dam was the first constructed on the mainstem in 1931, with a 63 MW capacity, followed in order downstream by the Beechwood Dam (built in 1956, 113 MW) and the Maqtaquac Dam, which at 672 MW is the largest hydro generating station in NB, built between 1960-82.²³⁹ These dams have created reservoirs that constitute nearly half of the river’s length in the middle section of the watershed.²⁴⁸ These and other dams have severely fragmented the river and regulated its flows, causing negative impacts for aquatic ecosystems and species as well as exacerbating water quality issues.

Many sites along the river experience substantial water level fluctuations due to the operation of hydroelectric facilities.^{241,250} Downstream of Beechwood Dam, for instance, flows are regularly pulsed in response to the changing demand for electricity; during the summer water levels are lowered in the evenings and then rapidly increased by as much as 2 m during the day, and in July and August of 2003 and 2004, monthly mean 24-hour flow changes ranged between 32 to 64%, with maximum 24-hour flow changes ranging from 76 to 91%.²⁵³ Such extreme changes in flow sometimes causes large sections of the river bottom to be dewatered downstream of dams; researchers have literally watched the river dry up around them while out sampling,²⁴⁹ and have observed nearly 100 dead young-of-year minnows in a portion of the exposed river bottom that appeared to have been killed by a combination of river level changes and low dissolved oxygen.²⁵³

The decline of Atlantic salmon in the Saint John River is strongly correlated with the construction of dams.^{240,250}

Hydroelectric dams on the Saint John are known to block or delay fish passage both upstream and down (despite the presence of fish passage facilities on some dams), kill fish as they pass through hydroelectric turbines, and alter the natural flow regime on which migrating salmon in the

Status of Environmental Flows: POOR

- 11 hydroelectric dams in watershed, 3 on mainstem creating artificial reservoirs for nearly half the river’s length^{238,240}
- River flow can change up to 91% in 24 hours downstream of dams, drying portions of the riverbed and stranding fish²⁵³
- Snowpack decreased 25-50% over last 30 years²⁵⁵
- Predicted: 4-5°C warming, more flooding, and extreme summer low flow conditions²⁵⁸

Saint John rely.²⁴⁶ One of the major problems caused by the alteration of environmental flows by dams on the Saint John River is the delay of downstream salmon migration.²⁴⁶ As water currents slow or disappear in the large reservoirs behind the dams, salmon smolts appear to lose their orientation and their downstream movements stop. One study found that up to 100% of sonically tagged migrating smolts that entered the 80 km long Mactaquac reservoir failed to find the downstream exit.²⁵¹ Another study found that the survival of salmon eggs to the eyed and hatch stages was lower in regulated portions of the watershed than in unregulated reaches.²⁵² Slowed river flow in reservoirs also results in higher than normal summer water temperatures that have been known to stress fish and restrict the growth of many species.²⁴⁰

The presence of dams in the watershed has also compounded water quality issues. The Saint John River has experienced problems with increased nutrient enrichment since the 1950s due to ongoing effluent discharge from pulp and paper mills and food processing plants, and runoff from agriculture and forestry.²⁵³ The formation of reservoirs above the mainstem dams on the St. John has reduced the assimilative capacity of the river for organic wastes; in these reservoirs, aeration decreases, toxins settle and accumulate on the river bottom, and anaerobic conditions are created in some places.²⁵⁰ A study by the Canadian Rivers Institute found that decreases in river flow downstream of the Beechwood Dam increased effluent concentration in the river 2.6 times during the drawdown period.²⁵³

Climate Change

In New Brunswick, air temperature increased significantly in the last century contributing to record high water temperatures and record low flow conditions in some locations.²⁵⁴ As a result of these higher temperatures, snowpack in northern New Brunswick has decreased by 25% over the last 30 years, and by about 50% in the southern part of the province.²⁵⁵

These climatic changes are influencing flow in the Saint John River. For instance, the number of mild days in January has increased since the early 20th century and, as a result, large peak flows in late winter are becoming more frequent.²⁵⁶ Researchers have also observed an increased frequency of midwinter ice breakup along the upper Saint John River over the last 40 years.²⁵⁷ Floods are already frequent occurrences along the Saint John River and its tributaries, and warmer spring temperatures and wet winters along with greater variability are causing earlier spring thaws and higher peak flows, which could have major implications for future flooding and ice-jam events.²⁵⁷ Changes in flood patterns will not only impact the natural environment but could increase flood damages and cause hydroelectric companies to change how they regulate river flows and reservoirs,²⁵⁶ further impacting environmental flows in the watershed.

Over the next 100 years, maximum and minimum air temperatures in New Brunswick are expected to increase by 4 to 5°C, with central regions warmer than the northerly and southerly regions of the province.²⁵⁸ Precipitation is expected to increase 25 to 50% in the northern portion of the province, which could lead to increases in river discharge of around 40% in the northern part of the province.²⁵⁸ However, no change in summer precipitation is anticipated in the southern portion of the Saint John River basin. Along with higher temperatures, this will likely mean a reduction in river discharge and available water resources in southern New Brunswick.²⁵⁸

Changes to flows in the Saint John River will have implications for aquatic ecosystems in the watershed. For instance, research suggests that when seasonally flooded wetlands dry up or water levels are extremely low in the Grand Lake Meadows, permanent wetlands provide important habitat for brood-rearing waterfowl.²⁴³ If river discharge decreases significantly as predicted in the lower

Saint John River basin, water levels in the Grand Lake Meadows may decline and the number and size of permanent wetlands could decrease, thereby decreasing suitable waterfowl habitat.

Management and Advocacy Initiatives

Though the Saint John River flows through an international watershed, there are no existing committees or boards that have specific water management authority over the entire watershed, and no consideration of water quantity or environmental flows from a transboundary perspective.²⁵³ In New Brunswick, the *Clean Water Act* gives the Minister of Environment the authority to set out terms and conditions on hydro-electric power project and dams, including those requiring the maintenance of a designated rate of water flow.²⁵⁹ While some dams in New Brunswick are required to operate according to minimum flow levels, these are generally arbitrarily defined and, currently, operating plans do not include requirements for dam operators to consider specific environmental flow needs.²⁴⁹ However it is recognized that in the face of an uncertain and changing climate, existing measures for instream flow protection in New Brunswick will need to be revised and adapted in order to protect environmental flows, and if flows in the Saint John River continue to decline as projected, some form of transboundary agreement may be needed to protect New Brunswick's water supply.^{230,254}

What's being done about it?

- Dam operators can be required to adhere to (arbitrary) minimum flows, but are not required to provide environmental flows to protect aquatic ecosystems²⁴⁹
- Canadian Rivers Institute conducts research, education and outreach on multiple stressors and cumulative effects in the St. John River.²⁶⁰ See www.unb.ca/cri
- Over 20 local stewardship and conservation groups in the St. John River watershed, including the Saint John River Society.²⁴⁰ See www.stjohnriver.org

One of the groups most active in working towards a better understood and better managed Saint John River is the Canadian Rivers Institute (CRI), based at the University of New Brunswick. Its mission is to carry out multi-disciplinary research, education, and outreach focusing on rivers for the purposes of water resources conservation, protection, restoration, and sustainable use.²⁶⁰ Much of this research, education and outreach has focused on the Saint John River, including development of the Saint John River Atlas, which provides public access to a wide variety of

important environmental, biological and social information for the watershed,²⁶¹ and ongoing work on the first "State of the Environment" report and report card for the Saint John River, which will include an environmental flows and habitat component.²⁴⁹

Researchers at the CRI are also at the forefront of the field of cumulative effects monitoring and assessment, and their research has concentrated on developing a framework for assessing the assimilative capacity of the Saint John River, as well as prioritizing areas of concern in order to focus remediation efforts.²⁴⁰ The lessons learned from this ground-breaking research — essentially aimed at answering the oft-posed question of "How much can a river take?" — will allow the Saint John to serve as a model for other rivers similarly affected by complex human impacts.

There are over 20 community and watershed groups influencing water management throughout the Saint John River watershed.²⁴⁰ There are groups active locally in many of the Saint John's tributary sub-watersheds, such as the Canaan-Washademoak Watershed Association whose activities include, among other things, undertaking community-based ecological monitoring, aquatic habitat restoration, and public education and outreach.²⁶² On a whole watershed scale, the St. John River Society is a volunteer-based organization dedicated to the appreciation and wise stewardship of the natural and cultural heritage of the St. John River and its tributaries.²⁶³ Founded in 1992, the Society holds river festivals,

gathers historic river-related information, produces educational brochures, posters, and maps, and holds symposiums and conferences related to the Saint John River. On a larger scale, Ducks Unlimited has worked to protect and restore waterfowl habitat in the Grand Lake Meadows, including creation of wetland impoundments to provide stable water environments for waterfowl.²⁴³

Figure 9. Summary of Environmental Flow Classification for the Saint John River

Indicators	Status of Indicators
River fragmentation and flow regulation	Strongly affected by fragmentation and flow regulation
Water withdrawals and diversions	Some withdrawals, not expected to increase dramatically in future
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change could result in changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows significantly altered from natural; major changes to high and low flows and connectivity
Timing of flows, flow patterns, seasonality	Timing of flows somewhat altered from natural; slight or infrequent changes in seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species and/or ecosystems dependent on natural flow regime are severely threatened by changes to flow regime
Water quality in relation to flow regime	Evidence that changes in flows are negatively impacting water quality

Status of Environmental Flows/Forecast: POOR/DECLINING

Skeena River

Nestled under the Alaska panhandle on British Columbia's northernmost coast, the swift, cold waters of the Skeena River rush southwest from near the Spatsizi Plateau in BC's northern interior through the dramatic Coast Mountains to the Pacific Ocean. The Skeena, the second longest river in BC and one of North America's longest undammed rivers,²⁶⁴ and its watershed offer all of the trademarks of a wild Pacific river: dense, moss-covered forests and rugged snow-capped mountains, home to grizzlies, ancient totem pole carvings, and salmon that return each year to spawn. Fortunately, the Skeena watershed has so far avoided much of the development pressure that has compromised environmental flows in many other large watersheds — it is sparsely populated and currently supports little industrial development.²⁶⁸ It is one of the few remaining pristine, free-flowing wilderness rivers and thus its flows are endangered only by the pervasive threat of climate change as well as future industrial development, in which interest in the watershed is rapidly growing.

at a glance...	Skeena River
Length:	580 km
Average Discharge:	1,760 m ³ /s
Drainage Area:	54,432 km ²
Major Drainage Basin:	Pacific Ocean
Jurisdiction:	British Columbia
Major Issues:	proposed industrial development, climate change

Status: **NATURAL**

Forecast: **STEADY**



On its journey south from its source in the Sacred Headwaters region of northern BC, the Skeena River is soon joined from the southeast by one of its largest tributaries, the Babine River, which drains Babine Lake and the Nechako Plateau in the eastern interior of the watershed. Further downstream, its other major tributary, the Bulkley River, joins the Skeena from the south at the town of Hazelton. From here, the Skeena continues to flow southwest through the mountains, passing the town of Terrace, to where it finally meets the Pacific Ocean just south of Prince Rupert.²⁸⁰ The climate of the Skeena watershed varies greatly throughout, with precipitation decreasing regularly from the coast to the interior.²⁶⁸

The Skeena River is home to numerous fish species, including lake, brown, cutthroat trout, Dolly Varden and oolichan, but most well-known are its salmon. The five salmon species (chinook, sockeye, coho, pink, and chum), as well as steelhead (an anadromous strain of rainbow trout) that make their legendary spawning runs up the Skeena every year make up what has become a world-renowned fishery, and Canada's second largest wild salmon fishery next to that of the Fraser River.²⁶⁵ In fact, a 2005 study found that Skeena salmon contribute almost \$110 million to the region's economy each year.²⁶⁶ Salmon

Important Ecological Features

- 5 salmon species, including IUCN red-listed sockeye²⁶⁵
- Canada's second largest wild salmon fishery²⁶⁵
- Lake trout, rainbow trout, cutthroat trout, Dolly Varden populations²⁶⁵

are also the foundation of the watershed's many and rich First Nations cultures, and traditional fishing and land use continues today as it has for millennia along the Skeena River.²⁶⁴

In general, salmon in the Skeena River are healthy, but many populations declined in the twentieth century, and some have continued to decline in the past few decades.²⁸⁰ Skeena salmon rely on a natural flow regime for survival throughout their life stages. For example, salmon traveling up the Skeena to spawn require sufficient streamflow at appropriate times of year for access to spawning beds.²⁸⁰ Once salmon have spawned, flows that are too high can scour gravel beds during egg incubation, and low flows can strand eggs, in both cases destroying spawning beds.^{267,283} Changes to these and other environmental flow variables could have severe consequences for salmon populations.

The Skeena is one of the world's few remaining wild rivers, but it is currently threatened by numerous development proposals. When considered with the threat of climate change, it is clear that the Skeena watershed is at a critical juncture; it is still a healthy and productive river, but is vulnerable to harm if we do not act quickly to protect this wild river and its flows into the future.

Threats to Environmental Flows

Land Use and Industrial Development

While the Skeena watershed has so far avoided much of the development pressure that has compromised river health elsewhere, such as dams and major water withdrawals, there are exceptions in specific locations, and the threat of future development looms. The Skeena is undergoing a period of unprecedented interest in industrial development, with proposals currently in the works for roads, mines, coalbed methane fields, oil and gas fields and pipelines, and run-of-river hydroelectric projects,²⁶⁷ all of which could represent serious threats to environmental flows in the watershed.

Land use in the Skeena watershed can alter watershed processes that ultimately influence the attributes of streams, rivers, lakes, and the estuary.^{268,269} For instance, linear development, or the building of roads, railways and pipelines, often requires culverts to cross waterways, which can act as barriers to fish, nutrient and woody debris movement in a stream, can increase stream velocity and change how water flows in a river.²⁷⁰ In the Skeena watershed, for example, a highway bridge over the Zymoetz River (a tributary of the Skeena) has caused 70% of the floodplain to be lost in this location.²⁸⁰

Coalbed methane extraction is another land use that could pose a substantial risk to environmental flows in the Skeena watershed. Coalbed methane (CBM) is a natural gas found in coal seams, and is typically extracted by pumping out the groundwater from underground gas deposits before gas begins to flow from wells.²⁷¹ There are currently no CBM developments in BC,²⁶⁷ but an area the size of Vancouver Island (412,000 ha) in the headwaters of the Skeena, Nass and Stikine rivers — known as the Sacred Headwaters — has been licensed to Shell Canada for CBM extraction.²⁷¹ A report commissioned by The Pembina Institute found that CBM development could change runoff patterns and groundwater regimes in the Sacred Headwaters, reducing groundwater contributions to streamflow and changing the streamflow dynamics on which sensitive species, including salmon, depend.²⁷¹ The full nature and extent of the impacts of CBM development on aquatic ecosystems are not known, and far more information is required before the risks can be understood.²⁶⁷ Faced with this reality, and strong opposition from local First Nations groups, communities and NGOs, the Government of BC recently took the landmark step of announcing a 2-year moratorium on CBM development in the Sacred Headwaters area.²⁷² Nevertheless, other CBM developments in the province are continuing to move forward, and if a consistent and responsible action plan is not implemented to guide future development, CBM could again threaten the Sacred Headwaters and environmental flows in the Skeena River.²⁷³

Status of Environmental Flows: NATURAL

- No dams, major water withdrawals or direct disruptions to environmental flows ... yet²⁶⁴
- Proposed industrial development — coalbed methane drilling in Sacred Headwaters, 15 run-of-river hydro applications, pipelines²⁶⁷
- Climate change: spring runoff 10-30 days earlier, streamflow declining in BC interior^{280,103}
- By 2050, winter snowpack expected to decline 56%; temperatures to rise 2.4 to 6.4°C^{103,283}

The multitude of proposed private “run-of-river” hydroelectric projects, which are being aggressively promoted by the BC government as a source of renewable power, could have more direct impacts on environmental flows in the Skeena watershed.^{274,275} Run-of-river projects involve construction of a weir to divert water into penstocks (pipes) that run beside the stream and send water through turbines before returning the water back into the stream.²⁷⁵ Though not as severe as those of conventional hydroelectric generation, the impacts of run-of-river projects can be significant, as large volumes of water can be diverted, significantly reducing flows (by up to 90%) along stretches of river often four to five kilometres in length.^{267,276} While run-of-river power can be environmentally sustainable, the cumulative impacts of such projects are of major concern, and are currently poorly understood.²⁷⁶

Licensing and development of independent run-of-river power in BC is happening at break-neck pace, without adequate public involvement or a strategic planning process to manage cumulative impacts and ensure that development avoids areas with high environmental values.

There are eight current licences and seven active applications for a total of 15 run-of-river water licenses in the Skeena watershed^{267,277} (an up-to-date map showing the details of all such licenses in BC can be found at www.ippwatch.info²⁷⁸). Of these, the contentious Sedan Creek proposal is of highest concern for its potential impacts on environmental flows and fish habitat²⁷⁹ — this project will dewater over 1.5 km of known salmon and rainbow trout spawning and rearing habitat (and would be the first project to do so in the Skeena watershed). According to critics, in assessing the project DFO has (inappropriately) ruled that this does not constitute an unacceptable Harmful Alteration, Disruption, or Destruction of fish habitat, has failed to consider the impacts of climate change over the 40-year project lifespan, and has not sought appropriate public input.²⁷⁹ If this project were to proceed as is, it could set a dangerous precedent for alteration to environmental flows and fish habitat in the Skeena watershed.

Climate Change

Even in the absence of major direct anthropogenic disruptions to environmental flows, undeveloped rivers like the Skeena cannot escape the pervasive threat of climate change. Over the past century in BC, spring run-off has shifted earlier by 10 to 30 days, depending on the region.¹⁰³ Average annual flows, and especially late summer flows, have declined in the interior (eastern) part of the Skeena watershed since the 1930s,^{280,281} a trend which is broadly attributed to a pattern of intensified summer drought in the BC interior caused by climate change.²⁸⁰ Low flows in the late summer and fall decrease the ability of sockeye and coho to reach spawning areas and utilize spawning gravels, and completely dry up some spawning streams, especially when experienced cumulatively with other watershed impacts.²⁸⁰ For example, though agriculture in the Skeena watershed is relatively minor, farming and ranching are prominent in the dry eastern part of the Skeena watershed. A combination of low rainfall amounts and water extraction by agriculture has led to concerns about low flows preventing salmon from being able to reach their spawning beds in Maxan Lake.^{267,280}

Indications suggest that historical trends will continue into the future. According to projections made by the Pacific Climate Impacts Consortium, the annual mean temperature in the Skeena watershed is expected to rise between 2.4 to 6.4°C by the 2050s, with the greatest warming expected to occur in the northern portion of the basin.¹⁰³ In the same time period, annual precipitation is projected to increase by 12 to 30 mm, again with the greatest increase expected in the north.¹⁰³ Although limited work has been done to project changes in streamflow across BC due to climate change, one study projected an increase in average streamflow in Pacific rivers (including the Skeena) by 2050, with an earlier onset of the spring melt, increasing winter and early spring flows but decreasing flows in the summer and fall.²⁸² Winter snowpack is expected to decrease by 56% along the north coast of BC, resulting in lower streamflow during summer, which would cause stress for fisheries and aquatic ecosystems.^{103,283} Climate modeling suggests that the late summer droughts that have caused low stream flows and limited fish access in some areas of the Skeena watershed will persist and, on average, worsen with time.²⁸⁴

Despite the inherent uncertainty in climate change projections, it is broadly accepted that the hydrological system throughout Pacific North America is changing and will continue to do so with future climate change.¹⁰³ While the consequences of climate change on environmental flows are not yet fully understood, projected changes to flows and water availability in the Pacific Northwest will alter streamflow and impact species and aquatic ecosystems in the Skeena River.

Management and Advocacy Initiatives

In its recent *Living Water Smart* initiative, the BC Government sets out its vision for water management, including recognizing the need to protect environmental flows in the Province's lakes and rivers.¹¹² This policy also states that by 2012 water laws will improve protection of ecological values, and legislation will recognize water flow requirements for ecosystems and species.¹¹²

In the Skeena watershed, river management is mainly focused on protection and enhancement of wild salmon. DFO, through the *Wild Salmon Policy*, the BC Ministry of Environment, and First Nations management bodies — the Skeena Fisheries Commission and North Coast-Skeena First Nations Stewardship Society — are responsible for managing fish and fish habitat in the Skeena. While there are no policies directed at protecting environmental flows, the *Wild Salmon Policy* includes the aim of maintaining habitat and ecosystem integrity,¹¹⁰ which could include protection of environmental flows in salmon rivers like the Skeena. Nevertheless, the Skeena Independent Scientific Review Panel recently expressed concerns that current regulation of development and water management in the Skeena watershed is inadequate, and that the Skeena watershed does not have adequate regulations in place to safeguard habitat for wild salmon and steelhead²⁶⁷ (and, by extension, aquatic ecosystems more broadly).

In the face of impending and unprecedented human activity, the Panel also identified the need for increased monitoring of hydrological conditions in the Skeena watershed, and to consider the potential cumulative effects of development proposals,²⁶⁷ a concern echoed by many local groups and stakeholders.^{276,285} Also, while much effort has been put towards understanding salmon and their habitat, knowledge of other ecosystem components in the Skeena River and watershed is critically lacking.

What's being done about it?

- 2 year moratorium on coalbed methane in Sacred Headwaters.²⁸⁶ (www.concernedaboutcbm.org)
- Watershed awareness and local advocacy. See: Skeena Watershed Conservation Coalition (www.skeenawatershed.com) Watershed Watch Salmon Society (www.watershed-watch.org)
- WWF-Canada facilitating dialogue around creating a local “champion” for conservation. See: www.togetheronthecoast.org and www.wwf.ca/conservation/pacific/

The good news is that there are many people working to keep the Skeena River wild and many groups active in advocating for its protection. While some Aboriginal people welcome industrial development, First Nations in the watershed have spoken out against irresponsible development. In the case of coalbed methane, a 2-year long protest and blockade by members of the Tahltan First Nation against Shell contributed, along with NGO advocacy, to the recently announced 2-year moratorium on CBM development in the Sacred Headwaters.²⁸⁶

Locally, the Skeena Watershed Conservation Coalition and Friends of the Wild Salmon have called on the BC government to end CBM activities in the Sacred Headwaters and engage in meaningful consultation with northwest BC residents.²⁸⁷

Run-of-river power development is being watched closely by local residents and groups. Watershed Watch Salmon Society, along with Northwest Watch, has been active in advocating for responsible development of independent power in the Skeena watershed, as well as educating the public about issues surrounding run-of-river hydro in BC through information sessions and their 2007 “Citizen’s Guide to Understanding Approvals, Impacts and Sustainability of Independent Power Projects”.²⁷⁵ There is also growing opposition to a proposed pipeline that would bring oil from the Athabasca oil sands through the Skeena watershed to a potential supertanker port on the B.C. coast.

Work is also underway to create a strong community-based voice for conservation through a balanced approach to the numerous development issues facing the region. To this end, WWF-Canada recently participated as a co-sponsor for the “Together on the Coast” workshop, and is in the process of facilitating ongoing dialogue toward developing a network or organization to act as a “champion” for addressing the multiple issues surrounding development and resource use in the Skeena region.^{288,289}

Figure 10. Summary of Environmental Flow Classification for the Skeena River

Indicators	Status of Indicators
River fragmentation and flow regulation	Unaffected by fragmentation and flow regulation
Water withdrawals and diversions	No or very few minor withdrawals (<1%); no evidence that demand will increase in the future
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change could result in changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows slightly altered from natural, minor losses of connectivity
Timing of flows, flow patterns, seasonality	Timing of flows not altered from natural; no changes in seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species/ecosystems dependent on natural flow regime are healthy; no negative impacts from changes to flow s
Water quality in relation to flow regime	No flow-related water quality problems

Status of Environmental Flows/Forecast: NATURAL/STEADY

South Saskatchewan River

Flowing steeply from its headwaters high in Alberta's Rockies and winding its way eastward across the dry plains to its mouth in central Saskatchewan, the South Saskatchewan River has been described as the 'lifblood' of the Canadian Prairies. It provides precious water resources that support most of Canada's irrigated agriculture, as well as hydropower generation and a rapidly growing population. However while the river provides water for countless and growing human needs, environmental flows in the South Saskatchewan are highly threatened. Too much water is taken from the system without being returned and the natural flow regime in the river and its tributaries has been highly modified, and the harm this is causing to the ecosystems of the South Saskatchewan River Basin (SSRB) is increasingly evident. Strong action to protect environmental flows in the South Saskatchewan River Basin is urgently needed and long overdue.

The three main tributaries of the South Saskatchewan, the Bow, Oldman and Red Deer Rivers, begin in Alberta as melting snow and alpine glaciers — roughly 90% of the water in the South Saskatchewan River originates in the Rocky Mountains.^{290,291} These rivers support cool and coldwater fish in their upper reaches, including rainbow trout, mountain whitefish and cutthroat trout.²⁹² Where the Bow and Oldman Rivers join to form the main stem of the South Saskatchewan, approximately 100 km upstream of Medicine Hat, Alberta, the river widens and slows, meandering and braiding eastward through a wide, deep valley surrounded by prairie farmlands, until it reaches its confluence with the North Saskatchewan River in central Saskatchewan. This section of river supports a very different aquatic ecosystem, and provides important habitat for lake sturgeon.²⁹³ All along the banks of the South Saskatchewan and its tributaries, the riparian zone supports significant stretches of a number of species of cottonwood trees, which much evidence suggests are very sensitive to changes in river flow regime.^{294,292}

The majority of the South Saskatchewan River Basin is located in the semi-arid Palliser Triangle region of the southern Prairies, hence the region is prone to severe droughts and water supply is highly variable.^{73,291} Naturally dry conditions and inconsistent water supplies, coupled with 70% of Canada's irrigated agriculture, a rapidly growing population and economy, and a changing climate, mean that competition for and pressure on water resources in the SSRB are intense and will only increase into the future.^{293,73}

Important Ecological Features

- Significant riparian cottonwood forests²⁹⁴
- Coldwater fish in headwaters, including cutthroat trout, rainbow trout and mountain whitefish²⁹²
- Lower river provides important spawning habitat for lake sturgeon²⁹³

Driven by the numerous pressures on scarce water resources in the basin, the natural flow regime in the South Saskatchewan River and its tributaries has been highly modified by numerous dams and reservoirs and a high level of withdrawals and diversions — it is recognized as the worst affected of the rivers in the western Prairie Provinces.⁷³ As a result of flow regulation and withdrawals, both the quantity and timing of river flows has been substantially altered from natural in much of the system,²⁹² and the status of environmental flows in the river is classified as Poor.

at a glance... South Saskatchewan River

Length:	1,392 km
Average Discharge:	280 m ³ /s
Drainage Area:	148,000 km ²
Major Drainage Basin:	Hudson Bay
Jurisdictions:	Alberta and Saskatchewan
Major Issues:	withdrawals for irrigation, dams, fragmentation and flow modification, climate change

Status: POOR

Forecast: DECLINING



Threats to Environmental Flows

Status of Environmental Flows: POOR

- Summer flows have been reduced by **84%** since the early 20th century²⁹⁰
- **70%** of natural river flow is currently allocated, mostly for irrigation (but **85%** of natural river flow is required to maintain aquatic ecosystems)²⁹⁵
- **13** hydroelectric developments and **hundreds** of smaller dams regulate and fragment the river²⁹¹
- Size of source glaciers has decreased by **50%** from 1975-1998³⁰²
- Climate change predicted to cause **8.4%** average decrease in surface water availability in the basin²⁹¹

Water Withdrawals for Irrigation

Water in the South Saskatchewan River Basin is generally highly (and in some cases over-) allocated. In Alberta, water allocations in the basin total approximately 5.6 billion m³, which corresponds to almost 70% of the natural river flow.²⁹⁵ The percentage allocated varies across the basin; in the St. Mary's River, a tributary of the South Saskatchewan in Alberta, as much as 118% of the median flow is now allocated.²⁹⁵ Water withdrawals from the South Saskatchewan River are generally for agriculture, power

generation and municipal use,⁷³ but the greatest water user in the South Saskatchewan River Basin by far is irrigation agriculture, which uses most (86.5%) of all surface water used in the basin.²⁹¹

The high proportion of withdrawals for irrigation represents a significant threat to environmental flows in the South Saskatchewan River, especially since irrigation is largely a consumptive water use, meaning that most of the water withdrawn for irrigation is not directly returned to the river after use. That means that withdrawals for irrigation represent a greater threat than withdrawals for, say, municipal use, which generally returns three quarters of its water back into the river.²⁹⁶ In the SSRB, even though it must support a rapidly growing population of 1.7 million people (almost one million people in Calgary alone), non-irrigation demand is not expected to pose a significant risk to water resources.^{291,297}

Water allocations in much of the South Saskatchewan River Basin exceed environmental flow needs, and the aquatic environment is suffering. Recent analysis suggested that maintaining necessary environmental flows in the South Saskatchewan system would require 85% of natural flows, which is impossible with existing allocations in much of the basin.²⁹⁶ As a result, ecosystem health in the South Saskatchewan is believed to be declining downstream of major water withdrawals.²⁹³ The massive amount of water withdrawn for irrigation is impacting the quantity and timing of flows in the South Saskatchewan, and consequently placing the river's ecosystems at risk. In the mainstem South Saskatchewan River, summer flows have been reduced by 84% since the early 20th century.²⁹⁰ On the Bow River, the diversion of up to 90% of streamflow for irrigation at the Eastern Irrigation District dam dramatically reduces river discharge to the point where it is sometimes possible to walk across the river bed below the dam, which clearly has negative impacts on the fish populations in the remaining length of the river.²⁹²

Dams and Diversions

The South Saskatchewan River and its tributaries are heavily regulated and modified by dams, weirs, and other infrastructure; it is strongly affected by fragmentation and flow regulation.³⁰ This comes as no surprise considering that there are thirteen large hydroelectric dams in the South Saskatchewan River Basin (twelve in Alberta, one in Saskatchewan), and hundreds more smaller dams.²⁹¹ In fact the Bow River, the South Saskatchewan's largest tributary, is the most regulated river system in Alberta.²⁹² Overall, reservoirs in the South Saskatchewan River Basin in Alberta are capable of storing nearly 40% of the river's annual flows.²⁹⁶

The operation of dams in the South Saskatchewan River Basin has greatly altered the natural flow regime. For example, spring runoff is generally collected in reservoirs and then released from dams in the summer and fall, resulting in lower spring flows and higher summer and fall flows than would be natural.²⁹² In the South Saskatchewan, evidence has shown that the rapid water level fluctuations caused by hydroelectric dams is causing aquatic habitat instability and limiting fish production downstream of dams.²⁹² Dams also control natural flood events, which can negatively affect species that are adapted to such conditions. For example, periodic flooding helps to maintain riparian trees, especially cottonwoods, which are very common in the floodplains of the South Saskatchewan River, and these forests have been found to decline below dams on the river system.²⁹⁴

Perhaps one of the most significant examples of river fragmentation and flow modification can be seen at the Gardiner Dam in Saskatchewan, which forms Lake Diefenbaker, the largest impoundment on the South Saskatchewan River system. The reservoir is 43,000 ha in area and contains 9.4 billion m³ of water when full. It supplies drinking water for 40% of Saskatchewan's population, water for irrigation, industry and recreation, and flood control.²⁹⁸ Recent analysis has found that the portion of the SSRB located in Saskatchewan is under high stress from aquatic fragmentation, and the Gardiner Dam has significantly modified the condition of the river, both upstream and down.^{73,299}

Alarming, even with evidence of the declining health of the South Saskatchewan River due to previous river modification, the risk of future development continues to threaten the river. In what has been termed a 'redux' of the 1970s development model (focused on engineering solutions to water supply issues) a recent federally-funded report (the "Agrivision report")³⁰⁰ proposed the construction of four more major dams on the South Saskatchewan River downstream of the Gardiner Dam, which would effectively "drown" the river under a series of artificial reservoirs. The impacts of such a project would clearly be environmentally devastating, and environmental groups have been quick to condemn the recommendations.³⁰¹

Climate Change

Climate change is predicted to significantly impact water supply in the South Saskatchewan River. For instance, since the 1850s most of the large glaciers that form the headwaters of Prairie rivers have shrunk considerably, and this change has accelerated in recent years. From 1975 to 1998 the size of glaciers decreased by 50% in the South Saskatchewan River Basin, and though glacial inputs only constitute a small proportion of total annual flows, in a hot dry summer they can make up 50% of flows in upper reaches of the Basin, thus less glacier meltwater will mean less water in the river itself, particularly during dry periods.³⁰² Increasing water temperatures are also an issue in the South Saskatchewan Basin, as some of the valued trout species in the system are subjected to lethal temperatures in late summer when streamflow is low.³⁰³

While precipitation may increase in this region, this will be less than increases in evapotranspiration due to warming; overall, the already drought-prone basin is predicted to be much drier in the future.⁷³ A recent study on climate change and water in the South Saskatchewan River Basin concluded that there is a risk of significant decrease in surface water availability, with an average decrease in water supply of 8.4% across all basins.²⁹¹ When the majority of the river's flow is already allocated to human uses, any decrease in water supply will only exacerbate the stress on aquatic ecosystems in the Basin.

The effects of climate change, especially when considered cumulatively with the impacts of increasing demand and river modification, are predicted to contribute to what is now recognized as an “impending water crisis” in Canada’s western Prairie Provinces.⁷³ This crisis will be acutely felt in the water-stressed South Saskatchewan River Basin, and as water in the basin becomes scarcer, the challenge of providing environmental flows to sustain nature’s water needs will become even more urgent.

Management and Advocacy Initiatives

Despite explicit recognition of the need to balance economic and environmental needs, government action towards protecting environmental flows in the South Saskatchewan River Basin has generally been weak. In its *Water Act*,³⁰⁴ and *Water for Life* strategy,³⁰⁵ Alberta has voiced its commitment to protecting aquatic ecosystems. As a result, the Alberta Water Council was created, which is working towards developing a provincial action plan to improve the health of significantly impacted aquatic ecosystems by exploring opportunities to advance the healthy aquatic ecosystems element of the *Water for Life* strategy.³⁰⁷ The province also developed a Water Management Plan for the South Saskatchewan River Basin, which recommends that Water Conservation Objectives (WCOs) be established to meet instream flow needs (IFNs), which was followed in 2006 by a moratorium on new water licence applications in the Bow, Oldman and South Saskatchewan River sub-basins.³⁰⁶

While commendable, these actions have been criticized for failing to adequately protect environmental flows.⁷⁹ For instance, a comprehensive assessment of environmental flow needs in the SSRB found that flow needs are approximately 85% of the natural rate of flow.²⁹² Nevertheless, the WCOs in the Plan are typically only 45% of natural flows at any point in time — much less than recommended.³⁰⁷ Also, despite acknowledging that water in most of the Basin has reached or exceeded its limits, the Government of Alberta will not cancel or reduce existing allocations due to the “first in time, first in right” provisions of the *Water Act*, which they admit makes it impossible to maintain environmental flows. Their hands are tied somewhat by the history of irrigation water use and public consensus; the trade-offs that would be required to manage the South Saskatchewan for environmental flows are unacceptable. The decision to stop issuing licences is environmentally beneficial but is seen as coming too late³⁰⁸ — well after extensive damage has been done to the South Saskatchewan and its tributaries.

One positive outcome of this water crisis is that people are paying closer attention to water issues,³⁰⁸ and numerous groups and organizations are actively advocating for the protection of environmental flows in the Basin. The result of one such initiative is the Prairie Water Directive. A “collective call to action for water security in the prairie provinces”, put out jointly by a number of influential organizations, it calls for protection and restoration of aquatic ecosystems, and for governments to explicitly recognize ecosystems as legitimate water users and to restore and protect flows by legislating environmental flow needs.³⁰⁹ Individual groups have also lent prominent voices — Water Matters, a non-profit organization focused on championing watershed conservation in Alberta, is one such group that provides leadership, research and outreach on such issues.³¹⁰ Similarly, the Saskatchewan Environmental Society has been vocal in its opposition to further dam construction on the South Saskatchewan River.³¹¹

What’s being done about it?

- Government recognizes the need to protect environmental flows but can’t reduce current allocations - making it virtually impossible to provide them adequately^{79,308}
- Numerous groups advocating for environmental flows in the SSRB. See:
 - Prairie Water Directive (www.prairiewaterwatch.ca)
 - Water Matters Society of Alberta (www.water-matters.org)

There has also been consideration of market-based initiatives such as ‘water trusts’, private entities that would purchase water licences to meet ecosystem needs, as a way to protect environmental flows in the SSRB. According to Water Matters, because much of southern Alberta's water has been allocated, a water trust could complement to Alberta's tradable rights system as a way to ensure water flows for environmental needs remain in the system.³¹² While legal provisions do not currently enable the establishment of water trusts in Alberta, this could change in the future, and proponents of the idea believe that water trusts could contribute to the protection of environmental flows in water-stressed prairie rivers.³¹³

Figure 11. Summary of Environmental Flow Classification for the South Saskatchewan River

Indicators	Status of Indicators
River fragmentation and flow regulation	Strongly affected by fragmentation and flow regulation
Water withdrawals and diversions	High level of withdrawals or diversions; evidence that future demand will increase
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change expected to result in significant changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows significantly altered from natural; major changes to high and low flows and connectivity
Timing of flows, flow patterns, seasonality	Timing of flows significantly altered from natural; frequent changes in natural seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species and/or ecosystems dependent on natural flow regime are somewhat impacted by changes
Water quality in relation to flow regime	Evidence that changes in flows are moderately impacting or may impact water quality

Status of Environmental Flows/Forecast: POOR/DECLINING

St. Lawrence River

By any measure, the mighty St. Lawrence is one of the most important rivers on the planet. Draining the world's largest freshwater system, the Great Lakes, it ranks among the top in the world, and second in North America, in terms of discharge (16,800 m³/s below its confluence with the Saguenay River³¹⁴). It supports an amazing diversity of habitats in freshwater, saltwater and everything in between, and its fast, clear waters are home to sturgeon, river otters, and beluga whales, to name but a few. Forming a natural route inland from the Atlantic, the St. Lawrence River sustained the Algonquin and Iroquoian people who first populated its shores and guided the founders of our nation inland to forge the fur trade

at a glance...	St. Lawrence River
Length:	1,197 km
Average Discharge:	16,800 m ³ /s (including Saguenay)
Drainage Area:	1,030,000 km ²
Major Drainage Basin:	Atlantic Ocean
Jurisdictions:	Quebec, Ontario, New York (USA)
Major Issues:	Fragmentation and flow modification, navigation, climate change

Status: POOR

Forecast: DECLINING



and settle Upper and Lower Canada. To take advantage of its potential for transportation and hydroelectricity, the St. Lawrence and Great Lakes system has been dammed, diverted and dredged to form the St. Lawrence Seaway, one of the world's most important transportation and industrial corridors. One quarter of North America's population resides along the Seaway, which extends 3,790 km inland from the Gulf of St. Lawrence to the western end of Lake Superior.^{315,320}

As always, these benefits have not come without costs. To facilitate commercial navigation and hydropower, flows and water levels have been and continue to be

highly modified, at the expense of the natural environment. In fact, in 2008, the St. Lawrence was named one of America's most endangered rivers due to the fact that management of environmental flows (or the lack thereof) acutely threatens river health and quality of life in its watershed.³¹⁶

From the outlet of Lake Ontario, the St. Lawrence flows in a northeasterly direction forming the border between Canada and the US in its upper reaches, with Ontario on its north shore and New York State to the south. Continuing northeast, it flows entirely into Quebec, joined by its largest tributary, the Ottawa River, at the city of Montreal. Past here, the large river is fringed by agricultural land and mixed wood forest, as well as a major population centre at Quebec City. The river widens further and, around the Île d'Orléans, its freshwater begins to mix with saline tidal water, which continues until the St. Lawrence is joined from the north by the Saguenay River at the beginning of its lower estuary, where the river finally spills into the Atlantic at the Gulf of St. Lawrence.³¹⁴

The mainstem of the St. Lawrence River is considered "continentally outstanding" in terms of its biological distinctiveness.³¹⁷ In the fluvial, or most "river-like", section it is wide and slow-flowing with large floodplains, home to many freshwater species and wetlands, including the Lac Saint-Pierre UNESCO World Heritage and Ramsar site, the largest freshwater floodplain in Quebec.^{315,318} Mixing with saltwater, the river extends out into its estuary, which is narrow with extensive bulrush marshes along each shore that provide important habitat for numerous water birds. In order to survive, these wetlands and aquatic ecosystems need a sufficient outflow of water from the Great Lakes as well as maintenance of seasonal changes in water levels;³¹⁹ ultimately, the sustainability of the St. Lawrence's ecosystems depends on adequate protection and provision of environmental flows.

Important Ecological Features

- 87 freshwater fish species and 18 diadromous species³¹⁴
- ~20 animals and plants that are vulnerable, threatened or endangered³¹⁴
- Many important wetlands; Lac Saint-Pierre Ramsar site,³¹⁸ the St. Lawrence is a seasonal staging area for virtually all of the world's snow geese³¹⁵

Though attention tends to be focused on the Great Lakes as opposed to the St. Lawrence, the river itself is an integral component of the system, providing numerous benefits for millions of people. Along its entire length, a diverse range of significant ecosystems depends critically on its flows. Its position as the outflow of the Great Lakes makes it especially vulnerable; impacts throughout the Great Lakes affect downstream ecosystems in the St. Lawrence, and there is much to lose if we fail to protect it. In order to prevent irreversible harm to one of the world's great river ecosystems, it is essential that a cooperative and sustainable river management plan be put in place for the St. Lawrence River that will ensure protection of environmental flows for the benefit of its people and ecosystems alike.

Threats to Environmental Flows

Fragmentation and Flow Regulation

Flows in the St. Lawrence River are strongly affected by fragmentation and flow regulation;³⁰ they have been and continue to be extensively regulated and modified for the dual purposes of navigation and hydroelectric generation. There are four hydroelectric dams on the river's main stem, and many more on its tributaries.³¹⁴ There are also numerous channel control structures that redirect the river's flow, and seven locks that enable ships to navigate through the 68 m drop in elevation along the St. Lawrence from Lake Ontario to Lac Saint-Pierre, the downstream-most freshwater basin of the St. Lawrence River, west of Trois-Rivières, QC.^{314,320}

The Great Lakes St. Lawrence Seaway system, which came into operation in 1959 as a bi-national partnership between Canada and the US, serves as a vital transportation corridor for the world's largest concentration of industry.³²⁰ Navigation has had numerous environmental impacts on the St. Lawrence system, including stresses to shorelines and channels as a result of dredging and channel maintenance and impacts caused directly by ships, such as pollution and introduction of invasive species.³²⁰ In order to make the system navigable, entire villages were submerged along the St. Lawrence River and connecting channels were widened and deepened, resulting in the removal of islands and destruction of wetlands.³²¹ Locks and canals have been built to raise and lower vessels across and around natural barriers such as waterfalls and rapids, and a channel has had to be dredged to a depth of 8.2 m to allow for large ocean-going ships.³²⁰

Status of Environmental Flows: POOR

- Strongly affected by fragmentation and flow regulation;³⁰ 4 dams on mainstem, many more on tributaries; locks and canals for navigation³¹⁴
- Regulation has reduced water level variability by 70%, from 0.6 m to just 0.15 m³²³
- Water level regulation has negatively impacted sensitive wetland habitat and water birds^{325,326,327}
- Flow into St. Lawrence predicted to decrease 4 to 24% due to climate change³³⁰

With respect to environmental flows, the greatest impacts have come from the management of water levels for navigational and hydroelectric requirements, which has been identified as one of the stressors of highest concern on the St. Lawrence.³²⁰ Water levels on the St. Lawrence River, as well as lake levels upstream on Lake Ontario, are regulated by the Moses-Saunders hydroelectric generating station, which crosses the river at Cornwall, ON and Massena, NY and began operation in 1958.³²⁰ A major effect of this regulation has been to reduce natural water level fluctuations in the St. Lawrence River, whereby the magnitude of spring flooding is reduced to protect shoreline properties and low water levels are augmented to allow for shipping traffic.³²⁰ In general, spring flow is reduced by as much as 2000 m³/s and increased between September and March by 300 to 900 m³/s.³²² Since regulation, the annual water level variation at the mouth of Lac Saint-François, downstream of the Moses-Saunders dam, has been reduced by almost 70%, from 0.6 m to just 0.15 m.³²³ On average, flow regulation in the St. Lawrence has also reduced the average maximum flow in summer and increased the minimum flow in winter.³²⁴

Artificial stabilization of water levels has negatively affected ecosystems and specifically wetlands along the St. Lawrence River. For example, the reduced variability on Lac Saint-François was found to have coincided with a decline in wetland species diversity.³²⁵ Where reaches of the St. Lawrence have been permanently flooded by dams and creation of the Seaway, wetlands have been lost and forever changed; vegetation has dramatically shifted from shallow riparian marshland to a primarily aquatic environment, a change that has major implications for overall biological production in the St. Lawrence.³¹⁹ Since regulation was implemented in the late 1950s, there has been a 50% reduction in meadow-marsh and emergent floating vegetation.³²⁶ Research has also shown that unnatural water level regulation can destabilize plant communities and favour the colonization of invasive species.³¹⁹

Water level fluctuations and subsequent vegetation changes are known to adversely affect wildlife, especially the many wetland birds that utilize freshwater habitats along the St. Lawrence, particularly during the breeding season. One study found that a number of indicator species showed a statistically and biologically meaningful response to water level fluctuations along the St. Lawrence.³²⁷ For example, observed breeding populations of Black Tern (Vulnerable in Ontario), Marsh Wren, Common Moorhen, and American Bittern were reduced by 84% or more when there were rapid or moderate increases in St. Lawrence water levels. In order to preserve the integrity of freshwater ecosystems in the St. Lawrence, a management regime is needed that will minimize the alteration of natural hydrological dynamics.³²⁷

Climate Change

Generally, climate change is expected to result in warmer temperatures and lower water levels in the Great Lakes-St Lawrence River basin. From 1895 to 1999, annual mean temperatures increased by 0.7°C in the southern portion of the Great Lakes-St. Lawrence basin, and from 1948 to 2005 a warming trend of 0.5°C has been observed.^{328,329} A WWF-Canada study found that the basin will likely warm by 2.2°C to 4°C in the next 100 years, accompanied by a 1% to 16% increase in precipitation which will likely be offset by increased evapotranspiration (an 8% to 27% increase).³²⁸ This will result in a drop in water levels in the Great Lakes-St. Lawrence system.³²² Modeling suggests that the flow of water from Lake Ontario into the St. Lawrence River could decrease by 4 to 24% annually by 2050.³³⁰ Based on this and other studies, it is estimated that water levels on the St. Lawrence at Montreal could be reduced by 0.2 to 1.2 m, depending on the scenario.³³¹

The most significant impacts of water level changes in the St. Lawrence will be on wetlands, coastal and riverine habitats, and such changes would have dramatic effects on the overall character of the St. Lawrence and its ecosystems. For instance, lower water levels will shrink the area of open water, especially in shallower reaches such as Lac Saint-Pierre, which could reduce the size, complexity, and accessibility of its globally significant wetlands.³³² Modeling has found that if climate change drives changes in hydrological cycles or reduces water levels in the Great Lakes-St. Lawrence system, important wetland functions and values including primary productivity, use for wildlife, waterfowl and fish, water quality, areal extent and diversity will be adversely affected.³³³

Changes in St. Lawrence water levels will also impact human uses of the river, which could lead to further modification of the system and its flows. Lower water levels will require adaptation for navigation and shipping, potentially including the need for further dredging and river regulation.³³² It has also been shown that 2°C warming would translate into a 2 to 17% decrease in hydropower production on the St. Lawrence River, at an annual loss of \$240 to \$350 million (at 2002 prices).³²⁸

Of further concern, this reduction in hydropower would likely lead to increased generation from fossil fuel or nuclear plants, further contributing to climate change and other environmental problems.³²⁶

Management and Advocacy Initiatives

Water levels and flows in the St. Lawrence River are regulated by the International Joint Commission (IJC), a bi-national organization established by the Boundary Waters Treaty of 1909 to approve projects that might affect boundary waters.³³⁴ The current plan guiding St. Lawrence regulation is Plan 1958-D, put in place by the IJC in October 1963.³²⁶ This outdated plan consists of rules for releasing water from Lake Ontario every week based on water supplies, lake levels, time of year, ice conditions, Ottawa River flows, and a series of other rules.³²⁶ Since environmental considerations were not part of the planning process in the 1950s, the existing plan is focused on managing the river for the benefit of commercial navigation and hydropower — the flow needs of the natural environment are not considered.³³⁵

In 2000, because of environmental concerns and increasing dissatisfaction among many interests, the IJC commissioned a 5-year, US\$20 million study to review the existing Plan 1958-D and develop a new plan that would incorporate environmental flow needs.³²⁶ The results of this study, released in 2006, put forth three new regulation options, each with different costs and benefits: Plans A+, B+ and D+.³²⁶ Plan B+, allowing for more natural variability in flows, was considered the best option for restoring the environmental health of the St. Lawrence, as well as for providing benefits for fishermen, municipal water authorities and other users, and was widely endorsed by a majority of IJC study board members, environmental groups and numerous government agencies, including the US Fish and Wildlife Service and the Ontario Ministry of Natural Resources.^{335,336,337} However, despite overwhelming public and scientific support for Plan B+, in March 2008 the IJC announced a new, hybrid option that was developed behind closed doors — Plan 2007 — which basically represented a “business as usual” approach to regulation.³³⁶ Faced with intense public backlash and a lack of support for Plan 2007, the IJC agreed to postpone plan implementation while they undertake a one year process to resolve the issues and develop a plan that will help restore more natural flows in the St. Lawrence.³³⁸ This process, which disappointingly does not include any plans for public involvement, is scheduled to be concluded by June 2009, but it does not appear likely that this timeline will be met.³³⁹

What’s being done about it?

- The IJC reviewed the outdated Plan 1958-D, but failed to adopt the widely endorsed Plan B+, which would have restored a great deal of natural variability to the river and its ecosystems³³⁶
- A 1-year process is currently underway to decide on a new regulation plan within the IJC — with no planned public involvement^{338,339}
- Numerous groups advocate for environmental flows in the St. Lawrence, including Save the River/Upper St. Lawrence Riverkeeper and Great Lakes United. See www.savetheriver.org and www.glu.org

Numerous environmental and conservation groups on both sides of the border have spoken out in support of Plan B+ and restoring environmental flows in the St. Lawrence, such as Save the River/Upper St. Lawrence Riverkeeper, Ducks Unlimited, The Nature Conservancy, Citizens Campaign for the Environment, Great Lakes United, Sierra Club, the Ottawa Riverkeeper and many more.³⁴⁰ Save the River/Upper St. Lawrence Riverkeeper, based in New York but representing interests in the US and Canada, has been especially active in advocating for Plan B+, but also more broadly by engaging and educating people at a grassroots level on river issues, and pressuring government to implement policies and programs that protect river health.³⁴¹

In Canada, governments are working together to learn more about flows in the St. Lawrence River. The St. Lawrence Plan for a Sustainable Development (2005-2010) is the fourth phase of the *Canada-Québec Agreement on the St. Lawrence*, first signed in 1989.³⁴² Phase III, St. Lawrence Vision 2000, was the first to include water level management as a research priority, and aimed to assess the impacts of water level variations due to climate change and regulation.³⁴³ Under Phase IV, effort is focused on “State of the St. Lawrence” monitoring, which includes measuring ecosystem health in response to changes in water levels and flows on the river.^{322,344}

Figure 12. Summary of Environmental Flow Classification for the St. Lawrence River

Indicators	Status of Indicators
River fragmentation and flow regulation	Strongly affected by fragmentation and flow regulation
Water withdrawals and diversions	Few, infrequent withdrawals; evidence that demand may increase in the future
Predicted and/or observed impacts of climate change on flow regime	Predicted and/or observed impacts of climate change expected to result in significant changes to flow regime
Quantity of water flows, high and low flow events, impacts on connectivity	Quantity of flows significantly altered from natural; major changes to high and low flows and connectivity
Timing of flows, flow patterns, seasonality	Timing of flows significantly altered from natural; frequent changes in natural seasonal flow patterns
Species/ecosystem condition in relation to flow regime	Evidence that species/ecosystems dependent on natural flow regime are severely threatened by changes to flow regime
Water quality in relation to flow regime	Evidence that changes in flows are moderately impacting or may impact water quality

Status of Environmental Flows/Forecast: POOR/DECLINING

CONCLUSIONS

While we are lucky enough to still have some magnificent wild rivers in Canada, where environmental flows are in relatively Natural or Good condition, this assessment has revealed that environmental flows in many of our rivers are under threat, in Fair or Poor condition. The results of this assessment are summarized in Table 1, below.

Table 1: Summary of Results

River	Status	Forecast	Rationale
Athabasca	Good	↓	<ul style="list-style-type: none"> Free-flowing, undammed Oil sands currently withdraw 1–2% of mean annual flow, but a much greater proportion of flow during winter, placing ecosystems at risk If left unchecked, current and projected oil sands withdrawals represent a significant threat to environmental flows. The current Phase I Management Framework is not sufficient to protect environmental flows.
Fraser	Good	↔	<ul style="list-style-type: none"> Environmental flows not in imminent danger, though climate change and water withdrawals in the interior have caused localized water shortages, low streamflow and stressed species Mainstem is free-flowing and moderately affected by fragmentation and regulation due to dams on major tributaries A number of provisions consider environmental flows, including the BC <i>Fish Protection Act</i> and BC Hydro's Water Use Planning process
Grand	Fair	↔	<ul style="list-style-type: none"> Highly regulated by more than 100 dams and control structures High level of water use and withdrawals, especially in summer when flows are naturally low Considerable restoration effort by the Grand River Conservation Authority and others, but years of modification and pressure from population growth and increasing water demand continue to impact environmental flows
Mackenzie	Natural	↔	<ul style="list-style-type: none"> Free-flowing, main stem undammed; pristine, wilderness river not significantly affected by fragmentation or regulation, or water withdrawals Upstream development (including Athabasca oil sands) and climate change will undoubtedly cause future impacts; essential to take a proactive approach to protection of Mackenzie
Nipigon	Fair	↑	<ul style="list-style-type: none"> Dams and diversions highly modified environmental flows, with devastating consequences for aquatic ecosystems, especially coaster brook trout Significant and ongoing improvement in environmental flows and ecological condition of the river since implementation of a community-based Water Management Plan in 1994
Ottawa	Fair	↓	<ul style="list-style-type: none"> One of the most highly regulated and fragmented river systems in Canada; environmental flows modified throughout the watershed No basin-wide strategy guiding water management or guidelines for protection of environmental flows; without these, status will likely continue in a downward trajectory
Saint John	Poor	↓	<ul style="list-style-type: none"> Complex system under pressure from extensive flow regulation and fragmentation Hydro dams have significant impacts on ecosystems and species such as Atlantic salmon Dam operating plans do not include requirements to consider specific environmental flow needs; without changes to how flows are managed, these impacts will not be reversed
Skeena	Natural	↔	<ul style="list-style-type: none"> Free-flowing; one of the world's few remaining truly wild rivers 2-year moratorium on coalbed methane development in Sacred Headwaters; federal <i>Wild Salmon Policy</i> includes mechanisms for maintaining habitat and ecosystem integrity, which could include protection of environmental flows in salmon rivers such as the Skeena
St. Lawrence	Poor	↓	<ul style="list-style-type: none"> Highly regulated by multiple dams and flow control structures for hydro and navigation Regulation has significantly modified natural flow regime, impacting wetlands and species Current management plan — Plan 1958D — is outdated and focused on managing the river for navigation and hydropower without considering the needs of the natural environment
South	Poor	↓	<ul style="list-style-type: none"> Water resources are highly (and in some cases over-) allocated and highly regulated; flow regime and ecosystems are highly modified

Saskatchewan

- Water Conservation Objectives are only 45% of natural flows — much less than the 85% deemed necessary, and current system makes reallocation of water for environmental needs all but impossible
- Environmental flows are not protected and in the absence of meaningful changes their status will continue to decline

We still have massive rivers, such as the Mackenzie and the mainstem of the Fraser, that flow naturally from source to sea, unimpeded by human development and provide innumerable benefits to ecosystems and people alike. This is great news, and is more than can be said for many places elsewhere in the world — but this is no reason to be complacent. We have not yet damaged any of our great rivers to the point where they no longer flow to the sea, for instance, but these rivers nevertheless face threats that could significantly undermine river health if we fail to protect them.

Worryingly, environmental flows in many of our rivers are already undeniably in deep trouble. The fact that six out of ten rivers were found to have environmental flows in Fair and Poor condition is cause for concern; it is clear that we are not doing enough to protect environmental flows in Canada. Our rivers are threatened by high and increasing water withdrawals, existing and proposed dams, land use practices, and the ubiquitous perils of climate change. Some - such as the South Saskatchewan River - to the point that flows are so highly modified that ecosystems are on the verge of collapse. But there is hope. As demonstrated in this report, it is never too late to make changes that will restore environmental flows and ecological integrity to rivers at risk, as has been done through the water management planning processes for the Nipigon River, and may be forthcoming for the St. Lawrence River. Though not an easy task, it is possible to strike a balance between environmental, social, and economic needs for water.

In highlighting different responses to the need for environmental flows in different rivers, ranging from integrated water use plans to no action at all, it is apparent that there is little explicit policy guidance on environmental flows in Canada. In the absence of any guidance or leadership, especially from the federal government, trade-offs are being made for short term economic gain at the expense of long term ecological sustainability, and environmental flows are dealt with inconsistently, resulting in fragmented and piecemeal actions to protect environmental flows.

Finally, it is clear that a common thread across all rivers and jurisdictions is the threat of climate change. The impacts of a changing climate are already being experienced in watersheds across Canada, and it is evident that the past trends on which we have traditionally based water management decisions are not likely to reflect future climatic realities, which will require a rethinking of how we manage our interaction with and use of water and rivers.

APPENDIX 1: Glossary

Anadromous	Fish that hatch and rear in fresh water, migrate to the ocean (salt water) to grow and mature, and migrate back to fresh water to spawn and reproduce; a specific type of diadromous fish.
Assimilative Capacity	The ability of a natural body of water to receive and process wastewater or pollution without harmful effects and or damage to aquatic life.
Baseflow	The component of total stream flow that is due predominantly to groundwater discharge into a stream; it is typically the low flow in a stream over the dry season.
Basin	See Watershed.
Benthic	Refers to material at the bottom of an aquatic ecosystem (e.g., on a riverbed), and can be used to describe the organisms that live on, or in, the bottom of a water body (i.e., benthic organisms).
Connectivity (river)	Streamflows or water levels in a watercourse that maintain sufficient flow depths over riffles to allow for fish passage between pools. Significant loss of connectivity indicates that interconnectedness is lost between pools.
Consumptive Water Use	Referring to a water taking, a use that completely removes the water from the watershed or water source. An example of consumptive use from a watershed is the taking for water bottling. An example of consumptive use from a source is the removal of water for irrigation; most irrigation water evaporates and is not returned to its source.
Cumulative Effects	The combined environmental impacts that accrue over time and space from a series of similar or related individual actions, contaminants, or projects. Although each action may seem to have a negligible impact, the combined effect can be serious.
Delta	The fan-shaped area formed where the mouth of a river flows into an ocean, sea, estuary, lake or another river, formed by eroded material that has been carried downstream and deposited.
Diadromous	Fish that spend part of their lives in fresh water and part in the ocean. Anadromous species (see above) are one type of diadromous fish.
Ecosystem Base Flow	A flow below which no withdrawals are recommended; it is based on the premise that at low flows, the aquatic ecosystem is more sensitive to water withdrawals.

Environmental Flows	The quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems.
Evapotranspiration	The vaporization of water into the atmosphere, occurring from both evaporation off the land surface and transpiration from plants.
Floodplain	The flat land adjacent to a stream channel that is inundated by water during high flow periods.
Fluvial	Pertaining to or happening in a river. E.g., fluvial lakes are lakes that occur within a river system.
Fragmentation	The interruption of a river's natural flow by dams or diversions, and is an indicator of the degree to which rivers have been modified by human activity.
Freshet	Peak river or stream flows, which often result in flooding, that are caused by spring or early summer snow and ice melt releasing large quantities of water into rivers and streams.
Groundwater	Water that exists beneath the earth's surface in underground streams and aquifers.
Instream Flow Needs	See Environmental Flows.
Natural Flow Regime	The characteristic pattern of a river's flow quantity, timing and variability that have been unaltered by human modification.
Ramsar-listed	A wetland that has been identified as being of international importance, especially as waterfowl habitat, under the Ramsar Convention (signed in 1971 in Iran).
Redd	A depression in the gravel of a riverbed, dug out by a female fish, into which she deposits her eggs during spawning.
Regulation (river)	A river is regulated when flow in all or a portion of its length is artificially controlled by one or more dams or other structures.
Reservoir	In water management, a structure used to hold water for storage and release; generally built behind a dam for more control of water supplies.
Riparian Zone	The land adjacent to a watercourse; a transitional area between aquatic and terrestrial environments that is directly affected by that body of water.
Run-of-River	A type of hydropower project with little or no reservoir storage capacity; power is derived from only the river's natural flow.

Smolt	A young salmon that is at the stage of development when it assumes the silvery color of the adult and is ready to migrate to the ocean.
Streamflow	The movement of water through a watercourse; streamflow is a combination of overland flow, interflow and groundwater discharge.
Transboundary	Across borders or boundaries. In this context, a river or watershed that flows across boundaries. E.g., the St. Lawrence is a transboundary river.
Water Withdrawal	The removal of water from a water body for consumptive or non-consumptive uses; also called water taking or water abstraction.
Water Allocation	The distribution and sharing of water resources among water users; specifies who gets how much water and under what circumstances.
Watershed	A topographical drainage basin that channels water over land and into streams that eventually flows to one main outlet channel; also called a basin, catchment or drainage basin.

APPENDIX 2: Data Collection and Status Assessment Framework

1. River Characterization and Background Information

Key Question: What are the diverse significant features, uses and values of this river?

Identify and characterize river features, uses and values (economic, cultural, recreational, ecological values), not including all of the universal ecosystem services provided by most rivers (e.g., water supply, flood control, nutrient cycling and transport, fish and food, etc.).

Indicators of Ecological Value of Rivers and Associated Ecosystems	References
Ramsar-listed or significant wetlands	Davis et al. 2001; Millennium Ecosystem Assessment 2005; Revenga and Kura 2003
Use of ecosystem by migratory birds	Davis et al. 2001; Revenga et al. 1998
Presence of rare or endangered species	Davis et al. 2001; Smakhtin et al. 2007
Relative rareness of ecosystem type	Davis et al. 2001; Smakhtin et al. 2007
Free-flowing river	WWF 2006
Species and ecosystems dependent on natural flow volume/regime/hydrograph	Millennium Ecosystem Assessment 2005; Smakhtin et al. 2007
Canadian Heritage River designation or other protected areas designation	CHRS 2001; Smakhtin et al. 2007; Revenga et al. 1998

Indicators of Cultural Value of Rivers and Associated Ecosystems	References
First Nations significance	Davis et al. 2001
Canadian Heritage River designation	CHRS 2000
Recreational use	Davis et al. 2001; Postel and Richter 2003
Economic dependence on river	JP Morgan 2008; Postel and Richter 2003
Historical/heritage river uses/values	CHRS 2000; Postel and Richter 2003
Natural features of cultural significance to Canadians (e.g., Reversing Falls, Niagara Falls)	CHRS 2000

2. Status of Environmental Flows

Key Question: What is the status of a number of key drivers of threats to environmental flows and of the impacts on environmental flows in this river?

Identify and characterize the current status and future threats (where appropriate) with respect to a number of indicators of environmental flows/water quantity/natural flow regime status.

	Indicators	References	Measures to characterize status of indicators	References
Drivers	River fragmentation and alteration by dams and infrastructure	Environment Canada 2004; Millennium Ecosystem Assessment 2005; Malmqvist and Rundle 2002; WWAP 2006; Nilsson et al. 2005; Wong et al. 2007; EnvCan 2004; Revenga et al. 2000; Dyson et al. 2003; Brown and King 2003; UN WWAP 2006; Allan and Flecker 1993; Postel and Richter 2003; WWF 2004	Hydropower capacity (GW)	WWF-UK 2007; Revenga et al. 2000
			Number of dams (existing and under construction or proposed) and size/volume of reservoir/storage	Revenga et al. 2000; Revenga et al. 1998; WWF 2004
			Fragmentation and flow regulation index (unaffected, moderately, strongly) (Nilsson et al. 2005)	Nilsson et al. 2005; Revenga et al. 2000; UN WWAP 2006; WWF-UK 2007
	Water withdrawals and diversions	Environment Canada 2004; WWF 2007; Malmqvist and Rundle 2002; Dyson et al. 2003; Postel and Richter 2003	Total volume of withdrawals (km ³); % of flow allocated and/or withdrawn	WWF-UK 2007
			Projected increase in urban/industrial/ag. water demand (%) — indicator of future threats	NRCan 2007; AB Env. 2006
			Irrigation or consumptive use (%)	Revenga et al. 2000
Predicted and/or observed impacts of climate change on flow regime	IPCC 2007; NRCan (Lemmen and Warren) 2004; NRCan (Lemmen et al.) 2008; Millennium Ecosystem Assessment 2005	Predicted changes in streamflow (%), changes in glacier meltwater; changes in precipitation, evaporation, runoff	NRCan (Lemmen and Warren) 2004;	
		Vulnerabilities as identified by the IPCC	IPCC 2007; UN-WWAP 2006	
Other identified drivers of threats to environmental flows (e.g., deforestation, instream irrigation flows, infrastructure for navigation, etc.)	Brown and King 2003; Postel and Richter 2003; WWF-UK 2007	Dependent on drivers (e.g., number of weirs and locks; changes in runoff and discharge due to deforestation)	Brown and King 2003; Postel and Richter 2003; WWF-UK 2007	
Impacts	Quantity of water flows, magnitude of high and low flow events, connectivity	Dyson et al. 2003	e.g., Decrease in total basin storage, percent or volumetric change in average rivers flows, general information	
	Timing of flows, flow patterns, seasonality	Bunn and Arthington 2001	e.g., Days earlier ice melting or spring freshet, trends in high and low flows throughout the year, general information	
	Species/ecosystem condition in relation to flow regime	Millennium Ecosystem Assessment 2005	e.g., Decreasing numbers of fish stocks, salmon returns, changes in wetland area, general information	
	Water quality in relation to flow regime	Dyson et al. 2003; Brown and King 2003	e.g., Changes in number of days river exceeds minimum quality guidelines with changes in flows, general information	
Expert Opinion	Expert opinion on status of river and environmental flows	Information from secondary sources (e.g., peer-reviewed journal articles, published research reports) and primary sources (key informant interviews)		

3. Identifying Management and Advocacy Actions

Key Question: What actions are being taken towards providing for and protecting environmental flows, and who is advocating for environmental flows in this river?

Identify existing water management practices and other initiatives that are being implemented and contribute to the protection of environmental flows, and the agencies and organizations working towards advocating for environmental flows.

Examples of Actions Directed Towards Protecting Environmental Flows	References
Regulatory tools (municipal, watershed, provincial, federal) to protect or provide for environmental flows	Dyson et al. 2003; Schofield et al. 2003; Postel and Richter 2003
Formal allocation of water for environmental needs	Dyson et al. 2003; Postel and Richter 2003; Schofield et al. 2003
Water/river management plans that protect or provide for environmental flows	Arthington and Pusey 2003; Schofield et al. 2003
Limits on water withdrawals/diversions	Dyson et al. 2003
Special heritage or conservation designation for rivers and/or species within rivers	Postel and Richter 2003
Modification or decommissioning of infrastructure (e.g., changes in volume and timing of dam releases or dam removal)	Dyson et al. 2003; WWF 2004
Public awareness campaigns/initiatives	Millennium Ecosystem Assessment 2005
Research into environmental flow needs of ecosystems/species	Millennium Ecosystem Assessment 2005
Water demand management initiatives	Dyson et al. 2003
Economic incentive initiatives to protect environmental flows (e.g., water market provisions)	Postel and Richter 2003; Australian Conservation Foundation 2006

Framework References

- Allan, J.D. and A.S. Flecker. 1993. Biodiversity conservation in running waters. *BioScience*, 43(1):32-43.
- Arthington, A. and B.J. Pusey. 2003. Flow restoration and protection in Australian rivers. *River Research and Applications*, 19:377-395.
- Australian Conservation Foundation. 2006. *Market Mechanisms and Water Recovery for the Environment*. Australian Conservation Foundation: Carlton, VIC.
- Brown, C. and J. King. 2003. *Environmental Flows: Concepts and Methods*. Water Resources and Environment Technical Note C.1, eds. R. Davis and R. Hirji. The World Bank: Washington, DC.
- Bunn, S.E. and A.H. Arthington. 2001. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, 30(4):492-507.
- Canadian Heritage Rivers System. 2000. *A Cultural Framework for Canadian Heritage Rivers*. 2nd Edition. Minister of Public Works and Government Services Canada: Ottawa, ON.
- Canadian Heritage Rivers System. 2001. *A Framework for the Natural Values of Canadian Heritage Rivers*. 2nd Edition. Minister of Public Works and Government Services Canada: Ottawa, ON.
- Davis, J., Froend, R., Hamilton, D., Horwitz, P., McComb, A., Oldham, C. and D. Thomas. 2001. *Environmental Water Requirements to Maintain Wetlands of National and International Importance*. Environmental Flows Initiative Technical Report 1, Commonwealth of Australia: Canberra, ACT.
- Dyson, M., Bergkamp, G. and J. Scanlon (eds.). 2003. *Flow: The Essentials of Environmental Flows*. IUCN: Gland, Switzerland.
- Environment Canada. 2004. *Threats to Water Availability in Canada*. NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. National Water Research Institute: Burlington, ON.
<http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=OCD66675-1>
- Gordon, N.D., Finlayson, B.L., McMahon, T.A., and C.J. Gippel. 2004. *Stream Hydrology: An Introduction for Hydrologists*. John Wiley and Sons Ltd.: West Sussex, UK.
- Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson. Cambridge University Press: Cambridge, UK.
- JPMorgan. 2008. *Watching Water: A Guide to Evaluating Corporate Risks in a Thirsty World*. JPMorgan Environmental Social and Governance Research Series. JPMorgan Chase & Co.: New York, NY.
- Lemmen, D.S. and F.J. Warren (eds.). 2004. *Climate Change Impacts and Adaptation: A Canadian Perspective*. Natural Resources Canada: Ottawa, ON. http://adaptation.nrcan.gc.ca/assess/2007/index_e.php
- Lemmen, D.S., Warren, F.J., Lacroix, J., and E. Bush (eds.). 2008. *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Government of Canada: Ottawa, ON. http://adaptation.nrcan.gc.ca/perspective/index_e.php
- Malmqvist, B. and S. Rundle. 2002. Threats to the running water ecosystems of the world. *Environmental Conservation*, 29(2):134-153.
- Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Current State and Trends, Volume 1*. Chapter 20, Inland Water Systems. Costanza, R., Jacobi, P. and Rijsbermann, F., eds. World Resources Institute: Washington, DC.
<http://www.millenniumassessment.org/proxy/Document.289.aspx>
- Nilsson, C., Reidy, C.A., Dynesius, M. and C. Revenga. 2005. Fragmentation and flow regulation of the world's large rivers systems. *Science*, 308:405-408.
- Postel, S. and B. Richter. 2003. *Rivers for Life: Managing Water for People and Nature*. Island Press: Washington, DC.
- Revenga, C., Murray, S., Abramovitz, J. and A. Hammond. 1998. *Watersheds of the World: Ecological Value and Vulnerability*. World Resources Institute: Washington, DC.
- Revenga, C., Brunner, J., Henninger, N., Kassem, K. and R. Payne. 2000. *Pilot Analysis of Global Ecosystems (PAGE): Freshwater Systems*. World Resources Institute: Washington, DC. http://pubs.wri.org/pubs_pdf.cfm?PubID=3056
- Revenga, C. and Y. Kura. 2003. *Status and Trends of Biodiversity of Inland Water Ecosystems*. Technical Series No. 11. Secretariat of the Convention of Biological Diversity: Montreal, QC. <http://www.cbd.int/doc/publications/cbd-ts-11.pdf>

Schofield, N., Burt, A. and D. Connell. 2003. *Environmental Water Allocation: Principles, Policies and Practices*. Land and Water Australia: Canberra, Australia.

Smahktin, V., Arunachalam, M., Behera, S., Chatterjee, A., Das, S., Gautam, P., Joshi, G., Sivaramakrishnan, K.G. and K.S. Unni. 2007. *Developing the Procedures for Assessment of Ecological Value and Condition of Indian Rivers in the Context of Environmental Water Demand*. International Water Management Institute: Colombo, Sri Lanka.

Wong, C.M., Williams, C.E., Pittock, J., Collier, U. and P. Schelle. 2007. *World's Top 10 Rivers at Risk*. WWF-International: Gland, Switzerland.

WWF. 2004. *Rivers at Risk: Dams and the Future of Freshwater Ecosystems*. DamRight! WWF Dams Initiative: Surrey, UK.

WWF. 2006. *Free-Flowing Rivers: Economic Luxury or Ecological Necessity?* WWF Global Freshwater Programme: Zeist, Netherlands.

WWF-UK. 2007. Internal memo. From Oliver Smith, to Conservation Committee, re: Water Footprint Indicators. Monday 21 May 2007.

APPENDIX 3: Generic Key Informant Interview Protocol

Introductory

Can you tell me about your professional and/or personal experience with this river?

Status of Environmental Flows

From your perspective, what do you see as the most significant threats to this river's health? What is driving these threats?

Are there any current or imminent threats to the natural flow regime in this river?

What impacts are you seeing from disruptions to the natural flow regime? What is driving these impacts? What do you see as the most serious?

River Management and Advocacy

Have there been any major initiatives to mitigate any of these threats to river health?

Have there been any research initiatives to better understand the threats and/or manage this river? Who is undertaking this research?

Who are the major players working or advocating for this river (groups, people, partnerships, etc.)?

Concluding

From your perspective, what is the "take-home message" about environmental flows in this river?

What resources, other people, documents or materials, would you regard as essential to this study?

Is there anything else you'd like to add that hasn't been covered by my questions?

APPENDIX 4: South Africa's River Health Classification System

South Africa is known to be a world leader in the theory and practice of river health assessment. South Africa's *River Health Programme* (RHP) is essentially a bio-monitoring program that reports on river health based on selected ecological indices. In the RHP, the following indices are used to assess the health of rivers:

- South African Scoring System (SASS5),
- Fish Assemblage Integrity Index (FAII),
- Riparian Vegetation Index (RVI) and
- Index of Habitat Integrity (IHI).

South Africa makes use of a River Health Classification System to ensure standardization in assessment and therefore allow for comparison of the health data of several river systems. The river health indices are calibrated and results can be expressed as a specific river health category: natural, good, fair, poor or artificial. The ecological and management perspectives for each river health category are outlined in the table below:

River Health Category	Ecological Perspectives	Management Perspectives
Natural	No or negligible modification of in-stream and riparian habitats and biota.	Protected rivers; relatively untouched by human hands; no discharges or impoundments allowed.
Good	Ecosystems essentially in good state; biodiversity largely intact.	Some human-related disturbance but mostly of low impact potential.
Fair	A few sensitive species may be lost; lower abundances of biological populations are likely to occur, or sometimes, higher abundances of tolerant or opportunistic species occur.	Multiple disturbances associated with need for socio-economic development, e.g., impoundment, habitat modification and water quality degradation.
Poor	Habitat diversity and availability have declined; mostly only tolerant species present; species present are often diseased; population dynamics have been disrupted (e.g. biota can no longer reproduce or alien species have invaded the ecosystem).	Often characterized by high human densities or extensive resource exploitation. Management intervention is needed to improve river health — e.g., to restore flow patterns, river habitats or water quality.
Artificial	These systems may have water of good quality and are likely to be inhabited by a range of organisms. However, they have been transformed to such an extent that their habitat types, biological communities and ecosystem processes bears no or little resemblance to those that would occur under natural conditions.	Modified beyond rehabilitation to anything approaching a natural condition. Example: canalized rivers in urban environments.

More information on the South African River Health Programme can be found at: <http://www.csir.co.za/rhp/index.html>.

APPENDIX 5: Numerical Scoring of Results Exercise

Score assigned for each indicator category:

POOR - 3; FAIR - 2; GOOD - 1; NATURAL - 0

Overall Score Ranges:

POOR 17–21 (21 would be the score if all 7 indicators scored POOR)
 FAIR 11–16 (14 would be the score if all 7 indicators scored FAIR)
 GOOD 5–10 (7 would be the score if all 7 indicators scored GOOD)
 NATURAL 0–4 (0 would be the score if all 7 indicators scored NATURAL)

Indicator Scores and Aggregation of Overall Status:

River	Indicators + Scores							Overall Score	Status
	River fragmentation and flow regulation	Water withdrawals and diversions	Predicted and/or observed impacts of climate change	Quantity of water, high and low flow events, impacts on connectivity	Timing of flows, flow patterns, seasonality	Species/ ecosystem condition in relation to flow regime	Water quality in relation to flow regime		
Athabasca	0	2	3	1	1	1	2	10	GOOD
Fraser	1	2	2	1	1	2	1	10	GOOD
Grand	3	2	2	2	3	2	2	16	FAIR
Mackenzie	1	0	2	0	1	0	0	4	NATURAL
Nipigon	3	0	2	3	2	2	1	13	FAIR
Ottawa	3	1	2	1	2	2	2	15	FAIR
Skeena	0	0	2	1	0	0	0	3	NATURAL
South Saskatchewan	3	3	3	3	3	2	2	19	POOR
St. John	3	2	2	3	2	3	3	18	POOR
St. Lawrence	3	1	3	3	3	3	2	18	POOR

APPENDIX 6: Endnotes

- ¹ O'Keefe, J. and T. Le Quesne. 2009. *Keeping Rivers Alive: A Primer on Environmental Flows*. WWF Water Security Series 2. WWF-UK: Surrey, UK.
- ² WWF International, Zoological Society of London, Global Footprint Network, and Twente Water Centre. 2008. *Living Planet Report 2008*. WWF International: Gland, Switzerland. Available at: http://assets.panda.org/downloads/living_planet_report_2008.pdf.
- ³ Securing water for people and nature: Statement of the WWF network meeting on flows and water security [The Paarl Statement]. Paarl, South Africa, 27 February – 2 March 2009.
- ⁴ The Brisbane Declaration. Proclaimed at the 10th International Rivers *symposium* and International Environmental Flows Conference, Brisbane, Australia, 3–6 September, 2007.
- ⁵ Bunn, S. E. and A. Arthington. 2001. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, 30(4): 492–507.
- ⁶ Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestregard, K.L., Richter, B.D., Sparks, R.E. and Stromberg, J.C. 1997. The natural flow regime: a paradigm for river conservation and restoration. *BioScience*, 47: 769–784.
- ⁷ Arthington, A., S. E. Bunn, N. L. Poff, and R. J. Naiman. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. *Ecological Applications*, 16(4): 1311–1318.
- ⁸ Tharme, R. E. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications*, 19: 397–441.
- ⁹ Brandes, O.M., Ferguson, K., M'Gonigle, M. and C. Sandborn. 2005. *At A Watershed: Ecological Governance and Sustainable Water Management in Canada*. The POLIS Project on Ecological Governance: Victoria, BC. Available at: <http://www.polisproject.org/files/watershed.pdf>
- ¹⁰ de Loë, R.C., Varghese, J., Ferreyra, C. and R.D. Kreuzwiser. 2007. *Water Allocation and Water Security in Canada: Initiating a Policy Dialogue for the 21st Century*. Report prepared for the Walter and Duncan Gordon Foundation. Guelph Water Management Group, University of Guelph: Guelph, ON. Available at: http://www.environment.uwaterloo.ca/research/wpgg/Documents/1-de_Loe_et_al_2007_Final_Report.pdf
- ¹¹ Morris, T.J, D.R. Boyd, O.M. Brandes, J.P Bruce, M. Hudon, B. Lucas, T. Maas, L. Nowlan, R. Pentland, and M. Phare. 2007. *Changing the Flow: A Blueprint for Federal Action on Freshwater*. The Gordon Water Group of Concerned Scientists and Citizens. Available at: <http://www.gordonwatergroup.ca/uploads/File/PDF/ChangingtheFlow.pdf>
- ¹² United Nations World Water Assessment Programme. 2009. The 3rd United Nations World Water Development Report: Water in a Changing World. Available at: <http://www.unesco.org/water/wwap/wwdr/wwdr3/tableofcontents.shtml>.
- ¹³ Dyson, M., G. Bergkamp, and J. Scanlon. 2003. *Flow: The Essentials of Environmental Flows*, Gland, Switzerland: IUCN - The World Conservation Union.
- ¹⁴ The Nature Conservancy. Freshwater Conservation: What We Do. Changing water policies to protect environmental flows. Online: <http://www.nature.org/initiatives/freshwater/strategies/flows.html> (Accessed April 13, 2009).
- ¹⁵ Schindler, D.W. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. *Canadian Journal of Fisheries and Aquatic Sciences*, 58(1):18–29.
- ¹⁶ Postel, S. and Richter, B. 2003. *Rivers for Life: Managing Water for People and Nature*. Island Press: Washington, DC.
- ¹⁷ Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Current State and Trends, Volume 1. Chapter 20 in, Costanza, R., Jacobi, P. and Rijsbermann, F. (eds.) *Inland Water Systems*. World Resources Institute: Washington, DC. Available at: www.millenniumassessment.org/proxy/Document.289.aspx
- ¹⁸ Environment Canada. 2004. *Threats to Water Availability in Canada*. NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. National Water Research Institute: Burlington, ON. Available at: <http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=0CD66675-1>
- ¹⁹ Malmqvist, B. and S. Rundle. 2002. Threats to the running water ecosystems of the world. *Environmental Conservation*, 29(2):134–153.
- ²⁰ Revenga, C., Brunner, J., Henninger, N., Kassem, K. and Payne, R. 2000. *Pilot Analysis of Global Ecosystems (PAGE): Freshwater Systems*. World Resources Institute: Washington, DC. Available at: http://pubs.wri.org/pubs_pdf.cfm?PubID=3056

- ²¹ Canadian Dam Association. 2003. *Canadian Dam Register*, March 2003, as cited in Prowse, T.D., Wrona, F.J. and Power, G. 2004. Dams, reservoirs and flow regulation. Chapter 2 in *Threats to Water Availability in Canada*. NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. National Water Research Institute: Burlington, ON. Available at: <http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=0CD66675-1>
- ²² Prowse, T.D., Wrona, F.J. and Power, G. 2004. Dams, reservoirs and flow regulation. Chapter 2 in *Threats to Water Availability in Canada*. NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. National Water Research Institute: Burlington, ON. Available at: <http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=0CD66675-1>
- ²³ WWF. 2004. *Rivers at Risk: Dams and the Future of Freshwater Ecosystems*. DamRight! WWF Dams Initiative: Surrey, UK.
- ²⁴ Ward, J.V. 1998. Riverine landscapes: biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation*, 83: 269–78.
- ²⁵ Nilsson, C. and K. Berggren. 2000. Alterations of riparian ecosystems caused by river regulation. *BioScience*, 50(9):783–792.
- ²⁶ Kingsford, R. 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology*, 25:109–127.
- ²⁷ Palmer, M.A., Reidy Liermann, C.A., Nilsson, C. Florke, M. Alcamo, J., Lake, P.S. and N. Bond. 2008. Climate change and the world's river basins: anticipating management options. *Frontiers in Ecology and the Environment*, 6(2):81–89.
- ²⁸ Wong, C.M., Williams, C.E., Pittock, J., Collier, U. and P. Schelle. 2007. *World's Top 10 Rivers at Risk*. WWF-International: Gland, Switzerland.
- ²⁹ Smahktin, V., Arunachalam, M., Behera, S., Chatterjee, A., Das, S., Gautam, P., Joshi, G., Sivaramakrishnan, K.G. and K.S. Unni. 2007. *Developing the Procedures for Assessment of Ecological Value and Condition of Indian Rivers in the Context of Environmental Water Demand*. International Water Management Institute: Colombo, Sri Lanka.
- ³⁰ Nilsson, C., Reidy, C.A., Dynesius, M. and Revenga, C. 2005. Fragmentation and flow regulation of the world's large rivers systems. *Science*, 308:405–408.
- ³¹ Revenga, C., Murray, S., Abramovitz, J. and A. Hammond. 1998. *Watersheds of the World: Ecological Value and Vulnerability*. World Resources Institute: Washington, DC.
- ³² Environment Canada. 2008a. Freshwater Website: Water Use in Canada, 2005. Online: <http://www.ec.gc.ca/Water/images/manager/use/a4f1e.htm> (Accessed June 26, 2009).
- ³³ Healey, M. 1992. The importance of freshwater inflows into coastal ecosystems. In J.E. Windsor (ed.), *Water Export: Should Canada's Water Be For Sale?* Canadian Water Resource Association: Vancouver, B.C.
- ³⁴ Douglas, T. 2006. *Review of Groundwater-Salmon Interactions in British Columbia*. Watershed Watch Salmon Society: Coquitlam, B.C.
- ³⁵ Lemmen, D.S. and F.J. Warren. 2004. *Climate Change Impacts and Adaptations: A Canadian Perspective*. Climate Change Impacts and Adaptation Directorate, Natural Resources Canada: Ottawa, ON.
- ³⁶ Whitfield, P.H., Pilon, P.J., Burn, D.H., Arora, V., Lins, H.F., Ouarda, T., Sellars, C.D. and C. Spence. 2004. Climate Variability and Change – Rivers and Streams. Chapter 11 in *Threats to Water Availability in Canada*. NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. National Water Research Institute: Burlington, ON, p. 85–90. Available at: <http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=0CD66675-1>.
- ³⁷ Matthews, J.H. and T. Le Quesne. 2009. *Adapting Water Management: A Primer on Coping with Climate Change*. WWF Water Security Series 3. WWF-UK: Surrey, UK.
- ³⁸ Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P., and R.J. Stouffer. 2008. Stationary Is Dead: Whither Water Management? *Science*, 319 (5863): 573-574.
- ³⁹ Thormann, M.N., Bernier, P.Y., Foster, N.W., Schindler, D.W. and F.D. Beall. 2004. Land-use practices and changes – forestry. Chapter 8 in *Threats to Water Availability in Canada*. NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. National Water Research Institute: Burlington, ON, p. 85–90. Available at: <http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=0CD66675-1>.
- ⁴⁰ Boyle, C. A., L. Lavkulich, H. Schreier and E. Kiss. 1997. Changes in land cover and subsequent effects on Fraser Basin Ecosystems from 1823 to 1900. *Environmental Management*, 21(2): 185–196.

- ⁴¹ Strydom, W.F. 2003. Compiling State-of-Rivers Reports and Posters: A Manual.. NAEBP Report Series No. 17. Resources Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa. Available at: <http://www.csir.co.za/rhp/reports/reportseries17.pdf>.
- ⁴² Australian Government National Water Commission. 2007. Australian Water Resources 2005: Assessment of River and Wetland Health. Online: http://www.water.gov.au/RiverandWetLandHealth/Assessmentofriverandwetlandhealth/index.aspx?Menu=Level1_5_2 (Accessed June 10, 2009).
- ⁴³ European Commission, Water Information System for Europe. 2008. Water Note 6: Monitoring Programmes: Taking the Pulse of Europe's Waters. Available at: http://ec.europa.eu/environment/water/water-framework/pdf/water_note6_monitoring_programmes.pdf.
- ⁴⁴ Department of Fisheries and Oceans Canada. 2008. *Proceedings of the National Peer Review of the Lower Athabasca River Instream Flow Assessment and Water Management Framework*. Department of Fisheries and Oceans Canada Science Advisory Secretariat, Proceedings Series 2007/032.
- ⁴⁵ Syncrude Canada Ltd. 2008. Environmental Sustainability: Water Use. Online: <http://sustainability.syncrude.ca/sustainability2007/enviro/water/> (Accessed January 28, 2009).
- ⁴⁶ Shell Canada Limited. 2007. *Oil Sands: Water*. Available at: http://www.shell.com/static/ca-en/downloads/about_shell/what_we_do/oil_sands/aosp/oilsands_water.pdf
- ⁴⁷ Suncor Energy. 2008. *Sustainability Report 2007 Update*. Available at: <http://www.suncor.com/doc.aspx?id=178>
- ⁴⁸ Shell Canada Ltd., *Application for the Approval of the Muskeg River Mine Expansion Project*, (2005), Volume 1, Section 10.5, 10–22.
- ⁴⁹ Schindler, D.W., Donahue, W.F., and J.P. Thompson. 2007. Future Water Flows and Human Withdrawals in the Athabasca River. In *Running out of Steam? Oil Sands Development and Water Use in the Athabasca River-Watershed: Science and Market based Solutions*. Edmonton: University of Alberta Environmental Research and Studies Centre. Available at: <http://www.ualberta.ca/ERSC/water.pdf>.
- ⁵⁰ Woynillowicz, D. and C. Severson-Baker. 2006. *Down to the Last Drop? The Athabasca River and Oil Sands*. Oil Sands Issue Paper No. 1. The Pembina Institute: Calgary, AB.
- ⁵¹ Canadian Heritage Rivers System. No date. Athabasca River Fact Sheet. Online: http://www.chrs.ca/Rivers/Athabasca/Athabasca-F_e.htm (Accessed January 7, 2009).
- ⁵² The Ramsar Convention on Wetlands. 2001. *Canada 7: Peace-Athabasca Delta, Alberta – Information Sheet on Ramsar Wetlands*. The Ramsar Convention Secretariat: Gland, Switzerland. Available at: <http://ramsar.wetlands.org/Database/Searchforsites/tabid/765/Default.aspx>
- ⁵³ Prowse, T.D. and F.M. Conly. 2000. Multiple-hydrologic stressors of a northern delta ecosystem. *Journal of Aquatic Ecosystem Stress and Recovery*, 8:17–26.
- ⁵⁴ Northern Rivers Ecosystem Initiative. 2004. *Northern Rivers Ecosystem Initiative: Key Findings*. Government of Canada, Government of Alberta, and Government of the Northwest Territories.
- ⁵⁵ Wolfe, B.B., Hall, R.I., Edwards, T.W.D., Vardy, S.R., Falcone, M.D., Siunneskog, D., Sylvestre, F., McGowan, S., Leavitt, P.R. and P. van Driel. 2008. Hydroecological responses of the Athabasca Delta, Canada, to changes in river flow and climate during the 20th century. *Ecohydrology*, 1:13–148.
- ⁵⁶ Peters, D.L., Prowse, T.D., Marsh, P., Lafleur, P.M., and J.M. Buttler 2006. Persistence of water within Perched Basins of the Peace-Athabasca Delta, Northern Canada. *Wetlands Ecology and Management* 14: 221–243.
- ⁵⁷ Courtney, R.F. 2006. *Lower Athabasca River In-stream Flow Needs (IFN) Recommendation and Rationale*. Unpubl. Rept. Dept. Fisheries and Oceans Fish Habitat Management, Calgary District Office, 7646 8th Street N.E., Calgary, AB T2E 8X4
- ⁵⁸ Holroyd, P. and T. Simieritsch. 2009. *The Waters that Bind Us: Transboundary Implications of Oil Sands Development*. The Pembina Institute: Drayton Valley, AB.
- ⁵⁹ Golder Associates Ltd. 2004. Athabasca River Instream Flow Needs Scoping Study. Report Prepared for the Cumulative Environmental Management Association Surface Water Working Group.
- ⁶⁰ Canadian Association of Petroleum Producers. 2008. *Canada's Oil Sands: A Different Conversation. What we heard from Canadians – summary*. CAPP: Available at: <http://www.canadasoilsands.ca/en/pdf/Canadasoilsands%20report1.pdf>
- ⁶¹ Courtney, R. 2006. *Lower Athabasca River Instream Flow Needs (IFN) Recommendation, Fisheries Act Implementation Plan and Rationale [Draft]*. Department of Fisheries and Oceans Canada.

- ⁶² Alberta Environment. 2008. Water Diversion by Oilsands Mining Projects in 2007. Data received from Alberta Environment, September 2008.
- ⁶³ Golder Associates Ltd. 2005. *A Compilation of Information and Data on Water Supply and Demand in the Lower Athabasca River Reach*, prepared for the Cumulative Environmental Management Surface Water Working Group. Golder Associates Ltd.: Calgary, AB.
- ⁶⁴ Dyer, S., Moorhouse, J., Laufenberg, K. and R. Powell. 2008. *Under-Mining the Environment: The Oil Sands Report Card*. The Pembina Institute and WWF-Canada.
- ⁶⁵ Alberta Environment. 2009. Water Use Oil Sands Monthly 2008. Data provided from Alberta Environment on June 8, 2009.
- ⁶⁶ National Energy Board. 2006. *Canada's Oil Sands – Opportunities and Challenges to 2015: An Update*. An Energy Market Assessment June 2006. National Energy Board: Calgary, AB.
- ⁶⁷ Personal communication with Rick Courtney, Shell Canada Energy. January 12, 2009.
- ⁶⁸ Government of Alberta. *Investing in our Future: Responding to the Rapid Growth of Oil Sands Development*. Final Report. Available at: <http://www.alberta.ca/home/395.cfm>.
- ⁶⁹ Canadian Association of Petroleum Producers. 2008. *Canada's Oil Sands: A Different Conversation – Water*. Online: <http://www.canadasoilsands.ca/en/issues/water.aspx> (Accessed January 9, 2009).
- ⁷⁰ Alberta Environment and Department of Fisheries and Oceans Canada. 2007. *Water Management Framework: Instream Flow Needs and Water Management System for the Lower Athabasca River*. Alberta Environment and Department of Fisheries and Oceans Canada. Available from: http://environment.alberta.ca/documents/Athabasca_RWMF_Technical.pdf.
- ⁷¹ OSDG (Oil Sands Developers Group). 2008. Oil Sands Mining Cooperation to Meet the Athabasca River Water Management Framework. Presentation at CAPP Environmental Forum by Stuart Lunn, January 21, 2008. Available at: <http://oilsandsdevelopers.ca/pdfs/Water%20Presentation%20to%20CAPP%20Forum%202008%20LUNN.pdf>
- ⁷² Bruce, J.P. 2006. Oil and Water – Will they Mix in a Changing Climate? The Athabasca River Story. *Implications of a 2°C Global Temperature Rise on Canada's Water Resources*. Sage Centre.
- ⁷³ Schindler, D.W. and W.F. Donahue. 2006. An impending water crisis in Canada's western prairie provinces. *Proceedings of the National Academy of Sciences*, 103(19):7210–7216.
- ⁷⁴ Burn, D.H., Aziz, O.I.A. and A. Pietroniro, 2004. A comparison of trends in hydrological variables for two watersheds in the Mackenzie River basin, *Canadian Water Resources Journal*, 29(4):283–298.
- ⁷⁵ Woo, M. and R. Thorne. 2003. Streamflow in the Mackenzie Basin, Canada. *Arctic*, 56(4):328–340.
- ⁷⁶ Watson, E. and B.H. Luckman. 2004. Tree-ring based mass-balance estimates for the past 300 years at Peyto Glacier, Alberta, Canada. *Quaternary Research*, 62: 9–18.
- ⁷⁷ Gan, T.Y., and E. Kerkhoven. 2004. Modeling the Hydrology and Possible Impact of Climate Change on the Athabasca River Basin by a Modified ISBA with GCM-Scale Data. *Proceedings of the 10th Annual Scientific Meeting of Mackenzie GEWEX Study (MAGS)*: 163–176.
- ⁷⁸ Natural Sciences and Engineering Research Council and Environment Canada. The Mackenzie GEWEX Study (MAGS). Online: http://www.usask.ca/geography/MAGS/index_e.htm (Accessed March 16, 2009).
- ⁷⁹ Wenig, M.M., Kwasniak, A.J. and M.S. Quinn. 2006. Water under the bridge? The role of instream flow needs (IFNs) determinations in Alberta's river management. *Water: Science and Politics*. H. Epp and D. Ealey (eds.). Proceedings of the Conference of the Alberta Society of Professional Biologists, March 25–28, 2006, Calgary, AB. Alberta Society of Professional Biologists: Edmonton, AB.
- ⁸⁰ Adamowicz, V. 2008. Water use and Alberta oil sands development – science and solutions: an analysis of options. In *Running out of Steam? Oil Sands Development and Water Use in the Athabasca River-Watershed: Science and Market based Solutions*. Edmonton: University of Alberta Environmental Research and Studies Centre. Available at: <http://www.ualberta.ca/ERSC/water.pdf>.
- ⁸¹ Reynoldson, T.B., Culp, J., Lowell, R. and J.S. Richardson. 2005. Fraser River Basin. In A.C. Benke and C.E. Cushing (Eds.) *Rivers of North America*. Elsevier Academic Press: Amsterdam, Netherlands. p. 697–731.
- ⁸² Canadian Heritage Rivers System. 2002. Fraser River. Online: http://www.chrs.ca/Rivers/Fraser/Fraser-F_e.htm (Accessed March 17, 2009).
- ⁸³ Fraser Basin Council. 2004. Fraser River Basin. Online: http://www.fraserbasin.bc.ca/fraser_basin/index.html (Accessed March 17, 2009).

- ⁸⁴ Angelo, M. 2008. *BC Endangered Rivers List*. Outdoor Recreation Council of British Columbia. Available at: <http://www.orcbc.ca/documents/bkgrd2008.pdf>.
- ⁸⁵ Marshall, D. 1998. Watershed management in British Columbia: the Fraser River Basin experience. *Environments*, 25(2/3): 64–79.
- ⁸⁶ Fraser Salmon & Watersheds Program. 2009. Home Page. Online: <http://www.fswp.ca/index.htm> (Accessed March 27, 2009).
- ⁸⁷ Fraser Basin Council. 2009. 2009 State of the Fraser Basin Report: Sustainability Snapshot 4 – The Many Faces of Sustainability. Fraser Basin Council: Vancouver, BC.
- ⁸⁸ Hume, M., 2009. Fraser River's salmon stocks 'beyond a crisis'. *The Globe and Mail*, Aug. 13, 2009, pg. A6.
- ⁸⁹ Committee on the Status of Endangered Wildlife in Canada. 2008. Canadian Wildlife Species at Risk. December 2008. COSEWIC: Gatineau, QC. Available at: http://www.cosewic.gc.ca/eng/sct0/rpt/dsp_booklet_e.htm.
- ⁹⁰ Nelson, T.C., Gazey, W.J. and K.K. English. 2008. *Status of White Sturgeon in the Lower Fraser River: Report on the Findings of the Lower Fraser River Sturgeon Monitoring and Assessment Program 2007*. Fraser River Sturgeon Conservation Society: Vancouver, B.C. Available at: <http://www.frasersturgeon.com/pdf/fraserwhitesturgeon2007.pdf>.
- ⁹¹ Hatfield, T., McAdam, S. and T. Nelson. 2004. *Impacts to Abundance and Distribution of Fraser River White Sturgeon: A Summary of Existing Information and Presentation of Impact Hypotheses*. Prepared for Fraser River Sturgeon Conservation Society, Fraser River White Sturgeon Working Group.
- ⁹² Ducks Unlimited Canada. 2009. Fraser River Delta. Online: <http://www.ducks.ca/province/bc/priorities/coast/fraser.html> (Accessed March 27, 2009).
- ⁹³ Bird Studies Canada. 2009. IBA Site Listing: Boundary Bay – Roberts Bank – Sturgeon Bank (Fraser River Estuary). Online: <http://www.bsc-eoc.org/iba/site.jsp?siteID=BC017> (Accessed March 27, 2009).
- ⁹⁴ Fraser Basin Council. 2009. About the Fraser Basin: Frequently Asked Questions. Online: http://www.fraserbasin.bc.ca/about_us/faq.html#17 (Accessed March 27, 2009).
- ⁹⁵ French, T.D. and P.A. Chambers. 1997. Reducing flows in the Nechako River (British Columbia, Canada): potential response of the macrophyte community. *Canadian Journal of Fisheries and Aquatic Sciences*, 54: 2247–2254.
- ⁹⁶ Rood, K. and C. R. Neill. 1987. A study of some aspects of the geomorphology of the Nechako River. Reid Crowther and Partners Ltd. and Northwest Hydraulic Consultants Ltd. Prepared for Fisheries and Oceans Canada, Vancouver, B.C. DSS File #FP501-6-0142/01-SB. 84 pp.
- ⁹⁷ Environment Canada. 2008. Flooding Events in Canada – British Columbia. Online: http://www.ec.gc.ca/water/en/manage/floodgen/e_bc.htm (Accessed March 30, 2009).
- ⁹⁸ Blomquist, W., Calbrick, K.S. and A. Dinar. 2005. *Institutional and Policy Analysis of River Basin Management: The Fraser River Basin, Canada*. World Bank Policy Research Working Paper 3525. World Bank, Agriculture and Rural Development Department: Washington, D.C.
- ⁹⁹ British Columbia Ministry of Environment. 2007. *Environmental Trends in British Columbia: 2007*. Available at: http://www.env.gov.bc.ca/soe/et07/EnvironmentalTrendsBC_2007.pdf.
- ¹⁰⁰ Watershed Watch Salmon Society. 2007. *Water and salmon issues and options for conservation and governance improvements in the lower Fraser River*. Prepared for the Fraser Salmon and Watershed Program, Pacific Salmon Foundation and Fraser Basin Council.
- ¹⁰¹ Rosenau, M.L. and M. Angelo. 2003. *Conflicts between People and Fish for Water: Two British Columbia Salmon and Steelhead Rearing Streams in Need of Flows*. Vancouver, BC: Pacific Fisheries Resource Conservation Council.
- ¹⁰² Douglas, T. 2007. Nicola Water Use Management Plan: Case Study. Prepared for Watershed Watch Salmon Society and the 17th *Speaking for the Salmon Workshop* on Groundwater and Salmon.
- ¹⁰³ Rodenhuis, D., Bennett, K.E., Werner, A., Murdock, T.Q. and D. Bronaugh. 2007. *Climate Overview 2007: Hydro-climatology and future climate impacts in British Columbia*. Pacific Climate Impacts Consortium, University of Victoria: Victoria, BC. Available at: <http://www.pacificclimate.org/publications/PCIC.ClimateOverview.pdf>.
- ¹⁰⁴ Fraser Basin Council. 2007. *Backgrounder – Preparing for Climate Change in the Fraser Basin: How can our Water Management Systems Adapt?* Fraser Basin Council: Vancouver, B.C.

- ¹⁰⁵ Pike, R.G., Spittlehouse, D.L., Bennett, K.E., Egginton, V.N., Tschaplinski, P.J., Murdock, T.Q. and A.T. Werner. 2008. Climate Change and Watershed Hydrology: Part I – Recent and Projected Changes in British Columbia. *Streamline Watershed Management Bulletin*, 11(2): Spring 2008. Available at: http://www.forrex.org/Streamline/ISS37/streamline_vol11_no2.pdf.
- ¹⁰⁶ Morrison, J. Quick, M.C. and M.G.G. Foreman. 2002. Climate change in the Fraser River watershed: flow and temperature predictions. *Journal of Hydrology*, 263: 230–244.
- ¹⁰⁷ Farrell, A.P., Hinch, S.G., Cooke, S.J., Patterson, D.A., Crossin, G.T., Lapointe, M. and M.T. Mathes. 2008. Pacific salmon in hot water: applying aerobic scope models and biotelemetry to predict the success of spawning migrations. *Physiological and Biochemical Zoology*, 81(6): 697–709.
- ¹⁰⁸ Nelitz, M., Wieckowski, K., Pickard, D., Pawley, K. and D. Marmorek. 2007. *Helping Pacific Salmon Survive the Impact of Climate Change on Freshwater Habitats: Pursuing Proactive and Reactive Adaptation Strategies*. Prepared for the Pacific Fisheries Resource Conservation Council.
- ¹⁰⁹ Pacific Fisheries Resource Conservation Council. 2008. *Mountain Pine Beetle: Salmon are Suffering Too*. PFRCC: Vancouver, B.C. Available at: http://www.fish.bc.ca/files/PFRCC_pinebeetle_brochure_WEB.pdf.
- ¹¹⁰ Fisheries and Oceans Canada. 2005. *Canada's Policy for Conservation of Wild Pacific Salmon*. Fisheries and Oceans Canada: Vancouver, BC. Available at: http://www-comm.pac.dfo-mpo.gc.ca/publications/wsp/wsp_e.pdf.
- ¹¹¹ British Columbia Ministry of Environment, Environmental Stewardship Division. 2008. Instream Flow Guidelines for British Columbia – Working Drafts. Online: http://www.env.gov.bc.ca/wld/BMP/instreamflow_wkgdrft.html (Accessed March 31, 2009).
- ¹¹² Government of British Columbia. 2008. *Living Water Smart: British Columbia's Water Plan*. British Columbia Ministry of Environment: Victoria, BC. Available at: http://www.livingwatersmart.ca/docs/livingwatersmart_book.pdf
- ¹¹³ Personal communication with Craig Orr, Executive Director, Watershed Watch Salmon Society. March 30, 2009.
- ¹¹⁴ BC Hydro. 2009. Water Use Planning. Online: http://www.bchydro.com/planning_regulatory/water_use_planning.html (Accessed March 31, 2009).
- ¹¹⁵ Quadra Planning Consultants Ltd., Regional Consulting Ltd. and L. Nowlan. 2004. *Preliminary Review of Fisheries Conservation Gains within BC Hydro's Water Use Planning Process*. Prepared for Watershed Watch Salmon Society, Coquitlam, B.C.
- ¹¹⁶ Fraser Basin Council. 2009. Fraser Basin Council – One of BC's Best-Kept Secrets! Online: http://www.fraserbasin.bc.ca/about_us/index.html (Accessed March 31, 2009).
- ¹¹⁷ Fraser Salmon and Watersheds Program. 2009. What we do. Online: <http://www.fswp.ca/whatwedo.htm> (Accessed March 31, 2009).
- ¹¹⁸ Grand River Conservation Authority. 2009. About the Grand River Watershed. Online: <http://www.grandriver.ca/index/document.cfm?sec=74&sub1=0&sub2=0> (Accessed January 31, 2009).
- ¹¹⁹ Wichert, G.A. and D.J. Rapport. 1998. Fish community structure as a measure of degradation and rehabilitation of riparian systems in an agricultural drainage basin. *Environmental Management*, 22(3):425–433.
- ¹²⁰ Scott, R. and J. Imhof. 2005. *Exceptional Waters Reach State of the Resource Report*. Exceptional Waters Reach Community Advisory Committee, Grand River Conservation Authority: Cambridge, ON.
- ¹²¹ Plummer, R., Spiers, A., FitzGibbon, J. and J. Imhof. 2005. The expanding institutional context for water resources management: the case of the Grand River watershed. *Canadian Water Resources Journal*, 30(3):227–244.
- ¹²² Mitchell, B. and D. Shrubsole. 1992. *Ontario Conservation Authorities: Myth and Reality*. Canadian Water Resources Association: Waterloo, ON.
- ¹²³ Krause, P., Smith, A., Veale, B. and M. Murray. 2000. Achievements of the Grand River Conservation Authority, Ontario, Canada. *Water Science and Technology*, 43(9):45–55.
- ¹²⁴ Six Nations Council. 2007. Six Nations of the Grand River: Community Profile. Online: <http://www.sixnations.ca/CommunityProfile.htm> (Accessed February 2, 2009).
- ¹²⁵ Grand River Fisheries Management Plan Implementation Committee. 2004. *Grand River Fisheries Update 2004*. Available at: <http://www.grandriver.ca/fisheriesmanagement/2004FishPlanComplete.pdf>.
- ¹²⁶ Personal communications, Barbara Veale, Grand River Conservation Authority
- ¹²⁷ Canadian Heritage Rivers System. 2009. Grand River. Online: http://www.chrs.ca/Rivers/Grand/Grand_e.htm (Accessed February 4, 2009).

- ¹²⁸ International River Foundation. 2007. International Thiess Riverprize Winners. Online: http://www.riverfoundation.org.au/index.php?option=com_content&task=view&id=64&Itemid=83 (Accessed February 4, 2009).
- ¹²⁹ Grand River Conservation Authority, Parish Geomorphic, Trout Unlimited Canada, University of Guelph and University of Waterloo. 2005. *Establishing Environmental Flow Requirements for Selected Streams in the Grand River Watershed: Pilot Project*. Conservation Ontario: Newmarket, ON. Available at: <http://www.conservationontario.ca/projects/pdf/Grand%20River.pdf>.
- ¹³⁰ Grand River Conservation Authority. 2009. Facts about the Grand River watershed. Online: <http://www.grandriver.ca/index/document.cfm?Sec=74&Sub1=4> (Accessed January 31, 2009).
- ¹³¹ Grand River Conservation Authority. 2005. *Grand River Fisheries Management Plan: A Community-Based Approach to Fisheries Management in the Grand River Watershed*. GRCA: Cambridge, ON.
- ¹³² Grand River Conservation Authority. 2008. *2008 Report on Surface Water Quality*. Report No. CW-11-08-90. November 17, 2008. Available at: <http://www.grandriver.ca/governance/CW110890.pdf>.
- ¹³³ Ontario Ministry of Natural Resources. 2004. *Grand River Tailwater Fisheries Management Plan: 2005–2010*. Ontario Ministry of Natural Resources – Guelph District. 36 pp.
- ¹³⁴ Water Resources Information, Ontario Ministry of Natural Resources. 2004. Water Use - Average Annual Flow Conditions. Queen's Printer for Ontario. Available at: http://www.ene.gov.on.ca/envision/env_reg/er/documents/2004/ra04e0011-mapa.pdf.
- ¹³⁵ Bellamy, S. and D. Boyd. 2005. *Water Use in the Grand River Watershed*. Grand River Conservation Authority: Cambridge, ON.
- ¹³⁶ Water Resources Information, Ontario Ministry of Natural Resources. 2004. Water Use – Summer Low Flow Conditions. Queen's Printer for Ontario. Available at: http://www.ene.gov.on.ca/envision/env_reg/er/documents/2004/RA04E0011-mapB.pdf.
- ¹³⁷ Grand River Conservation Authority. 2009. Low Water Response: Middle Grand River. Online: <http://www.grandriver.ca/index/document.cfm?Sec=8&Sub1=89&sub2=70> (Accessed February 2, 2009).
- ¹³⁸ Grand River Conservation Authority. 2007. Living within our water budget. *The Grand*. Watershed Report Fall 2007. Available at: http://www.grandriver.ca/Publication/2007_Fall_Grand.pdf.
- ¹³⁹ Grand River Conservation Authority. 2007. Facing the new challenges. *The Grand*. Watershed Report Fall 2007. Available at: http://www.grandriver.ca/publication/2007_fall_grand.pdf.
- ¹⁴⁰ Ontario Ministry of Public Infrastructure Renewal. 2006. *Places to Grow: Growth Plan for the Greater Golden Horseshoe*. Government of Ontario: Toronto, ON. Available at: <http://www.placestogrow.ca/images/pdfs/fplan-eng-web-all.pdf>.
- ¹⁴¹ Bellamy, S., Boyd, D. and L. Minshall. 2002. *Determining the effect of climate change on the hydrology of the Grand River Watershed*. Grand River Conservation Authority: Cambridge, ON.
- ¹⁴² Grand River Conservation Authority. 2007. Mapping out climate change scenarios. *The Grand*. Watershed Report Fall 2007. Available at: http://www.grandriver.ca/publication/2007_fall_grand.pdf.
- ¹⁴³ FitzGibbon, J.E., Rideout, V., L. Kadonaga. 1993. The impact of climate change on water quality. In M. Sanderson (Ed.), *The Impact of Climate Change on Water in the Grand River Basin, Ontario*. Department of Geography Publication Series No. 40. Department of Geography, University of Waterloo, Waterloo, ON. pp. 137–158.
- ¹⁴⁴ de Loë, R., Kreuzwiser, R. and L. Moraru. 2001. Adaptation options for the near term: climate change and the Canadian water sector. *Global Environmental Change*, 11:231–245.
- ¹⁴⁵ *Water Taking and Transfer Regulation*, under the *Ontario Water Resources Act*, O. Reg. 387/04, Section 4(2), 1(i).
- ¹⁴⁶ Ontario Ministry of the Environment. 2008. *Technical Guidance Document for Surface Water Studies in Support of Category 3 Applications for Permit to Take Water*. Ontario Ministry of the Environment, Operations Division. Available at: <http://www.ene.gov.on.ca/publications/6643e.pdf>.
- ¹⁴⁷ Maunder, D. and B. Hindley. 2005. *Establishing Environmental Flow Requirements: Synthesis Report*. Conservation Ontario: Newmarket, ON. Available at: <http://www.conservationontario.ca/projects/pdf/Synthesis.pdf>.
- ¹⁴⁸ Government of Ontario. 2004. *Compendium to the Final Water Taking and Transfer Regulation (Ontario Regulation 387/04)*. December 2004. Available at: http://www.ene.gov.on.ca/envision/env_reg/er/documents/2004/RA04E0011-compendium.pdf.

- ¹⁴⁹ Ontario Ministry of Natural Resources, Ontario Ministry of Environment and others. 2003. *Ontario Low Water Response*. Available at: http://www.mnr.gov.on.ca/MNR_E002322.pdf.
- ¹⁵⁰ Grand River Conservation Authority. 2009. Low Water Response. Online: <http://www.grandriver.ca/index/document.cfm?sec=8&sub1=0&sub2=0> (Accessed February 4, 2009).
- ¹⁵¹ City of Guelph. 2009. Outside Water Use Program. Online: <http://guelph.ca/living.cfm?subCatID=1208&smocid=1792> (Accessed February 4, 2009).
- ¹⁵² Personal communication with Warren Yerex, Supervisor of Aquatic Resources, Grand River Conservation Authority. February 10, 2009.
- ¹⁵³ D'Amelio, S. 2008. Out, dammed spot! In *Currents*, Winter 2008, Vol. 14, No. 1. Trout Unlimited Canada. Available at: http://www.tucanada.org/images/publications/Currents_SP2008.pdf.
- ¹⁵⁴ Mackenzie River Basin Board. 2003a. The Mackenzie-Great Bear Sub-basin. Chapter 7 in, *Mackenzie River Basin State of the Aquatic Ecosystem Report 2003*. MRBB: Yellowknife, NT. Available at: <http://www.swa.ca/Publications/Documents/9%20MackGrBear.pdf>
- ¹⁵⁵ Canadian Geographic. 2007. Mackenzie River. *The Canadian Atlas Online: Canada's Rivers*. Online: http://www.canadiangeographic.ca/atlas/themes.aspx?id=RIVERS&sub=RIVERS_WEST_MACKENZIE&lang=En (Accessed December 11, 2008).
- ¹⁵⁶ Anielski, M. and S. Wilson. 2007. *The Real Wealth of the Mackenzie Region: Assessing the Natural Capital Values of a Northern Boreal Ecosystem*. Canadian Boreal Initiative: Ottawa, ON.
- ¹⁵⁷ Mackenzie River Basin Board. 2003b. *Highlights of the Mackenzie River Basin Board's State of the Aquatic Ecosystem Report 2003*. MRBB: Yellowknife, NWT. Available at: http://www.mrbba.ca/documents/Final_MRBB4_HighlightsEng1_pg.pdf
- ¹⁵⁸ WWF-Canada. 2008. Conservation – Mackenzie Valley. Online: <http://wwf.ca/conservation/mackenzie/index.cfm> (Accessed December 11, 2008).
- ¹⁵⁹ Emmerton, C.A., Lesack, L.F.W. and P. Marsh. 2007. Lake abundance, potential water storage, and habitat distribution in the Mackenzie River Delta, western Canadian Arctic. *Water Resources Research*, 43(5):W05419.
- ¹⁶⁰ Marsh, P. and L.F.W. Lesack. 1996. The hydrologic regime of perched lakes in the Mackenzie Delta: potential responses to climate change. *Limnology and Oceanography*, 41(5):849–856.
- ¹⁶¹ Nature Canada. 2008. *Protect Canada's Last Wild River: Mackenzie River Important Bird Areas*. Nature Canada.
- ¹⁶² Steward, R.E. 2000. The variable climate of the Mackenzie River Basin: its water cycle and fresh water discharge. Chapter in E.L. Lewis (ed.), *The Freshwater Budget of the Arctic Ocean*, 367–381. Kluwer Academic Publishers: Dordrecht, Netherlands.
- ¹⁶³ Holroyd, P. and T. Simieritsch. 2008. *The Waters that Bind Us: Transboundary Implications of Oil Sands Development*. The Pembina Institute: Drayton Valley, AB.
- ¹⁶⁴ Government of the Northwest Territories. 2008. Draft NWT Hydro Strategy: the foundation for a sustainable energy future. GNWT: Yellowknife, NT. Available at: <http://www.iti.gov.nt.ca/Publications/2008/energy/HYDROSTRATEGY.pdf>
- ¹⁶⁵ Government of the Northwest Territories. 2007. *Energy for the Future: An Energy Plan for the Northwest Territories*. GNWT: Yellowknife, NT. Available at: <http://www.iti.gov.nt.ca/Publications/2007/Energy/Energy%20for%20the%20Future.pdf>
- ¹⁶⁶ TransCanada. 2007. Slave River Hydro Development: Request for Proposal No. 5592 – Environmental Work.
- ¹⁶⁷ Bell, S. 2008. ATCO's VP to take on some Slave River consultation work. *Slave River Journal*, Dec. 2, 2008. Available at: <http://www.srj.ca/default.asp?sourceid=&smenu=88&twindow=Default&mad=No&sdetail=3263&wpage=1&skeyword=&sidate=&ccat=&ccatm=&restate=&restatus=&reoption=&retype=&repmin=&repmax=&rebed=&rebath=&subname=&pform=&sc=1957&hn=srj&he=ca> (Accessed December 15, 2008).
- ¹⁶⁸ Environment Canada, Alberta Environment and Government of the Northwest Territories. 2004. *Northern Rivers Ecosystem Initiative: Key Findings*. Federal Publications: Toronto, ON. Available at: www.environment.gov.ab.ca/info/library/6374.pdf
- ¹⁶⁹ Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008. *Climate Change and Water*. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.
- ¹⁷⁰ Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

- ¹⁷¹ Abdul Aziz, O.I. and D.H. Burn. 2006. Trends and variability in the hydrological regime of the Mackenzie Basin. *Journal of Hydrology*, 319:282–294.
- ¹⁷² Natural Resources Canada. 2008. Geological Survey of Canada: Permafrost and Climate Change. Online: http://cgc.nrcan.gc.ca/permafrost/climate_e.php (Accessed December 16, 2008).
- ¹⁷³ Kerr, J.A. 1997. Future water levels and flows for Great Slave and Great Bear Lakes, Mackenzie River and Mackenzie Delta. Chapter in, Cohen, S. (ed.) *Mackenzie Basin Impact Study Final Report*. Environment Canada.
- ¹⁷⁴ Burn, D.H. and N. Hesch. 2008. Trends in Mackenzie River Basin streamflows. Chapter 19 in, Woo, M. (ed.), *Cold Region Atmospheric and Hydrologic Studies: The Mackenzie GEWEX Experience*. Vol. 2 – Hydrologic Processes, 364–370. Springer-Verlag: New York.
- ¹⁷⁵ New, M. 2005. Arctic climate change with 2°C global warming. In L. Rosentrater (ed.) *2° is too Much! Evidence and Implications of Dangerous Climate Change in the Arctic*. WWF International Arctic Program: Oslo, Norway.
- ¹⁷⁶ Government of Northwest Territories. 2008. *Northern Voices, Northern Waters: Towards a Water Resources Management Strategy for the NWT*. GNWT:Yellowknife, NT. Available at: http://www.enr.gov.nt.ca/library/pdf/Northern_Voices_Northern_Waters-Discussion_Paper.pdf
- ¹⁷⁷ Mackenzie River Basin Board. 2001. Mackenzie River Basin Board website. Online: <http://www.mrb.bc.ca> (Accessed December 18, 2008).
- ¹⁷⁸ *Mackenzie River Basin Transboundary Waters Master Agreement*, between the Governments of Canada, the Provinces of British Columbia, Alberta and Saskatchewan, and the Yukon and the Northwest Territories, effective 1997.
- ¹⁷⁹ *Mackenzie River Basin Transboundary Waters Master Agreement*, Part C, 1.
- ¹⁸⁰ Keepers of the Water. 2008. Keepers of the Water III: Water is Boss. Online: <http://www.keepersofthewater.ca/keepers3/> (Accessed December 18, 2008).
- ¹⁸¹ Government of the Northwest Territories, Environment and Natural Resources. 2008. Protected Areas Web Links. Online: <http://www.nwtwildlife.com/pas/links.htm> (Accessed December 18, 2008).
- ¹⁸² Wilson, L. 1991. *Historical Literature Review of the Nipigon Area with Emphasis on Fisheries from 1654 to 1990*. Nipigon Bay Remedial Action Plan Technical Report #8. Ontario Ministry of Natural Resources: Nipigon, ON.
- ¹⁸³ Ontario Ministry of Natural Resources. 2001a. *Lake Nipigon Basin Signature Site: Ecological Land Use and Resource Management Strategy*. Ontario Ministry of Natural Resources, Ontario's Living Legacy: Nipigon, ON.
- ¹⁸⁴ Ontario Ministry of Natural Resources. 2001b. *Lake Nipigon Basin: Background Document*. Ontario Ministry of Natural Resources, Ontario's Living Legacy: Nipigon, ON.
- ¹⁸⁵ Schraeder, H.A. 1983. *Lake Nipigon Fisheries Management Plan, Background Information*. Ontario Ministry of Natural Resources: Nipigon, ON.
- ¹⁸⁶ Swainson, R. 2001a. *Water Resources, Limnology and Power Generation of the Lake Nipigon Basin, the Nipigon River and the Black Sturgeon River System*. Ontario's Living Legacy, Lake Nipigon Basin Signature Site. Ontario Ministry of Natural Resources: Nipigon, ON.
- ¹⁸⁷ Swainson, R. 2001b. *Fish and Fisheries of the Lake Nipigon Basin, Nipigon River and Black Sturgeon River System from 1840 to 2001*. Ontario's Living Legacy, Lake Nipigon Basin Signature Site. Ontario Ministry of Natural Resources: Nipigon, ON.
- ¹⁸⁸ MacCallum, M.E. 1989. *The Nipigon River: A Retrospective Summary of Information about the Fish Community*. Nipigon Bay RAP, North Shore of Lake Superior Remedial Action Plans. Technical Report Series. 38pp.
- ¹⁸⁹ D'Amelio, S. 2004. *Coaster Brook Trout Stream Habitat Evaluation*. Trout Unlimited Technical Report No. ON-001. A Report of Research in Progress to the Living Legacy Trust, Project #08-049. Available at: http://www.tucanada.org/reports/ON-001_CBTHabitat_2004.pdf.
- ¹⁹⁰ Swainson, R. 2009. Personal communication, February 20, 2009.
- ¹⁹¹ Schreiner, D.R., Cullis, K.I., Donofrio, M.C., Fischer, G.J., Hewitt, L., Mumford, K.G., Pratt, D.M., Quinlan, H.R. and S.J. Scott. 2008. Management perspectives on coaster brook trout rehabilitation in the Lake Superior Basin. *North American Journal of Fisheries Management*, 28:1350–1364.
- ¹⁹² Macdonough, A.R. 1889. *Scribner's Magazine*. Sept. 1889, Vol. 6, Issue 3, p. 271-283. As cited in, Ontario Ministry of Natural Resources. 2001a. *Lake Nipigon Basin Signature Site: Ecological Land Use and Resource Management Strategy*. Ontario Ministry of Natural Resources, Ontario's Living Legacy: Nipigon, ON.

- ¹⁹³ Hydro-Electric Power Commission of Ontario. 1950. *The 42nd Annual Report of the HEPC*. As cited in Swainson, R. 2001a. *Water Resources, Limnology and Power Generation of the Lake Nipigon Basin, the Nipigon River and the Black Sturgeon River System*. Ontario's Living Legacy, Lake Nipigon Basin Signature Site. Ontario Ministry of Natural Resources: Nipigon, ON.
- ¹⁹⁴ Karas, N. 1997. *Brook Trout, A Thorough Look at North America's Greatest Native Trout – Its History, Biology and Angling Possibilities*. The Lyons Press: New York, NY. 371pp.
- ¹⁹⁵ Holmes, G.L. 1976. *The Impact of the Ogoki Diversion on the Little Jackfish River and Ombabika Bay with Special Emphasis on Walleye and Sauger*. Ontario Ministry of Natural Resources. Unpublished report. 111pp.
- ¹⁹⁶ Atria Engineering Hydraulics Inc. 1993. *Nipigon River: Development of a Water Management Plan, Draft Options Report*. Prepared for the Nipigon River Management Committee. North Shore of Lake Superior Remedial Actions Plans Technical Report No. 18. 123pp.
- ¹⁹⁷ Curry, R.A., Gehrels, J., Noakes, D.L. and R. Swainson. 1994. Effects of river flow fluctuations on groundwater discharge through brook trout, *Salvelinus fontinalis*, spawning and incubation habitats. *Hydrobiologia*, 277: 121–134.
- ¹⁹⁸ B.A.R. Environmental Inc. 1995. *Monitoring of fish habitat enhancements and invertebrate drift in the Nipigon River two years after pipeline construction*. October 1994. Report prepared for Trans-Canada Pipelines, Calgary, AB by B.A.R. Environmental Inc., Guelph, ON. March 1995.
- ¹⁹⁹ Ontario Power Authority. 2007. *Incorporating Little Jackfish and East Lake Nipigon Renewable Resource Development*. EB-2007-0707, Exhibit E, Tab 3, Schedule 7.
- ²⁰⁰ Racey, G.D. 2005. *Preparing for Change: Climate Change and Resource Management in Northwest Region*. NWSI Technical Workshop Report TWR-04. Ontario Ministry of Natural Resources, Northwest Science and Information: Thunder Bay, ON.
- ²⁰¹ Wilson, L. 1991. *Nipigon Bay Walleye Historical Review*. A Report to the North Shore of Lake Superior Great Lakes Cleanup Fund Program, Remedial Action Plan. 94pp.
- ²⁰² Ontario Ministry of Natural Resources. 2008. The view from here: are walleye in hot water? *The Green Scene*, Summer 08, Vol. 1, Iss. 4.
- ²⁰³ *Lakes and Rivers Improvement Act*. R.S.O. 1990, Chapter L.3. Section 23.1.
- ²⁰⁴ Ontario Ministry of Natural Resources. 2002. *Water Management Planning Guidelines for Waterpower*. Ministry of Natural Resources, Waterpower Project: Peterborough, ON. Available at: <http://www.mnr.gov.on.ca/251983.pdf>.
- ²⁰⁵ Metcalfe, R.A., Chang, C. and V. Smakhtin. 2005. Tools to support the implementation of environmentally sustainable flow regimes at Ontario's waterpower facilities. *Canadian Water Resources Journal*, 30(2): 97–110.
- ²⁰⁶ Atria Engineering Hydraulics Inc. 1994. *Nipigon River: Development of a Water Management Plan, Final Report*. Prepared for the Nipigon River Management Committee. North Shore of Lake Superior Remedial Actions Plans Technical Report No. 20.
- ²⁰⁷ Atria Engineering Hydraulics Inc. 1994. *Nipigon River: Development of a Water Management Plan, Options Report*. Prepared for the Nipigon River Management Committee. North Shore of Lake Superior Remedial Actions Plans Technical Report No. 19. 66pp.
- ²⁰⁸ Environment Canada. 2008. Canadian Remedial Action Plans: Nipigon Bay Area of Concern. Online: <http://www.ec.gc.ca/raps-pas/default.asp?lang=En&n=1FEF0867-1> (Accessed February 24, 2009).
- ²⁰⁹ Parks Canada. 2008. Lake Superior National Marine Conservation Area of Canada: Regional Committee Recommendations. Online: http://www.pc.gc.ca/amnc-nmca/on/super/plan/pc-ep/rec/rec3_e.asp#n01 (Accessed February 24, 2009).
- ²¹⁰ WWF-Canada. 2007. Newsroom: A Superior Day for Canada. Online: <http://wwf.ca/newsroom/?1335> (Accessed March 26, 2009).
- ²¹¹ Trout Unlimited Canada. 2006. *Nipigon River Land Acquisition Proposal: Gapen's Pool*. Available at: http://www.tucanada.org/images/documents/NLAP_Gapen.pdf.
- ²¹² Trout Unlimited Canada. 2008. National Projects: Gapen's Pool Acquisition Project. Online: http://www.tucanada.org/NP_GapensPool.shtml (Accessed February 24, 2009).
- ²¹³ Ottawa Riverkeeper. 2006. *Ottawa Riverkeeper's River Report: Issue No. 1 – Ecology and Impacts*. Ottawa Riverkeeper/Sentinelles Outaouais: Ottawa, ON. Available at: http://ottawariverkeeper.ca/rr_en.pdf.
- ²¹⁴ Haxton, T. and D. Chubbuck. 2002. *Review of the historical and existing natural environment and resource uses on the Ottawa River*. Ontario Ministry of Natural Resources, Science and Information Branch, Southcentral Science and Information Section Technical Report #119. 76pp. Available at: http://ottawariverkeeper.ca/files/tim_haxton_report.pdf.

- ²¹⁵ Ottawa River Heritage Designation Committee. 2006. *Nomination Document for the Ottawa River, Ontario*. Submitted to the Canadian Heritage Rivers Board by the Government of Ontario, Ministry of Natural Resources, Ontario Parks. QLF Canada. Available at: <http://ottawariver.org/pdf/N-0-ORHDC.pdf>.
- ²¹⁶ Ottawa Riverkeeper. 2007. Impacts: Dams. Online: <http://ottawariverkeeper.ca/impacts/dams> (Accessed March 2, 2009).
- ²¹⁷ Thorp, J.H., Lamberti, G.A. and A.F. Casper. 2005. St. Lawrence River Basin: The Ottawa River. In A.C. Benke and C.E. Cushing (Eds.) *Rivers of North America*. Elsevier Academic Press: Amsterdam, Netherlands.
- ²¹⁸ Ottawa River Heritage Designation Committee. 2005. *A Background Study for Nomination of the Ottawa River under the Canadian Heritage Rivers System*. QLF Canada. Available at: <http://ottawariver.org/pdf/0-ORHDC.pdf>.
- ²¹⁹ Legget, R. 1975. *Ottawa Waterway: Gateway to a Continent*. University of Toronto Press: Toronto, ON. 291 p. Cited in Haxton, T. and D. Chubbuck. 2002. *Review of the historical and existing natural environment and resource uses on the Ottawa River*. Ontario Ministry of Natural Resources, Science and Information Branch, Southcentral Science and Information Section Technical Report #119. 76pp.
- ²²⁰ Hanrahan, C. and S. Darbyshire. 1998. The Natural Values and Ecological Significance of the Petrie Islands. For submission to the Regional Municipality of Ottawa-Carleton, on behalf of the Conservation Committee of the Ottawa Field-Naturalists' Club. Online: <http://petrieisland.startlogic.com/documents/Hanrahan98.html> (Accessed March 3, 2009).
- ²²¹ Brunton, D.F. 2008. Natural environment assessment (existing conditions): Ottawa River Interprovincial Crossing Corridors, Ottawa, Ontario/Gatineau, Quebec. Brunton Consulting Services: Ottawa, ON. Available at: [http://www.ncrcrossings.ca/UserFiles/REPORT%20\(Interprovincial%20Crossings%203%20small%20file%20size\).pdf](http://www.ncrcrossings.ca/UserFiles/REPORT%20(Interprovincial%20Crossings%203%20small%20file%20size).pdf).
- ²²² Haxton, T. 2002. An assessment of lake sturgeon (*Acipenser fulvescens*) in various reaches of the Ottawa River. *Journal of Applied Ichthyology*, 18: 449–454.
- ²²³ Scott, D., Jones, B. and H. Abi Khaled. 2005. *The Vulnerability of Tourism & Recreation in the National Capital Region to Climate Change*. Technical Report to the Government of Canada's Climate Change Action Fund (Impacts and Adaptation Programme).
- ²²⁴ Burn, D.H. and M.A. Hag Elnur. 2002. Detection of hydrologic trends and variability. *Journal of Hydrology*, 255: 107–122.
- ²²⁵ Pacific Climate Impacts Consortium. 2008. PCIC Regional Analysis Tool: Scatter Plots. Experiment: SRES AR4 – CCCMA_CGCM3 A2-run4. Timeslice: 2050s. Variable: Precipitation. Time of Year: Annual. Window: Canada. Region: Custom Region. Online: <http://www.pacificclimate.org/tools/select> (Accessed March 4, 2009).
- ²²⁶ Fagherazzi, L., Guay, R. and T. Sassi. 2005. Climate change analysis of the Ottawa River system: report to the International Joint Commission Lake Ontario-St. Lawrence River Study on Discharge Regulation. 72pp. Cited in Bourque, A. and G. Simonet. 2008. Quebec. In *From Impacts to Adaptation: Canada in a Changing Climate 2007*. D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush (Eds.). Government of Canada: Ottawa, ON, p. 171–226. Available at: http://www.ouranos.ca/en/pdf/ouranos_chapitre-quebec_vivreaveclesc en.pdf.
- ²²⁷ Brown, M. 2008. A river runs through them. *The Ottawa Citizen*, Tuesday July 22, 2008. Available at: <http://www2.canada.com/ottawacitizen/news/story.html?id=7a664e15-3cb2-4a9c-89ad-ef7c6807c6c8> (Accessed March 4, 2009).
- ²²⁸ Ottawa River Regulation Planning Board. 2008. Ottawa River Regulation Planning Board: Organization and Purpose. Online: <http://www.ottawariver.ca/emain.htm> (Accessed March 4, 2009).
- ²²⁹ Ottawa River Regulation Planning Board. 2003. *Summary of Questions and Responses: Ottawa River Regulation Planning Board Public Meeting*. Mattawa, ON. August 26, 2003.
- ²³⁰ Bruce, J.P., Martin, H., Colucci, P., McBean, G., McDougall, J., Shrubsole, D., Whalley, J., Halliday, R., Alden, M., Mortsch, L. and B. Mills. 2003. *Climate Change Impacts on Boundary and Transboundary Water Management*. A Climate Change Action Fund Project, Natural Resources Canada Project A458/402.
- ²³¹ Personal communication with Kirby Punt, Madawaska Area Biologist, OMNR. March 19, 2009.
- ²³² Personal communication with Meredith Brown, Ottawa Riverkeeper. March 9, 2009.
- ²³³ Dewar, P. 2008. Ottawa River to become a Canadian Heritage River. Media Release, May 9, 2008. Online: <http://www.pauldewar.ca/en/node/277> (Accessed March 4, 2009).
- ²³⁴ Smith, E.L. 2007. *River restoration through dam removal efforts, with a particular focus on the Ottawa River at Chaudière Island*. Discussion Paper. Available at: http://www.asinabka.com/Archives/Chaudiere_restoration_11july07.pdf.

- ²³⁵ Commanda, W. 2007. *A Proposal for a Special National Historic Centre at Asinabka/ Chaudière Falls, Ottawa, Canada*. Available at: <http://www.asinabka.com/Archives/COANBNbrochureFre&Eng.pdf>.
- ²³⁶ Ottawa Riverkeeper. 2007. Ottawa Riverkeeper: About Us. Online: http://ottawariverkeeper.ca/about/about_us/ (Accessed March 4, 2009).
- ²³⁷ Canadian Parks and Wilderness Society. 2009. Dumoine River. Online: <http://cpaws.org/dumoine/> (Accessed March 24, 2009).
- ²³⁸ Cunjak, R.A. and R. Newbury. 2005. Atlantic Coast Rivers of Canada: St. John River. In A.C. Benke and C.E. Cushing (Eds.), *Rivers of North America: The Natural History*. Elsevier Academic Press: Burlington, MA.
- ²³⁹ Great Canadian Rivers. 2007. Great Canadian Rivers: The Saint John River. Online: <http://www.greatcanadianrivers.com/rivers/john/john-home.html> (Accessed February 9, 2009).
- ²⁴⁰ Munkittrick, K.R., Curry, R.A., Culp, J.M., Cunjak, R.A., McLatchy, D.L., Kidd, K.A., Dalton, S.E., Baird, D.J. and R. Newbury. 2007. The Saint John River. In C. King, J. Ramkisson, M. Clusener-Godt, and Z. Afeel (Eds.), *Water and Ecosystems: Managing Water in Diverse Ecosystems to Ensure Human Well-being*. United Nations University – International Network on Water, Environment and Health (INWEH): Hamilton, ON. Available at: http://www.inweh.unu.edu/inweh/River/Water_Eco_Book/4_SectionII_Casestudies5-8.pdf.
- ²⁴¹ Curry, R.A. and K.R. Munkittrick. 2005. Fish assemblage structure in relation to multiple stressors along the Saint John River, New Brunswick, Canada. *American Fisheries Society Symposium* 45: 505–521.
- ²⁴² Menges, E.S. 1990. Population viability analysis for an endangered plant. *Conservation Biology*, 4(1): 52–62.
- ²⁴³ Connor, K.J. and S. Gabor. 2006. Breeding waterbird wetland habitat availability and response to water-level management in Saint John River floodplain wetlands, New Brunswick. *Hydrobiologia*, 567: 169–181.
- ²⁴⁴ Bird Studies Canada, Nature Canada and BirdLife International. 2004. Important Bird Areas of Canada. IBA Site Summary – Lower St. John River (Sheffield/Jemseg), Oromocto, New Brunswick. Online: <http://www.bsc-eoc.org/iba/site.jsp?siteID=NB010> (Accessed February 15, 2009).
- ²⁴⁵ Committee on the Status of Endangered Wildlife in Canada. 2009. The Prioritized Candidate Species List - February 9, 2009. Online: http://www.cosewic.gc.ca/eng/sct3/sct3_1_e.cfm (Accessed February 13, 2009).
- ²⁴⁶ Whoriskey, F. 2003. Wild Atlantic salmon in North America: status and perspectives. In *Proceedings of the World Summit on Salmon*. Simon Fraser University, Vancouver, BC, June 14–16, 2003. Available at: <http://www.sfu.ca/cstudies/science/resources/summit/pdf/06-whoriskey.pdf>.
- ²⁴⁷ Fisheries and Oceans Canada. 2003. *Atlantic Salmon Maritime Provinces Overview for 2002*. Stock Status Report 2003/026. DFO Science, Gulf and Maritimes Region. Available at: http://www.mar.dfo-mpo.gc.ca/science/rap/internet/SSR_2003_026_E.pdf.
- ²⁴⁸ Fitton, M. 2004. The St. John/Wolastoq “beautiful river”: a potential Canadian Heritage River. *Proceedings of the 4th Canadian River Heritage Conference*. Guelph, ON, June 6–9, 2004.
- ²⁴⁹ Personal communication with Allen Curry, Director, Canadian Rivers Institute. March 9, 2009.
- ²⁵⁰ Dominy, C.L. 1973. Recent changes in Atlantic salmon (*Salmo salar*) runs in the light of environmental changes in the Saint John River, New Brunswick, Canada. *Biological Conservation*, 5(2): 105–113.
- ²⁵¹ Carr, J. W. 2001. *A review of downstream movements of juvenile Atlantic salmon (Salmo salar) in the dam-impacted Saint John River drainage*. Canadian Manuscript Report of Fisheries and Aquatic Sciences No 2573. Fisheries and Oceans Canada. 76 pp.
- ²⁵² Flanagan, J.J. 2003. The impacts of fine sediments and variable flow regimes on the habitat and survival of Atlantic salmon (*Salmo salar*) eggs in some New Brunswick streams. Published M.Sc. thesis. University of New Brunswick, Fredericton, NB.
- ²⁵³ Culp, J.M., Luiker, E., Noel, L., Foster, E., R.A. Curry and D. Hryn. 2006. *Status and Effects of Nutrient Loading on the Saint John River: Final Report*. Prepared for the New Brunswick Environmental Trust Fund. New Brunswick Cooperative Fish and Wildlife Research Unit Report #06-03. Canadian Rivers Institute, University of New Brunswick: Fredericton, NB.
- ²⁵⁴ El-Jabi, N., Hebert, C., Savoie, N., Swansburg, E., Caissie, D., Burrell, B., Hughes, R. and D. Pupek. 2004. *Climate change impacts on low flow characteristics of New Brunswick Rivers and adaptation strategies for instream flow needs*. Climate Change Impacts and Adaptations Program Project A367. Available at: http://adaptation.nrcan.gc.ca/projdb/pdf/50_e.pdf.
- ²⁵⁵ Government of New Brunswick. 2007. *New Brunswick Climate Change Action Plan 2007–2012*. New Brunswick Department of Environment: Fredericton, NB. Available at: <http://www.gnb.ca/0009/0369/0015/0001-e.pdf>.
- ²⁵⁶ Natural Resources Canada. 2007. Climate change impacts and adaptation. The tides of change: Climate change in Atlantic Canada. Freshwater Issues. Online: http://adaptation.nrcan.gc.ca/posters/ac/ac_05_e.php (Accessed February 16, 2009).

- ²⁵⁷ Beltaos, S., Ismail, S. and B.C. Burrell. 2003. Midwinter breakup and jamming on the upper Saint John River: a case study. *Canadian Journal of Civil Engineering*, 30: 77–88.
- ²⁵⁸ Swansburg, E., N. El-Jabi and D. Caissie. 2004. *Climate change in New Brunswick (Canada): statistical downscaling of local temperature, precipitation, and river discharge*. Canadian Technical Report of Fisheries and Aquatic Sciences 2544. 42pp.
- ²⁵⁹ *Clean Water Act*, S.N.B. 1989, c. C.6-1, Section 15(1.01).
- ²⁶⁰ Canadian Rivers Institute. 2009. Canadian Rivers Institute Homepage. Online: <http://www.unb.ca/cri/> (Accessed March 10, 2009).
- ²⁶¹ Canadian Rivers Institute. 2008. Saint John River Atlas. Online: <http://cri.nbwaters.unb.ca/sjratlas/site/index.castle> (Accessed March 10, 2009).
- ²⁶² Canaan-Washademoak Watershed Association. 2005. Canaan-Washademoak Watershed Association Homepage. Online: <http://www.unb.ca/enviro/cwwa/index.html> (Accessed March 10, 2009).
- ²⁶³ St. John River Society. 2008. St. John River Society Homepage. Online: <http://www.stjohnriver.org/> (Accessed March 10, 2009)
- ²⁶⁴ Great Canadian Rivers. 2007. Great Canadian Rivers: The Skeena River. Online: <http://www.greatcanadianrivers.com/rivers/skeena/skeena-home.html> (Accessed January 26, 2009).
- ²⁶⁵ Skeena Watershed Conservation Coalition. 2007. About the Skeena Watershed. Online: http://skeenawatershed.com/index.php/about/article/about_the_skeena_watershed/ (Accessed January 26, 2009).
- ²⁶⁶ IBM Business Consulting Services. 2005. *Valuation of the Wild Salmon Economy of the Skeena River Watershed*. Northwest Institute for Bioregional Research: Smithers, BC. Available at: http://northwestinstitute.ca/downloads/IBM_skeena_report_06.pdf.
- ²⁶⁷ Walters, C.J., Lichatowich, J.A., Peterman, R.M. and J.D. Reynolds. 2008. *Report of the Skeena Independent Science Review Panel*. A report to the Canadian Department of Fisheries and Oceans and the British Columbia Ministry of the Environment. May 15, 2008, 144 p.
- ²⁶⁸ Gottesfeld, A.S. and K.A. Rabnett. *Skeena River Fish and Their Habitat*. Skeena Fisheries Commission: Hazelton, BC. 340 pp.
- ²⁶⁹ Chamberlin, T.W., R.D. Harr, and F.H. Everest. 1991. Timber harvesting, silviculture, and watershed processes. In W.R. Meehan [ed.] *Influences of forest and rangeland management on salmonid fishes and their habitats*. Special Publication 19. American Fisheries Society: Bethesda, Maryland.
- ²⁷⁰ The Pembina Institute. 2006. Fact Sheet – Resource Development in the North: How Oil, Gas & Pipelines Can Impact Fish.
- ²⁷¹ GW Solutions. 2008. *Coalbed Methane and Salmon: Assessing the Risks*. The Pembina Institute: Drayton Valley, AB.
- ²⁷² ForestEthics, Dogwood Initiative, Wildsight, The Pembina Institutue and West Coast Environmental Law. 2008. Media Release: Environmental Groups Praise Landmark Step Towards Responsible Coalbed Methane Development. December 9, 2008.
- ²⁷³ Citizens Concerned About Coalbed Methane. 2008. Action Centre. Online: <http://www.concernedaboutcbm.org/support-plan> (Accessed January 23, 2009).
- ²⁷⁴ Government of British Columbia. 2002. *Energy for our Future: A Plan for BC*. Available at: http://www.gov.bc.ca/empr/down/energy_for_our_future_sept_27.pdf
- ²⁷⁵ Watershed Watch Salmon Society. 2007. *Run-of-River Hydropower in BC: A Citizen's Guide to Understanding Approvals, Impacts and Sustainability of Independent Power Projects*. Watershed Watch Salmon Society: Coquitlam, BC. Available at: <http://www.watershed-watch.org/publications/files/RoR-CitizensGuide.pdf>
- ²⁷⁶ Douglas, T. 2007. *"Green" Hydro Power: Understanding Impacts, Approvals, and Sustainability of Run-of-River Independent Power Projects in British Columbia*. Watershed Watch Salmon Society: Coquitlam, BC. Available at: <http://www.watershed-watch.org/publications/files/Run-of-River-long.pdf>
- ²⁷⁷ British Columbia Water Stewardship Division. 2009. Water Licenses Query. Query: Purpose = POWER-GENERAL(cubic ft/s); Watershed = Skeena River – 400. Online: http://a100.gov.bc.ca/pub/wtrwhse/water_licences.input (Accessed January 27, 2009).
- ²⁷⁸ Private Power Watch. 2009. Private Hydro Power Map. Online: <http://www.ippwatch.info/w/> (Accessed January 27, 2009).
- ²⁷⁹ Personal communication with Aaron Hill, Watershed Watch Salmon Society. January 27, 2009.

- ²⁸⁰ Gottesfeld, A.S., Rabnett, K.A. and P.E. Hall. 2002. *Conserving Skeena Fish Populations and their Habitat*. Skeena Fisheries Commission: Hazelton, BC. Available at: http://www.skeenafisheries.ca/publication_Conserving%20Skeena%20Fish%20and%20their%20Habitat.pdf
- ²⁸¹ Woo, M., Thorne, R. and K.K. Szeto. 2006. Reinterpretation of streamflow trends based on shifts in large-scale atmospheric circulation. *Hydrological Processes*, 20:3995–4003.
- ²⁸² Clair, T.A., Ehrmann, J. and K. Higuchi. 1998. Changes to the runoff of Canadian ecozones under a doubled CO₂ atmosphere. *Canadian Journal of Fisheries and Aquatic Science*, 55: 2464–2477.
- ²⁸³ Battin, J., Wiley, M.W., Ruckelshaus, M.H., Palmer, R.N., Korb, E., Bartz, K.K. and H. Imaki. 2007. Projected impacts of climate change on salmon habitat restoration. *Proceedings of the National Academy of Sciences*, 104(16):6720–6725.
- ²⁸⁴ Price, D.T., McKenney, D.W., Caya, D.W. and H. Côté. 2001. *Transient climate change scenarios for high-resolution assessment of impacts on Canada's forest ecosystems*. Report to the Climate Change Action Fund and Canadian Institute for Climate Studies.
- ²⁸⁵ Personal communication with Ken Rabnett, Suskwa Research. January 22, 2009.
- ²⁸⁶ Simpson, S. 2008. Shell faces two-year moratorium on coal-bed methane in Klappan. *Vancouver Sun*, December 6, 2008.
- ²⁸⁷ Skeena Watershed Conservation Coalition. 2007. Skeena Watershed Conservation Coalition: Sign the Sacred Headwaters Resolution. Online: <http://skeenawatershed.com/> (Accessed January 26, 2009).
- ²⁸⁸ North Coast Skeena First Nations Stewardship Society. 2008. Together on the Coast. Online: <http://www.togetheronthecoast.org/> (Accessed January 26, 2009).
- ²⁸⁹ WWF-Canada. 2008. Focus Group: A follow-up to “Together on the Coast” North Coast Forum. Online: http://pacificmarine.wwf.ca/get_involved/focus_group/ (Accessed January 26, 2009).
- ²⁹⁰ Schindler, D.W. and W.F. Donahue. 2005. A case study of the Saskatchewan River system. Presented at the *Rosenberg Conference on Managing Change in Upland Watersheds in an Era of Global Change*, Banff, AB: 6–11 September 2005.
- ²⁹¹ Martz, L., Bruneau, J. and J.T. Rolfe (eds.). 2007. *Climate Change and Water*. South Saskatchewan River Basin Final Technical Report. Prairie Adaptation and Research Collaborative (PARC): Regina, SK.
- ²⁹² Clipperton, G.K., Koning, C.W., Locke, A.G.H., Mahoney, J.M. and B. Quazi. 2003. *Instream Flow Needs Determinations for the South Saskatchewan River Basin, Alberta, Canada*. Publication No. T/719. Alberta Environment and Alberta Sustainable Resource Development: Edmonton, AB.
- ²⁹³ Alberta Environment. 2003. *South Saskatchewan River Basin Water Management Plan Phase II: Background Studies*. Alberta Environment: Edmonton, AB.
- ²⁹⁴ Rood, S.B. and J.M. Mahoney. 1990. Collapse of riparian poplar forests downstream from dams in western prairies: Probable causes and prospects for mitigation. *Environmental Management*, 14(4):451–464.
- ²⁹⁵ Alberta Environment. 2005. *South Saskatchewan River Basin Water Allocation*. Regional Services, Southern Region. Alberta Environment: Edmonton, AB.
- ²⁹⁶ Alberta Institute of Agrologists. 2005. *People to Water, Water to People*. Discussion paper. AIA: Sherwood Park, AB.
- ²⁹⁷ Statistics Canada. 2007. Calgary, Alberta. 2006 Community Profiles. 2006 Census. Statistics Canada Catalogue no. 92-591-XWE. Ottawa. Released March 13, 2007. <http://www12.statcan.ca/english/census06/data/profiles/community/index.cfm?Lang=E> (accessed November 28, 2008).
- ²⁹⁸ Saskatchewan Watershed Authority. 2008. Dams and Reservoirs: Lake Diefenbaker. Online: <http://www.swa.ca/WaterManagement/DamsAndReservoirs.asp?type=LakeDiefenbaker> [Accessed December 1, 2008].
- ²⁹⁹ Saskatchewan Watershed Authority. 2007. *State of the Watershed Report: 2007 State of the Environment Report*. SWA, Monitoring and Assessment Branch, Stewardship Division: Regina, SK. Available at: <http://www.swa.ca/Publications/Documents/aaStateOfTheWatershedReport.pdf>
- ³⁰⁰ Saskatchewan Agrivision Corporation Inc. and Clifton Associates Ltd.. 2004. *Water Wealth: A Fifty-Year Water Development Plan for Saskatchewan*. November 2004.
- ³⁰¹ Saskatchewan Environmental Society. 2006. *A Critical Analysis of AgriVision's Report – Water Wealth: A Fifty Year Water Development Plan for Saskatchewan*. SES: Saskatoon, SK.

- ³⁰² Pietroniro, A. and M. Demuth. 2006. Current and Future Trends in Runoff in the Headwaters of the Saskatchewan River. Paper presented at the Proceedings Climate Change and Water in the Prairies, Saskatoon, SK: June 21–23, 2006.
- ³⁰³ David Schindler, Personal Communication. June 1, 2009.
- ³⁰⁴ *Water Act*, R.S.A. 2000, c. W-3.
- ³⁰⁵ Alberta Environment. 2008. *Water for Life: A Renewal*. Alberta Environment: Edmonton, AB.
- ³⁰⁶ Alberta Environment. 2004. Highlights - Approved Water Management Plan for the South Saskatchewan River Basin. Pub. No. I/012. Alberta Environment: Edmonton, AB.
- ³⁰⁷ Doug Ohrn, Planner, Alberta Environment. Personal Communication, January 21, 2009.
- ³⁰⁸ Christensen, R. and D. Droitsch. 2008. *Fight to the Last Drop: A Glimpse into Alberta's Water Future*. EcoJustice and Bow Riverkeeper: Vancouver and Banff. Available at: <http://www.ecojustice.ca/publications/reports/fight-to-the-last-drop-a-glimpse-into-alberta2019s-water-future/attachment>
- ³⁰⁹ Prairie Water Coalition. 2008. *Prairie Water Directive* (Draft).
- ³¹⁰ Water Matters Society of Alberta. 2008. Water Matters homepage. Online: <http://www.water-matters.org/> [Accessed December 3, 2008].
- ³¹¹ Saskatchewan Environmental Society. 2008. Saskatchewan Environmental Society homepage. Online: <http://www.environmentalsociety.ca/> [Accessed December 3, 2008].
- ³¹² Water Matters. 2008. Water Trusts: Keeping Water in Rivers. In *The Water Log*, October 2008. Online: <http://www.water-matters.org/node/30> [Accessed December 3, 2008].
- ³¹³ Kwasniak, A. 2006. Quenching instream thirst: a role for water trusts in the Prairie Provinces. *Journal of Environmental Law and Practice*, 16:211–231.
- ³¹⁴ Thorp, J.H., Lamberti, G.A. and A.F. Casper. 2005. St. Lawrence River Basin: St. Lawrence River. In A.C. Benke and C.E. Cushing (Eds.), *Rivers of North America: The Natural History*. Elsevier Academic Press: Burlington, MA, p. 986–996.
- ³¹⁵ Great Canadian Rivers. 2007. Great Canadian Rivers: The St. Lawrence River. Online: <http://www.greatcanadianrivers.com/rivers/stlawer/stlawer-home.html> (Accessed March 6, 2009).
- ³¹⁶ American Rivers. 2008. *America's Most Endangered Rivers: 2008 Edition*. American Rivers: Washington, D.C. Available at: http://www.americanrivers.org/site/DocServer/MER_Report2008opt.pdf?docID=7681.
- ³¹⁷ Abell, R.A., Olson, D.M., Dinerstein, E., Hurley, P.T., Diggs, J.T., Eichbaum, W., Walters, S. Wettengel, W., Allnut, T., Loucks, C. and P. Hedao. 2000. *Freshwater Ecoregions of North America: A Conservation Assessment*. Island Press: Washington, D.C.
- ³¹⁸ The Ramsar Convention on Wetlands. 2001. The Annotated Ramsar List: Canada. Online: http://www.ramsar.org/profile/profiles_canada.htm (Accessed March 12, 2009).
- ³¹⁹ Hudon, C. 1997. Impact of water level fluctuations on St. Lawrence River aquatic vegetation. *Canadian Journal of Fisheries and Aquatic Sciences*, 54:2853–2865.
- ³²⁰ Transport Canada, U.S. Army Corps of Engineers, U.S. Department of Transportation, The St. Lawrence Seaway Management Corporation, Saint Lawrence Seaway Development Corporation, Environment Canada, and U.S. Fish and Wildlife Service. 2007. *Great Lakes St. Lawrence Seaway Study*. Available at: <http://www.glsis-study.com/Supporting%20documents/GLSLs%20finalreport%20Fall%202007.pdf>.
- ³²¹ Great Lakes United. 2009. Navigation. Online: <http://www.glu.org/en/campaigns/navigation> (Accessed March 19, 2009).
- ³²² Cantin, J.-F. and A. Bouchard. 2002. *Monitoring the State of the St. Lawrence River: Changes in Water Levels and Flow in the St. Lawrence River*. Environment Canada, Meteorological Service of Canada – Quebec Region.
- ³²³ St. Lawrence Centre. 1996. *State of the Environment Report on the St. Lawrence River*. Vols. 1–2: The St. Lawrence Ecosystem. St. Lawrence Update Series. Environment Canada – Quebec Region, Environmental Conservation.
- ³²⁴ Morin, J. and M. Leclerc, M. 1998. From pristine to present state: hydrology evolution of Lake Saint-François, St. Lawrence River. *Canadian Journal of Civil Engineering*, 25: 864–879.

- ³²⁵ Jean, M. and A. Bouchard. 1993. Riverine wetland vegetation: importance of small-scale and large-scale environmental variation. *Journal of Vegetation Science*, 4: 609–620.
- ³²⁶ International Lake Ontario – St. Lawrence River Study Board. 2006. Options for Managing Lake Ontario and St. Lawrence River Water Levels and Flows. Final Report to the International Joint Commission, March 2006. Available at: <http://www.losl.org/PDF/report-main-e.pdf>.
- ³²⁷ Desgrandes, J.-L., Ingram, J., Drolet, B., Morin, J., Savage, C. and D. Borcard. 2006. Modeling wetland bird response to water level changes in the Lake Ontario-St. Lawrence River hydrosystem. *Environmental Monitoring and Assessment*, 113: 329–365.
- ³²⁸ Tin, T. 2006. Hydrological changes in the Great Lakes-St. Lawrence Basin under climate change and impacts on hydropower generation. *Implications of a 2°C Global Temperature Rise on Canada's Water Resources*. Sage Centre.
- ³²⁹ Mortsch, L., Hengeveld, H., Lister, M., Lofgren, B., Quinn, F., Silvitzy, M. and L. Wenger. 2000. Climate change impacts on the hydrology of the Great Lakes-St. Lawrence system. *Canadian Water Resources Journal*, 25(2): 153–179.
- ³³⁰ Croley, T.E. 2003. *Great Lakes Climate Change Hydrological Assessment*. International Joint Commission Great Lakes-St. Lawrence River Regulation Study. National Oceanic and Atmospheric Administration Technical Memorandum GLERL-126.
- ³³¹ Lefavre, D. 2005. *Effet des changements climatiques sur la niveaux d'eau du fleuve Saint-Laurent entre Montréal et Québec*. Projections pour les années 2050. Report prepared for the Comité de concertation Navigation Plan d'Action Saint-Laurent Phase 4, Institut Maurice-Lamontagne Directions des Sciences océaniques. Cited in, Bourque, A. and G. Simonet. 2008. Quebec. In: D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush (Eds.), *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Government of Canada: Ottawa, ON. p. 171–226.
- ³³² Bourque, A. and G. Simonet. 2008. Quebec. In: D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush (Eds.), *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Government of Canada: Ottawa, ON. p. 171–226.
- ³³³ Mortsch, L.D. 1998. Assessing the impact of climate change on the Great Lakes shoreline wetlands. *Climatic Change*, 40: 391–416.
- ³³⁴ International Joint Commission. 2009. About Us: Who We Are. Online: http://www.ijc.org/en/background/ijc_cmi_nature.htm (Accessed March 20, 2009).
- ³³⁵ Save the River - Upper St. Lawrence Riverkeeper. Fact Sheet: Water Levels Regulation on the St. Lawrence River. Available at: http://savetheriver.org/docs/08_IJC_water_lvls_fact_sheet.pdf.
- ³³⁶ Save the River - Upper St. Lawrence Riverkeeper, Citizen's Campaign for the Environment, Environmental Advocates of New York, and Great Lakes United. 2008. *IJC Plan Fails the People and the Environment – Joint Statement on the Release of the International Joint Commission's Draft Water Levels Plan for St. Lawrence River and Lake Ontario*. Available at: <http://www.citizenscampaign.org/PDFs/statement%20on%20IJC%20decision%20032808-1.pdf>.
- ³³⁷ Remarks made by Ontario Natural Resources Minister Donna Cansfield to the Energy 2100: Making the Great Lakes Conference. MaRS Discovery Centre, South Tower, Room 100. Wednesday, April 23, 2008, Luncheon Address. Available at: http://www.energy2100.ca/pdf/Energy2100_Minister%20Cansfield%27s%20Address.pdf.
- ³³⁸ Brooks, Irene. Chair, US Section, International Joint Commission. Letter to Condoleeza Rice, Secretary of State. September 4, 2008. Available at: http://www.ijc.org/en/activities/losl/documents/2008_09_04_Rice_Emerson.pdf.
- ³³⁹ Personal communication with John Jackson, Director, Great Lakes United. March 19, 2009.
- ³⁴⁰ Remarks made by Jennifer Caddick, Executive Director of Save The River & Upper St. Lawrence Riverkeeper, to the International Joint Commission, June 25, 2008. Bonnie Castle Resort, Alexandria Bay, NY.
- ³⁴¹ Save the River - Upper St. Lawrence Riverkeeper. 2009. About Us. Online: <http://www.savetheriver.org/index.cfm?page=app.about> (Accessed March 23, 2009).
- ³⁴² St. Lawrence Plan for a Sustainable Development. 2008. Government Actions. Online: http://www.planstlaurent.qc.ca/sl_bm/interventions_g/accueil_e.html (Accessed March 23, 2009).
- ³⁴³ St.-Laurent Vision 2000. 2009. St. Lawrence Vision 2000 Action Plan, Phase III. Online: http://www.slv2000.qc.ca/plan_action/phase3/plan_action_a.htm (Accessed March 23, 2009).
- ³⁴⁴ St. Lawrence Plan for a Sustainable Development. 2008. Principles of the St. Lawrence Plan: Ecological Integrity. Online: http://www.planstlaurent.qc.ca/sl_bm/interventions_g/psl/phase_IV/fondements/integrite_e.html (Accessed March 23, 2009).